Contract USDI/BOR# R18AC00039 Enhanced Acoustic Tagging, Analysis, and Real-Time Monitoring of Wild and Hatchery Salmonids in the Sacramento River Valley – **2019 annual report**

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Executive summary

The University of California, Santa Cruz (UCSC), in affiliation with the National Marine Fisheries Service, Southwest Fisheries Science Center (SWFSC), acoustic-tagged and released over 2,395 juvenile Chinook salmon (*Oncorhynchus tshawytscha*) during water year (WY) 2019. UCSC also successfully performed all necessary associated tasks to accurately estimate the survival of outmigrating juvenile Chinook salmon, including receiver deployment and studies examining critical metrics including tag retention, tag life, tag effects, and receiver detection efficiency. Overall, Sacramento River Valley juvenile Chinook salmon outmigration survival during WY2019 was relatively high compared to previous years. In particular, outmigration survival (from release to the Golden Gate Bridge) was 4% for hatchery late fall-run, 20% for hatchery winter-run, 16% & 26% for hatchery spring-run (Gridley & Boyd's release, respectively), 1% for wild spring-run and 19% for hatchery fall-run Chinook salmon. River survival (from release to City of Sacramento) was 24% for hatchery late fall-run, 48% for hatchery winter-run, 38% & 63% for hatchery spring-run (Gridley release & Boyd's release, respectively), 17% for wild spring-run and 46% for hatchery fall-run Chinook salmon. Delta survival (from City of Sacramento to Chipps Island) was 29% for hatchery late fall-run, 57% for hatchery winter-run, 54% & 56% for hatchery spring-run (Gridley & Boyd's release, respectively), 16% for wild spring-run and 51% for hatchery fall-run Chinook salmon. Finally, San Francisco Bay survival (from Chipps Island to the Golden Gate Bridge) was 58% for hatchery late fall-run, 69% for hatchery winter-run, 79% & 73% for hatchery spring-run (Gridley & Boyd's release, respectively), 40% for wild spring-run and 80% for hatchery fall-run Chinook salmon. Preliminary real-time survival and movement metrics were successfully estimated and provided to the public via the CalFishTrack real-time website (https://calfishtrack.github.io/real-time/index.html).

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1. Introduction

To monitor the survival of outmigrating juvenile salmonids, the use of acoustic telemetry (AT) has become widespread in recent years. This technology allows researchers and resource managers to monitor fish outmigration in real-time, allowing for more informed management decisions. Currently, the Juvenile Salmon Acoustic Telemetry System (JSATS) is used throughout the California Central Valley (CCV) to track outmigrating juvenile salmon, and underwater hydrophones detect the presence of fish and allow for survival estimates to be generated in specific reaches of interest. Water management agencies in the CCV can utilize the detections of tagged salmonids in real-time to make decisions on water exports, while hatchery managers can utilize this technology to infer which release strategies are most effective in achieving the highest juvenile survival rates based on current conditions. In addition, information on wild salmonids can be obtained to help provide insight into the movement and survival dynamics of threatened and endangered runs, for which little information has been gathered to date.

As a result of the differences in outmigration timing for CCV juvenile salmon, the survival data summarized in this report span many months across the 2019 water year (October 2018 - September 2019, hereafter referred to as 2019). To analyze the survival dynamics temporally and to account for the variation in environmental conditions which may affect survival rates, we developed a mark-recapture model to estimate regional, reach-specific and cumulative survival for all study groups. The hatchery production of late fall-, winter- and spring-run Chinook salmon reported here were originally tagged as part of a Central Valley Project Improvement Act (CVPIA)-funded trawl efficiency study, which uses survival rates of tagged smolts to calibrate the capture efficiency of an ongoing trawl survey. In addition, we report the survival estimates of smolts outmigrating through the Sutter Bypass. We also report the findings from a study examining the effects of tag implantation on the growth and tag retention of juvenile Chinook salmon and present the results from battery life studies which track the duration of tag life from 5% of all tags used during the 2019 survival studies. Finally, appended to the end of the report are two scientific manuscripts that were generated as part of this work: *Ecological nonlinearities inform the design of functional flows for imperiled fish in a highly modified river* (in review), and *Outmigration survival of wild Chinook salmon smolts through the Sacramento River during historic drought and high water conditions* (published in 2020).

The findings in this report describe the survival dynamics for tagged smolts during an exceptionally wet winter and spring. The Sacramento River and its tributaries were all flowing above average for much of the outmigration season, resulting in good water conditions that led to improved smolt survival. These water conditions were abnormal for the CCV, with most water year types experiencing lower precipitation that results in lower stream flows. The survival estimates presented here are likely representative of the upper boundary for outmigration survival for some populations of Chinook salmon in the CCV. These high survival estimates could be used as a target for efforts aiming to achieve higher outmigration survival and ultimately higher adult returns by means of management actions. As California is expected to experience increasingly dramatic fluctuations in yearly precipitation rates due to climate change, it is important to understand the survival dynamics for outmigrating smolts during such extremely wet years.

2. Methods

2.1. Study Area

Sacramento River

The main area of focus in this report is the Sacramento River, Sacramento-San Joaquin Delta, and San Francisco Bay. In addition, the Feather River, Butte Creek, and Sutter Bypass are covered in this report as well. The Sacramento River is the longest river in California and was historically the second largest salmon producing river in the United States behind the Columbia River (Yoshiyama et al., 1998). It originates at the base of Mount Shasta and flows for 50 river kilometers (rkm) before becoming impounded by Shasta Reservoir. Below Shasta Reservoir, the Sacramento River flows for roughly 552 rkm to the Golden Gate Bridge, before joining the Pacific Ocean at the Gulf of the Farallones. For the purposes of this report, we delineate the Sacramento River into four distinct sections – the upper Sacramento (Redding to Colusa), the lower Sacramento River (Colusa to Sacramento), the Delta (Sacramento to Chipps Island), and the San Francisco Bay (Chipps Island to the Golden Gate Bridge).

The habitat features and general characteristics of the Sacramento River greatly change as it flows in a downstream direction. The upper Sacramento River is in a relatively natural state, and contains expansive gravel bars, large woody debris, braided channels, and riffle-pool complexes. Upon transitioning into the lower Sacramento River, near the town of Colusa, the river becomes channelized and its banks armored by revetment, primarily to protect the expansive agricultural fields which encroach closely to the river. The lower Sacramento River is also heavily diverted for agricultural practices, and contains three flood control weirs (Moulton, Colusa, and Tisdale) which bypass water around the channel during high flow events. Downstream of the City of Sacramento, the Sacramento River transitions into the Sacramento-San Joaquin Delta, which becomes tidally influenced, split between many different distributary channels (Sutter, Steamboat, and Georgiana sloughs), and largely impacted by water pumping for the State and Federal Water Projects. Downstream of Chipps Island, the Sacramento River turns brackish and ultimately transitions to saltwater as it enters the San Francisco Bay and finally the Pacific Ocean at the Golden Gate Bridge.

Feather River

The portion of the Feather River accessible to anadromous fishes extends from Oroville Dam to the Sacramento River near Verona, a distance of 104 rkm. The Feather River contains two distinct reaches, known as the “low flow” and “high flow” sections. The low flow section extends from Oroville Dam to the Thermalito Afterbay, and contains less water (hence the name) as a result of water being diverted for agricultural uses. Downstream of the Thermalito Afterbay, excess agricultural water is returned to the river which increases flow significantly. This report focuses on the high flow section of the Feather River, and primarily from the city of Gridley to Verona. The California Department of Fish and Wildlife (CDFW) and California Department of Water Resources (DWR) have primarily used two main release locations in the Feather River – Gridley and Boyd’s Pump. These sites are used to determine if differences in survival occur between the upstream release group (Gridley) versus the downstream release group (Boyd's Pump). This report focuses on the survival of tagged smolts released at each location, and includes survival estimates within these locations at finer spatial scales.

Sutter Bypass

The Sutter Bypass is a flood conveyance system which parallels the Sacramento and Feather rivers from roughly Butte City to Verona, where it converges with the Sacramento River. The Sutter Bypass is designed to relieve high flows from the Sacramento River at three locations – Moulton Weir, Colusa Weir, and Tisdale Weir. These weirs overtop and inundate the Sutter Bypass during high winter and spring flows, providing flood control for neighboring towns and agricultural fields, and offering excellent wetland habitat for rearing juvenile salmon (Sommer et al. 2001). When the Sutter Bypass is not inundated by flood water, Butte Creek provides flow year-round through two channels within the Sutter Bypass – the East Borrow and West Borrow. This report focuses on the East Borrow of the Sutter Bypass, downstream of the Weir 2 flood control gate operated by DWR. This section of the Sutter Bypass extends for 43 rkm before joining the Sacramento River, and is broken into separate reaches to estimate movement and survival of tagged smolts at finer spatial scales.

2.2. Receiver Deployment

2.2.1. Autonomous receivers

Autonomous receivers are located throughout the river and delta at fine spatial scales (every 10-30 km), and many sites have remained consistent across multiple study years, allowing for retrospective analyses of spatial survival dynamics. River segments delimited by receiver locations at their upstream and downstream ends are hereafter referred to as reaches. Autonomous receivers are named as such because they operate autonomously while entirely submerged underwater, but must be physically downloaded periodically to access their stored data (in contrast to real-time receivers; section 2.2.2).

Autonomous receivers are secured to a tree, bridge or other permanent structure using 0.6 cm stainless steel wire rope and fastened by a Nico sleeve which crimps the connection. Between 10 to 30 m of cable is extended from the shore to a location in the channel where the receiver can detect tags while not being too far into the channel where it could be compromised or rendered inoperable due to debris or high flow events. To anchor the receiver, 18 kg of weight is secured to the receiver by approximately 0.5 m length of wire rope which allows the receiver to float above the river bottom. The receiver is equipped with a fin to keep it from swaying under water, and to keep the hydrophone pointed towards the river surface. The receivers contain roughly 2 kg of buoyancy which allow them to float underwater without the need for extra floatation. At least 2 m of water is needed to deploy the receiver so that enough water is passing over the hydrophone to detect fish while being out of sight from the public. When retrieving the receivers, a boat is used to hook onto the main cable and back-up until the cable is free of debris and out of the silt and sand which deposits on top of the cable.

When deploying receivers at sites where it is too deep to anchor the receiver to shore (e.g., the Golden Gate Bridge), we used Vemco acoustic release receivers. The receiver is secured to a flotation device and an acoustic release Vemco receiver, which is then secured to 32 kg of weight and lowered over the side of a boat. For receiver retrieval, a boat is positioned above the receiver deployment site and the operator uses an acoustic modem to send a release signal to the receiver. This initiates the receiver to separate from the weight and float to the surface where it can be retrieved.

2.2.2. Real-time receivers

Real-time receivers are located at strategic locations throughout the CCV starting upstream on the Sacramento River at Butte City on the CA-162 bridge, at the City of Sacramento on Tower Bridge (CA-275) and the Interstate-business-80/highway-50 bridge (hereafter I80/50 Bridge), at various critical locations in the Sacramento/San Joaquin delta, and finally on the Interstate-680 bridge at the east end of the Carquinez Strait (hereafter Benicia Bridge; Figure 1). Single gate arrays (multiple receivers covering a single transect of the river channel) include Butte City, as well as Old River and Middle River at Bacon Island. Dual gate arrays (two parallel receiver lines covering two separate river transects) include City of Sacramento, both Sacramento River and Georgiana Slough near Walnut Grove, and at Benicia Bridge. Single arrays can provide real-time information on presence/absence and migration timing, while dual arrays can provide these metrics as well as survival and detection efficiency in real-time. We currently incorporate two types of real-time receivers including Teknologic shore-stations and Advanced Telemetry Systems SR3017s.

These receivers are deployed in two ways: bridge deployments and levee deployments. Bridge deployments are preferred as they provide protection from debris and vandalism. All real-time receivers have a similar deployment setup with slight differences based on vendor and where they are deployed. Levee deployments are used at certain key sites in the Delta where no bridges exist. These receivers (currently being managed by the U.S. Geological Survey (USGS)) are enclosed in a locked JOBOX that houses the receiver, modem, solar controller, and 12 V battery. A solar panel (50-85 W) is mounted outside of the JOBOX to recharge the battery. The hydrophones are mounted on fixed mounts and attached to the shore with 0.6 cm stainless steel wire cable. Bridge mounts have a waterproof housing (NEMA box) that encloses the receiver, modem, and solar controller and protects equipment from the damage due to rain, wind and solar radiation. The 12 V battery is housed separately near the NEMA box and the solar panel. Hydrophones are enclosed in ultra-violet-resistant, polyvinyl chloride (PVC) electrical conduit that protects the hydrophone cable from the environmental elements above water and debris below water. The conduits are mounted to the bridge fenders on the downstream side to protect the hydrophones from direct flow.

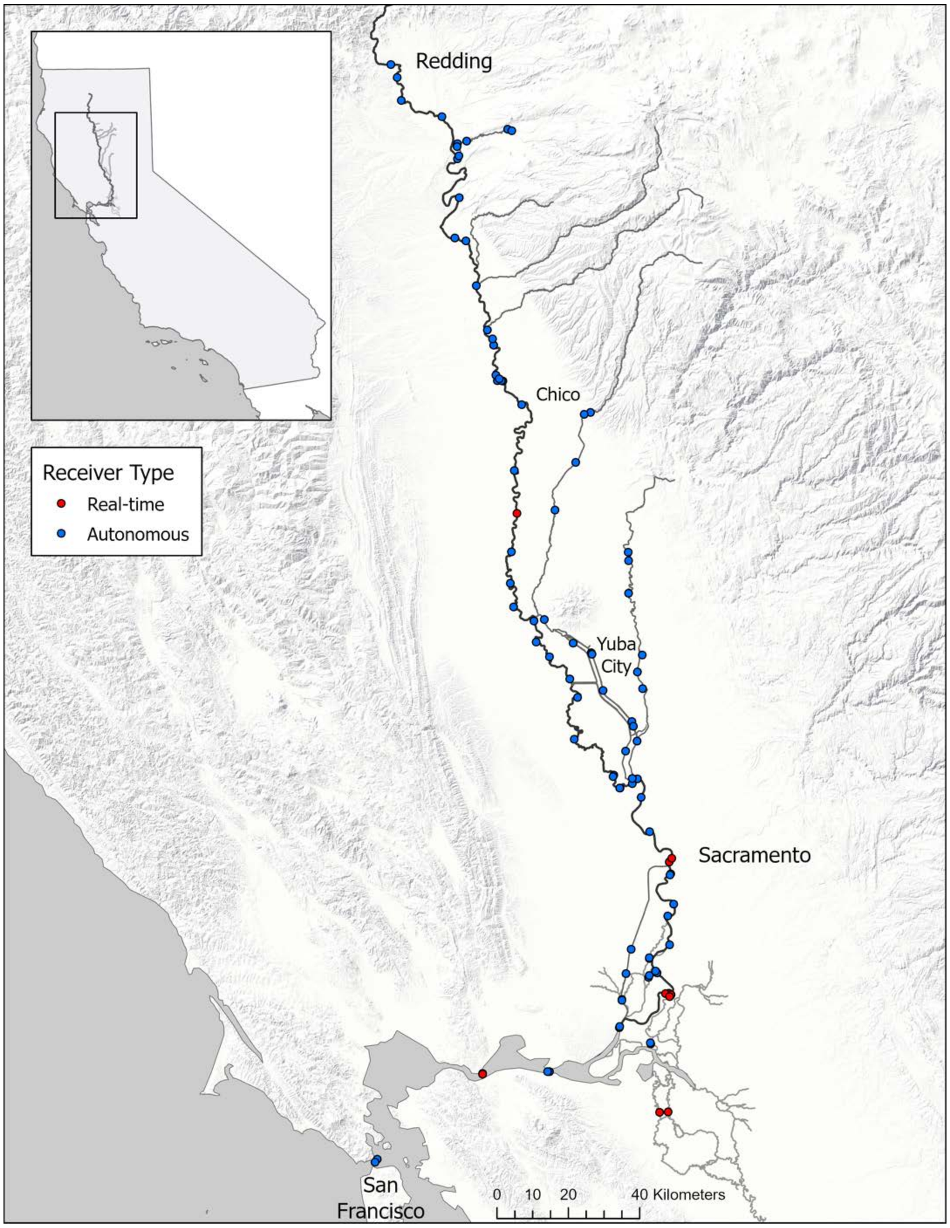

Figure 1. Map of receiver locations maintained collaboratively by the University of California, Santa Cruz, National Marine Fisheries Service, U.S. Geological Survey, and U.S. Fish and Wildlife Service. Points in blue are autonomous receiver locations; points in red are real-time receiver locations.

2.3. Acoustic Telemetry

There were five tagging studies that occurred in 2019; four studies that used hatchery produced fish and one using wild-origin fish (Table 1).

Table 1. The number of Chinook salmon juveniles tagged and release dates (2019) for each tagging study. Study ID refers to a unique study identifier that can be used to extract study specific detection data

from the EDDAP telemetry database (https://oceanview.pfeg.noaa.gov/erddap/tabledap/FED_JSATS_detects.html)

Run	Study ID	No. Of Fish Tagged	Release Date(s)
Late Fall	ColemanLateFall_2019	440	Nov 29, Nov 30
Winter	Winter_H_2019	650	February 14
Spring	FR_Spring_2019	600	April 22
Sutter Bypass Wild	SB_Spring_2019	205	May 5 to May 10
Fall	CNFH_FMR_2019	500	May 16, May 23

2.3.1. Tagging Protocol for all fish

Fish were captured from the hatchery raceways using nets and held in an indoor circular tank where tagging surgeries were performed. Fish were anesthetized individually in a bath of tricaine methanesulfonate (MS-222) buffered with sodium bicarbonate until they lost equilibrium and no longer responded to external stimuli. Each fish was then weighed, measured and placed on a foam surgery block. After making an incision anterior to the pelvic girdle and about 3 mm off the ventral midline, an ATS tag was inserted into the peritoneal cavity of the fish and the incision was then closed with sutures (6-0 absorbable monofilament). The incision length and number of sutures differed between the two tag types (standard or injectable tag type). For the standard tagged fish, we made an incision approximately 6mm long, inserted the transmitter, and closed the incision with two interrupted sutures. For the injectable tagged fish, we made an incision approximately 4mm long, inserted the transmitter, and closed the incision with a single suture. Fish were placed in a recovery basin until they regained equilibrium and were swimming normally, then transferred to holding tanks at the hatchery. Fish were held for at least 24 hours and released into the river following the same protocols as untagged fish at the hatchery, unless otherwise noted below.

2.3.2. Hatchery Tagged Fish for CVPIA Trawl Efficiency study (Late Fall-, Winter-, Spring-run)

Most hatchery fish summarized in this report (late fall, winter, and spring-run) were tagged and released as part of a hybrid design trawl efficiency study (CVPIA charter). This study uses detections of tagged fish at Sacramento and Chipps Island to calibrate the capture efficiency of an on-going trawl survey, which is intended to estimate the outmigration survival and timing of juvenile Chinook salmon through the Delta. This study uses detections of acoustic-tagged fish at each location to infer the survival of hatchery release groups to that particular location, and then estimates the total number of hatchery fish (tagged and untagged) present per day based on the survival estimates to that location, and the distribution of arrival times. Using this assumption, the daily capture efficiency of the trawl net can be estimated by comparing the total number of hatchery fish captured in the net compared to how many were deemed present at the sampling location during that particular day.

In order to acoustically tag a representative size distribution from the hatchery production, fish were randomly selected from each raceway. However, due to restrictions in tagging size, we used 85 mm fork length (FL) and 6 grams as a minimum size threshold for tagging, which in some cases resulted in the size of study fish being larger than average for the raceways. Because it is assumed that larger fish exhibit higher survival rates, the goal of this study was to tag an even proportion of size classes across the available range in each production group and from each raceway.

2.3.3. Pulse Flow Alternative Study Hatchery Tagged Fish (Fall-run)

Existing data from previous telemetry studies (Michel et al. 2015, Notch et al. 2020) show that increases in survival in the upper and lower Sacramento River have been strongly correlated with increases in flow in the mainstem river. These increases in flow during past telemetry studies were triggered by storm events resulting in increased outflow from Sacramento River tributaries. Furthermore, other changes in variables that may be related to storm events (e.g., changes in turbidity, temperature, predator densities), may also play a significant role in survival increases. University of California Santa Cruz, the National Marine Fisheries Service (NMFS), California Department of Fish and Wildlife (CDFW), and US Bureau of Reclamation (BOR) have therefore designed a multiyear telemetry study to evaluate the potential survival benefits for juvenile spring and fall-run Chinook salmon during a managed spring pulse flow on the Sacramento River. We hope to determine if managed pulse flow events (by temporarily increasing dam releases and/or decreasing in-stream diversions) can still impart measurable survival benefits to outmigrating salmon, in particular for the imperiled wild populations of spring-run Chinook salmon during the late-spring period. Results of this multiyear study will provide technical assistance towards developing and implementing potential future water management actions, among other salmon restoration actions, in the Sacramento River.

In 2019 flows on the Sacramento River were abnormally high due to the wet water year. As such, a managed spring pulse flow was not deemed to be necessary as a survival enhancing measure and was not enacted. Nonetheless, juvenile Chinook salmon survival data for the late-spring period in the CCV is scant, and therefore, tagged release groups were still released as part of an ‘alternative’ study design. Survival estimates for these release groups may serve as an estimate of survival for natural high flow events occurring in the spring period, to which survival measured during managed high flow events can be compared at a later date.

Study fish were selected from holding tanks at Coleman National Fish hatchery that were held specifically for this study. All fish were held in recovery tanks for a minimum of 24 hours before being removed using a sanctuary net and placed into ice chests with sufficient aeration for transport. Water temperature was checked prior to leaving the hatchery. These fish were then transported to the Red Bluff Recreation Area boat launch below the Red Bluff Diversion Dam (RBDD), following the study design for the WY2020 managed pulse flow study. Water temperature was monitored and then tempered within an hour so that the transport water in the ice chest and the river water were within 0.5° C of each other. Two release groups of 250 fish each were released, the first at 10:00 am on May 16, 2019 and the second at 10:00 am on May 23, 2019.

2.3.4. Wild Tagged Fish (Sutter Bypass)

The SWFSC and UCSC have been capturing, tagging, and releasing wild Chinook salmon from Sutter Bypass since 2015 in order to investigate the spatial and temporal dynamics of wild Chinook salmon outmigration movement and survival (see Cordoleani et al. 2018). As part of this long-term monitoring effort, SWFSC and UCSC again captured and tagged wild Chinook salmon from Sutter Bypass in 2019. While this project is primarily intended to track survival and movement of wild spring-run Chinook salmon, fall-run are also caught in Sutter Bypass and are impossible to distinguish without genetic identification techniques. Therefore, the resulting stock composition of tagged fish (as determined from genetic identification techniques) is a blend of spring-run and fall-run Chinook salmon individuals.

Wild Chinook salmon smolts were captured using a rotary screw trap (RST) in the Sutter Bypass at Weir 2. The RST was checked 3 times daily to minimize debris buildup and ensure that fish were in good condition. Fish were netted out of the live well, placed into an aerated ice chest, transported upstream of Weir 2, and held overnight in holding pens. The following day, fish were removed from their holding pens, placed in an aerated ice chest, and held for a minimum of 30 minutes prior to surgery. Fish were treated and tagged in the same manner as the above protocol except a tissue sample was taken via an upper caudal fin clip. Following recovery time, fish were transported to a post-surgery holding hamper located below Weir 2 and held for a minimum of 10 hours. The holding hampers have an auto release door that was set to open at 9:00 pm. Hampers were checked each morning to ensure the release door had opened the previous night and that all fish had been released. A total of 205 Chinook salmon smolts were tagged and released downstream of Weir 2 over the course of 6 consecutive days May 5 through May 10.

2.4. Tag Effects Study

In aquatic ecosystems where visually monitoring species can prove challenging due to environmental variables, acoustic telemetry provides the ability to track individuals over long distances and for extended periods of time. Acoustic telemetry has been used to monitor the movement and survival rates of a multitude of fish species including sturgeon (Beardsall et al. 2013; Melnychuk et al. 2017; Pendleton et al. 2019), rays (Cerutti-Pereyra et al. 2014; Braun et al. 2015; Ramsden et al. 2017), and sharks (Heupel and Simpfendorfer 2002; Jakobs and Braccini 2019; Tickler et al. 2019). It is one of the most effective ways to study the movement and survival of juvenile Chinook salmon out-migrating to the Pacific Ocean (Welch et al. 2008; Michel et al. 2015; Cordoleani et al. 2018; Notch et al. 2020). Once released, tagged fish are assumed to exhibit similar movement and survival rates as untagged fish. However, the surgical procedure and presence of the transmitter (tag burden) may negatively affect the swimming performance of the study fish (Lacroix et al. 2004) and ultimately survival. Additionally, a fish may shed its tag and be incorrectly assigned as a mortality. The failure to account for these factors will bias movement and survival estimates.

We examined four factors believed to influence acoustic tag retention, growth and survival in juvenile Chinook salmon: water temperature, surgeon experience, size at tagging, and tag type. Tagged fish released throughout the year experience significantly different water temperatures, which may impact tag retention rates and growth. To examine this we compared fish at two water temperatures representative of temperatures occurring during juvenile salmon out-migration in the CCV. Tagging studies often use surgeons with varying levels of experience. We examined the effects of this by utilizing experienced and non-experienced surgeons and analyzing how this affected tag retention and growth. We also tagged fish at a range of sizes to determine how size affects tag shedding and growth. Currently, the two smallest commercially available acoustic tags present a choice between a lighter but longer tag versus a heavier but shorter tag. Which factor is most important when tagging small juvenile salmon has not been previously examined. We addressed this question by comparing tag retention, growth and survival in juvenile salmon implanted with one of two types of acoustic transmitter.

Study design

We used 192 juvenile spring-run Chinook salmon (81-97mm FL) acquired on 4/18/2019 from the Feather River Fish Hatchery in Oroville, California for this tagging study. Fish were transported to the SWFSC in Santa Cruz, California where they were randomly assigned to one of two water temperature treatments, cool (13.4° C) or warm (17.8° C). These temperatures are representative of those experienced by outmigrating juvenile salmon in the Sacramento River. Fish assigned to the cool treatment were placed directly into the cool-water tanks upon arrival. Fish assigned to the warm treatment were gradually acclimated to the warmer water temperature over a period of three days to avoid thermal stress. To further reduce stress due to travel and temperature acclimation, fish were held in their respective temperature treatment for three days prior to surgery.

Fish were randomly assigned to one of two surgeons who were classified as ‘expert’ or ‘novice’ based on their surgical tagging experience level. The expert surgeon’s experience included implanting acoustic tags in over 2,100 juvenile Chinook salmon, while the novice surgeon’s experience included training but no actual tag implantation surgeries. Prior to implanting acoustic tags, all fish were injected with standard size (1.2 mm x 2.7 mm, weight negligible) Visible Implant Alphanumeric (VIA) tags (manufactured by Northwest Marine Technology, Inc.) next to the dorsal fin insertion. This allowed individual identification of fish to determine individual growth rates. Fish were assigned to one of three tag treatments: reference (no acoustic tag), standard tag or injectable tag Each standard tag was 10.7 mm long, 5.3 mm high, 3.0 mm wide, weighed 306 mg in air and had a volume of 0.170 mL. Each injectable tag was 15.0 mm long, 3.3 mm diameter, weighed 210 mg in air and had a volume of 0.128 mL. There were 16 fish assigned to each factor tested (water temperature, surgeon experience, and tag type). Fish size was randomly selected for each group.

During surgery, fish were anesthetized in a bath of 90 mg L-1 MS-222 buffered with 360 mg L-1 sodium bicarbonate until they lost equilibrium. Fish were weighed, fork length (FL) measured, injected with a VIA tag, and placed ventral side up on a foam surgery cradle. While in the cradle, the fish’s gills were irrigated with a continuous flow of anesthetic bath (30 mg L-1 MS-222 buffered with 120 mg L-1 sodium bicarbonate). An incision was made anterior to the pelvic girdle and about 3 mm off the ventral midline using a microsurgical knife (15° straight stab 3 mm blade). The incision length and number of sutures used to close the incision differed between the two tag types. For the standard tag treatment, an incision approximately 6 mm long was made, the transmitter was inserted through the incision into the coelom and the incision was closed with two interrupted sutures secured with a surgeon’s knots using 6-0 absorbable monofilament sutures. For the injectable tag treatment, a 4 mm incision was made in the same location and an injectable size acoustic transmitter was inserted through the incision site into the coelom. This smaller incision was closed with a single suture. All tags were disinfected prior to insertion by soaking in a 0.1% solution of chlorhexidine diacetate and then triple-rinsed in distilled water before implanting.

Surgery time was measured for each fish and is one of the metrics used to determine differences in surgeon experience. Surgery time included weighing, measuring, visual examination, implantation of the VIA tag, and implantation of the acoustic tag or air time for reference fish. Reference fish were placed in the cradle and given an ‘air time’ similar to acoustic-tagged fish based on tag type and surgeon. After tag implantation, fish were placed into the recovery bath and held until they were swimming normally at which point they were transferred to their assigned temperature treatment tank. Water temperature and dissolved oxygen were monitored in the surgery bath, drug bath, and recovery bath and kept consistent to assigned temperature treatments for each fish.

Fish were housed in four indoor circular tanks (91 cm high x 73 cm diameter, 490 L) with overhead lighting that mimicked the natural photoperiod. Two tanks were maintained as ‘cool’ tanks (mean water temperature of 13.4°C, range 11 to 17°C) and two as ‘warm’ tanks (mean water temperature of 17.8°C, range 14 to 23°C). Temperatures were held stable except for a spike in the cool tank due to a chiller failure on day 36 and an unusually high increase in ambient air temperature on day 50, which resulted in higher temperatures in both treatments. Tanks were checked daily for shed tags using a magnet sweeper and cleaned every other day or as needed using a siphon. Any mortalities were removed and frozen.

Prior to surgery, fish were fed commercial food pellets at 2% tank biomass per day. After surgery fish were fed 2% and 3.2% tank biomass per day for the cool and warm treatments respectively. The increase in feeding rate for the warm treatment was intended to equalize growth rate between the two temperature treatments by compensating for the higher metabolic rate of fish in warmer water. Daily feed amounts were increased by 1.5% each week. Prior to surgery and for the first six days post-surgery, fish were fed by hand over the course of 15 minutes. For the remainder of the trial, food was delivered via belt feeders over the course of approximately 6 hours.

At the end of the 60-day trial, all fish were removed and euthanized with an overdose of MS-222. Fish were individually identified based on their VIA tag or by reading the label on their acoustic tag. Fish were subsequently photographed, weighed and measured. Acoustic tagged fish were dissected, and the presence or absence of an acoustic tag was recorded, and the overall condition of the fish was noted.

Statistical Analysis

We analyzed differences in tag retention between water temperature, surgeon experience, size at tagging, and tag type using a proportion hazards regression (cox regression, package coxme) in R statistical software, version 3.3.0 (R Core Team, 2019). Proportion hazard models are frequently used in medical studies to examine the effect of multiple factors on the time to an event (e.g., recovering from an illness). The time to event for our trial was the time to tag shedding. If shedding had not occurred prior to, mortalities were marked as shed on the day of their death. All fish were censored on Day 60 if they had not shed their tag. This allows the model to account for all fish from the start of the trial to either tag shedding, mortality, or the end of the trial.

The effect of fish size on tag loss (shed tag or died) was further examined by binning fish into three size groups; small (81-85 mm FL), medium (86-90 mm FL), or large (91-97 mm FL). We tested for an effect of size bin on tag loss with a binomial generalized linear model with tag loss as the binary response variable (1 = lost tag or died, 0 = retained tag and survived to end of trial) and size bin as the categorical predictor.

We analyzed differences in individual fish growth for surgeon experience, size at tagging and tag type in R using an ANOVA (package car). We calculated the specific growth rate of weight for each fish at the end of the study, excluding all mortalities. Each temperature treatment was analyzed separately because growth rate is a function of temperature. For each temperature treatment, to investigate differences in growth between the three tag treatments, a post hoc Tukey Honest Significant Difference (package stats) test was used. The post hoc test allowed us to analyze if growth significantly varied between the three tag types (standard, injection or reference).

2.5. Tag Retention Studies

Tag retention is a critical component of acoustic tagging survival studies. If a fish sheds its acoustic tag before a true mortality or successful outmigration, the detection history for that fish, and the associated mark-recapture survival model, will both suggest that the fish died at the location of the tag shedding, when in reality, the fish survived to a later time and location. Therefore, studies with high tag shed rates can result in survival estimates that are biased low. It is therefore important to tag a subset of fish from a survival study and observe them in aquaria for the duration of study, so as to determine if and when tag shedding occurs.

When possible, hatchery fish of the same population are used to infer tag retention rates for survival studies described in this report. For Feather River spring-run, the tag retention study described above informed the shed rates for that study group. For other populations, such as wild fish captured in the Sutter Bypass, tag retention studies are not feasible due to the amount of time necessary to hold fish in-situ. Also, water conditions in riverine systems are dynamic and are constantly changing, so the conditions experienced by study may differ from tag retention fish held for a long duration of time, which may lead to differences in tag retention rates.

2.5.1. Late Fall-Run Chinook Salmon Tag Retention Study

The late fall-run Chinook salmon tag retention study was conducted at the Coleman National Fish Hatchery (CNFH) from November 29, 2018, to February 28, 2019. We examined the shed rate of tagged fish and the effect of tag implantation on growth using three tag treatments: control (no tag implanted), standard tag (model SS300, 300 mg dry weight, 10.7 mm long x 5.2 mm wide, 3.0 mm high), and injectable tag (model SS400, 210 mg dry weight, 15.0 mm long x 3.3 mm diameter). A random sample of 50 control fish, 25 standard tagged fish, and 25 injectable tagged fish were used. All acoustic tags used in this study were inactive (dummy) acoustic tags.

The control fish were exposed to the same treatment as the dummy acoustic tags in terms of handling, surgery time, and recovery time but were not implanted with an acoustic tag. The primary purpose of the control fish was to determine the difference in growth rates compared to the acoustic tagged groups. All fish groups (injectable, standard, and control fish) were held on-site at CNFH for 90 days. During the trial, the tanks were checked daily for shed tags and fish mortalities. Fish were measured and weighed at the start and end of the trial.

2.5.2. Winter-Run Chinook Salmon Tag Retention Study

The winter-run Chinook salmon tag retention study was conducted at the Livingston Stone National Fish Hatchery (LSNFH) from February 14–May 1, 2019. We examined the shed rate of tagged fish and the effect of tag implantation on growth. There were two tag treatment, control (no tag implanted) and standard tagged fish (model SS3000, 300 mg dry weight, 10.7 mm long x 5.2 mm wide, 3.0 mm high). A random sample of 50 control and 50 tagged fish were used in this study. The control fish were exposed to the same treatment as the dummy acoustic tags in terms of handling, surgery time, and recovery time but were not implanted with an acoustic tag. The primary purpose of the control fish was to determine the difference in growth rates compared to the acoustic tag group. All fish groups (standard and control fish) were held on-site at LSNFH for 77 days. During the trial, the tanks were checked daily for shed tags and fish mortalities. Fish were measured and weighed at the start and end of the trial.

2.6. Tag Life Studies

Similar to tag shedding, when an acoustic tag dies before the expected warranty life of the tag, as well as before the end of a tagged fish's outmigration, this will bias survival estimates low. Tags are purchased and programmed so that the battery is anticipated to last well beyond the expected outmigration period for tagged fish. Ideally, the tags should therefore perform for that entire period, but at times, premature failure does occur, and this can vary based on the manufacturing batch. As such, it is critically important to start a subset of acoustic tags at the same time as tags being used for a survival study, using the same manufacturing batch, and monitor the performance of those tags for the duration of the survival study and beyond.

To assess the percent of tags that make it to the warranty life, we randomly selected approximately 5% of the total number of tags used in each study and ran them in a tag life test. Tags were started using an ATS Pinger dish and individually taped to a nylon line hung in an outdoor tank of freshwater. A small electrical pump created a slight current for the tank. A single ATS receiver and two to three Lotek receivers were maintained in the tank for the duration of the study. The ATS receiver was downloaded every 3-14 days, at which time the memory was cleared and the receiver's internal clock was reset.

To remove false detections, the raw comma separated values file (csv) files were loaded into R and run through a 3-hit filter. This filter selects detections of the same ID within a time window of (15.6 x PRI) + 1, with the time between hits being a multiple of the expected rate pulse (e.g., 5 or 10 seconds per transmission). After running the filter, the processed file contains only detections of the same ID that occurred multiple times within the time window selected. The processed and filtered detection files for each receiver deployment were combined and filtered for the tags used in this trial. This file was used to determine the valid end time of each tag and to plot tag detections (by day) over the life of each tag. For the late fall- and winter-run Chinook salmon tag life studies, only the ATS receiver data was used in the analysis.

2.7 Detection Efficiency Study

Detection efficiency is an important consideration in the mark-recapture telemetry framework we employ to estimate survival. In general, with higher detection efficiency, we can generate more precise estimates of survival, which is an essential need for resource management. When certain key locations show evidence of having lower than expected detection efficiency, we conduct detection efficiency trials to narrow in on potential causes and fixes. Detection efficiency trials consist of drifting active acoustic tags past receivers is such a way as to mimic how a tagged juvenile salmon might pass receivers. These drifts are repeated several times, and under different river conditions or receiver configuration scenarios, so as to narrow in on conditions and configurations that lead to higher detection efficiency.

Such was the case at the Butte City real-time receiver array, where data from initial tagged study groups in WY2019 indicated poor detection efficiency, consistently below 50%. This site was therefore selected for detection efficiency trials to assist in improving efficiency at that site. Specifically, we conducted acoustic tag drifts before and after making some adjustments that were intended to increase the receivers' detection efficiency so as to assess the impact of the adjustments. The questions we were hoping to answer were the following:

1) Is there a difference in performance for autonomous receivers ATS SR3000 versus a shore station receiver ATS SR3017 when both are deployed on a bridge fender?

2) What is the detection range for tags drifting downriver about 1 m below the surface?

3) What was the detection efficiencies of receivers at their location for WY2019 compared to their altered location for WY2020?

We deployed four additional receivers (autonomous ATS SR3000) to pair with the ATS SR3017 real-time shore-stations that make up the array at this location (Figure 2, Table 2). One autonomous receiver was paired (within a few meters) with each real-time receiver to provide a direct comparison. The two additional autonomous receivers were deployed on the downstream portion of the river right fender and river left abutment. The real-time hydrophones were enclosed in ultraviolet (UV) light-resistant PVC electrical conduit that that orients the hydrophone tip into the water column parallel to the water surface and river bottom. The hydrophones were angled 45° degrees downstream and were less than 0.5 m from the river bottom. The autonomous receivers were deployed with the hydrophone facing up and 1.5-2m above the river bottom. This was the configuration of the array for all of WY2019, and was left in place for the first 6 acoustic tag drifts as part of the detection efficiency trial. For the following 6 drifts, autonomous receivers stayed in the same positions, but the real-time shore-stations were moved to what we thought would be better positions for the upcoming WY2020. SN 18002's hydrophone was moved ~10m upstream on the same face of the fender but placed directly behind a piling to help protect it from debris floating downstream. In addition, for both real-time stations (18002 and 19030), the hydrophone was raised up to ~2m below the surface during the lowest expected annual flows.

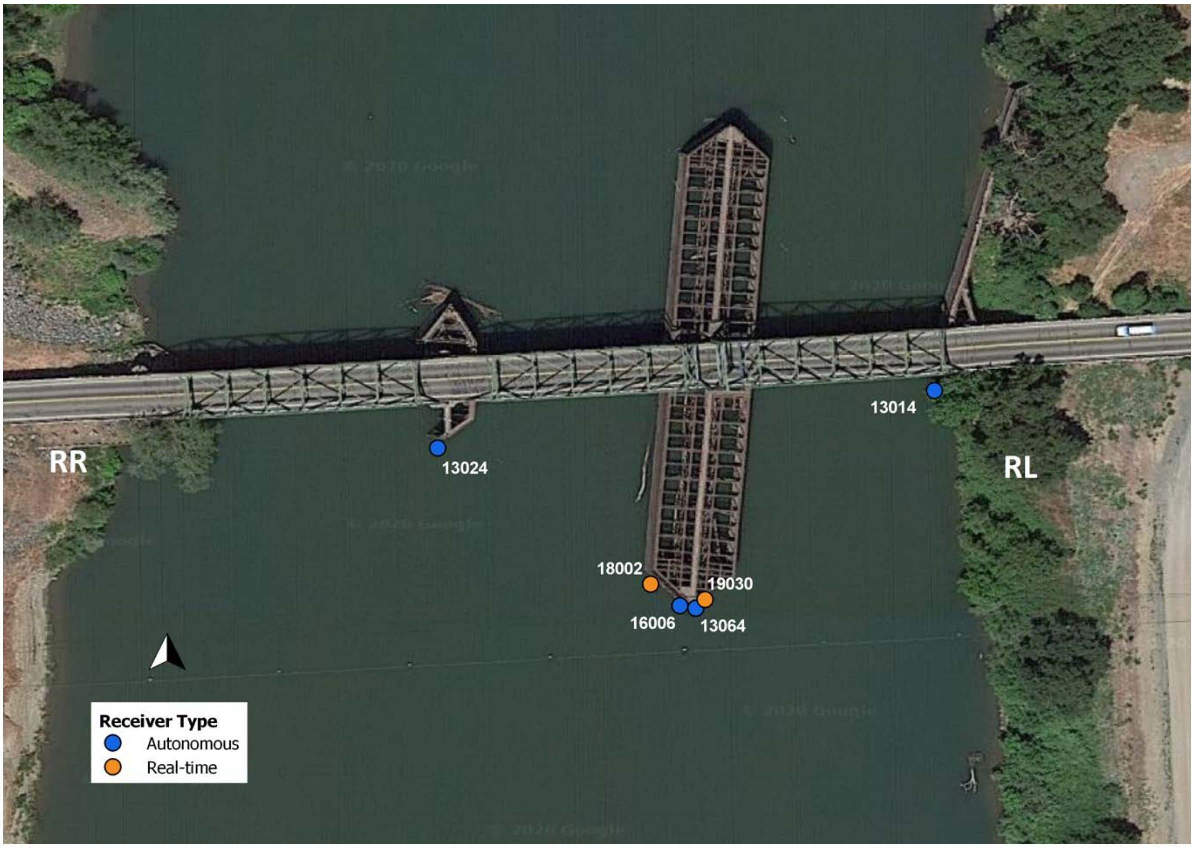

Figure 2. Map of Butte City real-time array and additional autonomous receivers used for detection efficiency trial. Note that the west bank is considered river right (RR) and the east bank is considered river left (RL) for this report.

Table 2. A description of acoustic receivers used for the Butte Bridge detection efficiency trial, including relative and exact position. Note that Receiver SN 18002 is listed twice to show the before (drift 1-6) and after (drift 7-12) locations.

Receiver SN	Make	Model	Receiver type	Channel	Location
13024	ATS	SR3000	Autonomous	River right	39.457138, -121.995348
18002	ATS	SR3017	Realtime	Middle	39.456873, -121.994933
18002	ATS	SR3017	Realtime	Middle	39.45685, -121.994900
16006	ATS	SR3000	Autonomous	Middle	39.456831, -121.994876
13064	ATS	SR3000	Autonomous	River left	39.456826, -121.994845
19030	ATS	SR3017	Realtime	River left	39.456843, -121.994287
13014	ATS	SR3000	Autonomous	River left	39.45725, -121.994380

We used ATS SS300 tags set at a 10 sec pulse rate interval (PRI; Table 2) for the detection efficiency trial. Tags were deployed on a trapeze attached to a surface float (5 kg buoyancy bullet float) and a 1 kg weight with 1 cm poly line. The tags were taped to the end of a large zip tie with transducer exposed and the zip ties were braced with a rigid rod to ensure proper positioning. Transmitters were 1 to 1.5 m below the surface with about 5 cm spacing between tags. A handheld GPS (Garmin GPSMAP 64MAPst) was attached to the top of the float to record latitude and longitude coordinates each second. The tags were placed in the water about 125–175 m upstream of the array and removed from the water about 125–150 m downstream of the array. On drift 1, the tag trapeze was pulled by a person paddling a kayak. Transmitter drifts were conducted in the middle of the channel. On the remaining drifts the kayak was attached to the R/V Osprey due to river conditions. The motor was off for the majority of the drifts except for steering purposes; the fathometer was also off so as to avoid acoustic interference with tag transmissions.

The nearest stream gauge station at Butte City (BTC) indicated that flows were 7874 cfs during the detection efficiency trial. The testing location is less than 100 m downstream of this gauge station, so conditions were likely identical. Drifts were conducted in each of the 3 channels created by the bridge fenders, river right (west; Drifts 1, 2, 7 and 8), middle (Drifts 3, 4, 9, and 10) and river left (east; Drifts 5, 6, 11 and 12). Drifts 1-6 were performed in the morning, followed by the subsequent position change of the real-time shore-station hydrophones as described above. Drifts 7-12 were performed in the afternoon after modifications to the real-time shore-station hydrophones had been completed.

All receiver data was processed using the same filter criteria used to process the real-time receiver data as listed on the CalFishTrack website ([https://calfishtrack.github.io/real-time/pageREAL.html)](https://calfishtrack.github.io/real-time/pageREAL.html) and as described below. The filtering protocol is as follows:

1) “Multipath detection removal”: All detections that occur within 0.3 sec after an initial tag detection on the same receiver, that share the same Tag Code, will be removed from the data. These detections are “multipath detections” and are created by echoes from the original tag transmission.

2) “3 detections within 6 minutes rule”: As a first step to remove obviously false detections, only detections of “potentially valid fish detections” are maintained in the database. Potentially valid fish detections occur when at least three consecutive detections of a tag code occur at a general location site with no more than 3-minute gaps in between the three detections. These potentially valid detections are kept in the general database, but stricter criteria need to be met for them to be associated with a released fish (see below).

3) “Is there a fish at large with that TagCode?”: For detections of a TagCode to be assigned to an actual released fish with that same TagCode, the detections need to fall between the release time of that fish, and the release time + 150% of the estimated tag life for that fish’s tag. For example, if a fish is released on 1/1/2019, and its tag has a 60-day battery life, detections of that fish’s TagCode must fall between 1/1/2019 and 4/1/2019 to be associated with that fish.

4) “Detection density filter”: Once potentially valid fish detections have been determined and assigned to a specific fish, any three consecutive tag detections at an individual receiver must occur in a time window shorter than ((PRI) x 1.3 x 12) + 1 second. For example, for a 10 sec PRI,

if a detection does not have at least two other detections within 157 seconds of it, it is removed. The total consecutive detections that fulfill this condition are considered a potentially valid fish visit.

5) “PRI filter”: the PRI from the previous detection and the PRI to the next detection on an individual receiver is estimated for each detection of a potentially valid fish visit. At least one of the PRIs must be within 20% of the tag’s programmed PRI <u>and</u> the standard deviation of the two PRIs must be smaller than 0.025. If these two conditions are not <u>both</u> met, the detection is dropped. If the detection is the first of a receiver visit, then the PRIs to the subsequent two detections are used. If the detection is the last of a receiver visit, the PRIs from the previous two detections are used.

6) “Detection density filter”: Filter Protocol #4 is rerun now that some detections have been dropped due to the PRI filter.

7) “4-hit filter”: Once all the previous filters have been applied, if there are less than 4 detections total for a potentially valid fish visit, those visits are dropped. All remaining fish detections are retained and considered valid.

2.8. Real-time analytics, data sharing, and website development

2.8.1. Real-time analytics and data sharing

Real-time analytics are made possible by the network of real-time JSATS receivers deployed in key locations of the Central Valley watershed. We utilize detections from two different real-time receiver types, ATS SR3017 and Teknologic real-time receiver. Both receiver models create hourly detection files that include all fish detections recorded within an hour. The two receiver models also have many differences, but the key difference is we “pull” files off the ATS receivers hourly, while the Teknologic receivers “push” their files off hourly. To pull the ATS files, a python script is programmed to execute every hour from a dedicated computer housed at the SWFSC in Santa Cruz, CA. This script communicates with each ATS receiver via cellular modems (Sierra Wireless RV50 units) and downloads the most recent hourly detection files, storing them locally as well as in the cloud (Google Drive). Conversely, the Teknologic receivers send their hourly files directly to the cloud via Dropbox, which runs on the Raspberry Pi microcomputer housed in each receiver. The same dedicated real-time computer then downloads these files from Dropbox.

An R script is programmed to automatically run hourly from the same dedicated computer. This R script triggers the creation of multiple RMarkdown HTML documents, which represent the webpages of the CalFishTrack website. RMarkdown is an authoring framework that blends together simple plain-text context (such as in a Word document) with products (e.g., figures and tables) from imbedded ‘chunks’ of programming code. As such, it allows the creation of dynamic documents (in this case HTML documents) that can be rerun periodically to incorporate the newest data. Any CalFishTrack webpage that is updated hourly is created automatically via this step (e.g., study detection webpages). Other webpages that do not update hourly are also created through RMarkdown, but are run manually as needed (e.g., the autonomous receiver webpage). Most importantly, it is the hourly creation of the “Real-time tracking diagnostics” page (https://calfishtrack.github.io/real-time/pageREAL.html) that actually compiles the latest hourly detection files and appends them to the existing database. Within the RMarkdown file for that page is R code which: 1) compiles the latest detection data and combines it with historic detection data, 2) runs detection filters on the entirety of the detection data, 3) assigns detections to specific tagged fish, and 4) produces different real-time detection diagnostics that are then hosted on the webpage.

Study detection webpages are updated hourly for any studies (SWFSC/UCSC or other) that have tags at large that are expected to still be operational. Data statistics and data visualization products are produced for each study webpage, and are often catered to the particular study group. The different statistics and visualizations which have been added incrementally since the beginning of the website, and as of the end of Water Year 2019, include:

- A table of fish summary statistics, including release location, release time, mean length and weight of tagged fish.
- Daily totals of fish arrivals (presented as a barplot) at key locations, including Butte City, City of Sacramento, and Benicia Bridge.
- Survival estimates (as produced by a Cormack-Jolly-Seber (CJS) survival model) to key locations (presented in tables), including survival to City of Sacramento, Georgiana Slough junction, and Benicia Bridge.
- Fish detection summary statistics for each real-time receiver location (presented in tables), including time of first, mean, and last new fish arrival and number of total unique fish detected.

All tables and figures on the CalFishTrack website are the product of a ‘chunk’ of R code embedded in the HTML document. The code chunks are hidden by default for aesthetic purposes, but a “Code” button appears to the top-right corner of all figures and tables. If the “Code” button is clicked, the R code used to produce that figure or table is revealed. As such, users have access to all the code needed to reproduce any of the data statistics, analytics, or visualizations hosted on the CalFishTrack website.

Additionally, the filtered real-time detection data is also easily available for download. These detections are hosted on NOAA’s ERDDAP data server (https://coastwatch.pfeg.noaa.gov/erddap/index.html). ERDDAP is a flexible data server designed to host data in many different formats, and allow custom downloads and visualizations of data in a variety of file formats (more details can be found here https://upwell.pfeg.noaa.gov/erddap/information.html). Real-time detection data can be found at this link: https://oceanview.pfeg.noaa.gov/erddap/tabledap/FEDcalFishTrack.html, and has the ERDDAP dataset ID of “FEDcalFishTrack”. From that link, detection data can be subset for download to include only data from a particular study, a particular time period, a particular geographic location, or combinations of these and other potential constraints. In addition, ERDDAP data can be accessed and download directly into R programming software for ease of further user-side data manipulations/analyses, via the Rerddap package. More details on this can be found in the Results section for this topic.

2.8.2. Website/analytics development

The real-time website and analytics it hosts were frequently updated and refined during the course of the 2019 study year based on user feedback and changing demands. The majority of updates occurred during the spring period, when the majority of fish were tagged and released, and the website experienced its highest user traffic. Requests for website/analytics updates are usually made through ITAG or CVEAT meetings, or via direct contact with Cyril Michel, the website developer. Details on website and analytics developments that occurred during the 2019 study year can be found in the Results section for this topic.

2.9. Survival Estimation

We used the Cormack-Jolly-Seber (CJS) model for live recaptures within Program MARK (White and Burnham, 1999) using the "RMark" package (Laake, 2013) in R statistical software (vers. 3.6.1; R core team, 2019) to estimate survival as well as detection probability. For species that express an obligate migratory behavior such as Chinook salmon, a spatial form of the CJS model can be used, in which recaptures (i.e., tagged fish detected downstream from release) occur along a migratory corridor. The model determines if a fish not detected at a given receiver location was ever detected at any receiver downstream of that specific receiver, thus enabling calculation of maximum-likelihood estimates for detection probability of all receiver locations (p), survival (Φ), and 95% confidence intervals for both (Lebreton et al., 1992).

Survival estimates are presented in three ways: 1) high-resolution reach-specific survival, 2) regional survival, and 3) cumulative survival. For the purposes of the reach-specific estimates, we performed an initial CJS model including all receiver locations, per release group. From that preliminary analysis, we selected only receiver locations that had a detection probability of at least 70% or higher. The CJS model was then rerun with only these higher-performing receiver locations, such that the resulting reach-specific survival estimates would have more reasonable confidence intervals. Regional survival was estimated by rerunning the CJS model using only receiver locations that delineate regions. Regions were the Upper Sacramento (release to Butte City), the Lower Sacramento (Butte City to Sacramento), the Delta (Sacramento to Chipps Island), and the Bay (Chipps Island to the Golden Gate Bridge). For the Sutter Bypass tagging effort, Sutter Bypass was also included as a region. Finally, cumulative survival was estimated by taking the cumulative product to each region transition of all upstream survival estimates. This represents a survival estimate from release to that point along the migration corridor. Error propagation for cumulative survival was estimated by use of the delta method.

2.10. Multi-year survival status and trends

The 2019 water year was extremely wet, with record rainfall occurring in particular during the end of the rainy season (April/May). This benefitted fish from many tagging studies in that year, since the majority of juvenile salmon, including those acoustically tagged, outmigrate during these months. Officially, 2019 was classified as "Wet" by the California Department of Water Resources' Water Year Hydrologic Classification Index for the Sacramento Valley (http://cdec.water.ca.gov/reportapp/javareports?name=WSIHIST), the wettest rating in that index. To further examine the WY2019 survival estimates in a broader context, we compiled key survival metrics for multiple acoustic-tagged populations over the course of many study years spanning a wide-range in hydrologic conditions.

The survival metrics of interest included through-Delta survival and survival from release to Benicia. These survival metrics are of interest to resource managers as the first represents survival through a critical region of management concern (the Delta), and the second approximately represents overall freshwater outmigration success. For this analysis, through-Delta survival is represented by survival from Freeport to Benicia. We compared survival across study years by compiling detection data from studies similar to those conducted by UCSC/SWFSC in 2019 (i.e., similar populations, release locations, and release times). Survival for both survival metrics was then calculated per release group using CJS survival models, allowing detection efficiency to be parameterized per general receiver location and per release group. Both survival metrics are dependent on detections at Benicia, and therefore, to appropriately account for detection efficiency to this point, additional receiver lines past Benicia were used in the survival model. These additional lines of receiver varied from 3 to 4; two receiver lines were always available at the Golden Gate Bridge, and in certain years a secondary line was also available at Benicia Bridge.

3. Results

3.1. WY2019 Survival estimates and trends

3.1.1. Late Fall-Run Chinook Salmon

Late fall-run Chinook salmon smolts, tagged as part of the Trawl Efficiency Study, were released on November 29, 2019 into Battle Creek before a winter storm brought heavy rain to northern California. Flows in the Sacramento River at Bend Bridge increased from ~6,500 cfs to 15,925 cfs one day after 440 fish were released on November 29, 2018. In addition, turbidity at Bend Bridge increased from 10 ntu to 130 ntu. CNFH typically releases their production of late fall-run smolts during the onset of the first big storm event of the year, usually between October and December. Despite these optimum conditions for outmigration survival, survival rates appear to be relatively low compared to previous study years. This may be due in part to the occurrence of tag failures as a result of compromised battery life, and is discussed further in section 3.6.1.

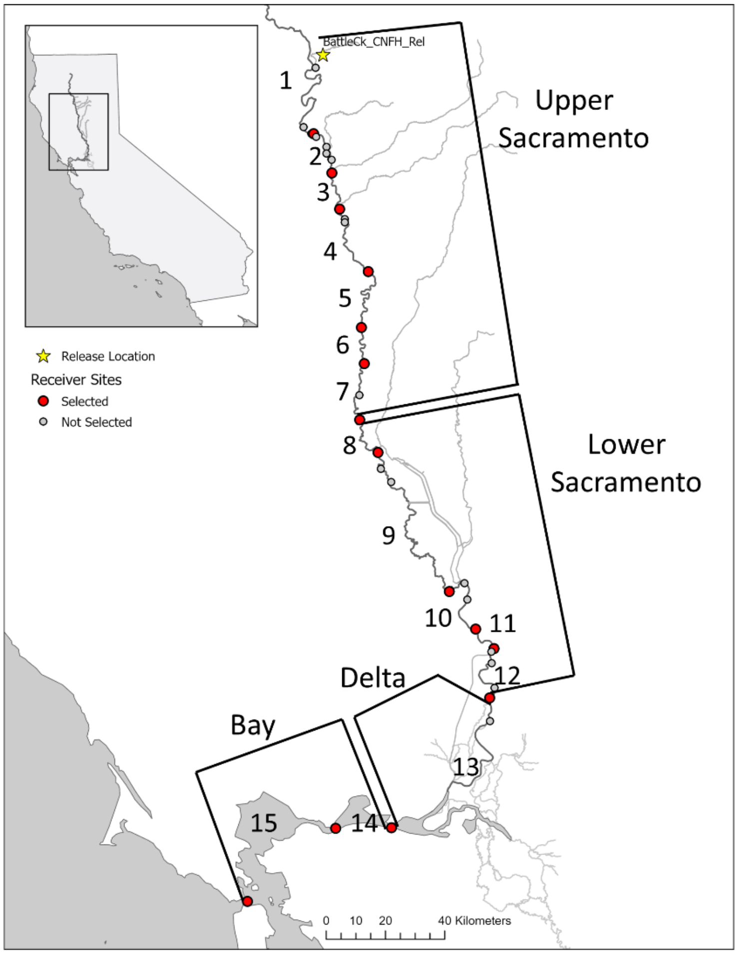

Figure 3. Map of receiver locations, release location, and regions for Coleman National Fish Hatchery late fall-run Chinook salmon juveniles in 2019. Points in red are receiver sites selected for survival estimation and points in gray are receivers that were deployed but not used.

Regional Survival

Survival through the upper Sacramento River from CNFH to Colusa was 38% (± 0.02) for acoustic-tagged fish (Figure 4, Table 3). Standardized survival rates through the upper Sacramento River region (per 10 km, hereafter referred to as standardized survival) was 95% (Figure 5, Table 3). Survival through the lower Sacramento River from Colusa to Clarksburg was 57% (± 0.04). Standardized survival through the lower Sacramento region was 97%. Survival through the Delta (Clarksburg to Chipps Island) was the lowest of all study regions at 32% (± 0.05). Standardized survival through the Delta region was 86%. Survival through the Bay region (Chipps Island to the Golden Gate Bridge) was 58% (± 0.12). Standardized survival through the Bay region was 92% (± 0.03).

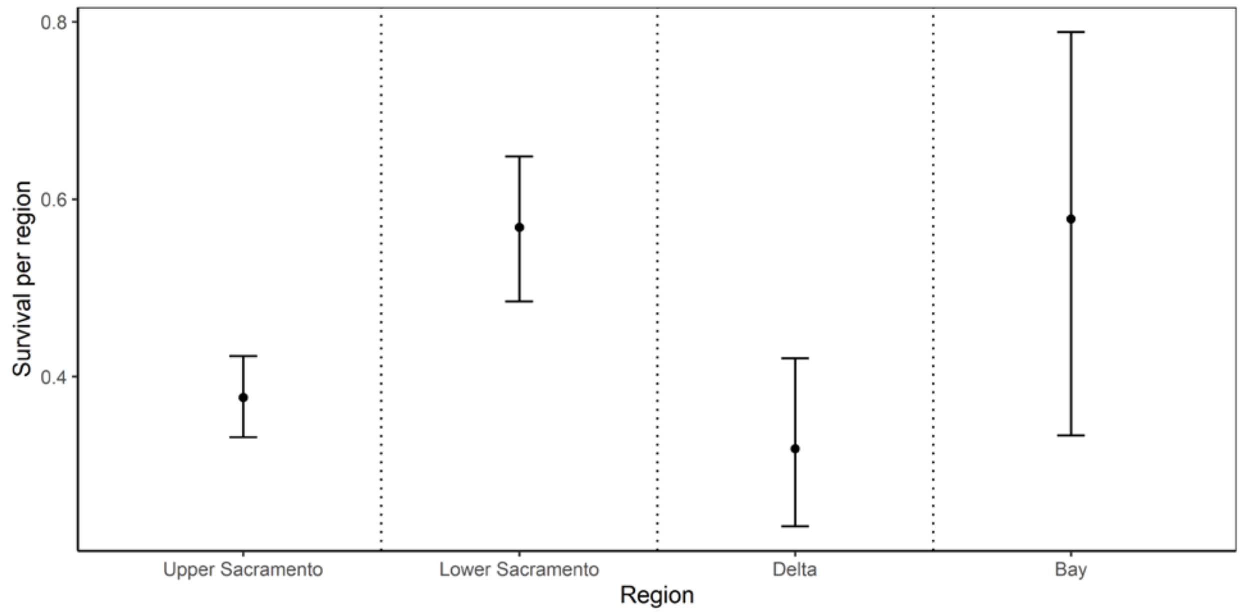

Figure 4. Survival estimates per region for Coleman National Fish Hatchery late fall-run Chinook salmon juveniles in 2019. Error bars represent the upper and lower 95% confidence intervals.

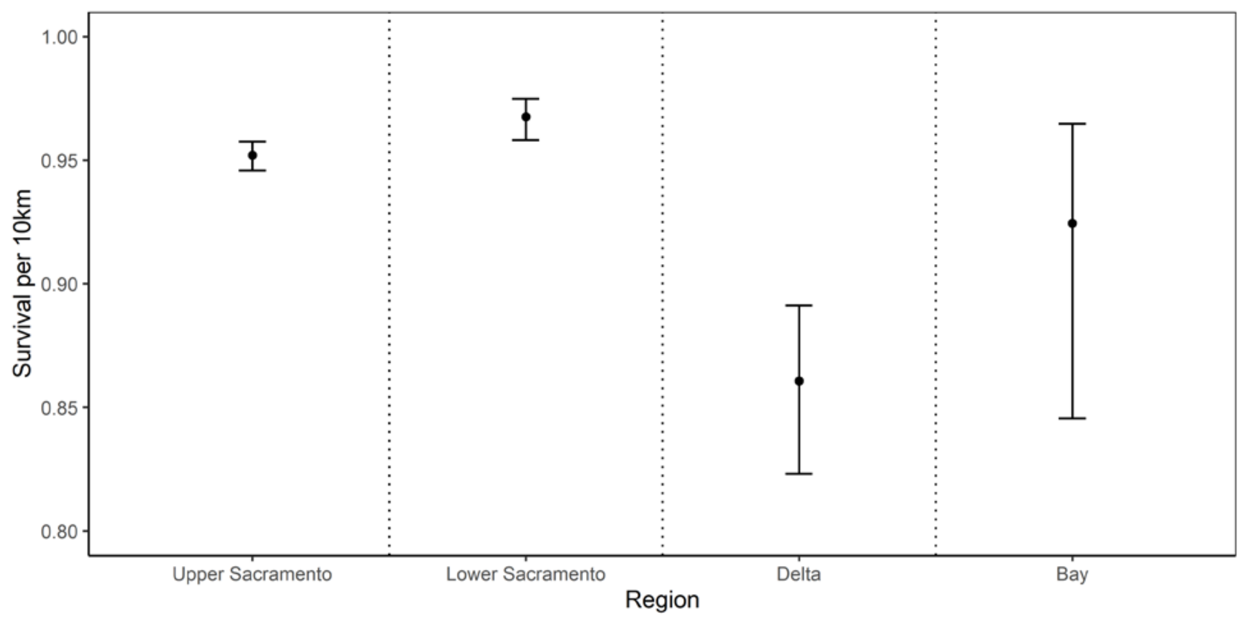

Figure 5. Survival estimates per 10km by region for Coleman National Fish Hatchery late fall-run Chinook salmon juveniles in 2019. Error bars represent the upper and lower 95% confidence intervals.

Table 3. Survival rates and standardized survival rates per 10 km by region for Coleman National Fish Hatchery late fall-run Chinook salmon juveniles in 2019.

Region	Reach	RKM	Survival (SE)	LCI	UCI	Survival per 10km (SE)	LCI	UCI
Upper Sacramento	BattleCk_CNFH_ Rel to Colusa AC2	517.34 to 318.61	0.38 (0.02)	0.33	0.42	0.95 (0.00)	0.95	0.96
Lower Sacramento	Colusa AC2 to Abv_Clarksburg	318.61 to 147.66	0.57 (0.04)	0.48	0.65	0.97 (0.00)	0.96	0.97
Delta	Abv_Clarksburg to Chipps	147.66 to 71.48	0.32 (0.05)	0.23	0.42	0.86 (0.02)	0.82	0.89
Bay	Chipps to GoldenGateE	71.48 to 1.71	0.58 (0.12)	0.33	0.79	0.92 (0.03)	0.85	0.96

Reach-Specific Survival

For this analysis, sites with greater than 70% detection efficiency were selected (see Figure 6 and Table 4). Using this criteria we selected 15 sites throughout all regions to estimate survival at fine scales (10-20 km). Receiver locations used for the Trawl Efficiency Study were also included in this analysis (Sac Trawl, Chipps Island). Reach-specific survival for late fall-run Chinook salmon juveniles was relatively high throughout the first three reaches of the upper Sacramento River, but was followed by decreasing survival in reaches 4-6 (Figure 7, Table 5). Survival generally improved through the lower Sacramento River, and remained consistent until the Delta region, where survival rates were the 86% (± 0.02). Survival remained relatively low in the San Francisco Bay reaches, with estimates of 85% (± 0.05) from Chipps Island to Benicia, and 95% (± 0.04) from Benicia to the Golden Gate Bridge.

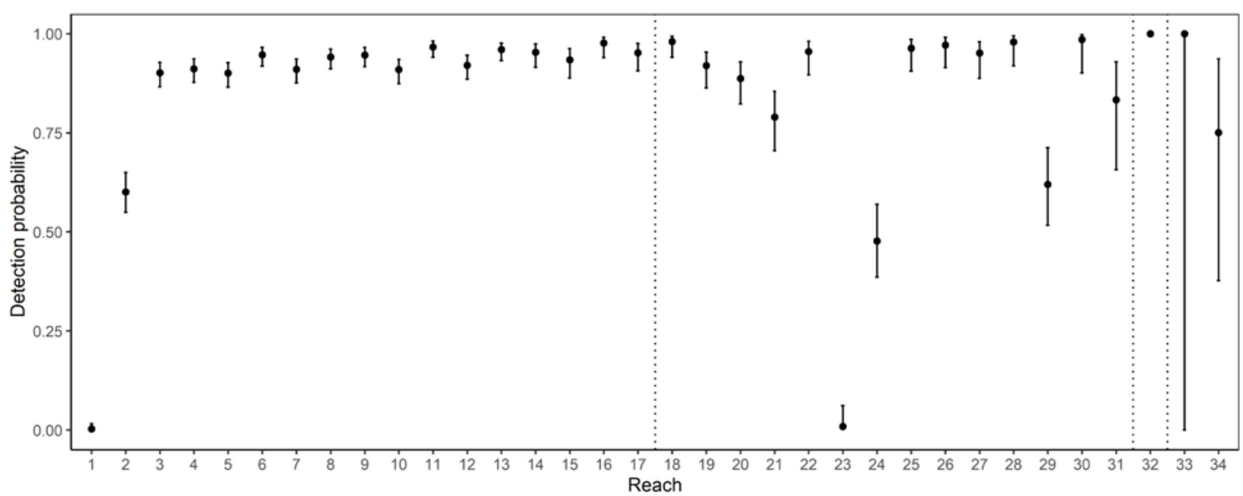

Figure 6. Detection probability per reach for Coleman National Fish Hatchery late fall-run Chinook salmon juveniles in 2019. The dotted lines represent breaks between each region (Upper Sacramento River, lower Sacramento River, Delta, and Bay). Error bars represent the upper and lower 95% confidence intervals.

Table 4. Detection probability per reach for Coleman late fall-run Chinook salmon juveniles in 2019.

Reach #	Reach	RKM	Region	Estimate (SE)	LCI	UCI
1	BattleCk_CNFH_Rel to Battle_Conf	517.34 to 507.48	Upper Sacramento	0.00 (0.00)	0.00	0.02
2	Battle_Conf to RB_Elks	507.48 to 464.50	Upper Sacramento	0.60 (0.03)	0.55	0.65
3	RB_Elks to Abv_RBPP	464.5 to 463.22	Upper Sacramento	0.90 (0.02)	0.87	0.93
4	Abv_RBPP to Abv_Altube1	463.22 to 460.40	Upper Sacramento	0.91 (0.01)	0.88	0.94
5	Abv_Altube1 to Abv_Altube2	460.40 to 460.07	Upper Sacramento	0.90 (0.02)	0.87	0.93
6	Abv_Altube2 to JV_Glide1	460.07 to 458.67	Upper Sacramento	0.95 (0.01)	0.92	0.97
7	JV_Glide1 to BankRobber	458.67 to 452.5	Upper Sacramento	0.91 (0.02)	0.88	0.94
8	BankRobber to Hunters	452.50 to 450.35	Upper Sacramento	0.94 (0.01)	0.91	0.96
9	Hunters to Lwr_Ant_Crk	450.35 to 447.20	Upper Sacramento	0.95 (0.01)	0.92	0.97
10	Lwr_Ant_Crk to Mill_Ck_Conf	447.20 to 441.31	Upper Sacramento	0.91 (0.02)	0.87	0.94
11	Mill_Ck_Conf to Abv_WoodsonBr	441.31 to 425.15	Upper Sacramento	0.97 (0.01)	0.94	0.98
12	Abv_WoodsonBr to Blw_Woodson	425.15 to 421.40	Upper Sacramento	0.92 (0.01)	0.89	0.95
13	Blw_Woodson to Abv_Otter_Island	421.40 to 419.39	Upper Sacramento	0.96 (0.01)	0.93	0.98
14	Abv_Otter_Island to Blw_IrvineFinch	419.39 to 394.66	Upper Sacramento	0.95 (0.01)	0.91	0.97
15	Blw_IrvineFinch to BlwOrd	394.66 to 361.72	Upper Sacramento	0.93 (0.02)	0.89	0.96
16	BlwOrd to ButteBr	361.72 to 344.10	Upper Sacramento	0.98 (0.01)	0.94	0.99
17	ButteBr to Colusa AC3	344.10 to 331.15	Upper Sacramento	0.95 (0.02)	0.91	0.98
18	Colusa AC3 to Colusa AC2	331.15 to 318.61	Lower Sacramento	0.98 (0.01)	0.94	0.99
19	Colusa AC2 to Colusa BC2	318.61 to 296.27	Lower Sacramento	0.92 (0.02)	0.86	0.95
20	Colusa BC2 to Colusa BC3	296.27 to 287.20	Lower Sacramento	0.89 (0.03)	0.82	0.93
21	Colusa BC3 to Colusa BC4	287.20 to 280.40	Lower Sacramento	0.79 (0.04)	0.71	0.85
22	Colusa BC4 to Blw_Knights_GS3	280.40 to 212.80	Lower Sacramento	0.95 (0.02)	0.9	0.98
23	Blw_Knights_GS3 to Blw_FRConf	212.80 to 203.46	Lower Sacramento	0.01 (0.01)	0.00	0.06
24	Blw_FRConf to Blw_FR_GS2	203.46 to 199.00	Lower Sacramento	0.48 (0.05)	0.39	0.57
25	Blw_FR_GS2 to Blw_Elkhorn_GS1	199.00 to 191.92	Lower Sacramento	0.96 (0.02)	0.91	0.99
26	Blw_Elkhorn_GS1 to TowerBridge	191.92 to 172.00	Lower Sacramento	0.97 (0.02)	0.91	0.99
27	TowerBridge to I80-50_Br	172.00 to 170.74	Lower Sacramento	0.95 (0.02)	0.89	0.98
28	I80-50_Br to SacTrawl	170.74 to 166.82	Lower Sacramento	0.98 (0.01)	0.92	0.99

Reach #	Reach	RKM	Region	Estimate (SE)	LCI	UCI
29	SacTrawl to Freeport	166.82 to 152.43	Lower Sacramento	0.62 (0.05)	0.52	0.71
30	Freeport to Abv_Clarksburg	152.43 to 147.66	Lower Sacramento	0.99 (0.01)	0.90	1.00
31	Abv_Clarksburg to Hood	147.66 to 138.22	Lower Sacramento	0.83 (0.07)	0.66	0.93
32	Hood to Chipps	138.22 to 71.48	Delta	1.00 (0.00)	1.00	1.00
33	Chipps to Benicia	71.48 to 52.14	Bay	1.00 (0.00)	0.00	1.00
34	Benicia to GoldenGateE	52.14 to 1.71	Bay	0.75 (0.15)	0.38	0.94

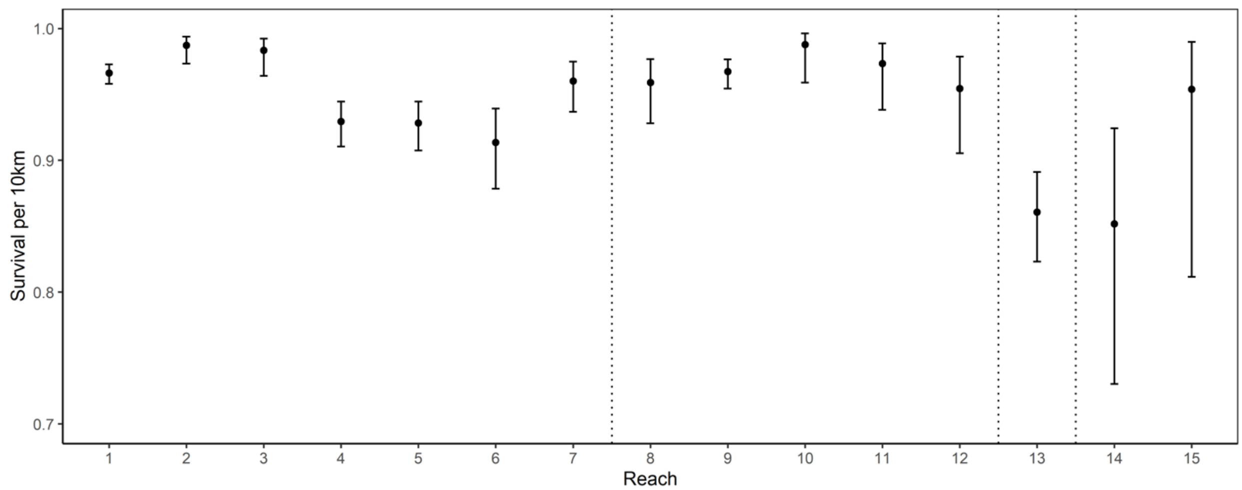

Figure 7. Survival estimates per 10 km by reach for Coleman National Fish Hatchery late fall-run Chinook salmon juveniles in 2019. The dotted lines represent breaks between each region (Upper Sacramento River, lower Sacramento River, Delta, and Bay). Error bars represent the upper and lower 95% confidence intervals.

Table 5. Standardized survival rates per 10 km by reach for Coleman National Fish Hatchery late fall-run Chinook salmon juveniles in 2019.

Reach #	Reach	RKM	Region	Survival per 10km (SE)	LCI	UCI
1	BattleCk_CNFH_Rel to Abv_Altube1	517.34 to 460.40	Upper Sacramento	0.97 (0.00)	0.96	0.97
2	Abv_Altube1 to Mill_Ck_Conf	460.40 to 441.31	Upper Sacramento	0.99 (0.00)	0.97	0.99
3	Mill_Ck_Conf to Abv_WoodsonBr	441.31 to 425.15	Upper Sacramento	0.98 (0.01)	0.96	0.99
4	Abv_WoodsonBr to Blw_IrvineFinch	425.15 to 394.66	Upper Sacramento	0.93 (0.01)	0.91	0.94
5	Blw_IrvineFinch to BlwOrd	394.66 to 361.72	Upper Sacramento	0.93 (0.01)	0.91	0.94
6	BlwOrd to ButteBr	361.72 to 344.10	Upper Sacramento	0.91 (0.02)	0.88	0.94
7	ButteBr to Colusa AC2	344.10 to 318.61	Upper Sacramento	0.96 (0.01)	0.94	0.97
8	Colusa AC2 to Colusa BC2	318.61 to 296.27	Lower Sacramento	0.96 (0.01)	0.93	0.98
9	Colusa BC2 to Blw_Knights_GS3	296.27 to 212.80	Lower Sacramento	0.97 (0.01)	0.95	0.98

Reach #	Reach	RKM	Region	Survival per 10km (SE)	LCI	UCI
10	Blw_Knights_GS3 to Blw_Elkhorn_GS1	212.80 to 191.92	Lower Sacramento	0.99 (0.01)	0.96	1.00
11	Blw_Elkhorn_GS1 to TowerBridge	191.92 to 172.00	Lower Sacramento	0.97 (0.01)	0.94	0.99
12	TowerBridge to Abv_Clarksburg	172.00 to 147.66	Lower Sacramento	0.95 (0.02)	0.91	0.98
13	Abv_Clarksburg to Chipps	147.66 to 71.48	Delta	0.86 (0.02)	0.82	0.89
14	Chipps to Benicia	71.48 to 52.14	Bay	0.85 (0.05)	0.73	0.92
15	Benicia to GoldenGateE	52.14 to 1.71	Bay	0.95 (0.04)	0.81	0.99

Cumulative Survival

Cumulative survival from release location at CNFH through the upper Sacramento River was 38% (± 0.02; Figure 8, Table 6). Survival from release location through the lower Sacramento River was 21% (± 0.02), and survival from release location through the Delta was 7% (± 0.01). Survival through the entire study area from release location to the Golden Gate Bridge was 4% (± 0.01).

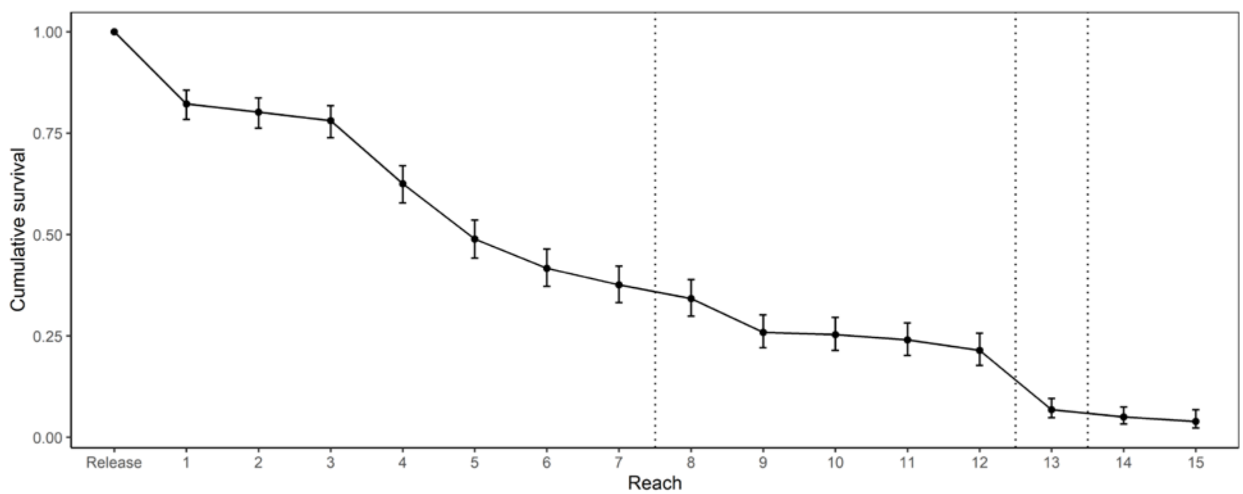

Figure 8. Cumulative survival by reach for Coleman National Fish Hatchery late fall-run Chinook salmon juveniles in 2019. The dotted lines represent breaks between each region (from left to right: Upper Sacramento River, lower Sacramento River, Delta, and Bay). Error bars represent the upper and lower 95% confidence intervals.

Table 6. Cumulative survival for Coleman National Fish Hatchery late fall-run Chinook salmon juveniles in 2019.

Reach #	Receiver Site	RKM	Region	Cumulative survival (SE)	LCI	UCI
1	Abv_Altube1	460.40	Upper Sacramento	0.82 (0.02)	0.78	0.86
2	Mill_Ck_Conf	441.31	Upper Sacramento	0.80 (0.02)	0.76	0.84
3	Abv_WoodsonBr	425.15	Upper Sacramento	0.78 (0.02)	0.74	0.82
4	Blw_IrvineFinch	394.66	Upper Sacramento	0.62 (0.02)	0.58	0.67
5	BlwOrd	361.72	Upper Sacramento	0.49 (0.02)	0.44	0.54
6	ButteBr	344.10	Upper Sacramento	0.42 (0.02)	0.37	0.46
7	Colusa AC2	318.61	Upper Sacramento	0.38 (0.02)	0.33	0.42
8	Colusa BC2	296.27	Lower Sacramento	0.34 (0.02)	0.30	0.39

Reach #	Receiver Site	RKM	Region	Cumulative survival (SE)	LCI	UCI
9	Blw_Knights_GS3	212.80	Lower Sacramento	0.26 (0.02)	0.22	0.30
10	Blw_Elkhorn_GS1	191.92	Lower Sacramento	0.25 (0.02)	0.21	0.30
11	TowerBridge	172.00	Lower Sacramento	0.24 (0.02)	0.20	0.28
12	Abv_Clarksburg	147.66	Lower Sacramento	0.21 (0.02)	0.18	0.26
13	Chipps	71.48	Delta	0.07 (0.01)	0.05	0.10
14	Benicia	52.14	Bay	0.05 (0.01)	0.03	0.08
15	GoldenGateE	1.71	Bay	0.04 (0.01)	0.02	0.07

3.1.2. Winter-Run Chinook

Winter-run Chinook salmon smolts, tagged as part of the Trawl Efficiency Study, were tagged at Livingston Stone National Fish Hatchery (LSNFH) and released into the Sacramento River at Caldwell Park on February 14, 2019. This release coincided with a large storm event which increased flows in the Sacramento River at Bend Bridge to 75,000 cfs shortly after release. This high water created optimum outmigration conditions for juveniles, but unfavorable conditions for receiver detection efficiencies (see Figure 12). As a result, many sites are removed from the reach-specific analysis due to poor detection efficiencies. In addition, because some fish entered the Yolo Bypass via the Fremont Weir, we do not present survival estimates at a resolution lower than the region spanning Fremont Weir to Chipps Island (which represents the region across which these two alternative routes exist). As such, regional breaks are slightly different from other study groups.

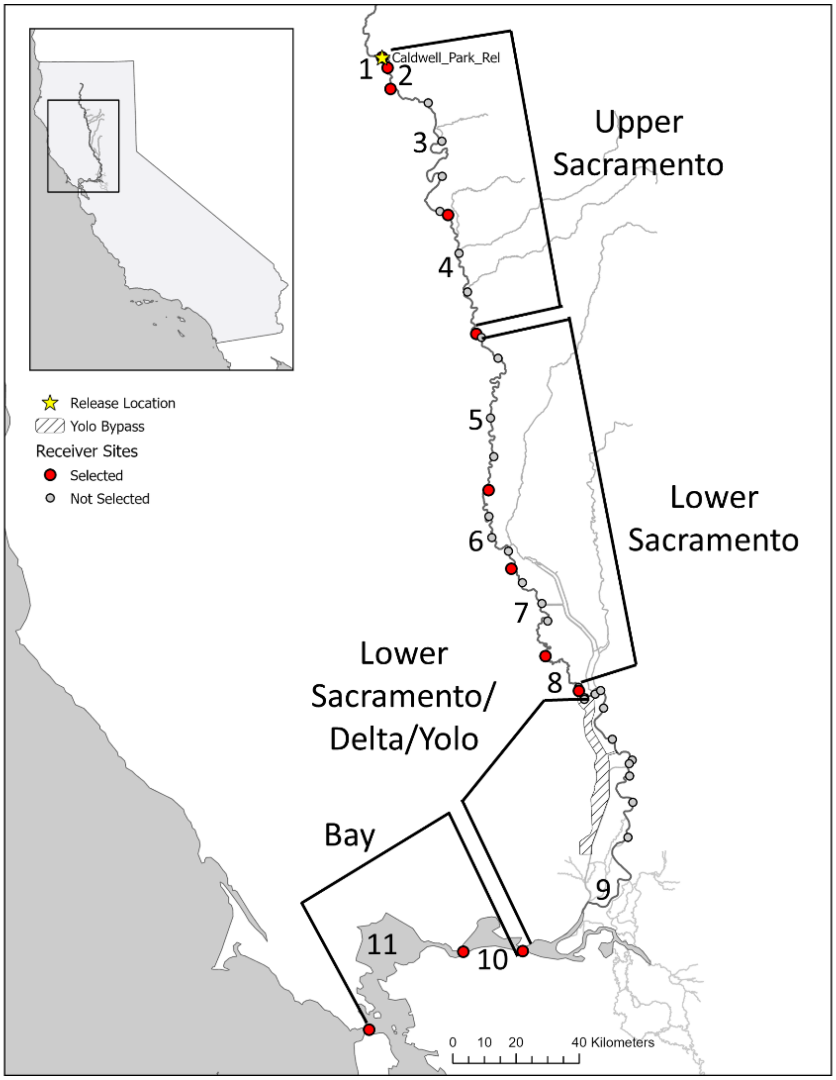

Figure 9. Map of receiver locations, release location, and regions for LSNFH winter-run Chinook salmon juveniles in 2019. Points in red are receiver sites selected for survival estimation and points in gray are receivers that were deployed but not used.

Regional Survival

Survival through the upper Sacramento River from Caldwell Park release to Colusa was 61% (± 0.02; Figure 9, Table 7) for acoustic-tagged fish, while standardized survival was 98% (± 0.00; Figure 10, Table 7). Survival through the lower Sacramento River from Colusa to Knight Landing was 83% (± 0.03), while standardized survival was 98% (± 0.00). Survival through the lower Sacramento/Delta/Yolo region from Knights Landing to Chipps Island was 57% (± 0.03), while standardized survival was 96% (± 0.00). Survival through the Bay from Chipps Island to the Golden Gate Bridge was 69% (± 0.04), while standardized survival was 95% (± 0.01).

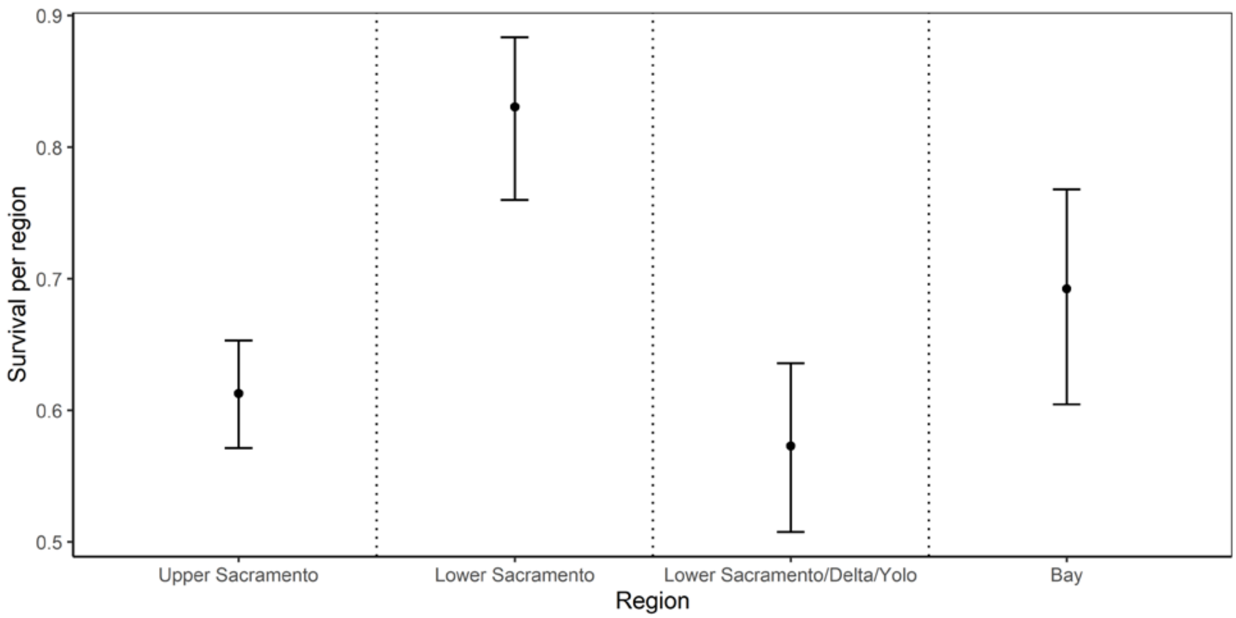

Figure 10. Survival estimates per region for LSNFH winter-run Chinook salmon juveniles in 2019. Error bars represent the upper and lower 95% confidence intervals.

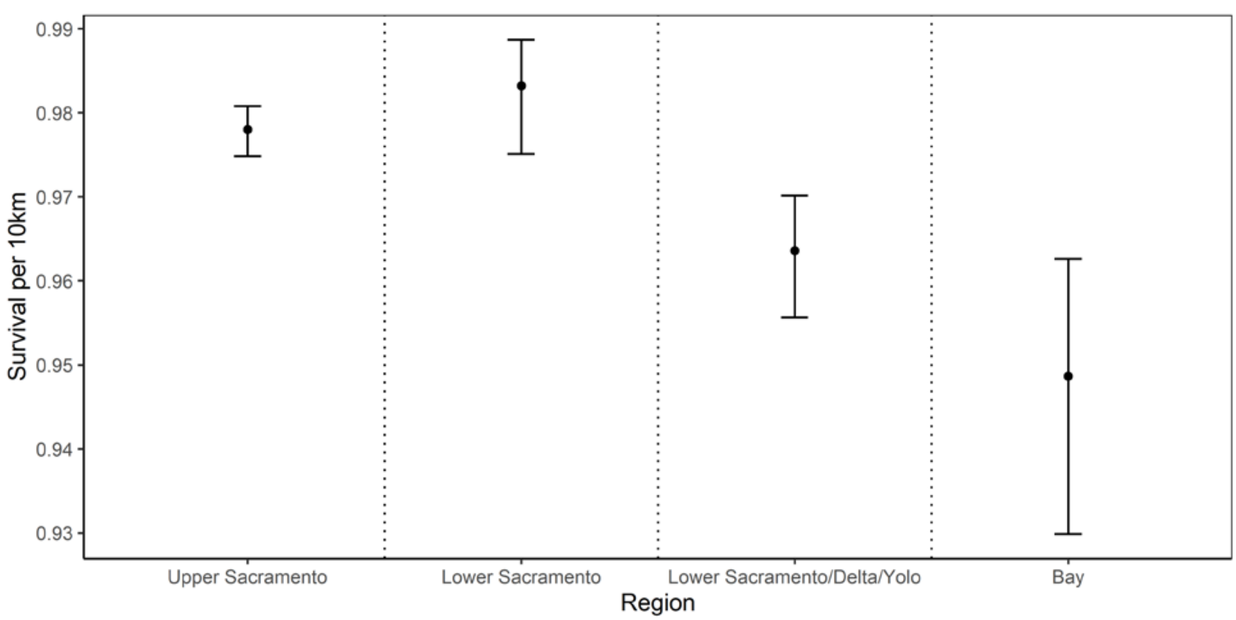

Figure 11. Survival estimates per 10 km by region for LSNFH winter-run Chinook salmon juveniles in 2019. Error bars represent the upper and lower 95% confidence intervals.

Table 7. Survival rates and standardized survival rates per 10 km by region for LSNFH winter-run Chinook salmon juveniles in 2019.

Region	Reach	RKM	Survival (SE)	LCI	UCI	Survival per 10km (SE)	LCI	UCI
Upper Sacramento	Caldwell_Park_Rel to Colusa AC3	551.28 to 331.15	0.61 (0.02)	0.57	0.65	0.98 (0.00)	0.97	0.98
Lower Sacramento	Colusa AC3 to KnightsBlwRST	331.15 to 221.58	0.83 (0.03)	0.76	0.88	0.98 (0.00)	0.98	0.99
Lower Sacramento/Delta/Yolo	KnightsBlwRST to Chipps	221.58 to 71.48	0.57 (0.03)	0.51	0.64	0.96 (0.00)	0.96	0.97
Bay	Chipps to GoldenGateE	71.48 to 1.71	0.69 (0.04)	0.60	0.77	0.95 (0.01)	0.93	0.96

Reach-Specific Survival

Of the 40 receiver sites deployed during this study, 11 were used to analyze reach-specific survival based on detection efficiencies greater than 70% (Figure 12, Table 8). Receiver locations used for the Trawl Efficiency Study were also included in this analysis. Standardized reach-specific survival trends through the upper Sacramento River was generally high but decreasing in reach 5 at 95% (± 0.00; Figure 13, Table 9), followed by increasing survival in reaches 6-8 in the lower Sacramento River. Survival rates decreased to 97% ± (0.00) in the Lower Sacramento/Delta/Yolo and were even lower in the San Francisco Bay. Survival from Benicia to the Golden Gate Bridge was 95% (± 0.01).

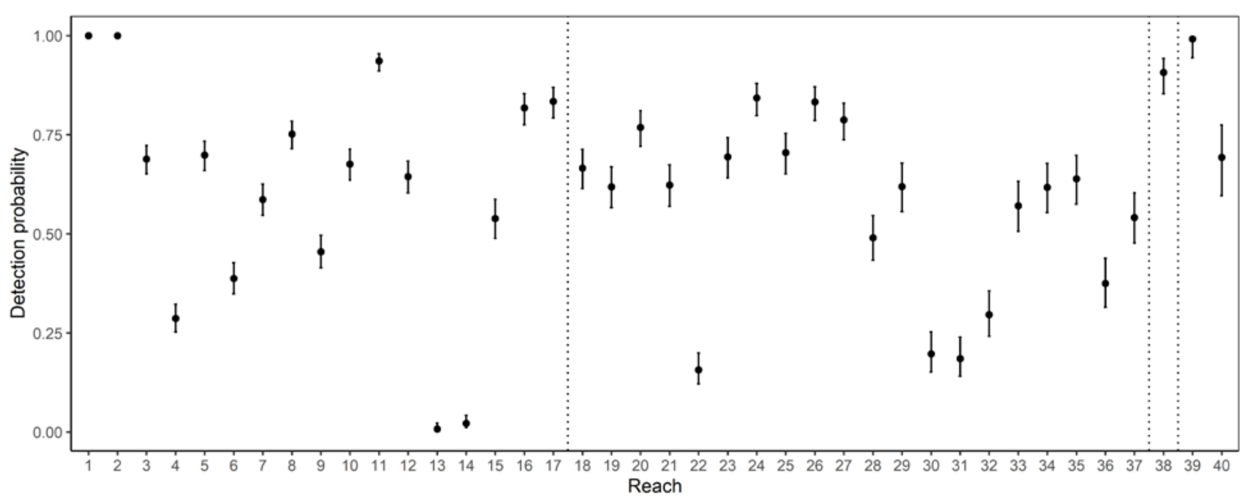

Figure 12. Detection probability per reach for 2019 LSNFH winter-run Chinook salmon juveniles. The dotted lines represent breaks between each region (Upper Sacramento River, lower Sacramento River, lower Sacramento/Delta/Yolo, and Bay). Error bars represent the upper and lower 95% confidence intervals.

Table 8. Detection probability per reach for LSNFH winter-run Chinook salmon juveniles in 2019.

Reach #	Reach	RKM	Region	Estimate (SE)	LCI	UCI
1	Caldwell_Park_Rel to Blw_Cypress	551.28 to 543.9	Upper Sacramento	1.00 (0.00)	1.00	1.00
2	Blw_Cypress to Blw_ClearCr	543.9 to 535.62	Upper Sacramento	1.00 (0.00)	1.00	1.00
3	Blw_ClearCr to BlwCowCr	535.62 to 520.69	Upper Sacramento	0.69 (0.02)	0.65	0.72
4	BlwCowCr to Battle_Conf	520.69 to 507.48	Upper Sacramento	0.29 (0.02)	0.25	0.32
5	Battle_Conf to Blw_Paynes_Ck	507.48 to 476.27	Upper Sacramento	0.70 (0.02)	0.66	0.73
6	Blw_Paynes_Ck to Abv_Altube1	476.27 to 460.4	Upper Sacramento	0.39 (0.02)	0.35	0.43
7	Abv_Altube1 to Abv_Altube2	460.4 to 460.07	Upper Sacramento	0.59 (0.02)	0.55	0.63
8	Abv_Altube2 to Blw_Salt	460.07 to 456.88	Upper Sacramento	0.75 (0.02)	0.72	0.78
9	Blw_Salt to Mill_Ck_Conf	456.88 to 441.31	Upper Sacramento	0.45 (0.02)	0.41	0.50
10	Mill_Ck_Conf to Abv_WoodsonBr	441.31 to 425.15	Upper Sacramento	0.68 (0.02)	0.64	0.71
11	Abv_WoodsonBr to GCID_abv	425.15 to 406.11	Upper Sacramento	0.94 (0.01)	0.91	0.95
12	GCID_abv to GCID_blw	406.11 to 404.42	Upper Sacramento	0.64 (0.02)	0.60	0.68
13	GCID_blw to Blw_IrvineFinch	404.42 to 394.66	Upper Sacramento	0.01 (0.00)	0.00	0.02
14	Blw_IrvineFinch to BlwOrd	394.66 to 361.72	Upper Sacramento	0.02 (0.01)	0.01	0.04
15	BlwOrd to ButteBr	361.72 to 344.1	Lower Sacramento	0.54 (0.03)	0.49	0.59
16	ButteBr to Colusa AC3	344.1 to 331.15	Upper Sacramento	0.82 (0.02)	0.78	0.85
17	Colusa AC3 to Colusa AC2	331.15 to 318.61	Upper Sacramento	0.83 (0.02)	0.79	0.87
18	Colusa AC2 to AbvColusaBr	318.61 to 307.73	Lower Sacramento	0.67 (0.03)	0.61	0.71
19	AbvColusaBr to Colusa BC2	307.73 to 296.27	Lower Sacramento	0.62 (0.03)	0.57	0.67
20	Colusa BC2 to Colusa BC3	296.27 to 287.2	Lower Sacramento	0.77 (0.02)	0.72	0.81
21	Colusa BC3 to Colusa BC4	287.2 to 280.4	Lower Sacramento	0.62 (0.03)	0.57	0.67
22	Colusa BC4 to AbvTisdale	280.4 to 269.23	Lower Sacramento	0.16 (0.02)	0.12	0.20
23	AbvTisdale to BlwTisdale	269.23 to 261.4	Lower Sacramento	0.69 (0.03)	0.64	0.74
24	BlwTisdale to BlwChinaBend	261.4 to 240.61	Lower Sacramento	0.84 (0.02)	0.80	0.88
25	BlwChinaBend to Knights_RST	240.61 to 222.05	Lower Sacramento	0.70 (0.03)	0.65	0.75
26	Knights_RST to KnightsBlwRST	222.05 to 221.58	Lower Sacramento	0.83 (0.02)	0.79	0.87
27	KnightsBlwRST to Abv_FremontWeir	221.58 to 215.18	Lower Sacramento	0.79 (0.02)	0.74	0.83
28	Abv_FremontWeir to Blw_Knights_GS3	215.18 to 212.8	Lower Sacramento	0.49 (0.03)	0.43	0.55

Reach #	Reach	RKM	Region	Estimate (SE)	LCI	UCI
29	Blw_Knights_GS3 to Blw_FremontWeir	212.8 to 210.36	Lower Sacramento	0.62 (0.03)	0.56	0.68
30	Blw_FremontWeir to Blw_FRConf	210.36 to 203.46	Lower Sacramento	0.20 (0.03)	0.15	0.25
31	Blw_FRConf to Blw_FR_GS2	203.46 to 199	Lower Sacramento	0.18 (0.02)	0.14	0.24
32	Blw_FR_GS2 to Blw_Elkhorn_GS1	199 to 191.92	Lower Sacramento	0.30 (0.03)	0.24	0.36
33	Blw_Elkhorn_GS1 to TowerBridge	191.92 to 172	Lower Sacramento	0.57 (0.03)	0.51	0.63
34	TowerBridge to I80-50_Br	172 to 170.74	Lower Sacramento	0.62 (0.03)	0.55	0.68
35	I80-50_Br to SacTrawl	170.74 to 166.815	Lower Sacramento	0.64 (0.03)	0.58	0.70
36	SacTrawl to Freeport	166.815 to 152.43	Lower Sacramento	0.37 (0.03)	0.32	0.44
37	Freeport to Hood	152.43 to 138.22	Lower Sacramento	0.54 (0.03)	0.48	0.6
38	Hood to Chipps	138.22 to 71.48	Delta	0.91 (0.02)	0.85	0.94
39	Chipps to Benicia	71.48 to 52.14	Bay	0.99 (0.01)	0.94	1.00
40	Benicia to GoldenGateE	52.14 to 1.71	Bay	0.69 (0.05)	0.60	0.78

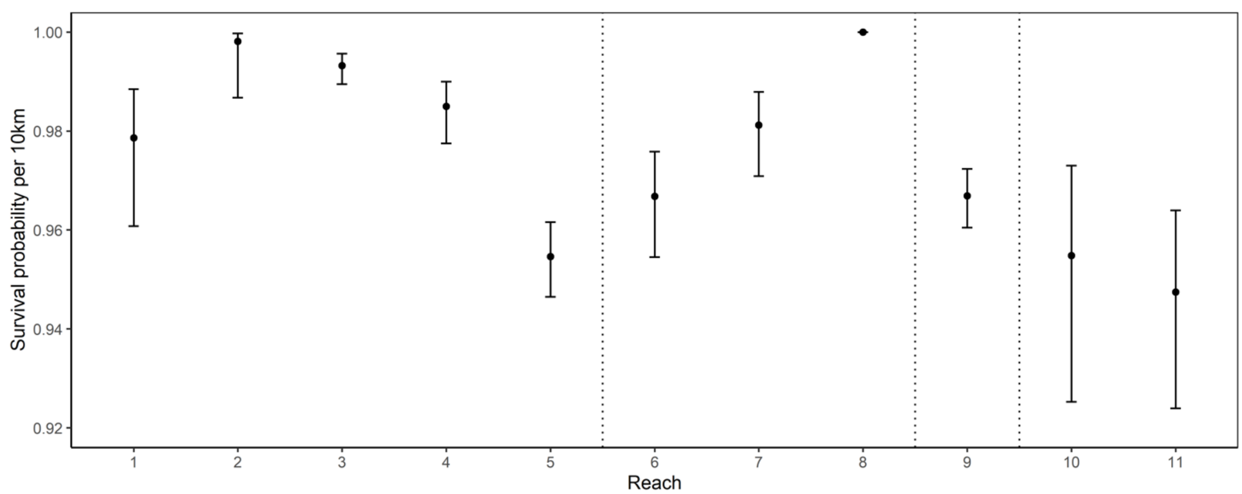

Figure 13. Survival estimates per 10 km by reach for LSNFH winter-run Chinook salmon juveniles in 2019. The dotted lines represent breaks between each region (Upper Sacramento River, lower Sacramento River, lower Sacramento/Delta/Yolo, and Bay). Error bars represent the upper and lower 95% confidence intervals.

Table 9. Standardized survival rates per 10 km by reach for LSNFH winter-run Chinook salmon juveniles in 2019.

Reach #	Reach	RKM	Region	Survival per 10km (SE)	LCI	UCI
1	Caldwell_Park to Blw_Cypress	551.08 to 543.9	Upper Sacramento	0.98 (0.01)	0.96	0.99
2	Blw_Cypress to Blw_ClearCr	543.9 to 535.62	Upper Sacramento	1.00 (0.00)	0.99	1.00
3	Blw_ClearCr to Blw_Salt	535.62 to 456.88	Upper Sacramento	0.99 (0.00)	0.99	1.00
4	Blw_Salt to GCID_abv	456.88 to 406.11	Upper Sacramento	0.98 (0.00)	0.98	0.99
5	GCID_abv to Colusa AC3	406.11 to 331.15	Upper Sacramento	0.95 (0.00)	0.95	0.96
6	Colusa AC3 to Colusa BC3	331.15 to 287.2	Lower Sacramento	0.97 (0.01)	0.95	0.98
7	Colusa BC3 to BlwChinaBend	287.2 to 240.61	Lower Sacramento	0.98 (0.00)	0.97	0.99
8	BlwChinaBend to KnightsBlwRST	240.61 to 221.58	Lower Sacramento	1.00 (0.00)	1.00	1.00
9	KnightsBlwRST to Chipps	221.58 to 71.48	Lower Sacramento/Delta/Yolo	0.97 (0.00)	0.96	0.97
10	Chipps to Benicia	71.48 to 52.14	Bay	0.95 (0.01)	0.93	0.97
11	Benicia to GoldenGateE	52.14 to 1.71	Bay	0.95 (0.01)	0.92	0.96

Cumulative Survival

Cumulative survival from release at Caldwell Park through the upper Sacramento River was 61% (± 0.02; Figure 14, Table 10), with the lowest survival observed in reach 5 of this section. Cumulative survival from release through the lower Sacramento River reach was 48% (± 0.02), which was a relatively short section due to the Yolo Bypass split. Cumulative survival from release through the remainder of the lower Sacramento River, Delta, and Yolo Bypass was 29% (± 0.02). Cumulative survival from release to the Golden Gate Bridge was 20% (± 0.02).

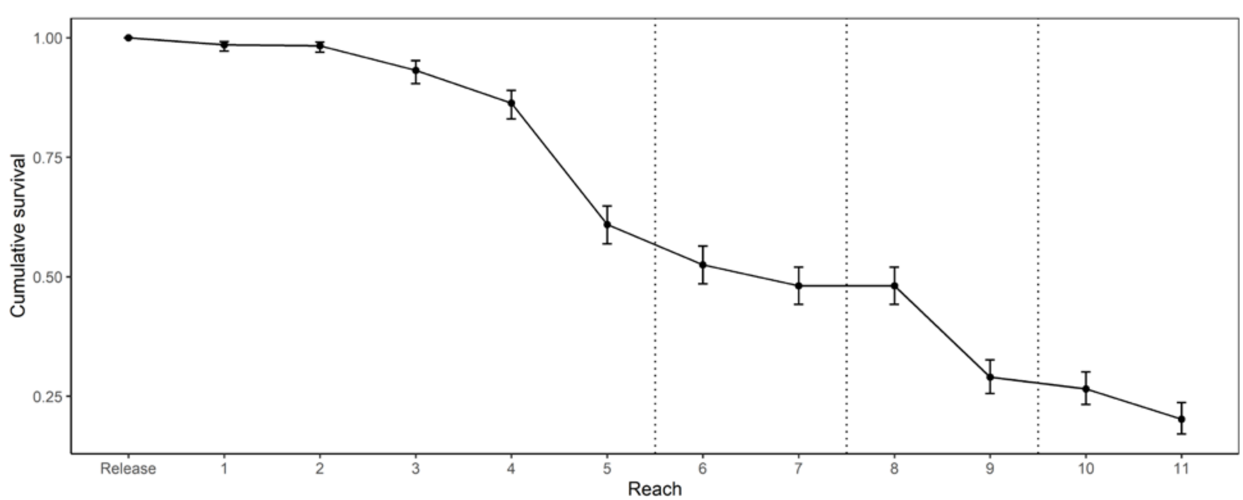

Figure 14. Cumulative survival by reach for LSNFH winter-run Chinook salmon juveniles in 2019. The dotted lines represent breaks between each region (Upper Sacramento River, lower Sacramento River,

lower Sacramento/Delta/Yolo, and Bay). Error bars represent the upper and lower 95% confidence intervals.

Table 10. Cumulative survival for LSNFH winter-run Chinook salmon juveniles in 2019.

Reach #	Receiver Site	RKM	Region	Cumulative survival (SE)	LCI	UCI
1	Blw_Cypress	543.9	Upper Sacramento	0.98 (0.00)	0.97	0.99
2	Blw_ClearCr	535.62	Upper Sacramento	0.98 (0.00)	0.97	0.99
3	Blw_Salt	456.88	Upper Sacramento	0.93 (0.01)	0.90	0.95
4	GCID_abv	406.11	Upper Sacramento	0.86 (0.02)	0.83	0.89
5	Colusa AC3	331.15	Upper Sacramento	0.61 (0.02)	0.57	0.65
6	Colusa BC3	287.2	Lower Sacramento	0.52 (0.02)	0.48	0.56
7	BlwChinaBend	240.61	Lower Sacramento	0.48 (0.02)	0.44	0.52
8	KnightsBlwRST	221.58	Lower Sacramento	0.48 (0.02)	0.44	0.52
9	Chipps	71.48	Lower Sacramento/Delta/Yolo	0.29 (0.02)	0.26	0.33
10	Benicia	52.14	Bay	0.26 (0.02)	0.23	0.30
11	GoldenGateE	1.71	Bay	0.20 (0.02)	0.17	0.24

Yolo Bypass Survival

High water conditions during the winter of 2019 allowed winter-run Chinook salmon passage over the Fremont Weir and into the Yolo Bypass. Two receivers located upstream of the Yolo Bypass (Abv_FremontWeir and Blw_Knights_GS3; hereafter referred to as Abv_Yolo) allowed for detections of fish prior to the split of the Yolo Bypass and the Sacramento River. A total of 248 fish were detected upstream of the Yolo Bypass, a large portion of which had the opportunity to enter the Bypass (Figure 15). Routing into the bypass was determined by whether or not a fish was detected downstream of the Yolo Bypass at various Sacramento River receiver locations (Blw_FremontWeir, Butte6, Blw_FRConf, Blw_FR_GS2, Blw_Elkhorn_GS1, TowerBridge, and I80-50_Br). If any fish was not detected at one of these Sacramento River locations it was assumed to have spilled into the Yolo Bypass. Of the 248 fish detected at Abv_Yolo, 151 of these fish were detected downstream of the Yolo Bypass in the Sacramento River, with the remaining 97 fish assumed to have entered the Yolo Bypass. Of the 97 fish that were believed to have entered the Yolo Bypass, 31 were detected at Chipps, while 94 of the 151 fish that went through the Sacramento River were detected at Chipps. Survival was estimated for the 97 fish that potentially entered the Yolo Bypass by assigning a “release” at Abv_Yolo, and a “recapture” location downstream at Chipps Island, a distance of 102 km. Survival from Abv_Yolo to Chipps was 43% (± 0.05) and standardized survival was 94% (± 0.01) through the region (Figure 16). For fish that remained in the Sacramento River, total survival from Abv_Yolo to Chipps was 67% (± 0.04) and standardized survival was 97% (± 0.00). It should be noted, though, that some of the 97 fish assumed to have entered Yolo Bypass may have instead stayed in the mainstem and been missed by receivers in the Sacramento River below the entrance to the Yolo Bypass. As such, survival estimates for the Yolo Bypass presented here are likely biased low, and should only be used for discussion purposes only.

Movement speeds for fish that were detected both at Abv_Yolo and Chipps Island varied substantially as a result of route taken, with fish that traveled by way of the mainstem Sacramento River travelling much faster (median 31.47 km/day) than fish that took Yolo Bypass (median 3.68 km/day; Figure 17).

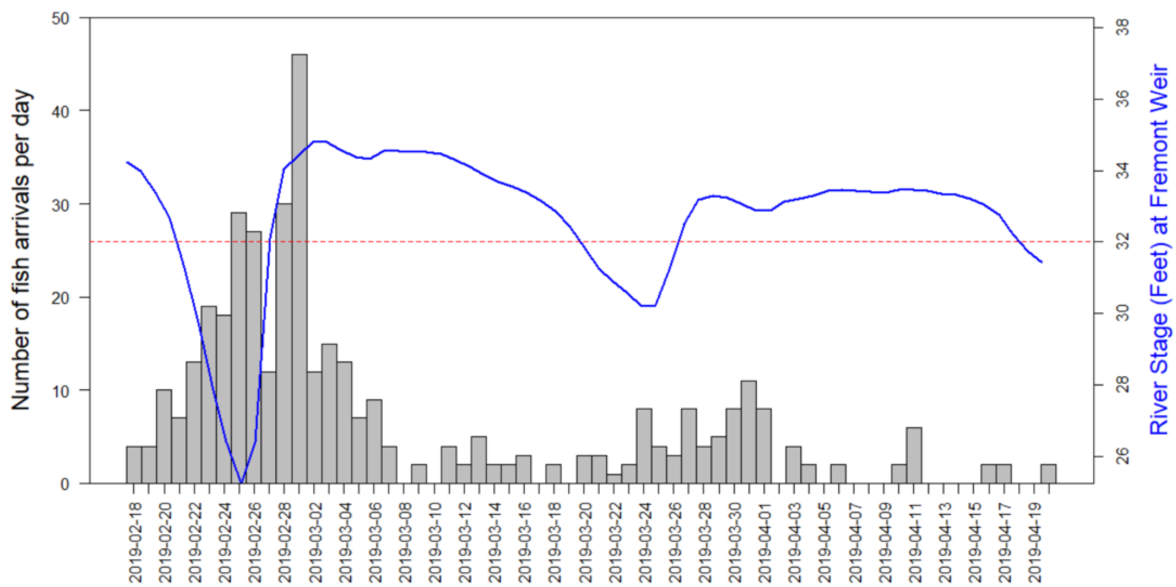

Figure 15. Number of unique fish arrivals per day upstream of the Yolo Bypass (Abv_FremontWeir and Blw_Knights_GS3) vs. river stage height (feet) for the Sacramento River at Fremont Weir. The red line indicates the stage height at which water flows over the weir.

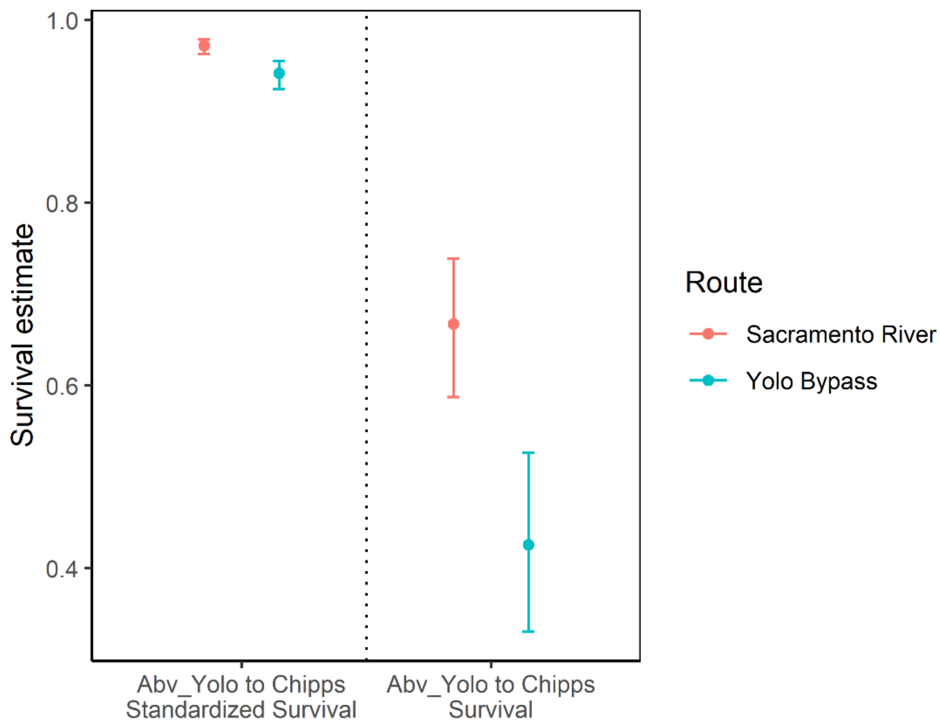

Figure 16. Standardized (per 10 km) and raw survival estimates for fish migrating down the Yolo Bypass and Sacramento River.

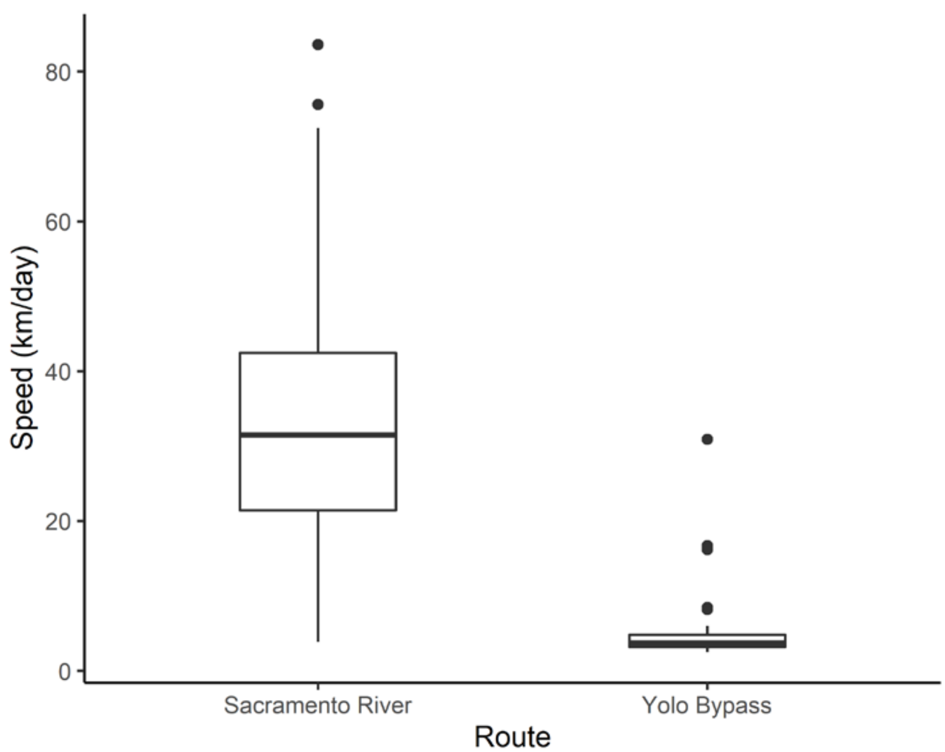

Figure 17. Movement speeds from above the Yolo Bypass to Chipps Island. Distance through the Sacramento River reach is 142 km, and distance through the Yolo Bypass reach is 102 km.

3.1.3. Spring-Run Chinook

Feather River spring-run Chinook salmon smolts, tagged as part of the Trawl Efficiency Study, were tagged at the Feather River Hatchery and released at two locations in the lower Feather River - Gridley and Boyd's Pump. These release locations are consistent with previous acoustic tagging studies and allow for survival comparisons between upstream (Gridley) and downstream (Boyd's Pump) release groups. On April 22, 2019, 600 fish were released into the Feather River, with 300 fish released at Gridley and 300 fish released at Boyd's Pump. Fish were released into the Feather River prior to an increase in flows from ~8,800 cfs to ~10,200 cfs, which likely improved survival through the Feather River compared to previous study years.

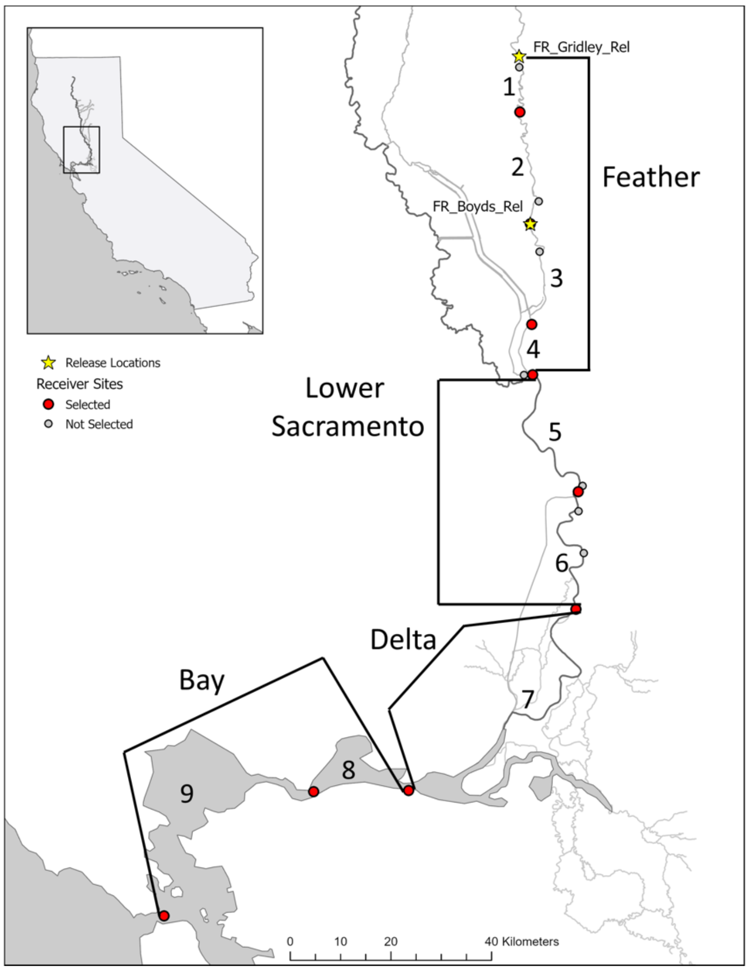

Figure 18. Map of receiver locations, release location, and regions for Feather River spring-run Chinook salmon in 2019. Points in red are receiver sites selected for survival estimation and points in gray are receivers that were deployed but not used. Fish were released in two groups (Gridley and Boyd's Pump).

Regional Survival

Survival through the Feather River was 39% (± 0.03) for the Gridley (more upstream) release group and 67% (± 0.03) for the Boyd's Pump (more downstream) release group (Figure 19).

Standardized survival for these release groups was 89% (± 0.01) for Gridley release and 90% (± 0.01) for the Boyd's Pump release (Figure 20; Table 11). Survival through the lower Sacramento River from Verona to Hood was 86% (± 0.06) for the Gridley release and 94% (± 0.05) for the Boyd's Pump release. Standardized survival through the lower Sacramento River was 98% (± 0.01) for Gridley release and 99% (0.01) for Boyd's Pump release. Regional survival through the Delta from Hood to Chipps Island was 61% (± 0.06) for the Gridley release and 56% (± 0.04) for the Boyd's Pump release groups. Standardized survival through the Delta was 93% (± 0.01) for the Gridley release and 92% (± 0.01) for the Boyd's Pump release. Regional survival through the San Francisco Bay from Chipps Island to the Golden Gate Bridge was 79% (± 0.05) for the Gridley release and 72% (± 0.05) for the Boyd's Pump release. Standardized survival through this region was 97% (± 0.01) for the Gridley release and 95% (± 0.01) for the Boyd's Pump release.

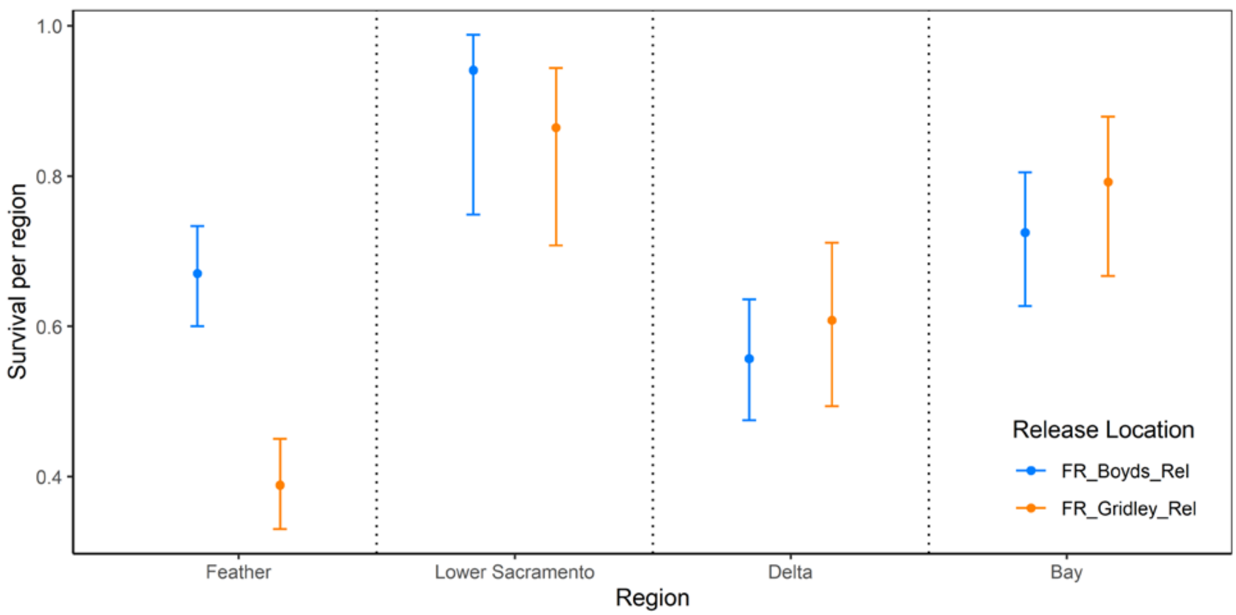

Figure 19. Survival estimates per region for Feather River spring-run Chinook salmon in 2019. Orange lines indicate the Gridley release group and blue lines indicate the Boyd's Pump release group. Error bars represent the upper and lower 95% confidence intervals.

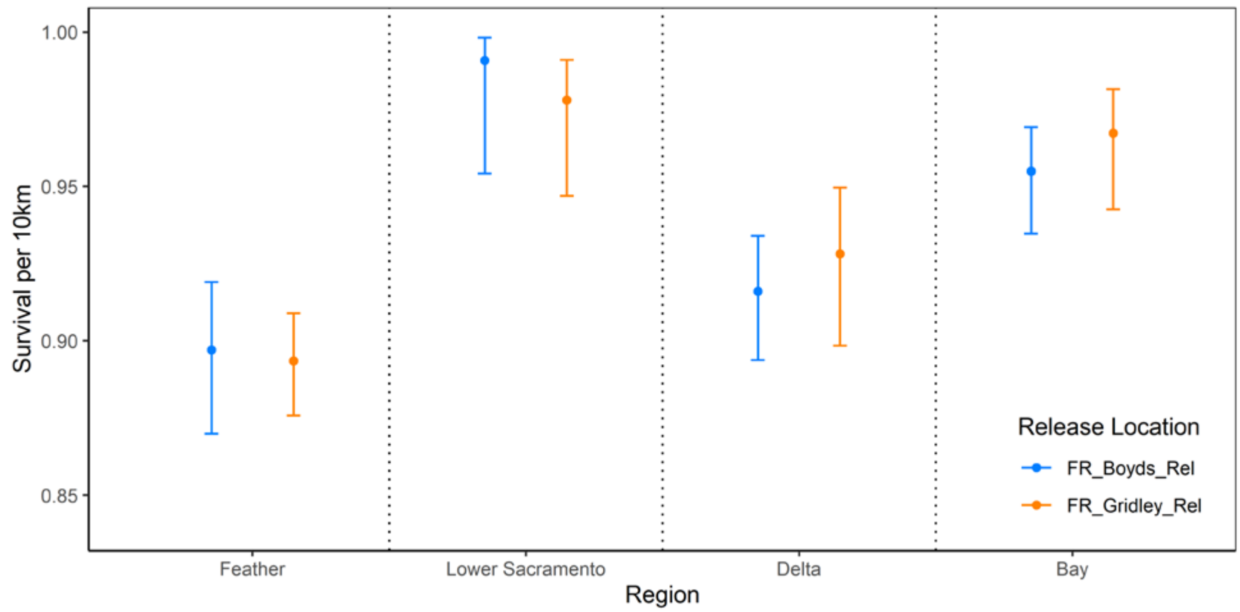

Figure 20. Survival estimates per 10 km by region for Feather River spring-run Chinook salmon in 2019. Orange lines indicate the Gridley release group and blue lines indicate the Boyd's Pump release group. Error bars represent the upper and lower 95% confidence intervals.

Table 11. Survival rates and standardized survival rates per 10 km by region for Feather River spring-run 2019.

Release Location	Region	Reach	RKM	Survival per region (SE)	LCI	UCI	Survival per 10km (SE)	LCI	UCI
Gridley	Feather	FR_Gridley_Rel to Blw_FRConf	287.38 to 203.46	0.39 (0.03)	0.33	0.45	0.89 (0.01)	0.88	0.91
	Lower Sacramento	Blw_FRConf to Hood	203.46 to 138.22	0.86 (0.06)	0.71	0.94	0.98 (0.01)	0.95	0.99
	Delta	Hood to Chipps	138.22 to 71.48	0.61 (0.06)	0.49	0.71	0.93 (0.01)	0.90	0.95
	Bay	Chipps to GoldenGateE	71.48 to 1.71	0.79 (0.05)	0.67	0.88	0.97 (0.01)	0.94	0.98
Boyds	Feather	BoydsPump to Blw_FRConf	240.27 to 203.46	0.67 (0.03)	0.60	0.73	0.90 (0.01)	0.87	0.92
	Lower Sacramento	Blw_FRConf to Hood	203.46 to 138.22	0.94 (0.05)	0.75	0.99	0.99 (0.01)	0.95	1.00
	Delta	Hood to Chipps	138.22 to 71.48	0.56 (0.04)	0.48	0.64	0.92 (0.01)	0.89	0.93
	Bay	Chipps to GoldenGateE	71.48 to 1.71	0.72 (0.05)	0.63	0.80	0.95 (0.01)	0.93	0.97

Reach-Specific Survival

Of the 19 receiver sites deployed during this study, 11 were used to analyze reach-specific survival based on detection efficiencies greater than 70% (Figure 21; Table 12). Receiver locations used for the Trawl Efficiency Study were also included in this analysis. Standardized reach-specific survival trends through the Feather River indicated low survival in reach 3 (85% (± 0.02) for Gridley release, 87% (± 0.01) for Boyd's Pump release), followed by increasing survival in reaches 4-6 in the lower Sacramento River (Figure 22; Table 13). Survival rates decreased in the Delta for both groups (reach 7, 93% (± 0.01) for Gridley release, 92% (± 0.01) for Boyd's Pump release), and increased slightly, but remained relatively low in the San Francisco Bay. Survival from Chipps Island to Benicia was 98% (± 0.01) for the Gridley release and 96% (± 0.01) for the Boyd's Pump release, and survival rates from Benicia to the Golden Gate Bridge was 96 %(± 0.01) for the Gridley release and 95% (± 0.01) for the Boyd's Pump release.

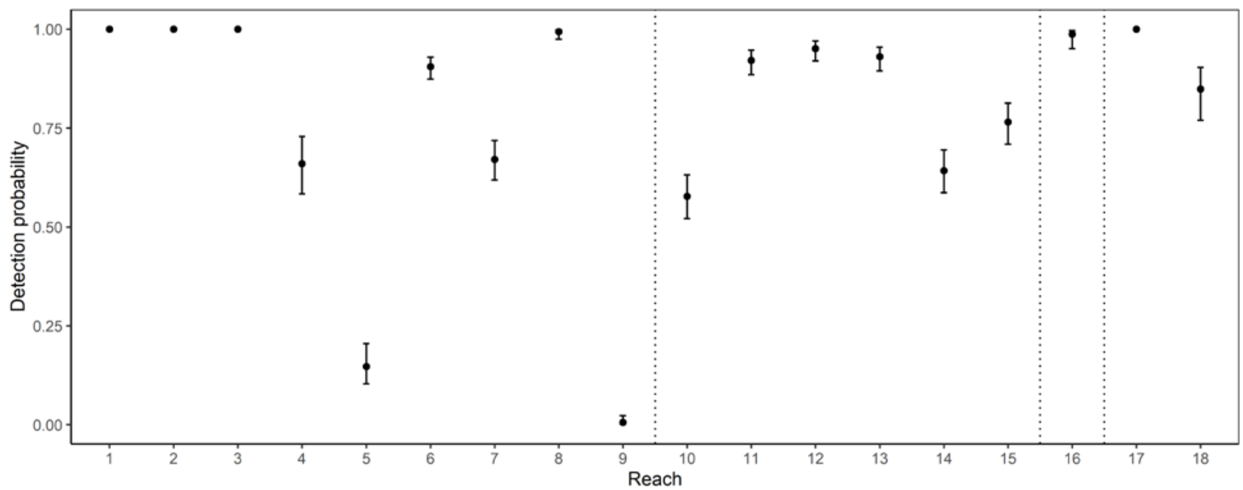

Figure 21. Detection probability per reach for Feather River spring-run Chinook salmon in 2019. The dotted lines represent breaks between each region (Feather River, lower Sacramento River, lower Delta, and Bay). Error bars represent the upper and lower 95% confidence intervals.

Table 12. Detection probability per reach for Feather River spring-run Chinook salmon in 2019. The dotted lines represent breaks between each region (Feather River, lower Sacramento River, lower Delta, and Bay). Error bars represent the upper and lower 95% confidence intervals.

Reach #	Reach	RKM	Region	Estimate	LCI	UCI
1	FR_Gridley_Rel to Gridley	287.38 to 287.02	Feather	1.00 (0.00)	1.00	1.00
2	Gridley to CoxRiffle	287.02 to 283.87	Feather	1.00 (0.00)	1.00	1.00
3	CoxRiffle to SunsetPumps	283.87 to 269.75	Feather	1.00 (0.00)	1.00	1.00
4	SunsetPumps to ShanghaiBend	269.75 to 245.45	Feather	0.66 (0.04)	0.58	0.73
5	ShanghaiBend to FR_Boyds_Rel	245.45 to 240.75	Feather	0.15 (0.03)	0.10	0.21
6	FR_Boyds_Rel to BoydsPump	240.75 to 240.27	Feather	0.90 (0.01)	0.87	0.93
7	BoydsPump to StarBend	240.27 to 234.92	Feather	0.67 (0.03)	0.62	0.72
8	StarBend to BC_Beach	234.92 to 217.31	Feather	0.99 (0.00)	0.97	1.00
9	BC_Beach to Butte6	217.31 to 206.48	Feather	0.01 (0.00)	0.00	0.02
10	Butte6 to Blw_FRConf	206.48 to 203.46	Lower Sacramento	0.58 (0.03)	0.52	0.63
11	Blw_FRConf to TowerBridge	203.46 to 172.00	Lower Sacramento	0.92 (0.02)	0.89	0.95
12	TowerBridge to I80-50_Br	172.00 to 170.74	Lower Sacramento	0.95 (0.01)	0.92	0.97

Reach #	Reach	RKM	Region	Estimate	LCI	UCI
13	I80-50_Br to SacTrawl	170.74 to 166.82	Lower Sacramento	0.93 (0.01)	0.89	0.95
14	SacTrawl to Freeport	166.82 to 152.43	Lower Sacramento	0.64 (0.03)	0.59	0.69
15	Freeport to Hood	152.43 to 138.22	Lower Sacramento	0.77 (0.03)	0.71	0.81
16	Hood to Chipps	138.22 to 71.48	Delta	0.99 (0.01)	0.95	1.00
17	Chipps to Benicia	71.48 to 52.14	Bay	1.00 (0.00)	1.00	1.00
18	Benicia to GoldenGateE	52.14 to 1.71	Bay	0.85 (0.03)	0.77	0.90

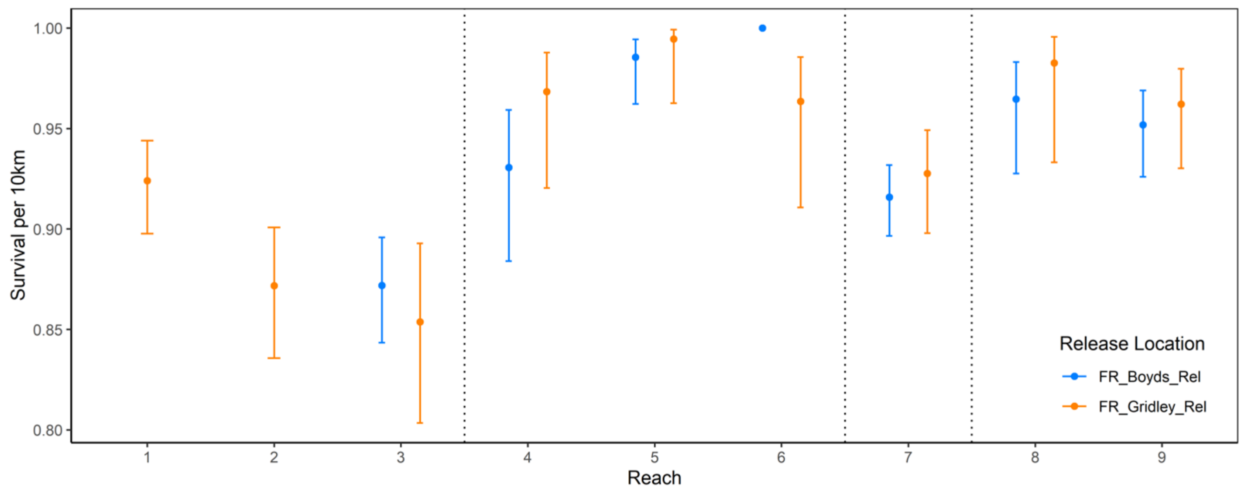

Figure 22. Survival estimates per 10 km by reach for Feather River spring-run Chinook salmon in 2019. Orange lines indicate the Gridley (more upstream) release group and blue lines indicate the Boyd's Pump (more downstream) release group. The dotted lines represent breaks between each region (Feather River, lower Sacramento River, Delta, and Bay). Error bars represent the upper and lower 95% confidence intervals.

Table 13. Standardized survival rates per 10 km by reach for Feather River spring-run Chinook salmon in 2019.

Reach #	Reach	RKM	Region	Gridley Survival per 10km (SE)	LCI	UCI	Boyds Survival per 10km (SE)	LCI	UCI
1	FR_Gridley_Rel to SunsetPumps	287.38 to 269.75	Feather	0.92 (0.01)	0.90	0.94			
2	SunsetPumps to BoydsPump	269.75 to 240.27	Feather	0.87 (0.02)	0.84	0.90			
3	BoydsPump to BC_Beach	240.27 to 217.31	Feather	0.85 (0.02)	0.80	0.89	0.87 (0.01)	0.84	0.90
4	BC_Beach to Blw_FRConf	217.31 to 203.46	Feather	0.97 (0.02)	0.92	0.99	0.93 (0.02)	0.88	0.96
5	Blw_FRConf to I80-50_Br	203.46 to 170.74	Lower Sacramento	0.99 (0.01)	0.96	1.00	0.99 (0.01)	0.96	0.99
6	I80-50_Br to Hood	170.74 to 138.22	Lower Sacramento	0.96 (0.02)	0.91	0.99	1.00 (0.00)	1.00	1.00
7	Hood to Chipps	138.22 to 71.48	Delta	0.93 (0.01)	0.90	0.95	0.92 (0.01)	0.90	0.93

8	Chipps to Benicia	71.48 to 52.14	Bay	0.98 (0.01)	0.93	1.00	0.96 (0.01)	0.93	0.98
9	Benicia to GoldenGateE	52.14 to 1.71	Bay	0.96 (0.01)	0.93	0.98	0.95 (0.01)	0.93	0.97

Cumulative Survival

Cumulative survival through the Feather River was 39% (± 0.03) for the Gridley release and 67% (± 0.03) for the Boyd's Pump release (Figure 23; Table 14). Cumulative survival from the Feather River through the lower Sacramento River was 34% (± 0.03) for the Gridley release and 63% (± 0.03) for the Boyd's Pump release. Cumulative survival from the Feather River through the Delta was 20% (± 0.02) for the Gridley release and 35% (± 0.03) for the Boyd's Pump release. Cumulative survival from the Feather River to the Golden Gate Bridge was 16% (± 0.02) for the Gridley release and 26% (± 0.03) for the Boyd's Pump release.

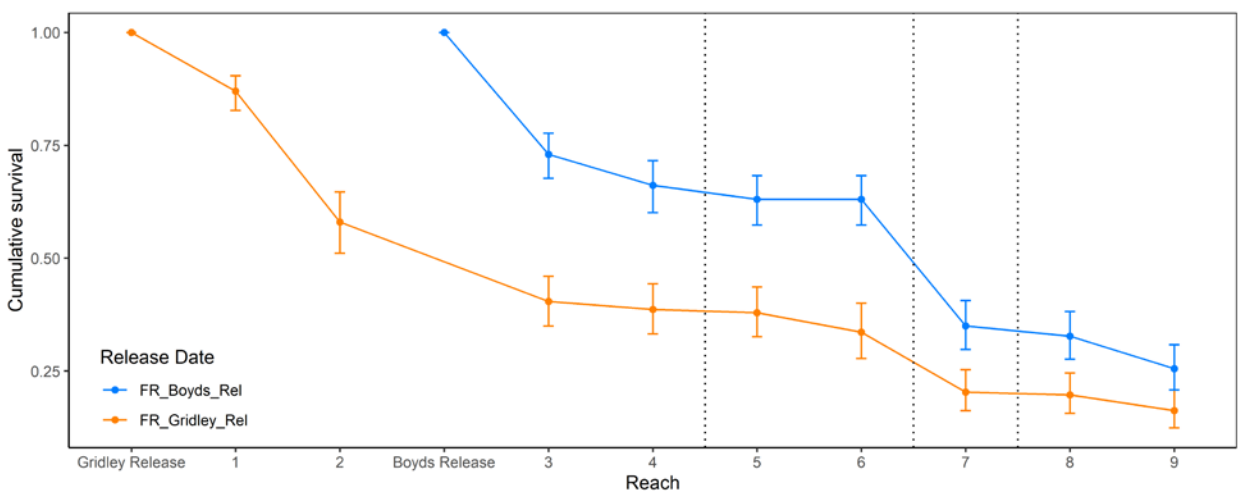

Figure 23. Cumulative survival by reach for Feather River spring-run Chinook salmon in 2019. Orange lines indicate the Gridley release group and blue lines indicate the Boyd's Pump release group. The dotted lines represent breaks between each region (Feather River, lower Sacramento River, Delta, and Bay). Error bars represent the upper and lower 95% confidence intervals.

Table 14. Cumulative survival for Feather River spring-run Chinook salmon in 2019.

Reach #	Receiver Site	RKM	Region	Gridley Cumulative survival (SE)	LCI	UCI	Boyds Cumulative survival (SE)	LCI	UCI
1	SunsetPumps	269.75	Feather	0.87 (0.02)	0.83	0.90			
2	BoydsPump	240.27	Feather	0.58 (0.04)	0.51	0.65			
3	BC_Beach	217.31	Feather	0.40 (0.03)	0.35	0.46	0.73 (0.03)	0.68	0.78
4	Blw_FRConf	203.46	Feather	0.39 (0.03)	0.33	0.44	0.66 (0.03)	0.60	0.72
5	I80-50_Br	170.74	Lower Sacramento	0.38 (0.03)	0.33	0.44	0.63 (0.03)	0.57	0.68
6	Hood	138.22	Lower Sacramento	0.34 (0.03)	0.28	0.40	0.63 (0.03)	0.57	0.68
7	Chipps	71.48	Delta	0.20 (0.02)	0.16	0.25	0.35 (0.03)	0.30	0.41

8	Benicia	52.14	Bay	0.20 (0.02)	0.16	0.25	0.33 (0.03)	0.28	0.38
9	GoldenGateE	1.71	Bay	0.16 (0.02)	0.12	0.21	0.26 (0.03)	0.21	0.31

3.1.4. Sutter Bypass Wild Chinook

Wild Chinook salmon smolts tagged for this study were captured in a RST below Weir 2 in the Sutter Bypass. These fish were a mix of wild-origin spring-run Chinook salmon from Butte Creek, and wild-origin fall-run Chinook salmon from the Sacramento River. This mix is a result of the Sacramento River spilling into the Sutter Bypass via Colusa Weir, which allows Sacramento River origin fish to enter the Sutter Bypass. Due to this spilling event and the extended period of time that the Sutter Bypass was inundated, tagging operations occurred later in the spring than anticipated. The extended period of flood water inundation also created unfavorable water conditions for acoustic tagging in the Sutter Bypass, with unseasonably warm water temperatures at the release location (19-22° C). As a result, survival rates through the Sutter Bypass were relatively low compared to previous study years (Figure 25). In total, 205 wild-origin Chinook salmon smolts were tagged and released below Weir 2 in the Sutter Bypass from May 5–May 10, 2019.

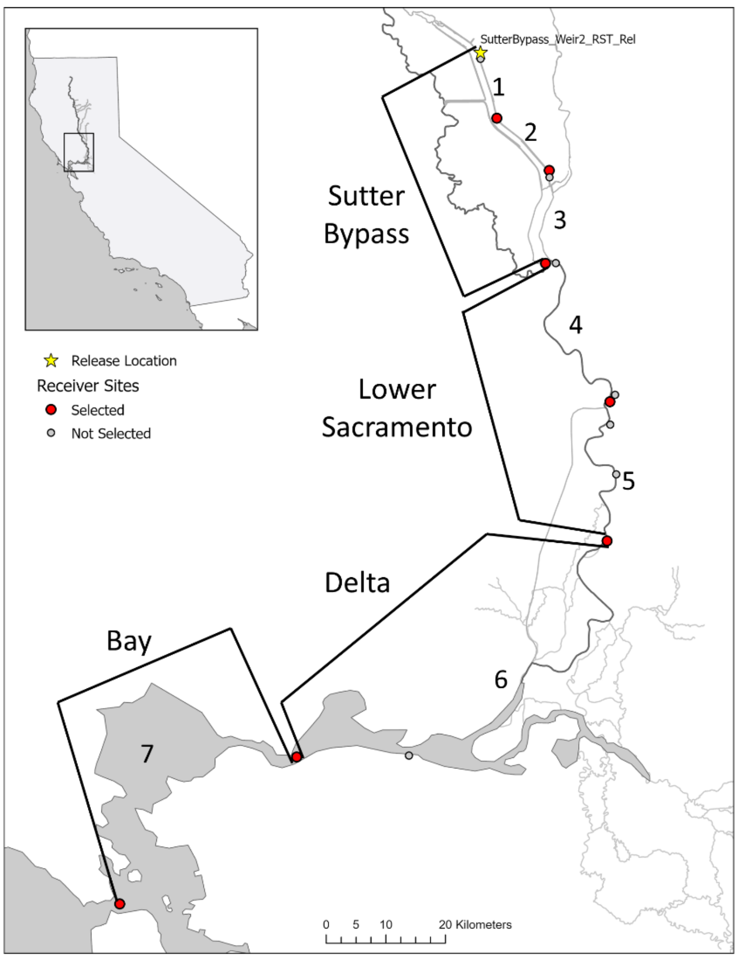

Figure 24. Map of receiver locations, release location, and regions for the Sutter Bypass in 2019. Points in red are receiver sites selected for survival estimation and points in gray are receivers that were deployed but not used.

Regional Survival

Survival through the Sutter Bypass from Weir 2 to the Sacramento River was 25% (± 0.03) for the study fish in 2019 (Figure 25; Table 15). Standardized survival through the region in 2019 was 73% (± 0.02) (Figure 26; Table 15). Regional survival through the lower Sacramento River from the confluence of the Sutter Bypass to Hood in 2019 was 63% (± 0.03). Standardized survival through the region was 94% (± 0.06). Regional survival through the Delta from Hood to Benicia was 9% (± 0.04). Standardized survival through the region was 76% (± 0.06). Regional survival through the San Francisco Bay from Benicia to the Golden Gate Bridge was 67% (± 0.17). Standardized survival through the region was 92% (± 0.07). Survival was notably low in the Sutter Bypass and Delta region when compared to previous years (Figure 25), despite the wet water year. It should be noted that despite the mostly wet conditions in the spring of 2019, the first two weeks of May (when these fish were outmigrating) were relatively dry with low river flows when compared to the remainder of the spring season (Figure 27).

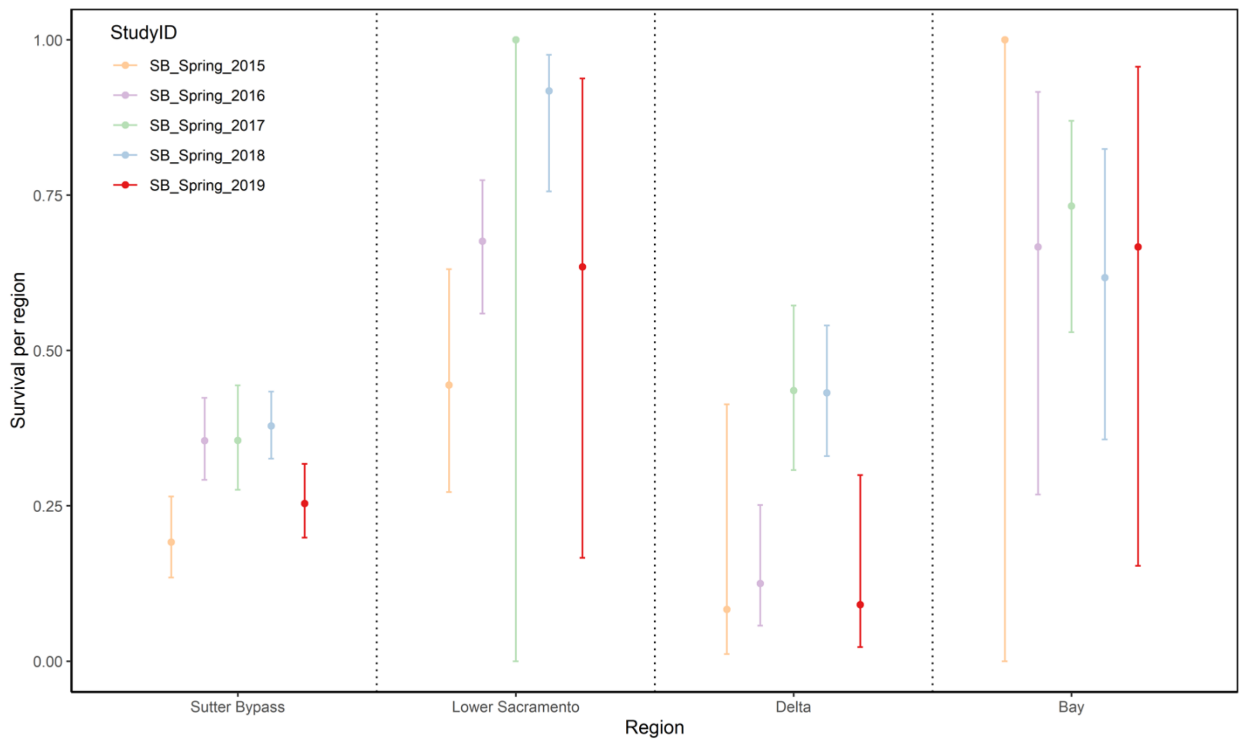

Figure 25. Survival estimates per region for the Sutter Bypass from 2015–2019. Error bars represent the upper and lower 95% confidence intervals.

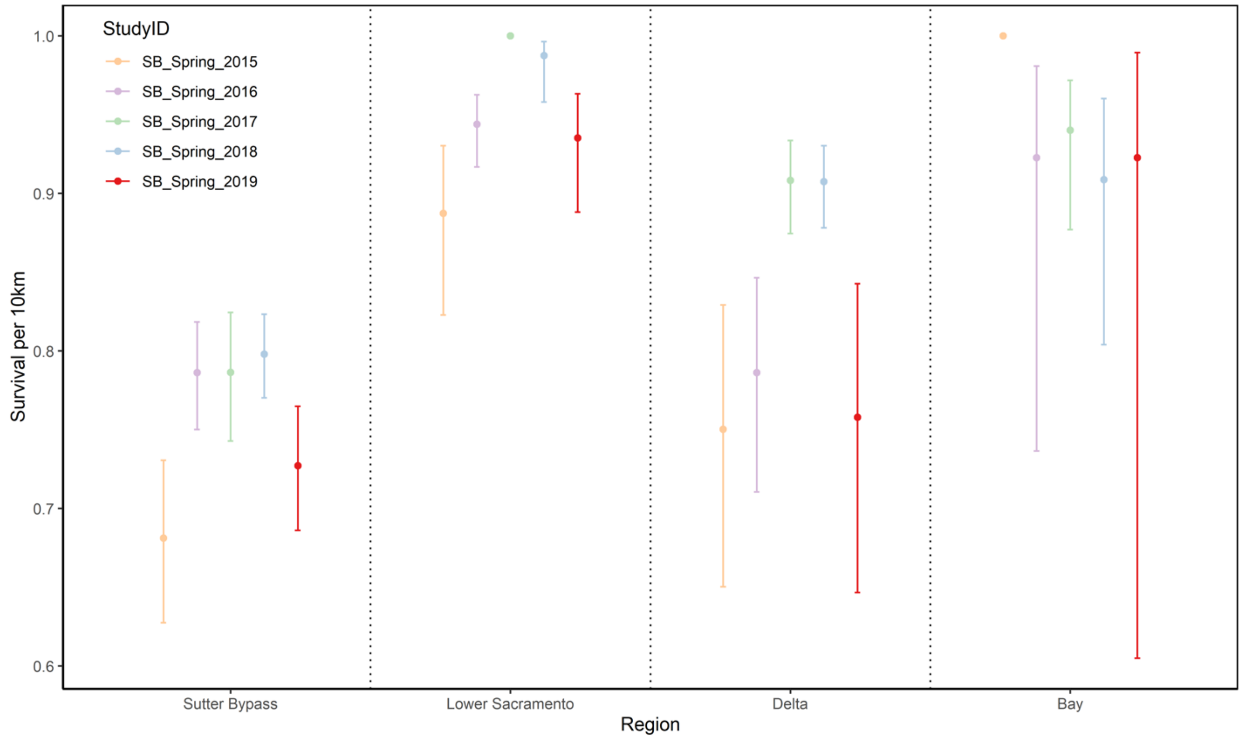

Figure 26. Survival estimates per 10 km by region for the Sutter Bypass from 2015–2019. Error bars represent the upper and lower 95% confidence intervals.

Table 15. Survival rates and standardized survival rates per 10 km by region for the Sutter Bypass in 2019.

Region	Reach	RKM	Survival (SE)	LCI	UCI	Survival per 10km (SE)	LCI	UCI
Sutter Bypass	SutterBypass Weir2 RST to Butte6	249.54 to 206.48	0.25 (0.03)	0.20	0.31	0.73 (0.02)	0.69	0.76
Lower Sacramento	Butte6 to Hood	206.48 to 138.61	0.63 (0.03)	0.57	0.70	0.94 (0.06)	0.71	0.99
Delta	Hood to Benicia	138.61 to 52.14	0.09 (0.04)	0.03	0.22	0.76 (0.06)	0.62	0.85
Bay	Benicia to GoldenGateE	52.14 to 1.71	0.67 (0.17)	0.30	0.90	0.92 (0.07)	0.61	0.99

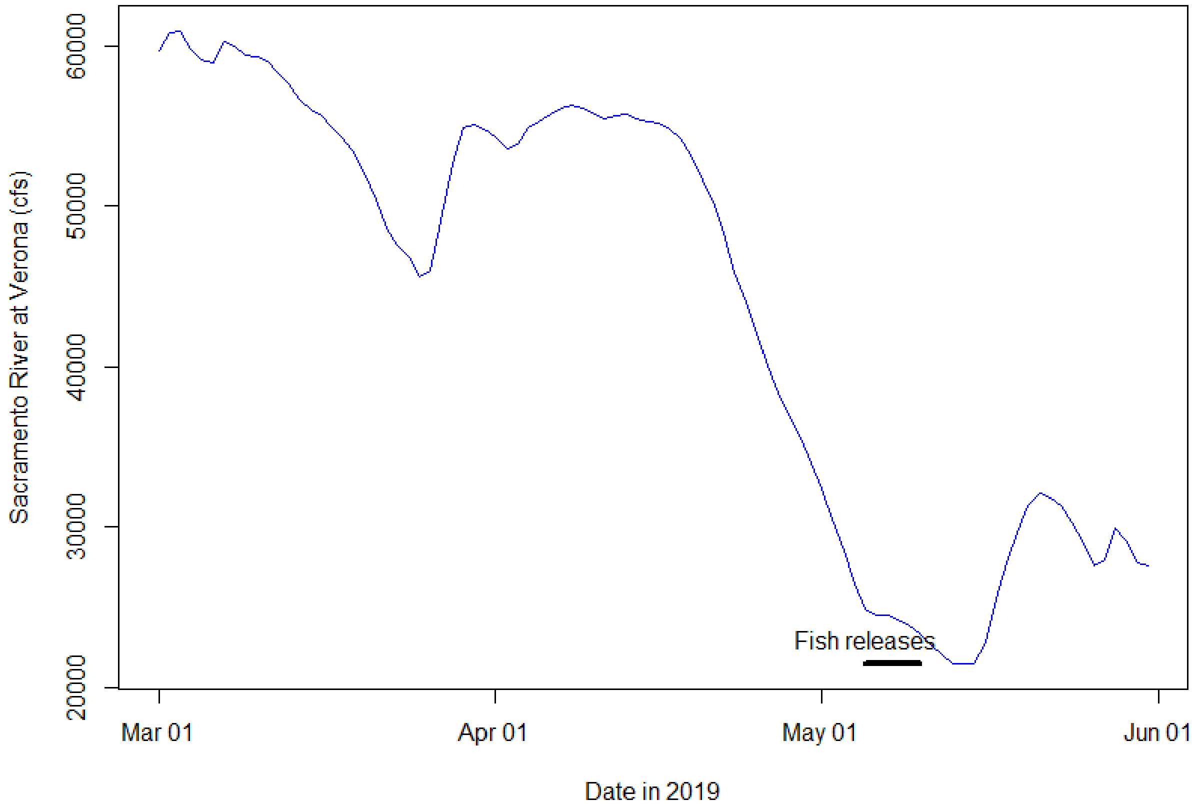

Figure 27. Sacramento River flow (cfs) as measured at Verona (just downstream of the confluence of the Sacramento and Feather Rivers) for the spring of 2019. Black horizontal bar represents the span of days during which Sutter Bypass fish releases occurred.

Reach-Specific Survival

To analyze reach-specific survival rates, nine receiver locations were included in the analysis based on detection efficiencies greater than 70% (Figure 28; Table 16). The general trend for reach-specific survival was low survival in the first reach from Weir 2 release to Butte 2 (57% (± 0.03)), followed by increased survival between Butte 2 and Butte 3 (88% (± 0.03)), and then low survival from Butte 3 to Butte 6 (75% (± 0.03)) (Figure 29; Table 17). Survival in the lower Sacramento River increased substantially compared to the Sutter Bypass, with standardized survival rates of 90% (± 0.03) from Butte 6 to I80/50 Bridge, and 98% (± 0.12) from I80/50 Bridge to Hood. Survival rates dropped in the Delta (76% (± 0.06)), and increased in the San Francisco Bay (92% (± 0.07)).

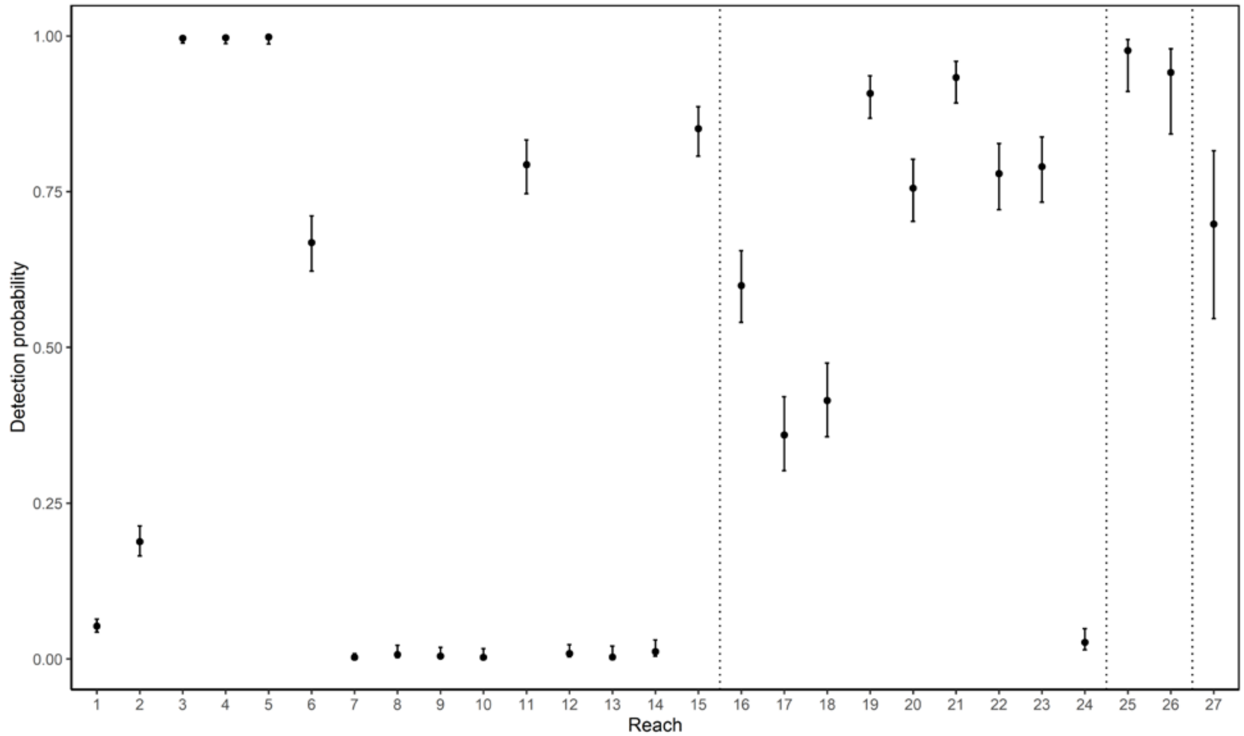

Figure 28. Detection probabilities for the Sutter Bypass in 2019. The dotted lines represent breaks between each region (Sutter Bypass, lower Sacramento River, Delta, and Bay). Error bars represent the upper and lower 95% confidence intervals.

Table 16. Detection probabilities for the Sutter Bypass in 2019.

Reach #	Reach	RKM	Region	Estimate (SE)	LCI	UCI
1	SutterBypass Weir2 RST to Butte0.5	249.54 to 249.5	Sutter Bypass	0.05 (0.01)	0.04	0.06
2	Butte0.5 to Butte0.8	249.5 to 249.5	Sutter Bypass	0.19 (0.01)	0.17	0.21
3	Butte0.8 to Butte1	249.5 to 249.05	Sutter Bypass	1.00 (0.00)	0.99	1.00
4	Butte1 to Butte2	249.05 to 238.46	Sutter Bypass	1.00 (0.00)	0.99	1.00
5	Butte2 to Butte3	238.46 to 226.46	Sutter Bypass	1.00 (0.00)	0.99	1.00
6	Butte3 to Butte4	226.46 to 224.89	Sutter Bypass	0.67 (0.02)	0.62	0.71
7	Butte4 to KnightsLanding	224.89 to 224.06	Lower Sacramento	0.00 (0.00)	0.00	0.01
8	KnightsLanding to KnightsLandingBr	224.06 to 224.05	Lower Sacramento	0.01 (0.00)	0.00	0.02
9	KnightsLandingBr to Knights_RST	224.05 to 222.05	Lower Sacramento	0.00 (0.00)	0.00	0.02
10	Knights_RST to KnightsBlwRST	222.05 to 221.58	Lower Sacramento	0.00 (0.00)	0.00	0.02
11	KnightsBlwRST to Butte5	221.58 to 216.98	Sutter Bypass	0.79 (0.02)	0.75	0.83
12	Butte5 to Abv_FremontWeir	216.98 to 215.18	Lower Sacramento	0.01 (0.00)	0.00	0.02
13	Abv_FremontWeir to Blw_Knights_GS3	215.18 to 212.8	Lower Sacramento	0.00 (0.00)	0.00	0.02
14	Blw_Knights_GS3 to Blw_FremontWeir	212.8 to 210.36	Lower Sacramento	0.01 (0.01)	0.00	0.03
15	Blw_FremontWeir to Butte6	210.36 to 206.48	Sutter Bypass	0.85 (0.02)	0.81	0.89

Reach #	Reach	RKM	Region	Estimate (SE)	LCI	UCI
16	Butte6 to Blw_FRConf	206.48 to 203.46	Lower Sacramento	0.60 (0.03)	0.54	0.66
17	Blw_FRConf to Blw_FR_GS2	203.46 to 199	Lower Sacramento	0.36 (0.03)	0.30	0.42
18	Blw_FR_GS2 to Blw_Elkhorn_GS1	199 to 191.92	Lower Sacramento	0.41 (0.03)	0.36	0.47
19	Blw_Elkhorn_GS1 to TowerBridge	191.92 to 172	Lower Sacramento	0.91 (0.02)	0.87	0.94
20	TowerBridge to I80-50_Br	172 to 170.74	Lower Sacramento	0.76 (0.03)	0.70	0.8
21	I80-50_Br to SacTrawl	170.74 to 166.82	Lower Sacramento	0.93 (0.02)	0.89	0.96
22	SacTrawl to Freeport	166.82 to 152.43	Lower Sacramento	0.78 (0.03)	0.72	0.83
23	Freeport to Hood	152.43 to 138.61	Lower Sacramento	0.79 (0.03)	0.73	0.84
24	Hood to Blw_Hood	138.61 to 134.42	Lower Sacramento	0.03 (0.01)	0.01	0.05
25	Blw_Hood to Chipps	134.42 to 71.48	Delta	0.98 (0.02)	0.91	0.99
26	Chipps to Benicia	71.48 to 52.14	Delta	0.94 (0.03)	0.84	0.98
27	Benicia to GoldenGateE	52.14 to 1.71	Bay	0.70 (0.07)	0.55	0.82

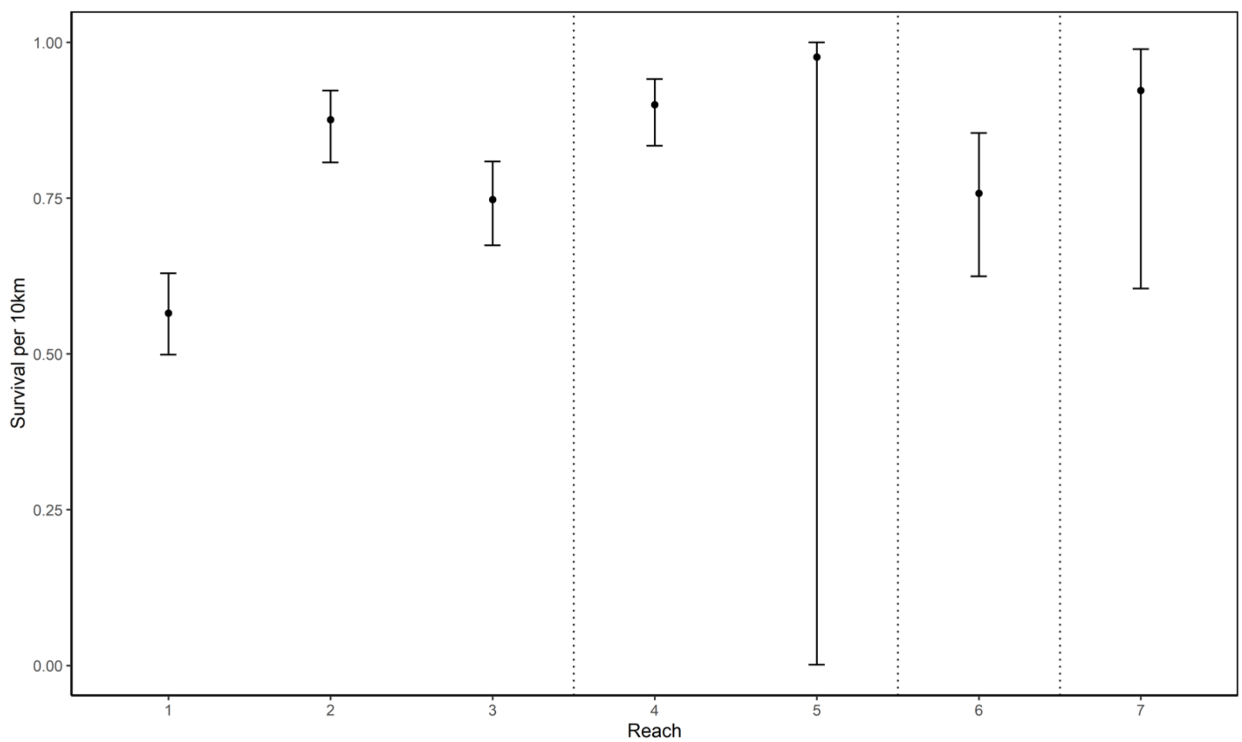

Figure 29. Survival estimates per 10 km by reach for the Sutter Bypass in 2019. The dotted lines represent breaks between each region (Sutter Bypass, lower Sacramento River, Delta, and Bay). Error bars represent the upper and lower 95% confidence intervals.

Table 17. Standardized survival rates per 10 km by reach for the Sutter Bypass in 2019.

Reach #	Reach	RKM	Region	Survival per 10 km (SE)	LCI	UCI
1	SutterBypass Weir2 RST to Butte2	249.54 to 238.46	Sutter Bypass	0.57 (0.03)	0.50	0.63
2	Butte2 to Butte3	238.46 to 226.46	Sutter Bypass	0.88 (0.03)	0.81	0.92
3	Butte3 to Butte6	226.46 to 206.48	Sutter Bypass	0.75 (0.03)	0.67	0.81
4	Butte6 to I80-50_Br	206.48 to 170.74	Lower Sacramento	0.90 (0.03)	0.83	0.94
5	I80-50_Br to Hood	170.74 to 138.61	Lower Sacramento	0.98 (0.12)	0.00	1.00
6	Hood to Benicia	138.61 to 52.14	Delta	0.76 (0.06)	0.62	0.85
7	Benicia to GoldenGateE	52.14 to 1.71	Bay	0.92 (0.07)	0.61	0.99

Cumulative Survival

Cumulative survival from release location at Weir 2 through the Sutter Bypass in 2019 was 25% (± 0.03) for study fish (Figure 30; Table 18). Cumulative survival from release location through the lower Sacramento River in 2019 was 16% (± 0.07). Cumulative survival from release location through the Delta was 2% (± 0.01), and cumulative survival from release location to the Golden Gate Bridge in 2019 was 1% (± 0.01).

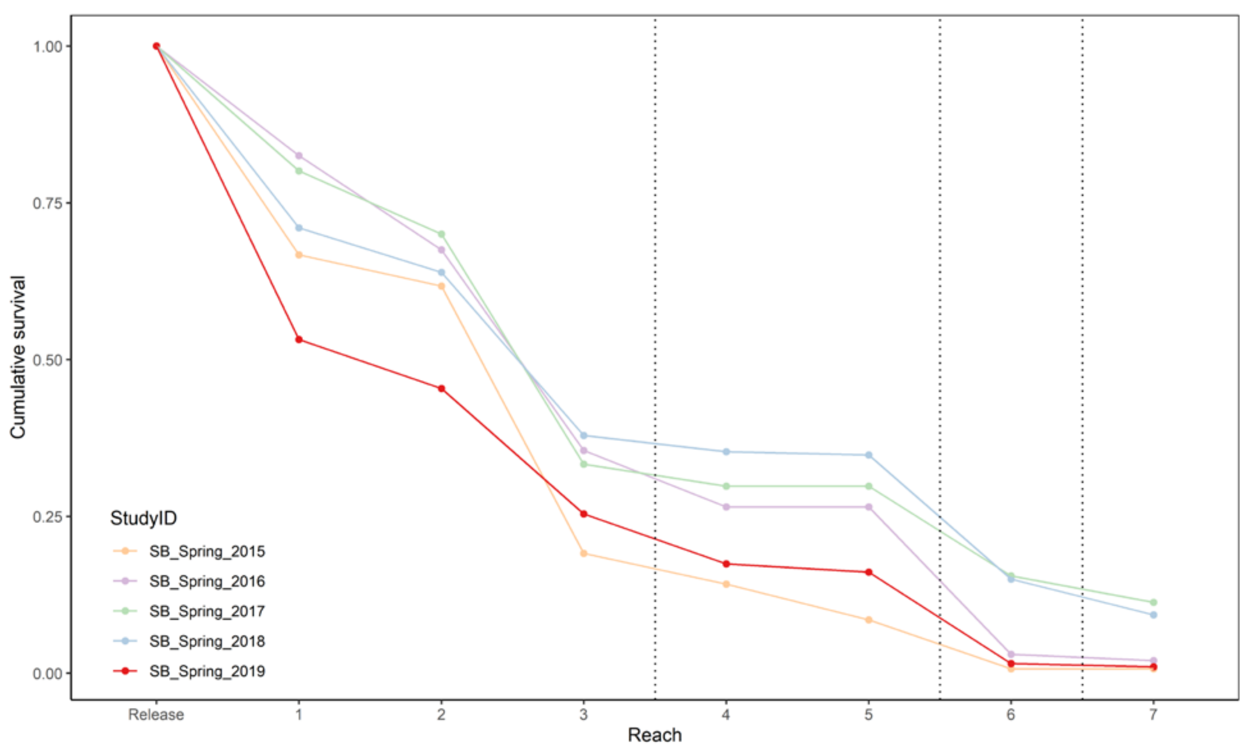

Figure 30. Cumulative survival by reach for the Sutter Bypass from 2015–2019. The dotted lines represent breaks between each region (Sutter Bypass, lower Sacramento River, Delta, and Bay). Error bars represent the upper and lower 95% confidence intervals.

Table 18. Cumulative survival for the Sutter Bypass in 2019.

Reach #	Receiver Site	RKM	Region	Cumulative survival (SE)	LCI	UCI
1	Butte2	238.46	Sutter Bypass	0.53 (0.04)	0.46	0.60
2	Butte3	226.46	Sutter Bypass	0.45 (0.04)	0.39	0.52
3	Butte6	206.48	Sutter Bypass	0.25 (0.03)	0.20	0.32
4	I80-50_Br	170.74	Lower Sacramento	0.17 (0.03)	0.13	0.24
5	Hood	138.61	Lower Sacramento	0.16 (0.07)	0.07	0.34
6	Benicia	52.14	Delta	0.02 (0.01)	0.00	0.04
7	GoldenGateE	1.71	Bay	0.01 (0.01)	0.00	0.04

3.1.5. Pulse Flow Alternative Study Hatchery Tagged Fish (Fall-run)

Fall-run Chinook salmon smolts from CNFH were used to examine smolt survival in relation to spring flows through the Sacramento River. This study was initially planned as a Spring Pulse Flow Study, but due to high flows in the Sacramento River resulting from above average precipitation in 2019, a pulse from Shasta Dam was not deemed necessary. Despite the fact that a pulse flow did not occur, fish were still tagged and released below RBDD to further examine the flow-survival relationship through the Sacramento River during the late spring when wild smolt outmigration typically peaks (as part of an "alternative" study design to the Pulse Flow Study). Two groups of 250 fish each were released over two consecutive weeks (May 16: "release 1", May 23: "release 2"), with the intention of obtaining survival rates during naturally high flow events during this critical late spring period.

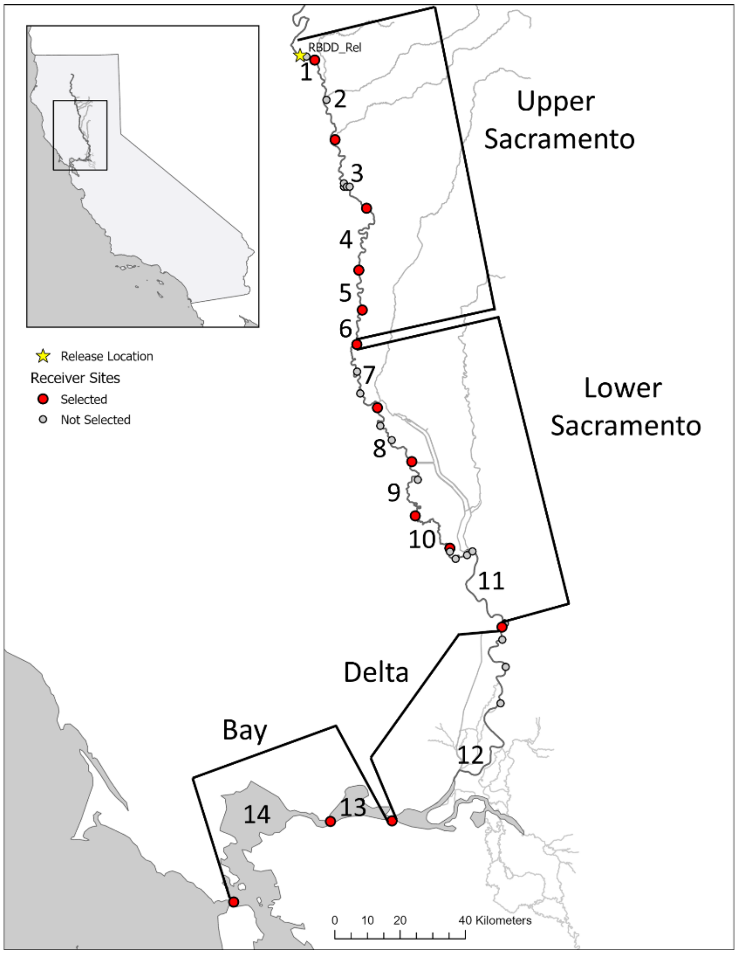

Figure 31. Map of receiver locations, release location, and regions for Coleman National Fish Hatchery fall-run Chinook salmon release in May 2019. Points in red are receiver sites selected for survival estimation and points in gray are receivers that were deployed but not used.

Regional survival

Survival through the upper Sacramento River from RBDD to Colusa was 72% (± 0.03) for release 1 and 56% (± 0.03) for release 2 (Figure 32; Table 19). Standardized survival through this region was 98% (± 0.00) for release 1 and 96% (± 0.00) for release 2 (Figure 33; Table 19). Survival through the lower Sacramento River from Colusa to I80/50 Bridge was 72% (± 0.03) for release 1 and increased to 70% (± 0.04) for release 2. Standardized survival through the lower Sacramento River for both releases was 98% (± 0.00). Survival through the Delta from I80/50 Bridge to Chipps Island was relatively low for each release compared to others, at 55% (± 0.04) for release 1 and 46% (± 0.05) for release 2. Standardized survival through the Delta was 94% (± 0.01) for release 1 and 93% (± 0.01) for release 2. Survival through the San Francisco Bay improved compared to the Delta, and was 82% (± 0.05) for release 1 and 78% (± 0.07) for release 2. Standardized survival through this region was 97% (± 0.01) for release 1 and 96% (± 0.01) for release 2.

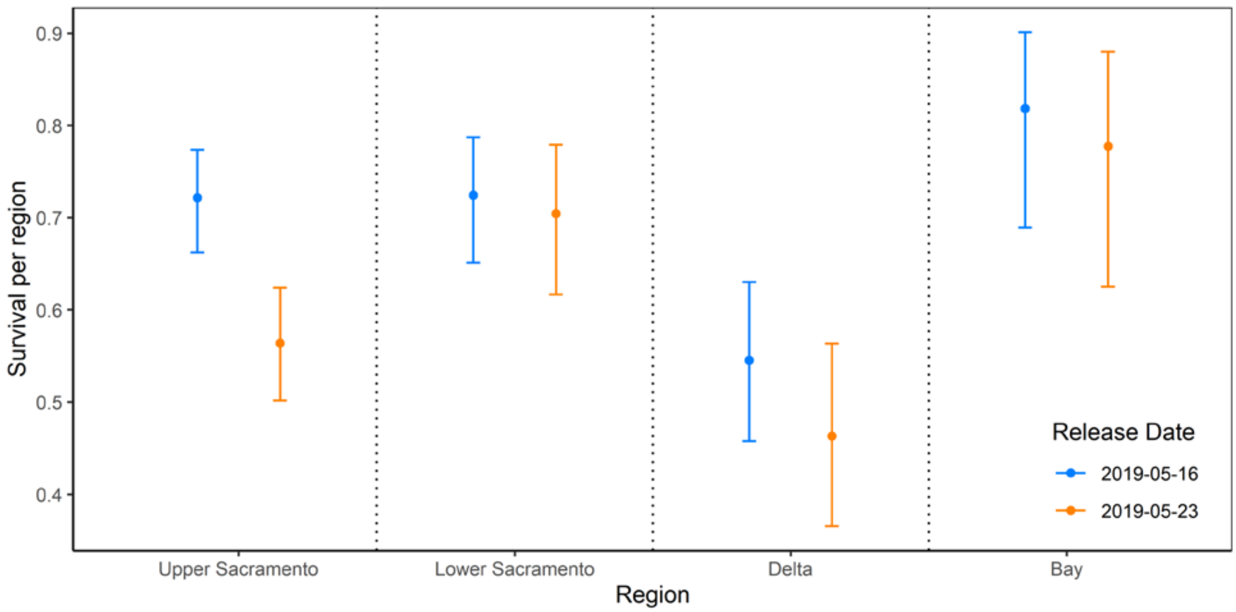

Figure 32. Survival estimates per region for Coleman National Fish Hatchery fall-run Chinook salmon May 2019 release. Blue lines indicate release 1 (2019-05-16) and orange lines indicate release 2 (2019-05-23). Error bars represent the upper and lower 95% confidence intervals.

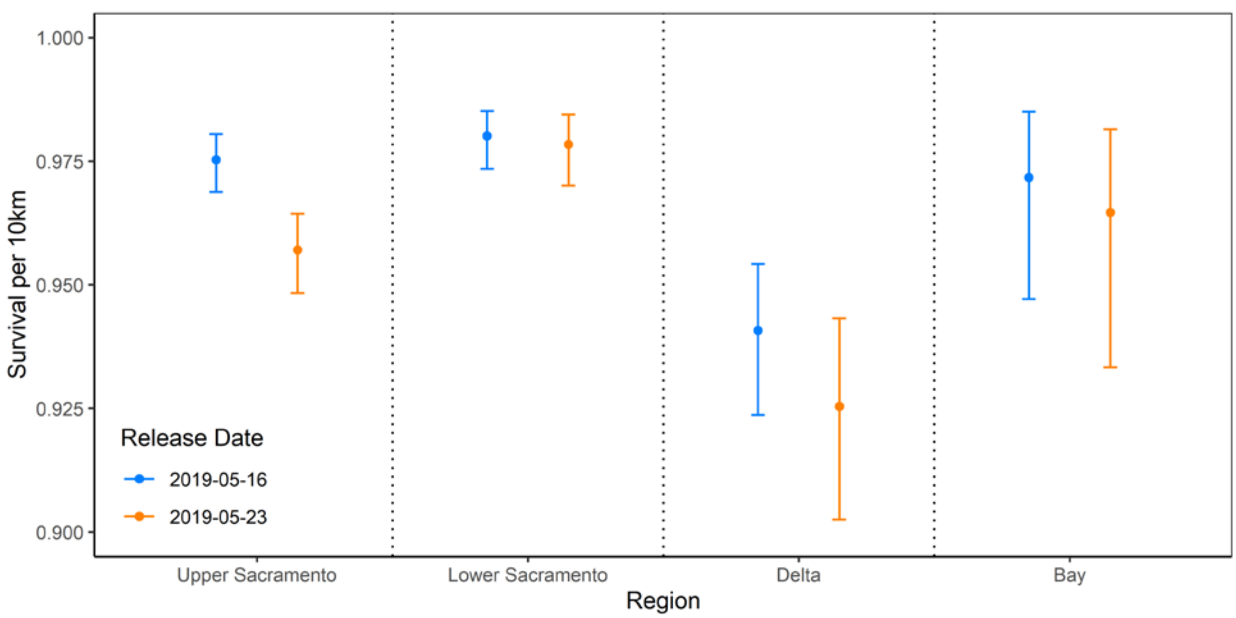

Figure 33. Survival estimates per 10 km by region for Coleman National Fish Hatchery fall-run Chinook salmon May 2019 release. Blue lines indicate release 1 (2019-05-16) and orange lines indicate release 2 (2019-05-23). Error bars represent the upper and lower 95% confidence intervals.

Table 19. Survival rates and standardized survival rates per 10 km by region for Coleman National Fish Hatchery fall-run Chinook salmon May 2019 release.

Release Date	Region	Reach	RKM	Survival per region (SE)	LCI	UCI	Survival per 10 km (SE)	LCI	UCI
5/16/2019	Upper Sacramento	RBDD_Rel to Colusa AC3	461.579 to 331.15	0.72 (0.03)	0.66	0.77	0.98 (0.00)	0.97	0.98
	Lower Sacramento	Colusa AC3 to I80-50_Br	331.15 to 170.74	0.72 (0.03)	0.65	0.79	0.98 (0.00)	0.97	0.99
	Delta	I80-50_Br to Chipps	170.74 to 71.48	0.55 (0.04)	0.46	0.63	0.94 (0.01)	0.92	0.95
	Bay	Chipps to GoldenGateE	71.48 to 1.71	0.82 (0.05)	0.69	0.9	0.97 (0.01)	0.95	0.99
5/23/2019	Upper Sacramento	RBDD_Rel to Colusa AC3	461.579 to 331.15	0.56 (0.03)	0.50	0.62	0.96 (0.00)	0.95	0.96
	Lower Sacramento	Colusa AC3 to I80-50_Br	331.15 to 170.74	0.70 (0.04)	0.62	0.78	0.98 (0.00)	0.97	0.98
	Delta	I80-50_Br to Chipps	170.74 to 71.48	0.46 (0.05)	0.37	0.56	0.93 (0.01)	0.90	0.94
	Bay	Chipps to GoldenGateE	71.48 to 1.71	0.78 (0.07)	0.63	0.88	0.96 (0.01)	0.93	0.98

Reach-Specific Survival

To analyze reach-specific survival rates, 16 receivers were selected out of 36 deployed throughout the study region, based on the performance of each receiver in detecting passing tags (detection efficiency, Figure 34, Table 20). The general trend in standardized reach-specific survival rates for each release group was low survival in the first reach (96% (± 0.02) for release 1, 92% (± 0.02) for release 2), followed by increased survival in the second reach, and then very low survival in reach 3 (95% (± 0.01) for release 1, 90% (± 0.01) for release 2) (Figure 35; Table 21). Downstream of reach 3, survival through the upper and lower Sacramento River remained relatively consistent, followed by a decline in the Delta region (94% (± 0.01) for release 1, 93% (± 0.01) for release 2). Survival improved slightly for each group in the San Francisco Bay between Chipps Island and Benicia (97% (± 0.01) for release 1, 95% (± 0.02) for release 2), and Benicia to the Golden Gate Bridge (97% (± 0.01) for release 1, 96% (± 0.01) for release 2).

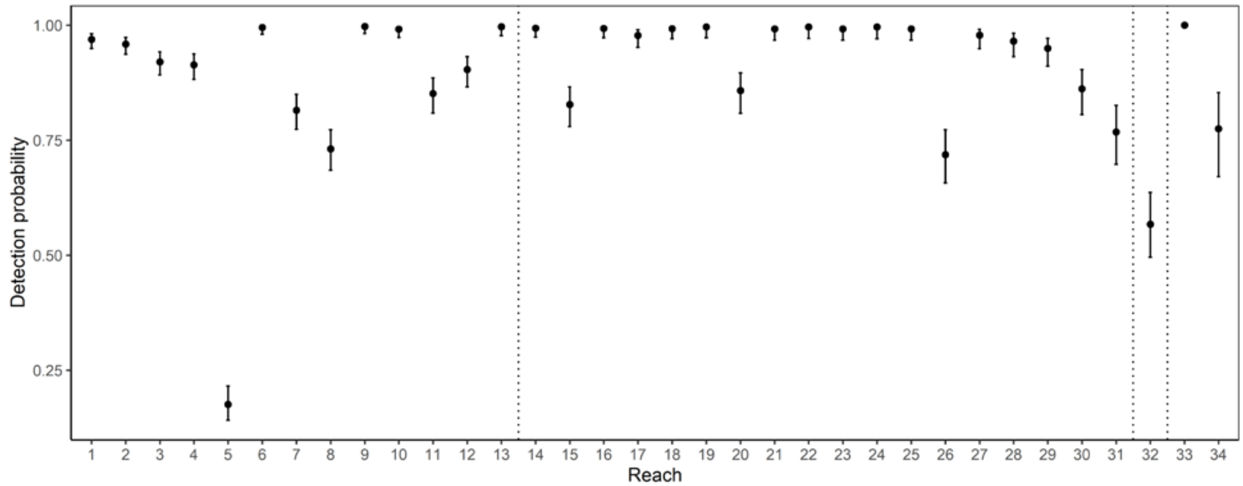

Figure 34. Detection probabilities for Coleman National Fish Hatchery fall-run Chinook salmon release in May 2019. The dotted lines represent breaks between each region (Upper Sacramento River, lower Sacramento River, Delta, and Bay). Error bars represent the upper and lower 95% confidence intervals.

Table 20. Detection probabilities for Coleman National Fish Hatchery fall-run Chinook salmon release in May 2019.

Reach #	Reach	RKM	Region	Estimate (SE)	LCI	UCI
1	RBDD_Rel to Abv_Altube1	461.579 to 460.40	Upper Sacramento	0.97 (0.01)	0.95	0.98
2	Abv_Altube1 to Blw_Salt	460.40 to 456.88	Upper Sacramento	0.96 (0.01)	0.94	0.97
3	Blw_Salt to Mill_Ck_Conf	456.88 to 441.31	Upper Sacramento	0.92 (0.01)	0.89	0.94
4	Mill_Ck_Conf to Abv_WoodsonBr	441.31 to 425.15	Upper Sacramento	0.91 (0.01)	0.88	0.94
5	Abv_WoodsonBr to GCID	425.15 to 406.25	Upper Sacramento	0.18 (0.02)	0.14	0.22
6	GCID to GCID_abv	406.25 to 406.11	Upper Sacramento	1.00 (0.00)	0.98	1.00
7	GCID_abv to GCID_Main	406.11 to 405.71	Upper Sacramento	0.81 (0.02)	0.77	0.85
8	GCID_Main to GCID_Conf	405.71 to 404.90	Upper Sacramento	0.73 (0.02)	0.68	0.77
9	GCID_Conf to GCID_blw	404.90 to 404.42	Upper Sacramento	1.00 (0.00)	0.98	1.00
10	GCID_blw to Blw_IrvineFinch	404.42 to 394.66	Upper Sacramento	0.99 (0.01)	0.97	1.00
11	Blw_IrvineFinch to BlwOrd	394.66 to 361.72	Upper Sacramento	0.85 (0.02)	0.81	0.89
12	BlwOrd to ButteBr	361.72 to 344.10	Upper Sacramento	0.90 (0.02)	0.87	0.93
13	ButteBr to Colusa AC3	344.10 to 331.15	Upper Sacramento	1.00 (0.00)	0.98	1.00
14	Colusa AC3 to Colusa AC2	331.15 to 318.61	Lower Sacramento	0.99 (0.00)	0.97	1.00
15	Colusa AC2 to AbvColusaBr	318.61 to 307.73	Lower Sacramento	0.83 (0.02)	0.78	0.87
16	AbvColusaBr to Colusa BC2	307.73 to 296.27	Lower Sacramento	0.99 (0.00)	0.97	1.00

Reach #	Reach	RKM	Region	Estimate (SE)	LCI	UCI
17	Colusa BC2 to Colusa BC3	296.27 to 287.20	Lower Sacramento	0.98 (0.01)	0.95	0.99
18	Colusa BC3 to Colusa BC4	287.20 to 280.40	Lower Sacramento	0.99 (0.01)	0.97	1.00
19	Colusa BC4 to AbvTisdale	280.40 to 269.23	Lower Sacramento	1.00 (0.00)	0.97	1.00
20	AbvTisdale to BlwTisdale	269.23 to 261.40	Lower Sacramento	0.86 (0.02)	0.81	0.90
21	BlwTisdale to BlwChinaBend	261.40 to 240.61	Lower Sacramento	0.99 (0.01)	0.97	1.00
22	BlwChinaBend to Knights_RST	240.61 to 222.05	Lower Sacramento	1.00 (0.00)	0.97	1.00
23	Knights_RST to KnightsBlwRST	222.05 to 221.58	Lower Sacramento	0.99 (0.01)	0.97	1.00
24	KnightsBlwRST to Abv_FremontWeir	221.58 to 215.18	Lower Sacramento	1.00 (0.00)	0.97	1.00
25	Abv_FremontWeir to Blw_FremontWeir	215.18 to 210.36	Lower Sacramento	0.99 (0.01)	0.97	1.00
26	Blw_FremontWeir to Blw_FRConf	210.36 to 203.46	Lower Sacramento	0.72 (0.03)	0.66	0.77
27	Blw_FRConf to TowerBridge	203.46 to 172.00	Lower Sacramento	0.98 (0.01)	0.95	0.99
28	TowerBridge to I80-50_Br	172.00 to 170.74	Lower Sacramento	0.96 (0.01)	0.93	0.98
29	I80-50_Br to SacTrawl	170.74 to 166.82	Lower Sacramento	0.95 (0.01)	0.91	0.97
30	SacTrawl to Freeport	166.82 to 152.43	Lower Sacramento	0.86 (0.02)	0.81	0.90
31	Freeport to Hood	152.43 to 138.22	Lower Sacramento	0.77 (0.03)	0.70	0.83
32	Hood to Chipps	138.22 to 71.48	Delta	0.57 (0.04)	0.50	0.64
33	Chipps to Benicia	71.48 to 52.14	Bay	1.00 (0.00)	1.00	1.00
34	Benicia to GoldenGateE	52.14 to 1.71	Bay	0.78 (0.05)	0.67	0.85

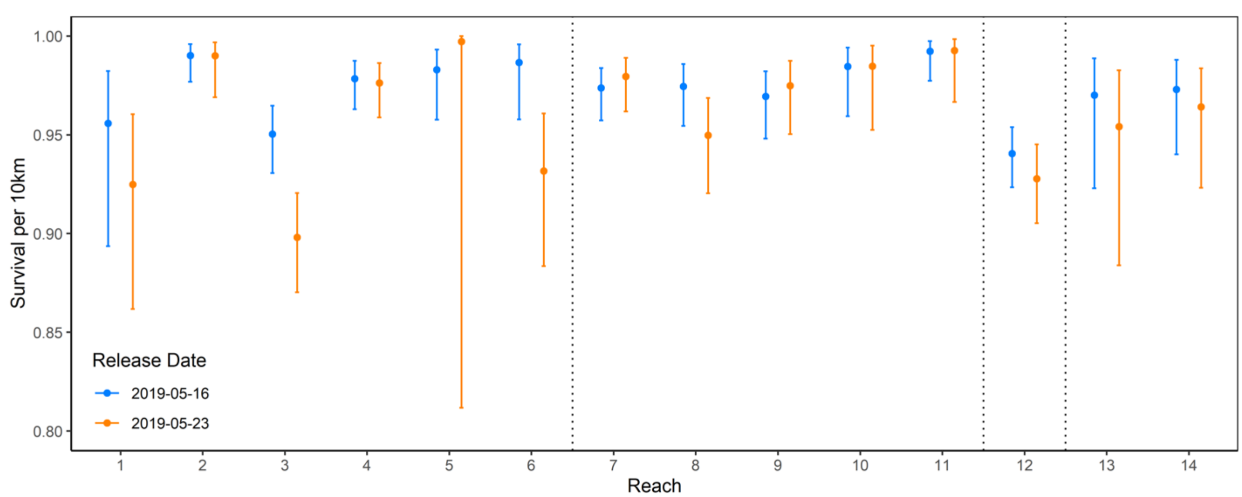

Figure 35. Survival estimates per 10 km by reach for Coleman National Fish Hatchery fall-run Chinook salmon release in May 2019. Blue lines indicate release 1 (2019-05-16) and orange lines indicate release

2 (2019-05-23). The dotted lines represent breaks between each region (Upper Sacramento River, lower Sacramento River, Delta, and Bay). Error bars represent the upper and lower 95% confidence intervals.

Table 21. Standardized survival rates per 10 km by reach for Coleman National Fish Hatchery fall-run Chinook salmon release in May 2019.

Reach #	Reach	RKM	Region	5/16 Survival per 10km (SE)	LCI	UCI	5/23 Survival per 10km (SE)	LCI	UCI
1	RBDD_Rel to Blw_Salt	461.579 to 456.88	Upper Sacramento	0.96 (0.02)	0.89	0.98	0.92 (0.02)	0.86	0.96
2	Blw_Salt to Abv_WoodsonBr	456.88 to 425.15	Upper Sacramento	0.99 (0.00)	0.98	1.00	0.99 (0.01)	0.97	1.00
3	Abv_WoodsonBr to Blw_IrvineFinch	425.15 to 394.66	Upper Sacramento	0.95 (0.01)	0.93	0.96	0.90 (0.01)	0.87	0.92
4	Blw_IrvineFinch to BlwOrd	394.66 to 361.72	Upper Sacramento	0.98 (0.01)	0.96	0.99	0.98 (0.01)	0.96	0.99
5	BlwOrd to ButteBr	361.72 to 344.10	Upper Sacramento	0.98 (0.01)	0.96	0.99	1.00 (0.01)	0.81	1.00
6	ButteBr to Colusa AC3	344.10 to 331.15	Upper Sacramento	0.99 (0.01)	0.96	1.00	0.93 (0.02)	0.88	0.96
7	Colusa AC3 to Colusa BC2	331.15 to 296.27	Lower Sacramento	0.97 (0.01)	0.96	0.98	0.98 (0.01)	0.96	0.99
8	Colusa BC2 to AbvTisdale	296.27 to 269.23	Lower Sacramento	0.97 (0.01)	0.95	0.99	0.95 (0.01)	0.92	0.97
9	AbvTisdale to BlwChinaBend	269.23 to 240.61	Lower Sacramento	0.97 (0.01)	0.95	0.98	0.97 (0.01)	0.95	0.99
10	BlwChinaBend to Knights_RST	240.61 to 222.05	Lower Sacramento	0.98 (0.01)	0.96	0.99	0.98 (0.01)	0.95	1.00
11	Knights_RST to I80-50_Br	222.05 to 170.74	Lower Sacramento	0.99 (0.00)	0.98	1.00	0.99 (0.01)	0.97	1.00
12	I80-50_Br to Chipps	170.74 to 71.48	Delta	0.94 (0.01)	0.92	0.95	0.93 (0.01)	0.91	0.95
13	Chipps to Benicia	71.48 to 52.14	Bay	0.97 (0.01)	0.92	0.99	0.95 (0.02)	0.88	0.98
14	Benicia to GoldenGateE	52.14 to 1.71	Bay	0.97 (0.01)	0.94	0.99	0.96 (0.01)	0.92	0.98

Cumulative Survival

Cumulative survival from release location at RBDD through the upper Sacramento River was 72% (± 0.03) for release 1 and 56% (± 0.03) for release 2 (Figure 36; Table 22). From release location through the lower Sacramento River was 52% (± 0.03) for release 1 and 40% (± 0.03) for release 2, and from release location through the Delta was 28% (± 0.03) for release 1 and 18% (± 0.02) for release 2. Cumulative survival through the entire study area to the Golden Gate Bridge was 23% (± 0.03) for release 1 and 14% (± 0.02) for release 2.

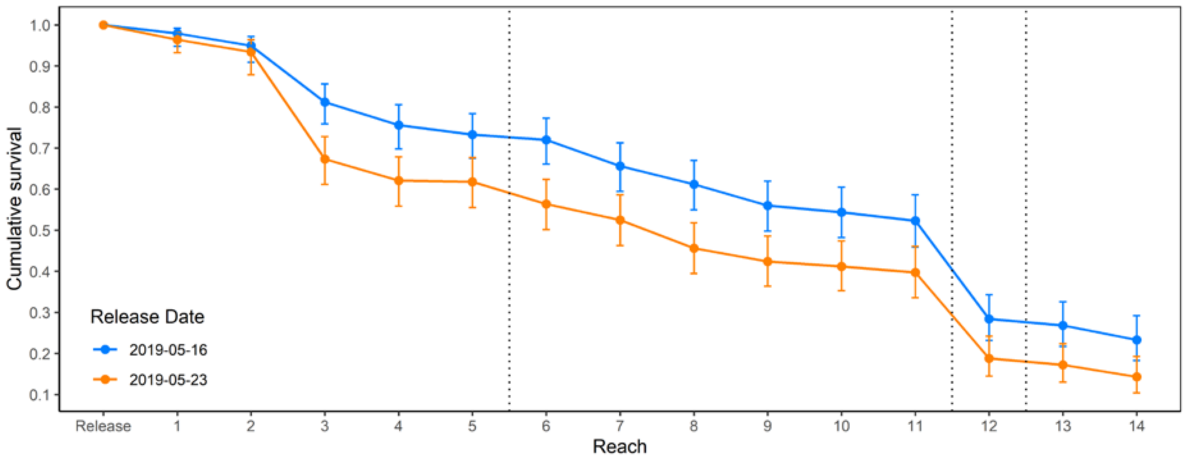

Figure 36. Cumulative survival by reach for Coleman National Fish Hatchery fall-run Chinook salmon release in May 2019. Blue lines indicate release 1 (2019-05-16) and orange lines indicate release 2 (2019-05-23). The dotted lines represent breaks between each region (upper Sacramento River, lower Sacramento River, Delta, and Bay). Error bars represent the upper and lower 95% confidence intervals.

Table 22. Cumulative survival for Coleman National Fish Hatchery fall-run Chinook salmon release in May 2019.

Reach #	Receiver Site	RKM	Region	5/16 Cumulative survival (SE)	LCI	UCI	5/23 Cumulative survival (SE)	LCI	UCI
1	Blw_Salt	456.88	Upper Sacramento	0.98 (0.01)	0.95	0.99	0.96 (0.01)	0.93	0.98
2	Abv_WoodsonBr	425.15	Upper Sacramento	0.95 (0.02)	0.91	0.97	0.93 (0.02)	0.88	0.96
3	Blw_IrvineFinch	394.66	Upper Sacramento	0.81 (0.02)	0.76	0.86	0.67 (0.03)	0.61	0.73
4	BlwOrd	361.72	Upper Sacramento	0.76 (0.03)	0.70	0.81	0.62 (0.03)	0.56	0.68
5	ButteBr	344.10	Upper Sacramento	0.73 (0.03)	0.68	0.78	0.62 (0.03)	0.56	0.68
6	Colusa AC3	331.15	Upper Sacramento	0.72 (0.03)	0.66	0.77	0.56 (0.03)	0.50	0.62
7	Colusa BC2	296.27	Lower Sacramento	0.66 (0.03)	0.60	0.71	0.52 (0.03)	0.46	0.59
8	AbvTisdale	269.23	Lower Sacramento	0.61 (0.03)	0.55	0.67	0.46 (0.03)	0.40	0.52
9	BlwChinaBend	240.61	Lower Sacramento	0.56 (0.03)	0.50	0.62	0.42 (0.03)	0.36	0.49
10	Knights_RST	222.05	Lower Sacramento	0.54 (0.03)	0.48	0.60	0.41 (0.03)	0.35	0.48
11	I80-50_Br	170.74	Lower Sacramento	0.52 (0.03)	0.46	0.59	0.40 (0.03)	0.34	0.46
12	Chipps	71.48	Delta	0.28 (0.03)	0.23	0.34	0.19 (0.02)	0.14	0.24
13	Benicia	52.14	Bay	0.27 (0.03)	0.22	0.33	0.17 (0.02)	0.13	0.22
14	GoldenGateE	1.71	Bay	0.23 (0.03)	0.18	0.29	0.14 (0.02)	0.10	0.19

GCID Routing and Survival Analysis

As an ancillary project to the Pulse Flow Alternative Study, a routing and survival analysis was conducted around the Glenn-Colusa Irrigation District (GCID) water diversion structure and intake canal. Due to water demands and resulting water diversions during the peak outmigration timing of wild

Chinook salmon smolts through this region of the Sacramento River, many agencies and stakeholders are interested in the routing probability and survival estimates of fish entering the GCID intake canal. In order to address this question, we deployed receivers upstream of the GDID intake canal, inside the GCID intake canal, inside the Sacramento River channel, and downstream of the rejoining of the two routes. By having these four locations covered with two receivers, we estimated the routing probability and survival of tagged smolts through the GCID region using a multi-state mark-recapture model.

Of the 500 fish released at RBDD, 403 fish were detected just upstream of the GCID junction. Of these fish, 314 were detected in the Sacramento River channel, 71 were detected in the GCID canal, and 390 fish were detected downstream of the junction. Routing probability into the GCID canal was 18% (0.07 SE) and 82% (0.07 SE) into the mainstem Sacramento River. Survival through the GCID canal was 100% (0.00 SE) and survival through the mainstem Sacramento River was 96% (0.01 SE) (Figure 37). Standardized (per 10 km) survival through the GCID canal was 100% and standardized survival through the Sacramento River was 70%. Movement speed through the GCID canal was 32.2 km/day, and movement speed through the Sacramento River was 51 km/day (Figure 38).

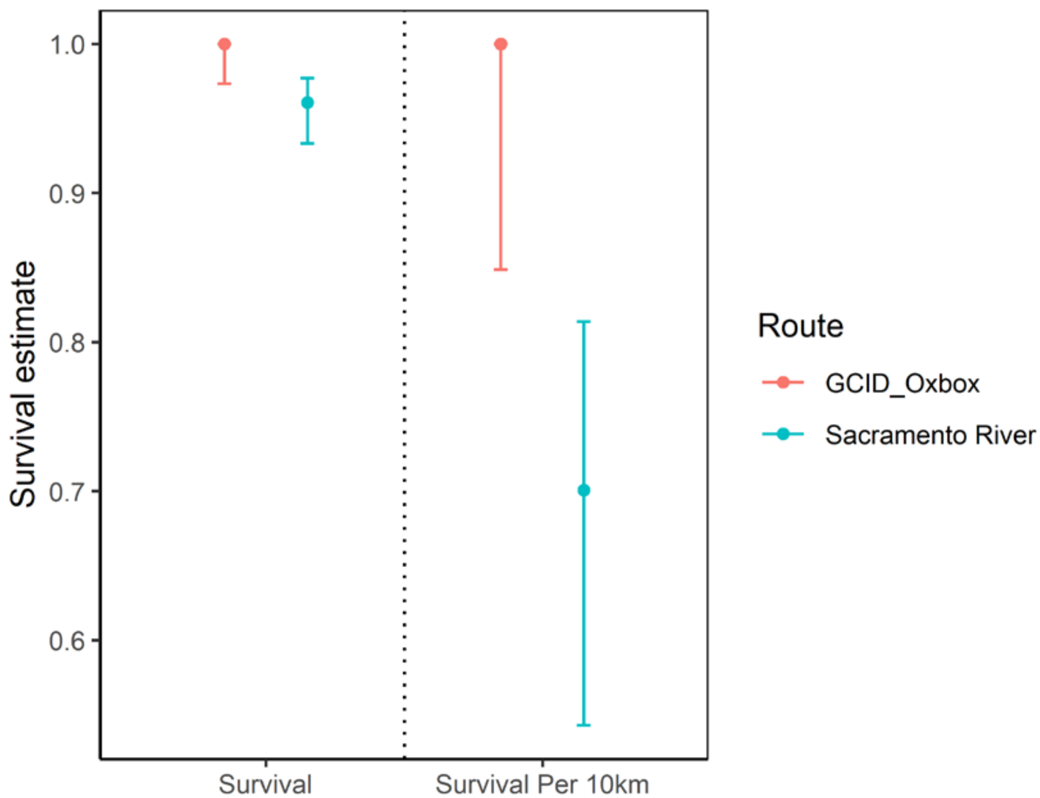

Figure 37. Total survival and standardized survival rates of smolts migrating through the GCID route (red) and Sacramento River route (green).

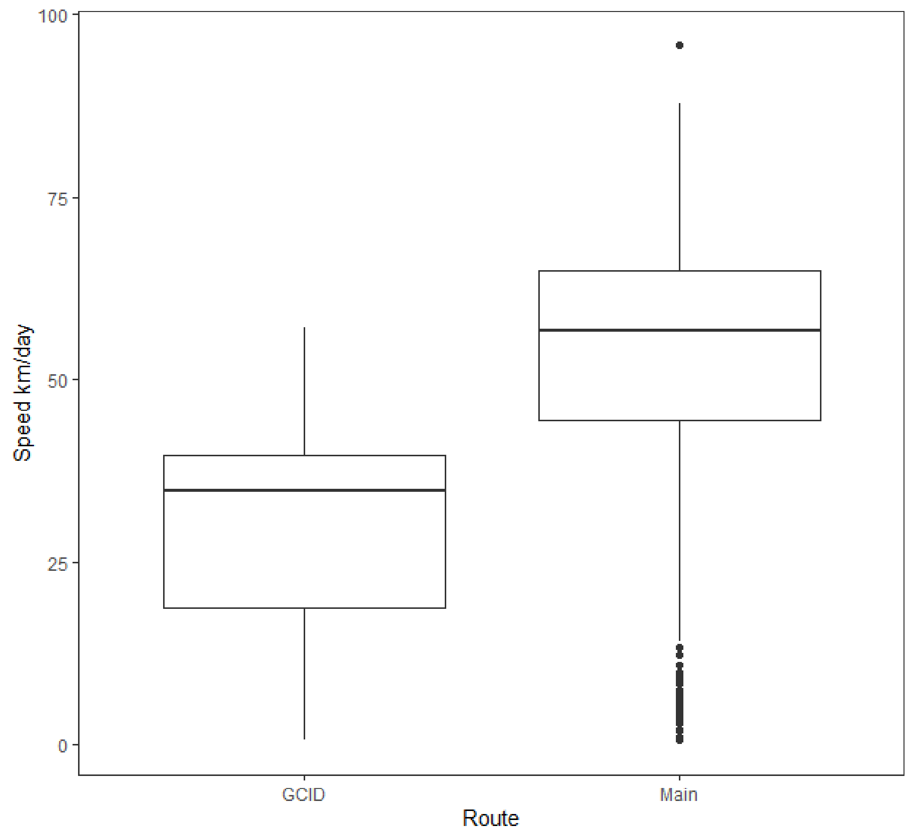

Figure 38. Boxplots of movement speeds of fish through two different route options; Sacramento River channel (right) and GCID channel (left). There were 314 fish detected in the Sacramento main channel and 71 fish detected in the GCID channel.

Survival of tagged smolts through the GCID canal was significantly higher than the mainstem route. While the exact mechanisms remain unclear, it may be due to the differences in habitat within each route; the mainstem route contains more water, and has more complex features such as scour pools, large boulders and braided channels. It should be noted that survival through the Sacramento River route was lower than survival in nearby portions of the Sacramento River (Table 19). Conversely, the GCID oxbow is designed to move water through quickly, with much of the route lined with revetment downstream of the water diversion, which increases water velocity. Despite this fact, mean movement speeds in the GCID route were slower compared to the Sacramento River route (32.2 km/day versus 51 km/day). Predator fish may favor the mainstem channel due to cover in the form of a deep scour pool which exists below large boulders, placed near the beginning of the channel to slow the Sacramento River and allow for flow into the GCID canal. This location is potentially favorable predator habitat, with ambush points where water spills over the boulders and into the deep pool. In addition, the river splits into two channels downstream of the pool which creates susceptibility to predation for migrating smolts as less water and ultimately less habitat is available to seek refuge.

3.2. Fish Movement

Fish movement speed (km/day) was calculated by subtracting the final detection time of an upstream receiver from the first detection at the next downstream receiver. Receivers used for this analysis were selected based on detection efficiencies, with only receivers having greater than 70% detection efficiency being selected. As a result of differences in receiver detection efficiencies between study groups, site selection varied according to study group. In addition, the distance between receiver sites used was greater than 10 river kilometers in order to reduce the number of outlier movement speeds. Results are displayed as the average group movement speed ± one standard deviation from the mean at each receiver location used in the analysis.

3.2.1. Late Fall-Run Chinook Movement

Late Fall Run Chinook were tagged between 11/28/2018 and 11/29/2018 at Coleman National Fish Hatchery and released between 11/29/2020 and 11/30/2020 at RKM 517. We tracked the movement of these fish over 15 reaches to the ocean.

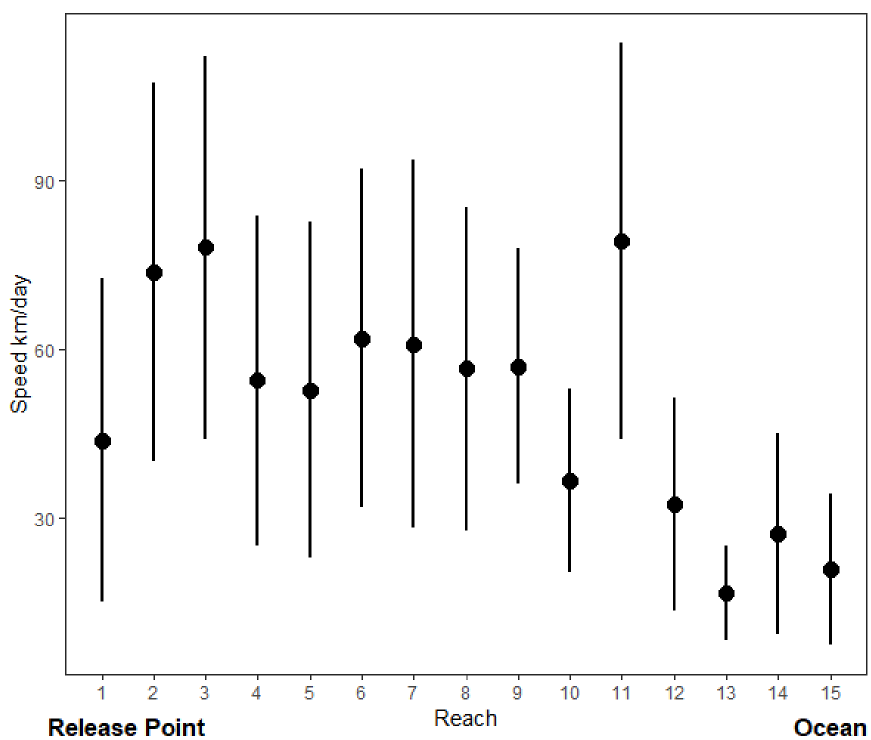

Figure 39. The mean movement speed (km/day) of acoustic-tagged late fall-run Chinook salmon smolts from release location at CNFH to the Golden Gate Bridge.

Table 23. The range of river kilometers and downstream receiver location name for each reach used to calculate movement speed (km/day) of late fall-run Chinook salmon. In addition, the mean, standard deviation (SD), minimum (min), and maximum (max) movement speeds, and the number of unique fish detections at each location are shown.

Reach	Receiver Site	RKM	Mean (SD)	Min/Max	Unique Detects
1	Abv_Altube1	517.34 - 460.4	43.71 (28.88)	3.09 / 101.82	328
2	Mill_Ck_Conf	460.4 - 441.31	73.74 (33.78)	1.69 / 214.32	302
3	Abv_WoodsonBr	441.31 - 425.15	78.13 (34.09)	2.30 / 145.70	307
4	Blw_IrvineFinch	425.15 - 394.66	54.36 (29.39)	2.08 / 134.36	255
5	BlwOrd	394.66 - 361.72	52.75 (29.89)	0.70 / 134.68	193
6	ButteBr	361.72 - 344.1	61.99 (30.28)	1.92 / 126.62	169
7	Colusa AC2	344.1 - 318.61	60.87 (32.82)	2.67 / 135.95	160
8	Colusa BC2	318.61 - 296.27	56.54 (28.86)	2.59 / 113.89	137
9	Blw_Knights_GS3	296.27 - 212.8	56.93 (20.96)	5.08 / 101.20	102
10	Blw_Elkhorn_GS1	212.8 - 191.92	36.54 (16.29)	0.99 / 64.28	103
11	TowerBridge	191.92 - 172	79.30 (35.30)	2.53 / 162.20	94
12	Abv_Clarksburg	172 - 147.66	32.30 (19.07)	0.69 / 67.65	86
13	Chipps	147.66 - 71.48	16.50 (8.34)	3.40 / 37.14	29
14	Benicia	71.48 - 52.14	27.06 (18.04)	12.43 / 97.83	21
15	GoldenGate	52.14 - 1.26	20.73 (13.34)	9.85 / 52.13	8

3.2.2. Winter-Run Chinook Movement

Winter Run Chinook were tagged between 2/12/2019 and 2/14/2019 at Livingston Stone National Fish Hatchery and released on 2/14/2019 at RKM 551. We tracked the movement of these fish over 11 reaches to the ocean.

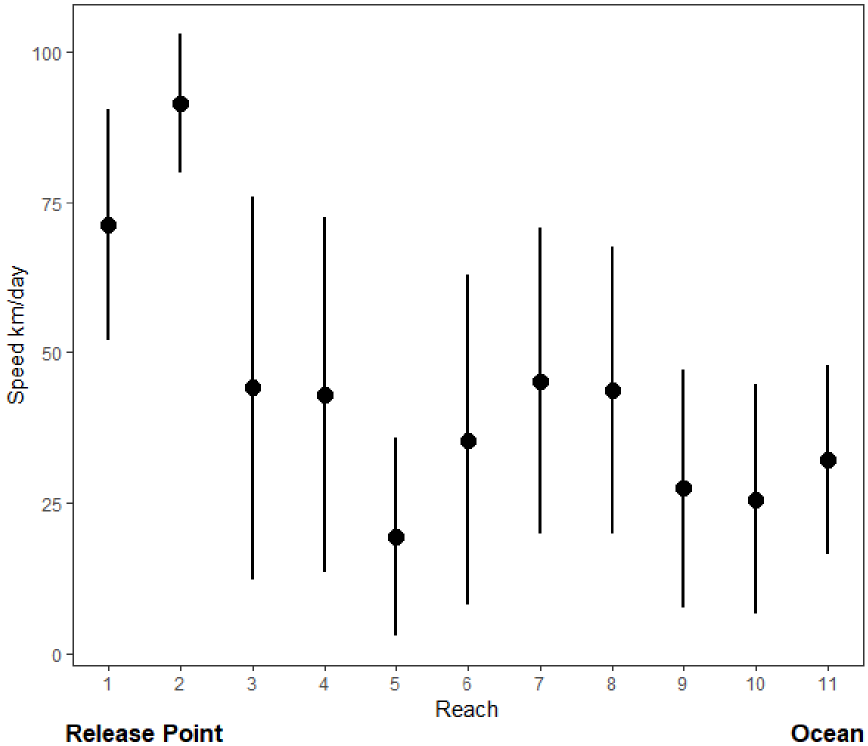

Figure 40. The mean movement speed (km/day) of acoustic tagged winter-run Chinook salmon smolts from release location at Caldwell Park to the Golden Gate Bridge.

Table 24. The range of river kilometers and downstream receiver location name for each reach used to calculate movement speed (km/day) of winter-run Chinook salmon smolts. In addition, the mean, standard deviation (SD), minimum (min), and maximum (max) movement speeds, and the number of unique fish detections at each location are shown

Reach	Receiver Site	RKM	Mean (SD)	Min/Max	Unique Detects
1	Blw_Cypress	551.08 - 543.90	71.32 (19.27)	1.84 / 107.92	636
2	Blw_ClearCr	543.90 - 535.62	91.47 (11.55)	2.70 / 109.39	639
3	Blw_Salt	535.62 - 456.88	44.18 (31.89)	2.22 / 146.84	446
4	GCID_abv	456.88 - 406.11	43.08 (29.52)	2.04 / 147.68	393
5	Colusa AC3	406.11 - 331.15	19.41 (16.43)	1.94 / 123.43	297
6	Colusa BC3	331.15 - 287.20	35.46 (27.47)	1.18 / 128.59	226
7	BlwChinaBend	287.20 - 240.61	45.30 (25.50)	1.55 / 107.47	220
8	KnightsBlwRST	240.61 - 221.58	43.72 (23.95)	0.87 / 87.35	249
9	Chipps	221.58 - 71.48	27.44 (19.83)	3.29 / 85.52	134
10	Benicia	71.48 - 52.14	25.62 (19.16)	3.06 / 132.69	154
11	GoldenGate	52.14 - 1.26	32.13 (15.79)	2.74 / 59.61	120

3.2.3. Feather River Spring-Run Chinook Movement

Feather River Spring Run Chinook were tagged between 4/16/2019 and 4/17/2019 at XX Fish Hatchery and released on 4/22/2019 at RKM 287 (Gridley Rel) or RKM 240 (Boyds Rel). We tracked the movement of these fish over 9 reaches to the ocean.

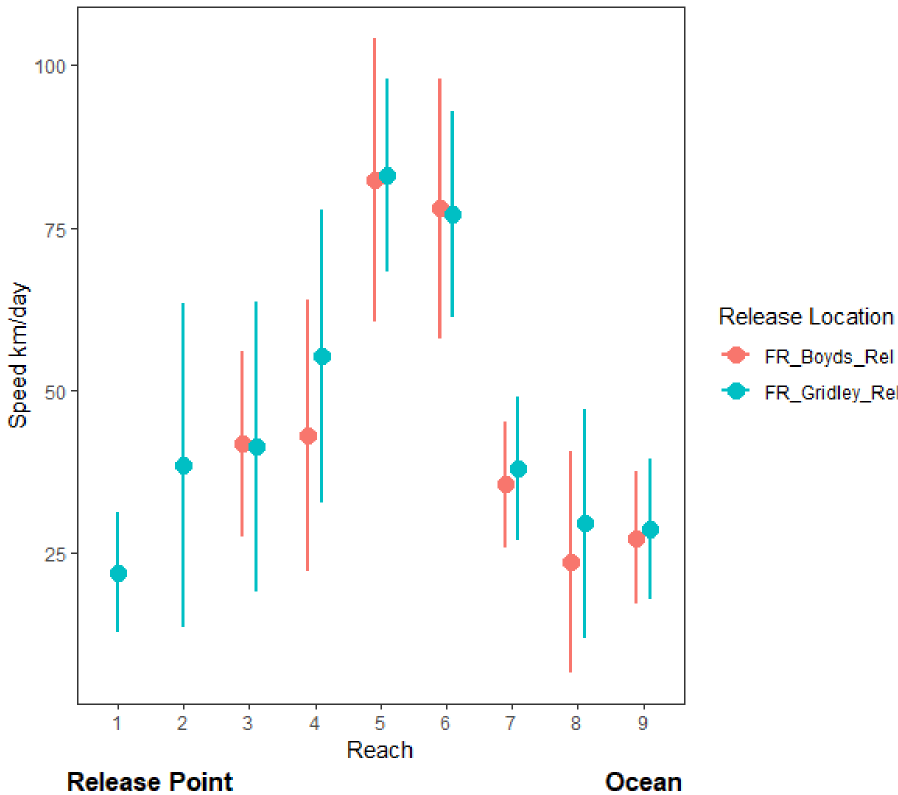

Figure 41. The mean movement speed (km/day) of tagged Feather River spring-run Chinook salmon as they traveled from the release site to the ocean. Fish were released on the same day in two locations, color indicates the release location.

Table 25. The range of river kilometers and downstream receiver location name for each reach used to calculate movement speed (km/day) of Feather River spring-run Chinook salmon. In addition, the mean, standard deviation (SD), minimum (min), and maximum (max) movement speeds, and the number of unique fish detections at each location are shown

Reach	Receiver Site	RKM	Mean (SD)	Min/Max	Unique Detects
1	SunsetPumps	287.38 - 269.75	21.90 (9.25)	0.86 / 62.32	261
2	BoydsPump	269.75 - 240.27	38.45 (24.89)	2.39 / 94.83	111
3	BC_Beach	240.27 - 217.31	41.59 (17.10)	1.42 / 83.94	269
4	Blw_FRConf	217.31 - 203.46	48.66 (22.41)	4.80 / 92.72	167
5	I80-50_Br	203.46 - 170.74	82.63 (18.83)	11.85 / 106.86	167
6	Hood	170.74 - 138.22	77.66 (18.69)	5.66 / 105.92	210
7	Chipps	138.22 - 71.48	36.34 (10.24)	8.19 / 68.95	126

Reach	Receiver Site	RKM	Mean (SD)	Min/Max	Unique Detects
8	Benicia	71.48 - 52.14	25.74 (17.36)	4.15 / 92.40	155
9	GoldenGate	52.14 - 1.26	27.71 (10.45)	4.03 / 50.26	123

3.2.4. Sutter Bypass Wild Chinook Movement

Sutter Bypass Wild Chinook were tagged between 5/5/2019 and5/10/2019 at the Sutter Bypass and released between 5/5/2019 and 5/10/2019 at RKM 249. We tracked the movement of these fish over 6 reaches to the ocean.

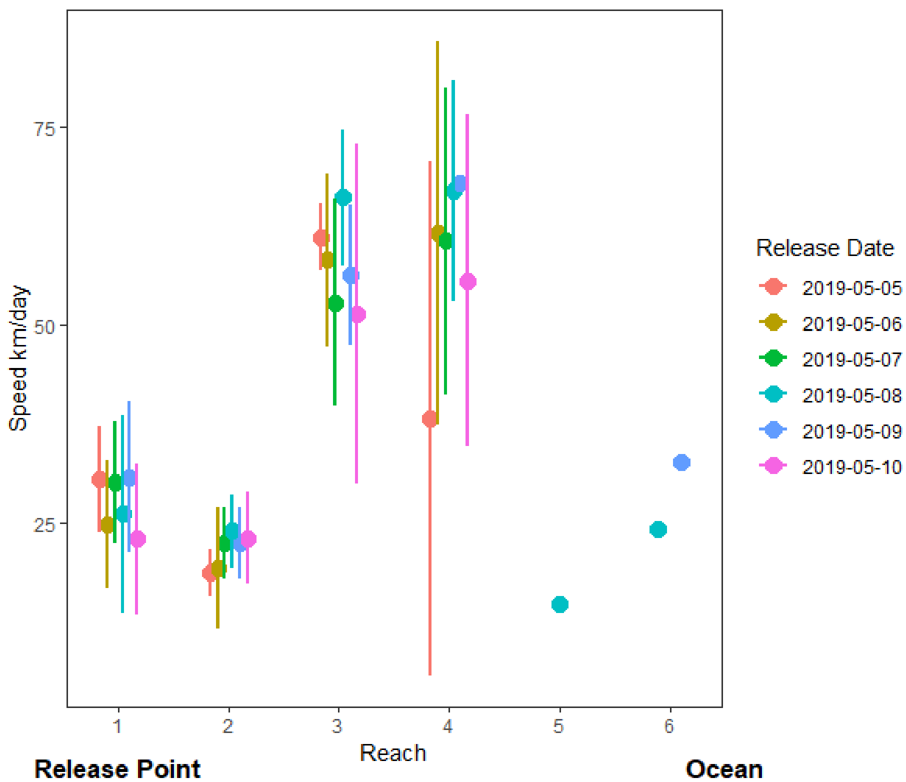

Figure 42. The mean movement speed (km/day) of tagged wild Sutter Bypass Chinook salmon as they traveled from the release site to the ocean. Fish were released on six different days; color indicates the release date.

Table 26. The range of river kilometers and downstream receiver location name for each reach used to calculate movement speed (km/day) of wild Sutter Bypass Chinook salmon. In addition, the mean, standard deviation (SD), minimum (min), and maximum (max) movement speeds, and the number of unique fish detections at each location are shown

Reach	Receiver Site	RKM	Mean (SD)	Min/Max	Unique Detects
1	Butte3	238.46 - 226.46	28.03 (9.48)	1.83 / 43.20	93
2	Butte6	226.46 - 206.48	21.88 (5.17)	10.96 / 32.44	52
3	I80-50_Br	206.48 - 170.74	58.75 (11.81)	30.43 / 77.22	31
4	Hood	170.74 - 138.61	59.38 (19.54)	15.23 / 89.48	19
5	Benicia	138.61 - 52.14	14.64 (0.37)	14.39 / 14.90	2
6	GoldenGate	52.14 - 1.26	28.42 (6.13)	24.08 / 32.76	2

3.2.5. Pulse Flow Alternative Study Chinook Salmon Movement

Fall Run Chinook were tagged between 5/12/19 and 5/20/19 at Coleman National Fish Hatchery and released on 5/14/19 and 5/21/19 at RKM 461. We tracked the movement of these fish over 13 reaches to the ocean.

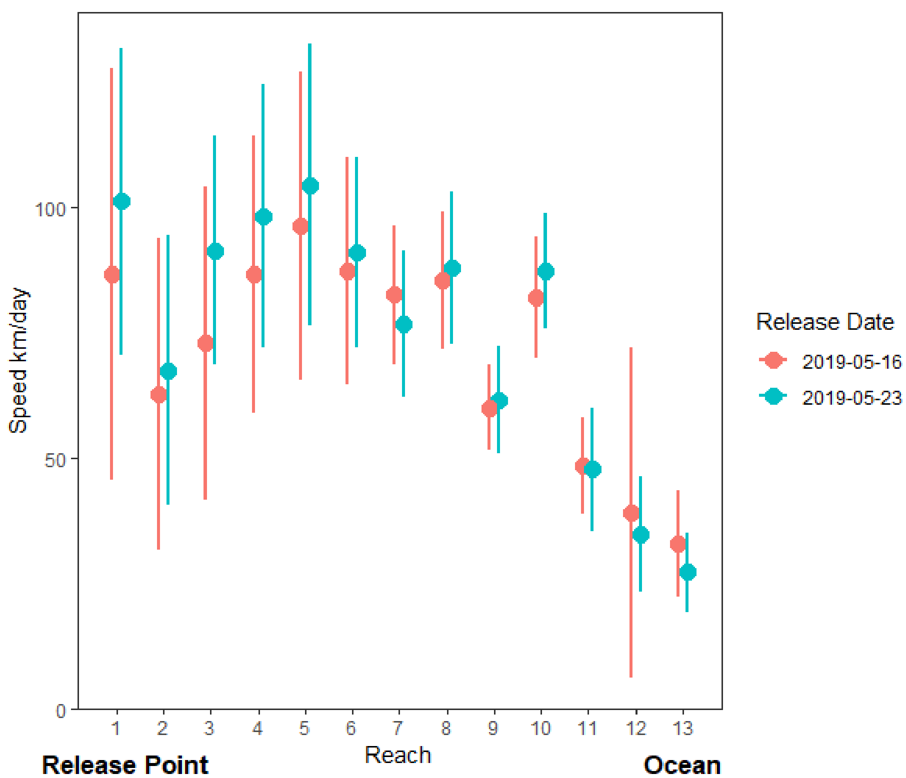

Figure 43. The mean movement speed (km/day) of tagged fall-run Chinook salmon as they traveled from the release site to the ocean. Color indicates the date that fish were released from the hatchery.

Table 27. The range of river kilometers and downstream receiver location name for each reach used to calculate movement speed (km/day) of fall-run Chinook salmon. In addition, the mean, standard deviation (SD), minimum (min), and maximum (max) movement speeds, and the number of unique fish detections at each location are shown

Reach	Receiver Site	RKM	Mean (SD)	Min/Max	Unique Detects
1	Abv_WoodsonBr	456.88 - 425.15	93.89 (36.80)	2.81 / 154.63	411
2	Blw_IrvineFinch	425.15 - 394.66	64.81 (29.38)	4.14 / 111.81	337
3	BlwOrd	394.66 - 361.72	81.25 (29.25)	3.92 / 123.33	291
4	ButteBr	361.72 - 344.10	91.82 (27.62)	2.51 / 132.73	261
5	Colusa AC3	344.10 - 331.15	99.81 (29.99)	2.83 / 144.67	289
6	Colusa BC2	331.15 - 296.27	88.91 (21.22)	20.71 / 171.68	293
7	AbvTisdale	296.27 - 269.23	79.97 (14.46)	25.97 / 109.32	264
8	BlwChinaBend	269.23 - 240.61	86.45 (14.39)	16.47 / 110.60	244
9	Knights_RST	240.61 - 222.05	60.64 (9.51)	19.03 / 88.55	237
10	I80-50_Br	222.05 - 170.74	84.24 (12.09)	39.73 / 111.99	221
11	Chipps	170.74 - 71.48	48.12 (10.63)	21.39 / 73.98	112
12	Benicia	71.48 - 52.14	37.41 (26.75)	6.28 / 123.18	108
13	GoldenGate	52.14 - 1.26	30.60 (10.05)	8.88 / 55.02	91

3.3. Multi-year Survival Status and Trends

3.3.1. Through-Delta survival

Through-Delta survival varied greatly during our 2013–2019 study period and was likely in response to highly variable hydrologic conditions. The lowest through-Delta survival rate recorded during the study period was 1.8% for hatchery Feather River spring-run Chinook salmon released in 2014, during the peak of an unprecedented drought (Figure 44). Conversely, the highest through-Delta survival was 79.0% for hatchery winter-run Chinook salmon in 2017, a record wet year. Through-Delta survival during in 2019 was similar or higher than the same study populations in other years. The only major exception was the relatively low survival of wild Sutter Bypass spring-run Chinook salmon compared to the 2017 and 2018 years, which is explored in more detail in section 3.1.4.

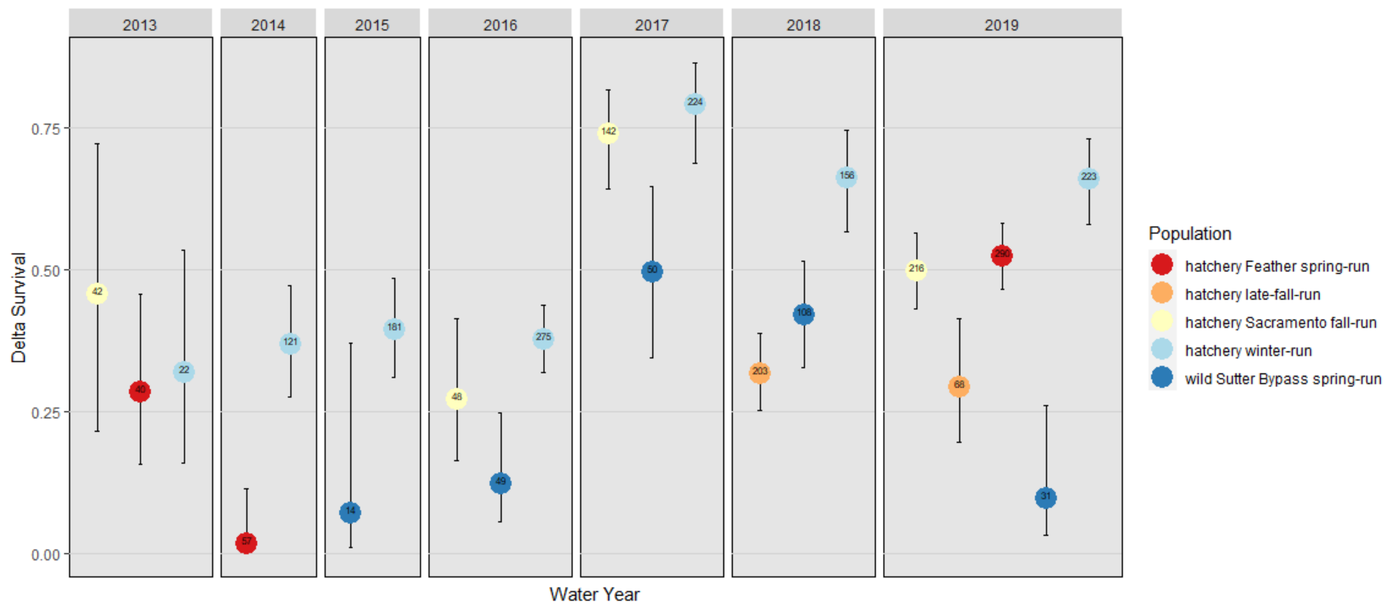

Figure 44. Through-Delta survival (from Freeport to Benicia) for five different Chinook salmon runs from 2013–2019, including 95% confidence intervals. The Chinook salmon runs are hatchery Feather River spring-run, hatchery Sacramento River late fall-run, hatchery Sacramento River fall-run, hatchery Sacramento River winter-run, and wild Sutter Bypass fall and spring-run. Number of fish known to have entered the Delta for each estimate (i.e., sample size) is displayed within the estimate point.

3.3.2. Survival during freshwater migration

Survival during freshwater migration (i.e., from release to Benicia Bridge) also varied substantially from year to year and between study populations. Freshwater migration survival ranged from near zero for multiple study populations in both 2014 and 2015 (during the drought), to as high as 39.7% for late fall-run Chinook salmon in 2011 (Figure 45). For years with more than one study release (2013–2019), hatchery winter-run Chinook salmon almost always had the highest survival of study populations within each year. This could be because these fish are typically released with a storm event, unlike most other study populations, and are typically released in the winter, before water temperatures warm and predators become more active. Besides winter-run Chinook, the other runs included in this study released during the drought years of 2013–2016 experienced extremely low survival, never exceeding 8% survival. Conversely, the majority of study populations released in the wetter years of 2017–2019 experienced survival of 10% or more to Benicia. The exceptions are hatchery late fall-run Chinook salmon in 2019 (as detailed in 3.1.1), and wild Sutter Bypass spring-run Chinook salmon in 2019 (as detailed in 3.1.4).

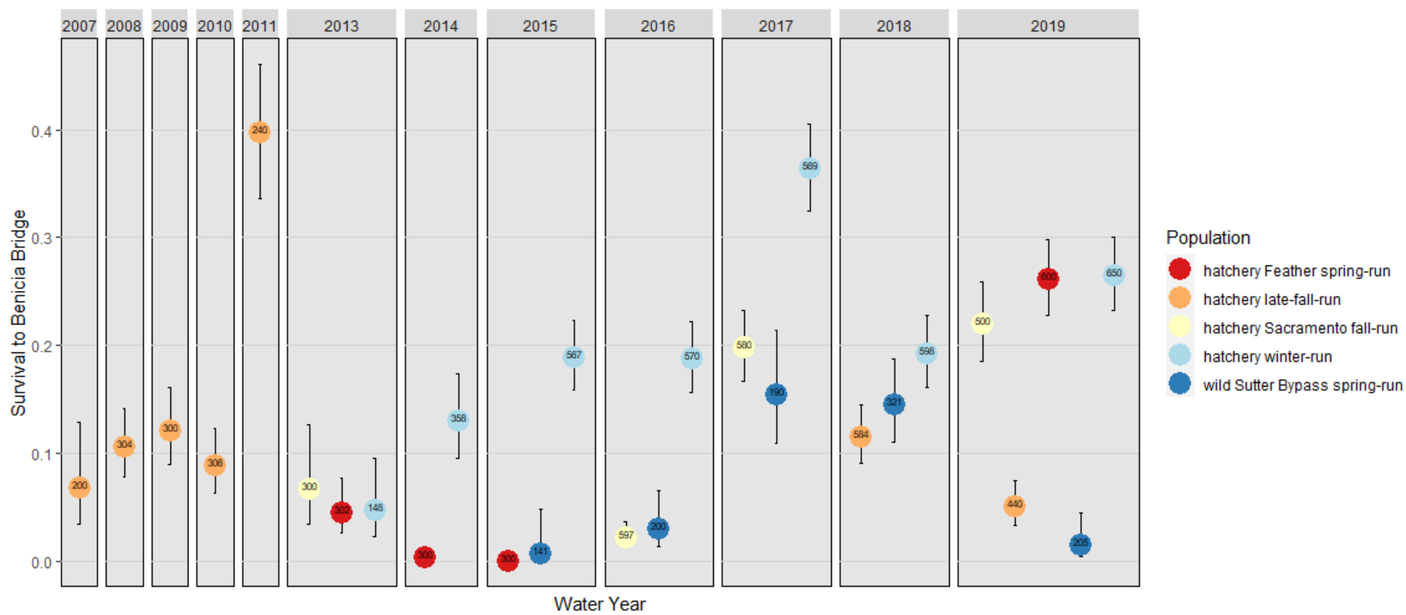

Figure 45. Survival from release to Benicia (synonymous with survival during freshwater outmigration) for multiple runs over multiple years (spanning 2007–2019), with 95% confidence intervals. The Chinook salmon runs are hatchery Feather River spring-run, hatchery Sacramento River late fall-run, hatchery Sacramento River fall-run, hatchery Sacramento River winter-run, and wild Sutter Bypass fall and spring-run. Number of fish released for each estimate (i.e., sample size) is displayed within the estimate point.

It should be noted that the multi-year survival estimates depicted in these figures have not been corrected for any battery life or tag shedding issues, since only some of these studies examined battery life or tag retention. In general, no critical issues were uncovered during the battery life and tag shedding studies that were performed (with perhaps the exception of late fall-run in 2019, see section 3.6.1). Nonetheless, some amount of premature tag shedding or premature battery failures likely occurred for a subset of these studies. In these instances, the overall estimate of survival for that release group would therefore be biased low. As such, the estimates provided above should serve as a minimum estimate of survival for the release groups, and are still useful for demonstrating the variability in survival estimates between study populations and years.

3.4. Tag Effects Study

We tested for differences in starting weight and fork length between tag type treatments using ANOVA and found that they were not significantly different for either the warm (weight $p = 0.815$, length $p = 0.852$) or cool (weight $p = 0.222$, length $p = 0.423$) temperature treatments (Table 1.). Tag burden by weight for cool treatment mean was higher for standard compared to injectable tag types, 4.1 and 3.1% respectively, and for warm treatment; 4.4 and 3.2% respectively. However, tag burden by length was lower for standard compared to injectable tag types, with cool treatment 12.2% versus 17.2% respectively and warm treatment 12.3% versus 17.3% respectively.

3.4.1 Tag Retention

Over the 60-day trial, 19 out of 128 (14.8%) tagged fish expelled their tags. All shed tags were recovered on the day shedding occurred, except for one (cool temperature treatment), which was found in the drainage assembly at the end of the trial. The date expelled for this tag was imputed based on the average shed date for standard tag/cool temperature treatment. Both tag types had similar loss rates; 15.6% of standard (10 tags) and 14.1% of injectable (9 tags). There was one mortality in the standard tag treatment and three in the injectable tag treatment. Total loss rate (shed tags + mortalities) for standard and injectable tag type was lower for the large size bin (5.6 and 9.1%) compared to the medium (25.0 and 18.2%) and small (18.2 and 23.8%) size bins respectively. However, these differences were not statistically significant.

The Cox proportional hazards model indicated that temperature significantly affected tag shedding ($p = 0.028$) with warm treatment fish (21.9%, 14 tags shed) more likely to shed a tag than cool treatment fish (7.8%, 5 tags shed). Additionally, three out of the four shed events in the cool temperature treatment occurred after day 45, while tags were shed consistently in the warm temperature treatment after day 12 (Figure 46). Tag shedding did not significantly differ between surgeon experience, size at tagging, or tag type.

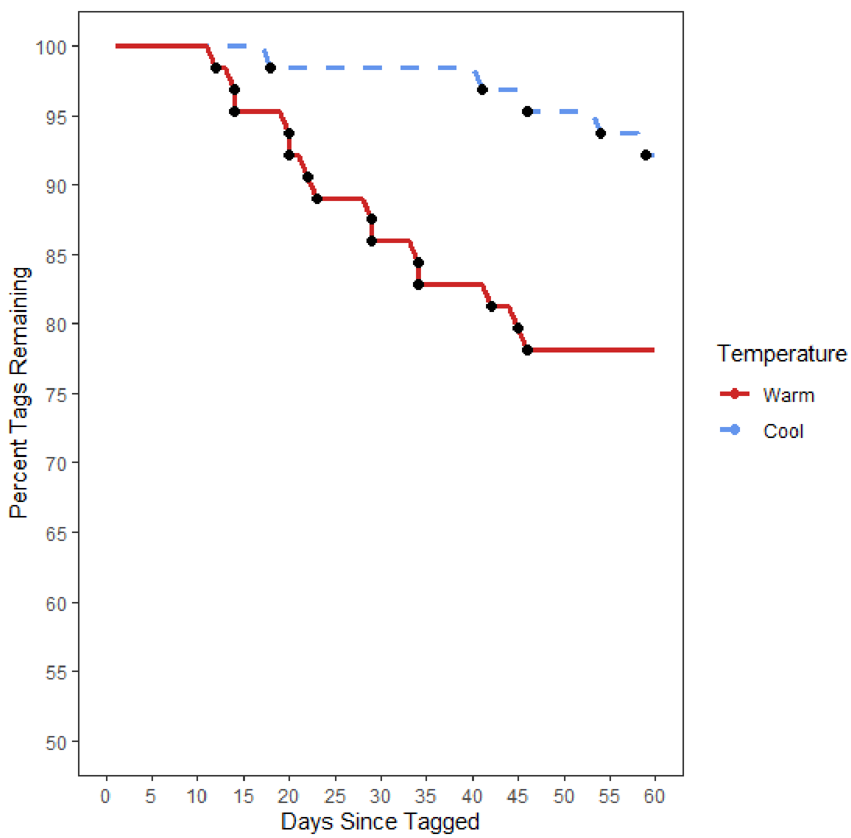

Figure 46. The percent of tags remaining for each temperature treatment over the 60-day tag retention trial.

3.4.2 Growth

Growth was highly variable among individuals, with a few fish losing weight and others gaining up to 36 g over the 60-day trial.

Warm treatment

Specific growth rate was significantly higher in the reference group compared to the injectable group (Figure 47). Standard growth rate varied significantly by tag treatment, with injectable fish (1.75 ± 0.63 g) having significantly lower growth than reference fish (2.22 ± 0.44 g) and slightly lower growth than standard tagged fish (2.03 ± 0.54 g). There was no statistically significant difference in growth between standard tagged and reference fish. Starting size did not significantly affect growth.

Cool treatment

Specific growth rate did not differ significantly in the cool treatment by tag treatment, starting size, or surgeon. The mean specific growth rate for the cool treatment was 1.47 ± 0.66 g.

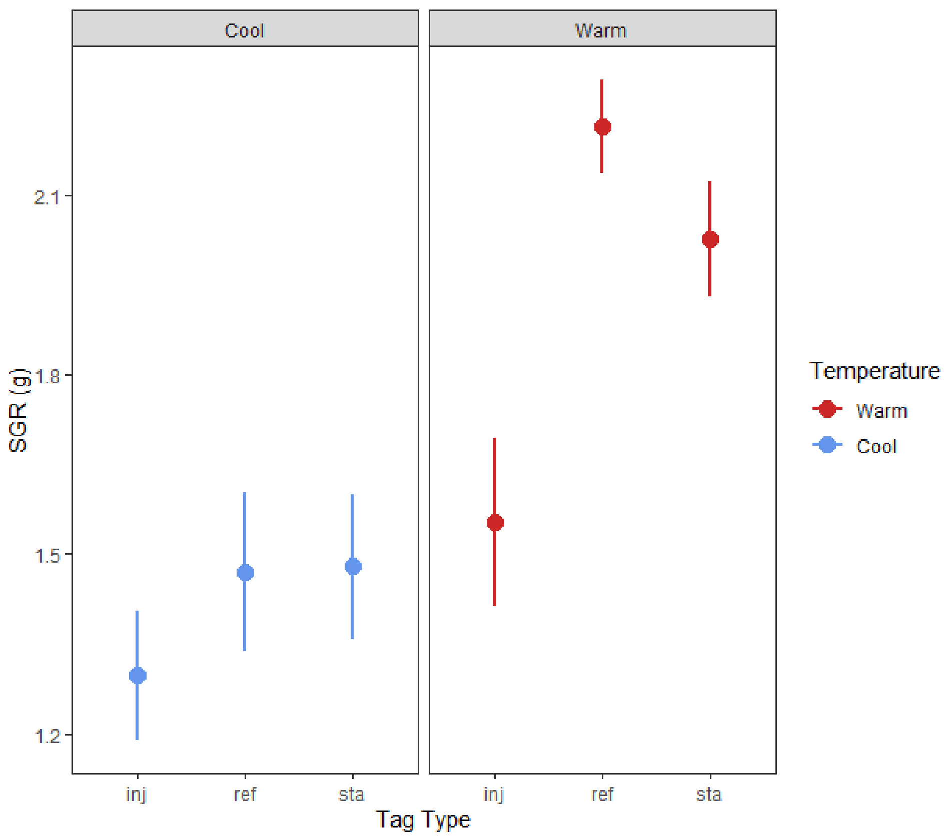

Figure 47. The standard growth rate (g) of fish from each tag treatment (inj = "injectable"; ref = "reference"; sta = "standard") in the warm and cool temperature treatments. Warm and cool growth rates were analyzed separately.

3.4.3 Surgeon Experience

We examined the effect of surgeon experience on tag retention, growth, and survivorship. While there were significant differences in surgery time between the two surgeons, we found no effect of surgeon experience on tag retention. Tag shedding was similar for both surgeons; 9 tags (7 standard and 2 injectable) were shed by fish tagged by the experienced surgeon, 10 tags (3 standard and 7 injectable) from the novice surgeon. Surgeon experience did not affect growth in either the warm or cool temperature treatment. Surgery time was significantly longer for the novice surgeon compared to expert surgeon for both standard and injectable tag types. The mean surgery time of the standard acoustic tag treatment was 2.2 (± 0.3) minutes (expert surgeon) and 3.9 (± 0.6) minutes (novice surgeon). For the injectable tag treatment, the mean surgery time was 1.4 (± 0.3) minutes (expert surgeon) and 2.8 (± 0.5) minutes (novice surgeon).

During the 60-day trial there were seven mortalities (3.6%, four warm temperature treatment, three cool temperature treatment), two control fish and five tagged fish (one standard, four injectable). All five tagged fish mortalities were tagged by the novice surgeon. One tagged fish mortality shed its tag prior to death, however, the other four did not shed their tags.

3.5. Tag Retention Studies

3.5.1. Late Fall-Run Chinook Tag Retention Study

There were no recorded fish mortality or tag shed events for this tag retention study. Two control, two injectable, and three standard tagged fish went missing over the course of the study. The mean weight of the injectable fish decreased from start to end of the trial. The control fish gained an average of 0.14 g, and 4.61 mm in length and the standard tagged fish gained an average of 1.06 g and 3.13 mm of length, while the injectable tagged fish lost an average of 0.24 g (Table 28).

Table 28. Comparing fish weight (g) and length (mm) from the start and end of the late fall-run Chinook salmon tag retention study between three treatments: control, injectable, and standard tagged groups.

Tag Type	Fish Count	Weight (SD)	Min/Max Weight	Length (SD)	Min/Max Length	Growth g (SD)	Growth mm (SD)
Control	50	28.99 (16.01)	7.2 / 83.1	133.66 (22.15)	90 / 190	0.14 (1.00)	4.61 (0.27)
Injectable	25	30.63 (10.83)	12.6 / 52.2	137.78 (16.74)	108 / 166	-0.24 (0.37)	3.16 (0.25)
Standard	25	33.35 (11.14)	12.0 / 55.3	142.73 (17.11)	104 / 173	1.06 (0.56)	3.13 (0.02)

3.5.2. Winter-Run Chinook Tag Retention Study

During the tag retention trial, eight fish expelled their tags, mainly in the latter portion of the study (March 23 – April 29, 2019) (Figure 48). At the end of the trial, an additional five fish were identified to have bulging at the implantation site, indicating the fish was in the process of expelling their tags. There were no fish mortalities during the trial, with fish increasing in weight and length from the beginning to the end of the trial period. The average weight increased by 10.97 g and 25.48 mm in length for the control group and 10.53 g and 24.10 mm in length for the standard tagged group (Table 29).

Table 29. Comparing fish weight (grams) and length (mm) from the start and end of the winter-run Chinook salmon tag retention study between two treatments: control and tagged fish.

Tag Type	Fish Count	Weight (SD)	Min/Max Weight	Length (SD)	Min/Max Length	Growth g (SD)	Growth mm (SD)
Control	50	8.87 (1.65)	6.70 / 14.10	94.28 (5.76)	85 / 112	10.97 (2.79)	25.48 (1.59)
Tagged	50	8.78 (1.50)	6.80 / 11.60	93.74 (4.96)	86 / 103	10.53 (3.14)	24.10 (2.29)

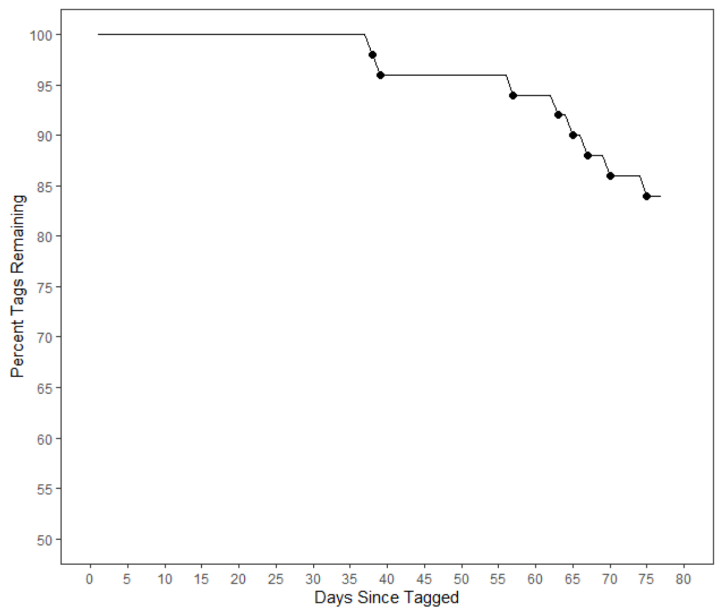

Figure 48. The percent tags remaining not yet shed over the course of the winter-run Chinook salmon tag retention study. Black dots indicate shed events.

3.6. Tag Life Studies

3.6.1. Late Fall-Run Chinook Tagging

Not all tags made it to the warranty life of 52 days (SS300 tags) or 78 days (SS400 tags). Of the 16 SS300 tags tested for tag life there were three (18.7%) that did not make it to warranty life. One tag only operated for 2.6 days, while two others ran for 12.4 and 32.4 days and the remaining five tags ran for over 80 days. Of the seven SS400 tags tested, two did not make it to warranty life (28.6%). These two ran for 31.1 and 32.4 days, the remaining five ran for over 80 days (Figure 49).

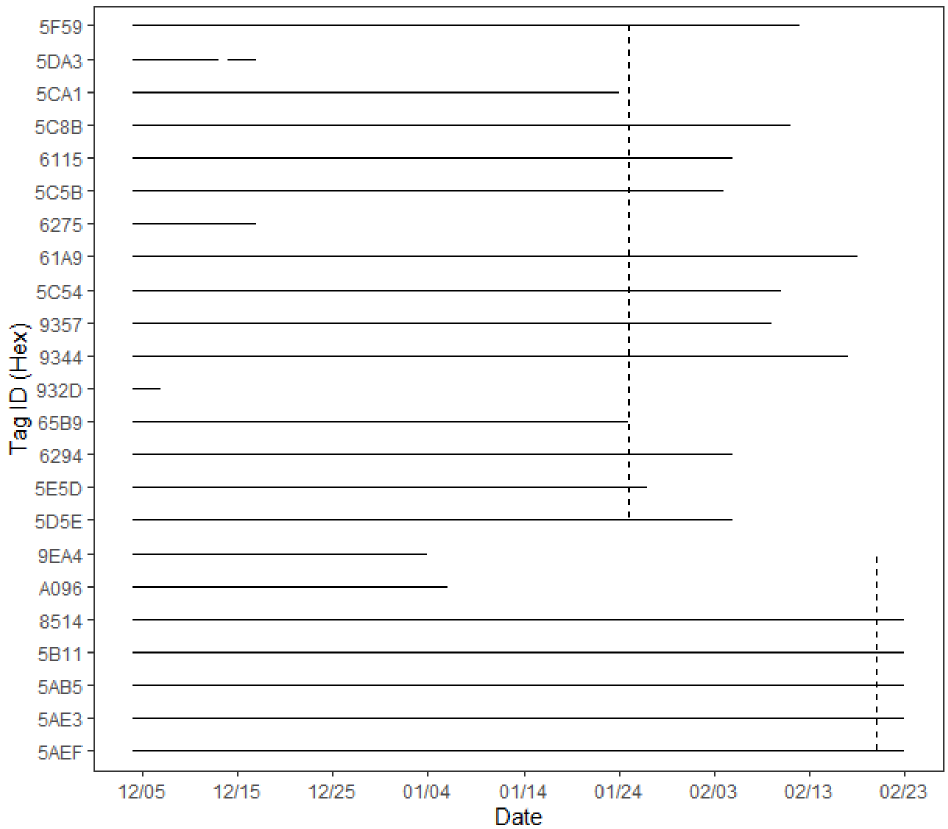

Figure 49. Detections of late fall-run Chinook salmon tags from 12/05/2018 to 02/23/2019. Dashed lines indicate the tag warranty life for the two tag types.

3.6.2. Winter-Run Chinook Tagging

All of the 36 tags made it to the warranty life of 68 days or 52 days (Figure 50). On average, tags ran for 93 days with a range of 63 to 128 days.

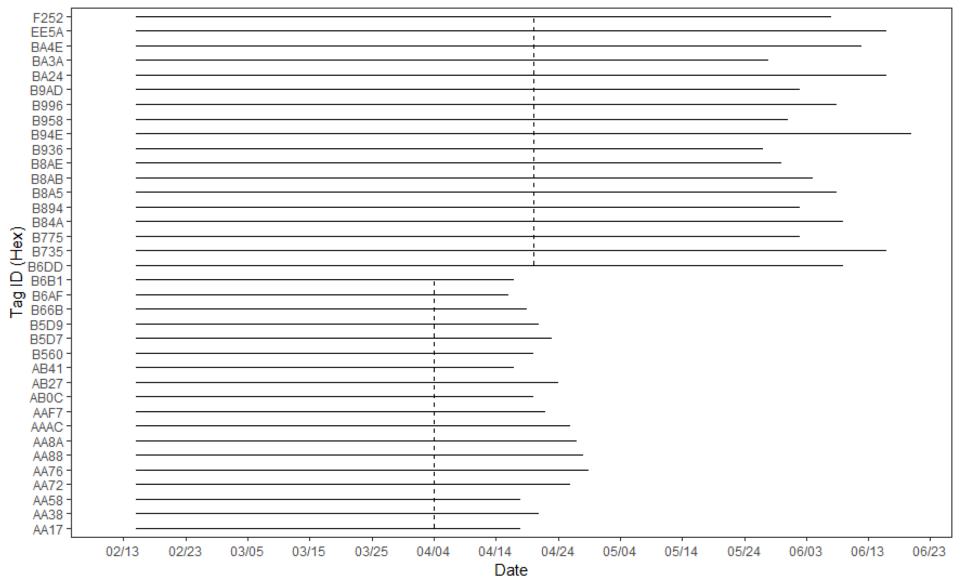

Figure 50. Detections of winter-run Chinook salmon tags from 2/13/2019 to 06/23/2019. Dashed lines indicate the tag warranty lives.

3.6.3. Spring-Run Chinook Tagging

All of the 40 tags made it to the warranty life of 26 days (Figure 51). One tag (F548) made it past the warranty life but was not detected consistently by the receivers. On average, tags ran for 38.9 days with a range of 31.1 to 89.1 days.

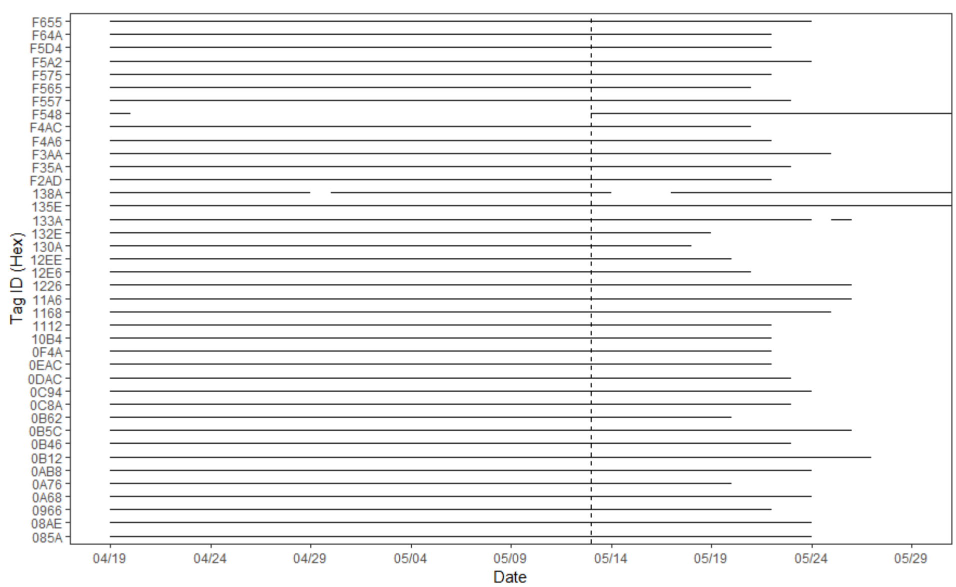

Figure 51. Detections of spring-run Chinook salmon tags from 4/19/19 to 5/30/19. Dashed line indicates the tag warranty life.

3.6.4. Sutter Bypass Wild Chinook Tagging

All of the 10 tags made it to the warranty life of 26 days and were detected consistently by the receivers (Figure 52). On average, tags ran for 36.1 days with a range of 33 days to 39 days.

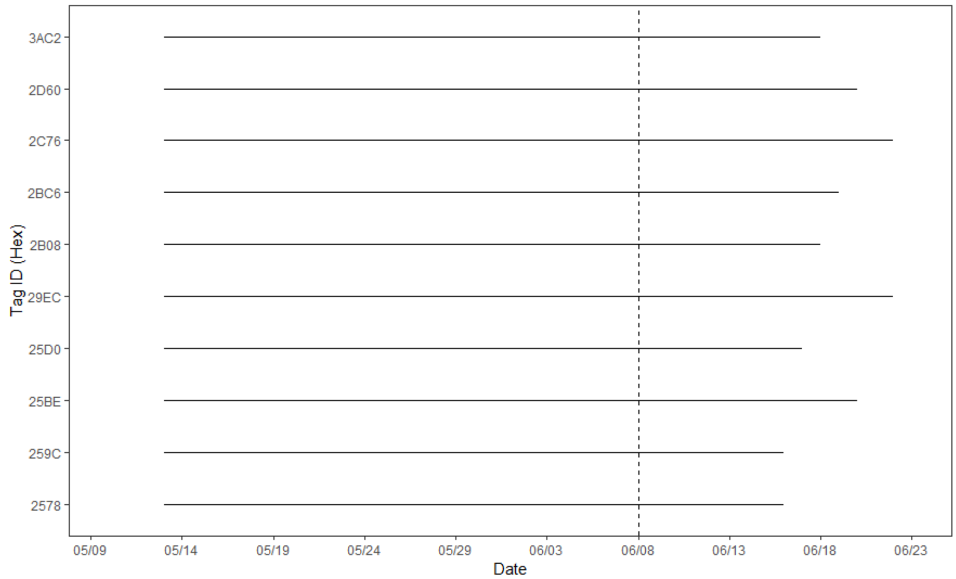

Figure 52. Detections of Sutter Bypass tags from 5/13/19 to 6/23/19. Dashed line indicates the tag warranty life.

3.6.5. Fall-Run Chinook salmon Tagging

Not all tags made it to the warranty life of 26 days (Figure 53). Of the 28 SS300 tags tested for tag life there was one (3.6%) that did not make it to warranty life. This tag remained operational for 17 days. Additionally, one tag made it past warranty life but was not detected consistently by the receivers. On average, tags ran for 33 days with a range of 17 days to 41 days.

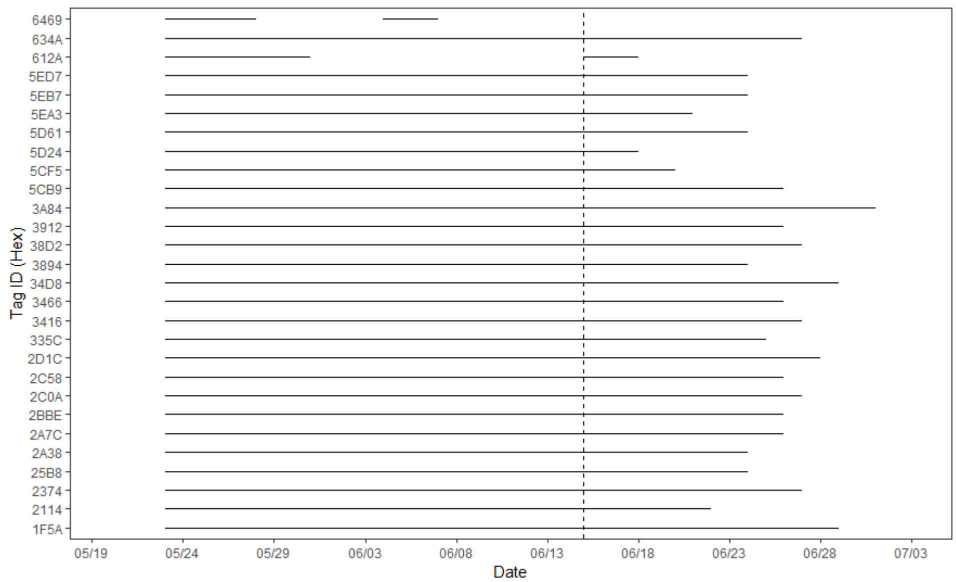

Figure 53. Detections of fall-run Chinook salmon tags from 5/20/19 to 7/03/19. Dashed line indicates the tag warranty life.

3.7. Receiver Deployments

3.7.1 Real-time Receiver Coverage

While individual receiver sites had periods of being non-operational, all real-time arrays were consistently functional during WY 2019 (Table 30). The one exception is when USGS removed the Georgiana Slough complex real-time array to avoid vandalism over the summer when no tagged fish were in the system (see "% of day in operation" for Sac_BlwGeorgiana and Georgiana_Slough sites in Table 30) . Since February 2019, USGS has maintained all Delta real-time receivers (Georgiana Slough complex, Old and Middle River). Two real-time receivers were deployed near Butte City Bridge (ButteBrRT) in the Sacramento River in January 2019. Individual receivers at the Georgiana Slough complex were not operational for various periods due to: theft, vandalism (both human and animal), flooding, wiring issues, individual receiver glitches, and damage to the hydrophones. Also, two of three receivers at Tower Bridge needed to be removed in July 2019 for bridge pier and fender replacement. No fish with live tags were present in the system during Tower Bridge receiver removal. Troubleshooting site visits were mostly done shortly after problems were identified, although dangerously high flow conditions and travel logistics related to the federal government shutdown resulted in some maintenance delays.

Table 30. Location of JSATS real-time shore stations with date first operational, % days in operation, and mean daily beacon detection efficiency (%) for WY2019.

General Location	Receiver name	Date first operational	Latitu de	Longitude	RKM	% of days in operation (11/2/18 – 9/30/2019)	Mean daily beacon detection efficiency (%) when in operation in WY2019
TowerBridge	TowerBr1	1/31/18	38.580	-121.509	172	100	89.9

TowerBridge	TowerBr2	1/31/18	38.580	-121.509	172	74.5	87.6
TowerBridge	TowerBr3	1/31/18	38.580	-121.509	172	74.5	83.8
I80-50_Br	I80-50_Br2	2/1/18	38.571	-121.516	171	100	90.6
I80-50_Br	I80-50_Br3	2/1/18	38.571	-121.516	171	100	90.2
Sac_BlwGeorgiana	BlGeorg_RT1.1	4/16/18	38.239	-121.527	119	72.0	55.3
Sac_BlwGeorgiana	BlGeorg_RT1.2	4/16/18	38.238	-121.527	119	77.2	82.9
MiddleRiver	RT_MiddleRiver	4/17/18	37.940	-121.534	150	76.6	84.1
Georgiana_Slough1	GeorgSlRT_1.1	4/17/18	38.234	-121.520	119	71.2	80.9
Georgiana_Slough1	GeorgSlRT_1.2	4/17/18	38.234	-121.519	119	74.8	82.4
Old River	RT_OldRiver	4/18/18	37.940	-121.561	153	100	86.6
Benicia_east	BeniciaRT_16	4/23/18	38.039	-122.119	52	100	88.3
Benicia_east	BeniciaRT_13	4/24/18	38.042	-122.122	52	100	83.0
Benicia_east	BeniciaRT_14	4/24/18	38.042	-122.121	52	100	85.4
Benicia_east	BeniciaRT_15	4/24/18	38.040	-122.120	52	100	87.3
Benicia_west	BeniciaRT_03	4/24/18	38.042	-122.125	52	100	85.2
Benicia_east	BeniciaRT_09	4/25/18	38.047	-122.125	52	93.4	85.2
Benicia_east	BeniciaRT_10	4/25/18	38.047	-122.125	52	83.2	86.9
Benicia_east	BeniciaRT_11	4/25/18	38.045	-122.124	52	100	82.2
Benicia_east	BeniciaRT_12	4/25/18	38.043	-122.123	52	100	85.9
Benicia_west	BeniciaRT_01	4/25/18	38.045	-122.127	52	83.5	83.8
Benicia_west	BeniciaRT_02	4/25/18	38.044	-122.126	52	100	86.1
Benicia_west	BeniciaRT_07	4/25/18	38.038	-122.121	52	100	82.1
Benicia_west	BeniciaRT_04	5/2/18	38.041	-122.124	52	100	85.4
Benicia_west	BeniciaRT_05	5/2/18	38.040	-122.123	52	94.6	85.2
Benicia_west	BeniciaRT_06	5/2/18	38.039	-122.122	52	94.3	85.2
Benicia_west	BeniciaRT_08	5/2/18	38.036	-122.120	52	99.4	85.6
TowerBridge	TowerBr3	5/9/18	38.580	-121.508	172	74.5	83.8
Sac_BlwGeorgiana2	BlGeorg_RT2.1	5/10/18	38.239	-121.535	118	77.2	83.5
Sac_BlwGeorgiana2	BlGeorg_RT2.2	5/10/18	38.238	-121.535	118	76.9	77.2
I80-50_Br	I80-50_Br1	5/14/18	38.571	-121.516	171	92.5	86.5
Georgiana_Slough2	GeorgSlRT_2.1	5/22/18	38.231	-121.523	119	66.4	84.2
Georgiana_Slough2	GeorgSlRT_2.2	5/22/18	38.231	-121.522	119	76.9	80.6
ButteBrRT	ButteBR_RT1	1/25/2019	39.457	-121.995	344	86.3	63.6
ButteBrRT	ButteBR_RT2	1/25/2019	39.457	-121.995	344	100	82.3

3.7.2 Study Area Autonomous and Real-time Receiver Coverage

A total of 475 real-time and autonomous receivers were deployed and/or retrieved between October 1, 2018 and September 30, 2019 across 18 different general locations (Figure 54). Each location contains multiple receiver sites (Table 31); receivers were swapped approximately every three months. Multiple agencies were responsible for maintaining the receivers including University of California, Santa Cruz (UCSC), University of California Davis (UC Davis), National Oceanic and Atmospheric Administration's Southwest Fisheries Science Center (SWFSC), United States Fish and Wildlife Service (USFWS), California Department of Fish and Wildlife (CDFW), United States Army Corps of Engineers (USACE), Department of Water Resources (DWR), and United States Geological Survey (USGS).

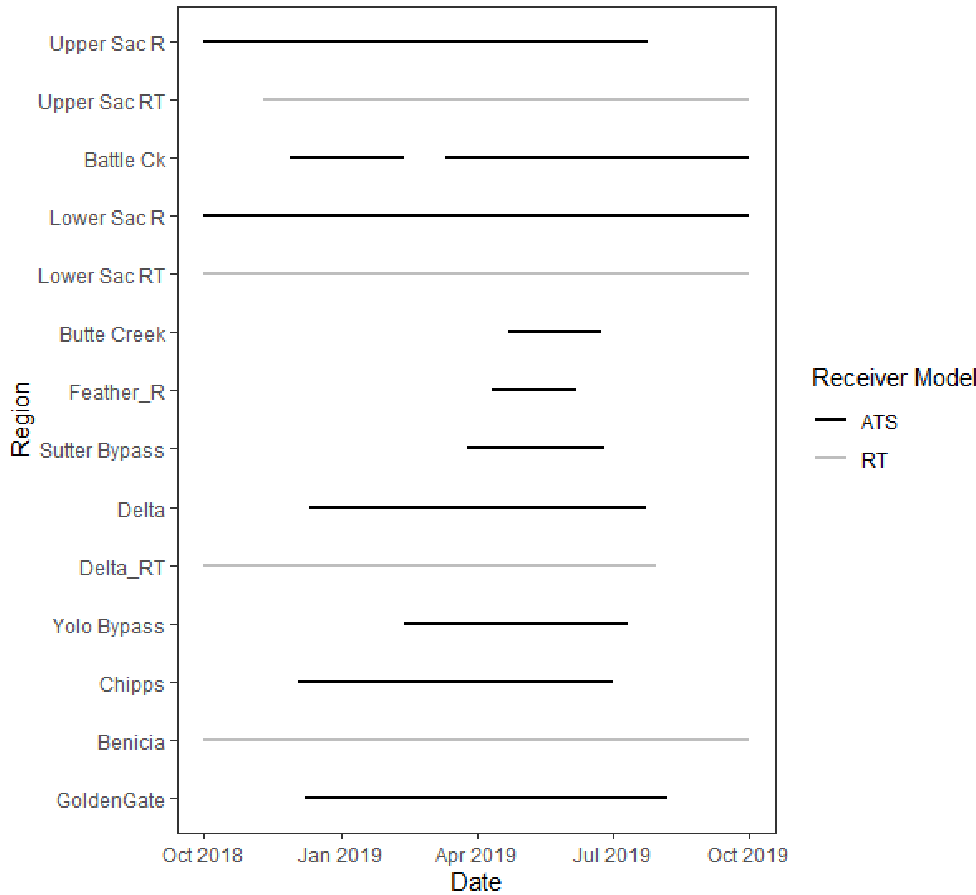

Figure 54. Autonomous (ATS) and Real-time (RT) receiver deployment coverage at each region for the 2019 water year. Not all individual receivers within a region were functional during this time.

Table 31. For each region, multiple receivers were deployed at different sites (Rec Sites), spanning a range of river kilometers (RKM). The coverage time varied at each region depending on when fish were in the system. Multiple agencies were responsible for the maintenance for receivers at each region.

Region	Rec Sites	RKM	Rec Coverage	Deployments	Agency
Upper Sac R	49	344 - 551	10/01/2018 - 07/25/2019	28	USFWS
Upper Sac RT	2	344 - 344	11/09/2018 - 09/30/2019	3	UCSC
Battle Ck	8	508 - 534	11/27/2018 - 09/30/2019	3	UCSC/USFWS
Lower Sac R	52	138 - 331	10/01/2018 - 09/30/2019	37	UCSC/SWFSC/ USACE/USFWS
Lower Sac RT	4	170 - 172	10/01/2018 - 09/30/2019	5	UCSC
Butte Creek	6	253 - 340	04/23/2019 - 06/24/2019	4	CDFW
Feather_R	15	217 - 287	04/11/2019 - 06/07/2019	2	DWR/SWFSC
Sutter Bypass	9	206 - 249	03/26/2019 - 06/26/2019	7	UCSC
Delta	28	97 - 153	12/10/2018 - 07/24/2019	12	UCSC/USGS

Region	Rec Sites	RKM	Rec Coverage	Deployments	Agency
Delta_RT	24	118 - 153	10/01/2018 - 07/30/2019	17	UCSC/USGS
Yolo Bypass	9	111 - 127	02/12/2019 - 07/11/2019	3	DWR/UC Davis
Chipps	10	71 - 71	12/03/2018 - 07/01/2019	2	SWFSC/USGS
Benicia	16	52.0 - 52.2	10/01/2018 - 09/30/2019	15	UCSC
GoldenGate	14	0.8 - 1.7	12/07/2018 - 08/07/2019	6	UCSC

3.7.3. Upper Sacramento River Receiver Coverage

Within the Upper Sacramento River region (RKM 551 to 361), autonomous and RT receivers were deployed at 28 general locations. The receiver coverage varied depending on when fish were in the system (Figure 55). There were three fish tagging studies that were detected at receivers in this region.

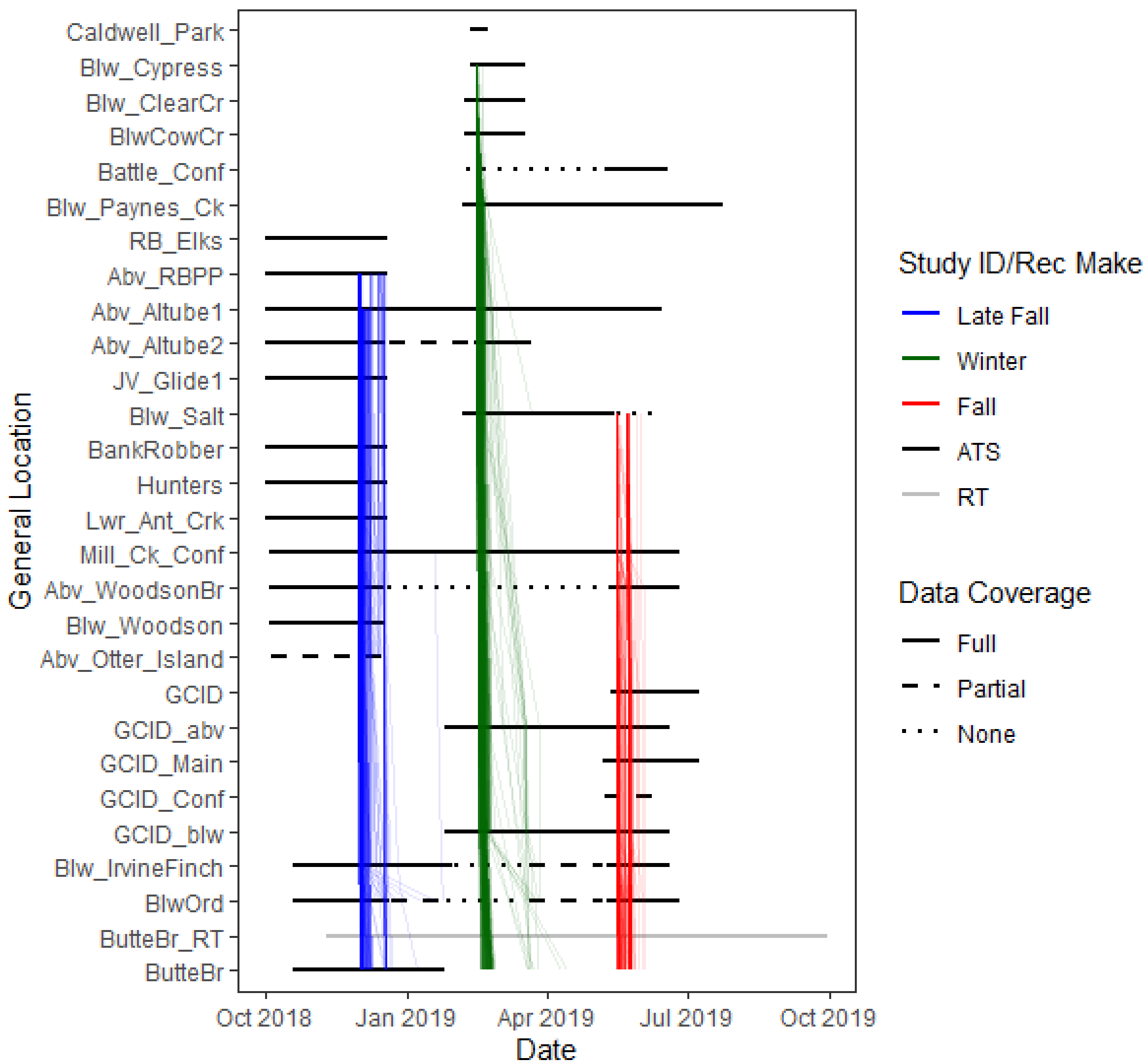

Figure 55. Receiver coverage at each general location in the upper Sacramento River Region. Solid horizontal black lines indicate autonomous receiver coverage through time, and gray horizontal black lines indicate real-time receiver coverage. Dashed horizontal lines indicate when one or more receivers at that site had partial coverage during that period, dotted horizontal lines indicate when one or more receivers at that site had no coverage during that period. Colored horizontal lines indicate when fish from each study were transiting each region so as to indicate which receivers were present to detect fish from each study.

3.7.4 Lower Sacramento River Receiver Coverage

Within the Lower Sacramento river region (RKM 344 to 128), autonomous and RT receivers were deployed at 24 general locations. The receiver coverage varied depending on when fish were in the system. There were five fish tagging studies that were detected at receivers in this region.

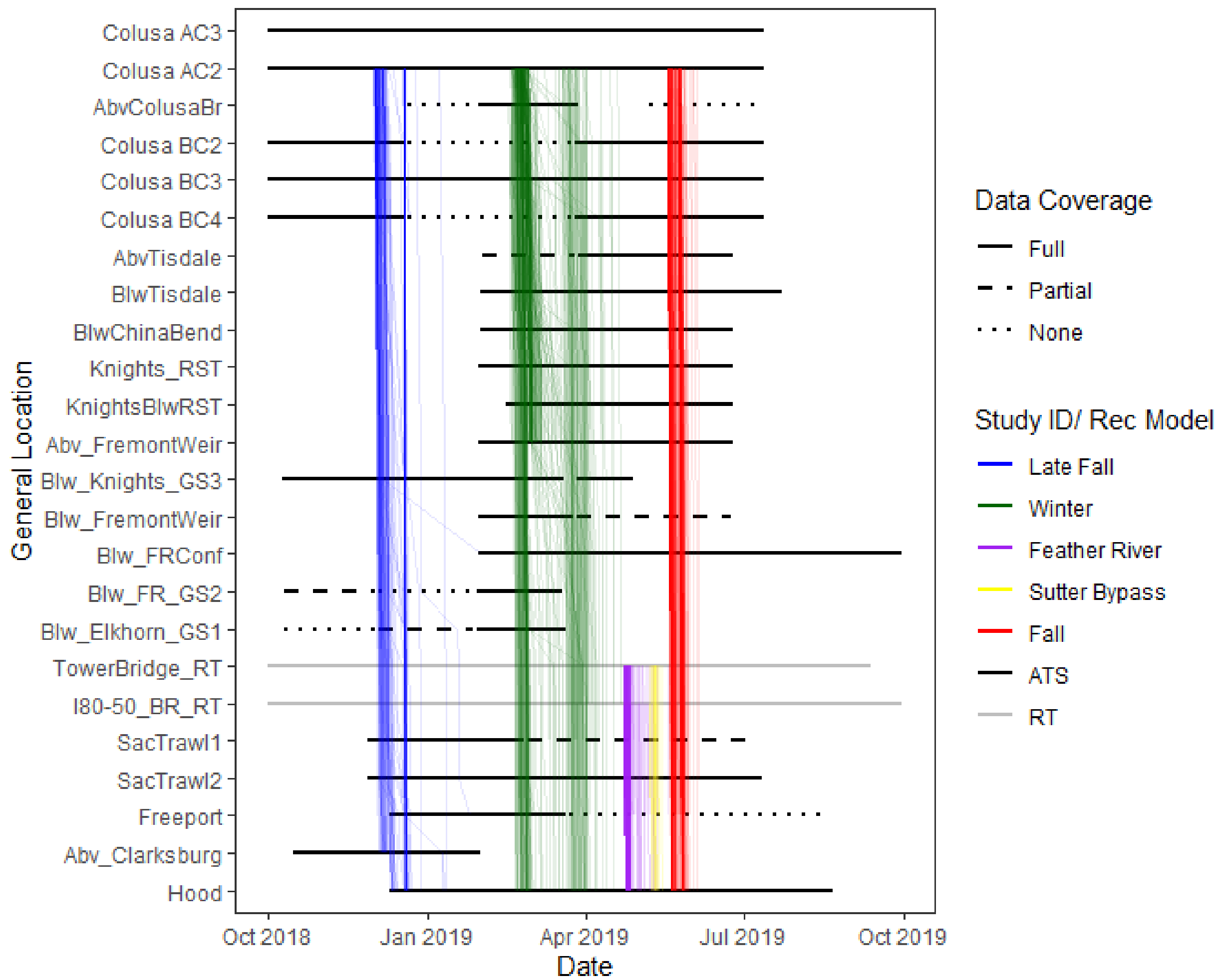

Figure 56. Receiver coverage at each general location in the Lower Sacramento River Region. Solid horizontal black lines indicate autonomous receiver coverage through time, and gray horizontal black lines indicate real-time receiver coverage. Dashed horizontal lines indicate when one or more receivers at that site had partial coverage during that period, dotted horizontal lines indicate when one or more receivers at that site had no coverage during that period. Colored horizontal lines indicate when fish from each study were transiting each region so as to indicate which receivers were present to detect fish from each study.

3.8. Detection Efficiency Study

During the October 2019 Butte City detection efficiency trial, extremely windy conditions made it difficult to keep tag drifts consistently straight and slow. Increased speeds and the need to turn the engine on to correct course likely lead to lower detections. Overall, the receivers performed poorly, which was also observed in detection efficiency of WY 2019 tagging studies at the Butte City receiver location, and warrants further research as to why this location has below average detection efficiency. Receivers located on the east (river left) channel showed the highest detection rates. Additional receivers (real-time or autonomous) at this location would be useful to increase overall detection efficiencies.

Receivers located closest to the west (river right) bank performed the poorest overall regardless of where the drift occurred (Figure 57). Receiver 13014, which was on the east bank, picked up the most detections of all receivers regardless of the drift location. The river left channel is typically the location of the thalweg, which is likely the reason this channel's receivers performed the best. While receiver 13064 and 19030 are less than 3 meters apart there is as large discrepancy in which tag transmissions they detected. The receivers (both autonomous and real-time) located on the west side of the middle fender were the poorest performers. The only receiver on the west fender was only really successful in detecting tags in the river right channel. This bridge's piers seem to cause a great deal of sediment deposition especially after long periods of high flows. This produces a very inconsistent bottom which may increase some of the discrepancies seen by the receiver's detection efficiencies.

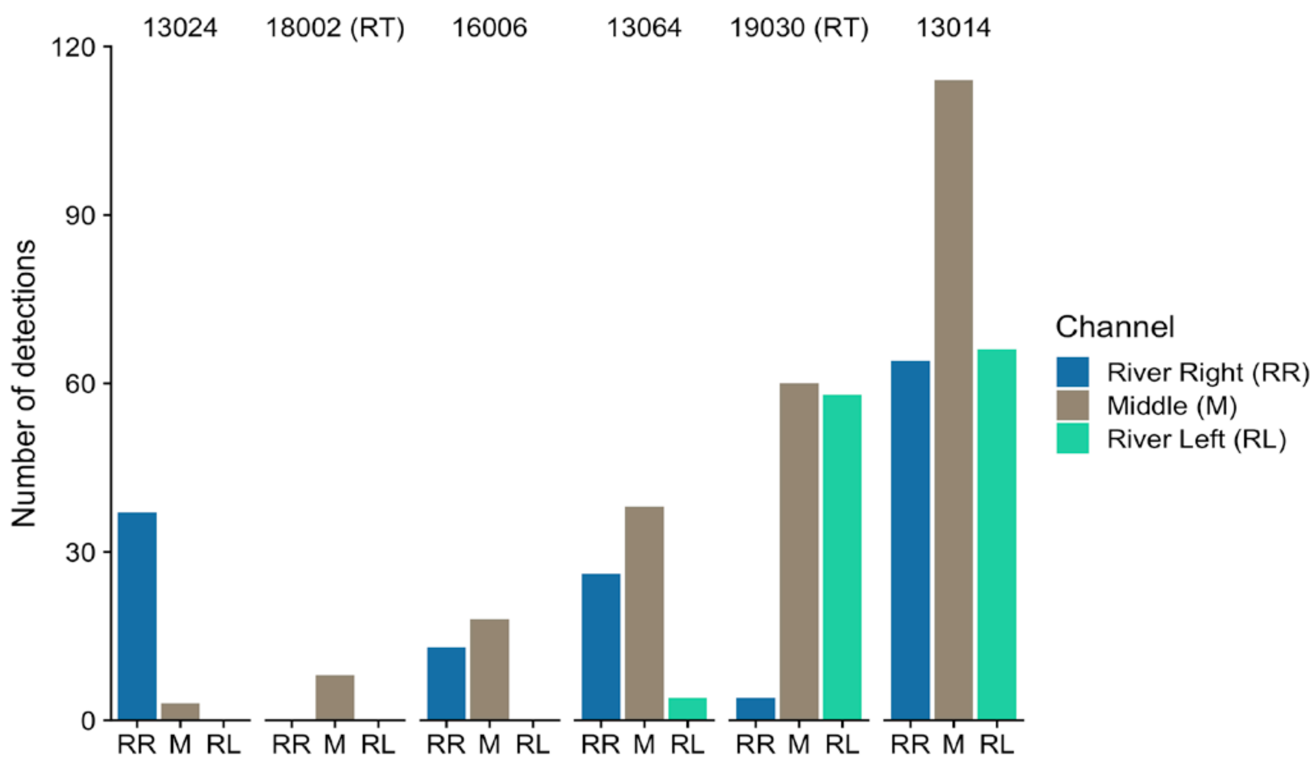

Figure 57. Detections by receiver for Butte Bridge detection efficiency trial in October 2019 according to which channel the drift occurred (river right – RR, middle – M, or river left – RL). Receivers are depicted as they are aligned across the river channel (e.g., left side of figure is west side of river).

While detection probabilities for the receivers overall were extremely poor, receivers in the river east channel of the river had the highest detection rates. Receiver 13024 had a mean detection probability (per tag drift) of 8%, 18002 had 2%, 16006 had 8%, 13064 had 16%, 19030 had 23% and 13064 had 40% (Figure 58). Altering the locations of real-time receivers did not affect the detection efficiency of

Receiver 18002. However, re-positioning the hydrophone for Receiver 19030 did have a significant effect on its detection efficiency. Receiver 18002 may require additional maintenance/servicing to check for equipment malfunction.

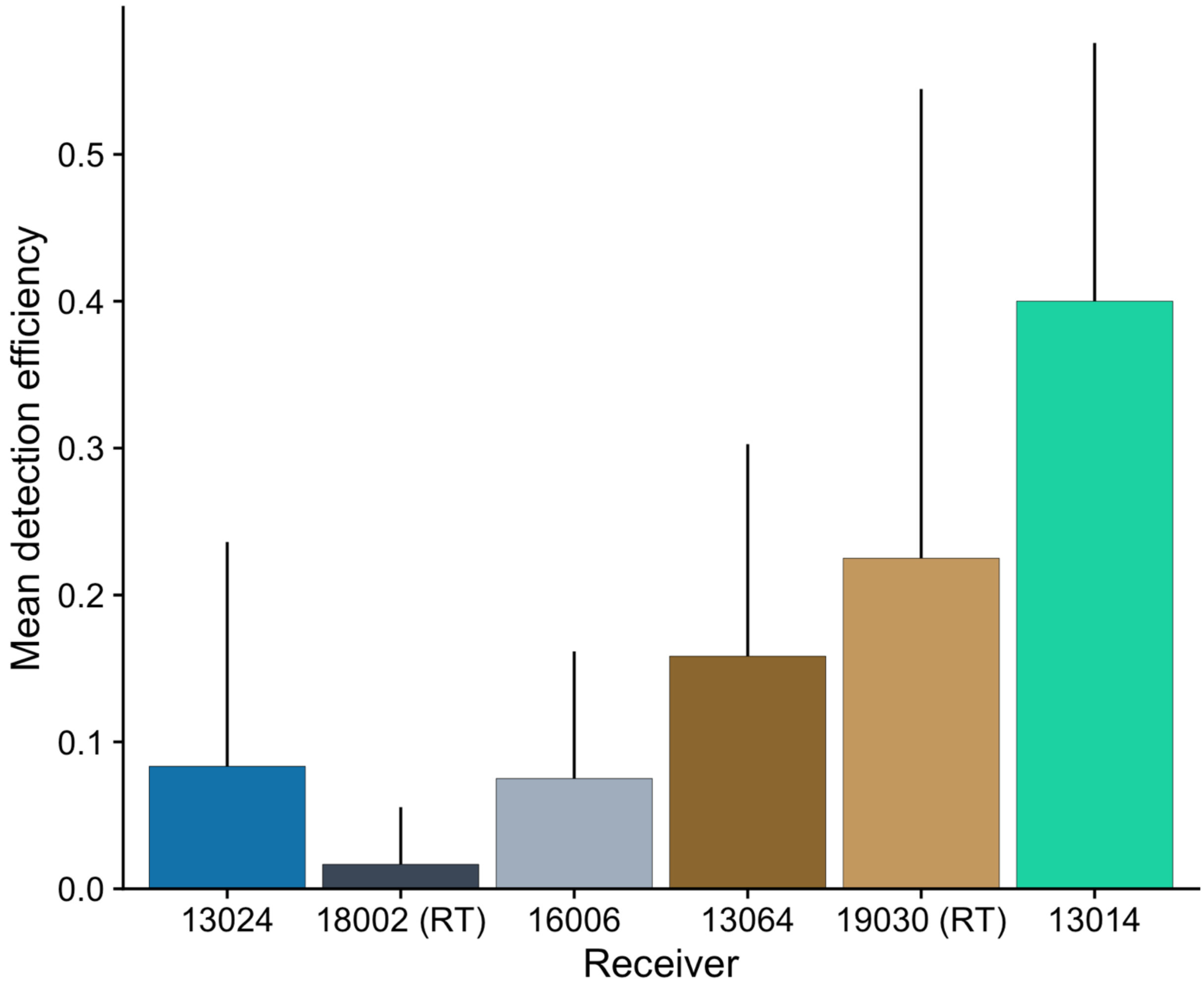

Figure 58. Mean detection efficiency (proportion of detections heard out of all available to be heard) by each receiver for Butte Bridge detection efficiency trial October 2019. Receiver names are depicted on the x-axis, followed by "(RT)" if they are a real-time receiver. All other receivers are autonomous.

As expected, receivers performed better when the tags were closer to them. The maximum detection range for this trial was as follows for each receiver; 13024 82m, 18002 26m, 16006 81m, 13064 115m, 19030 120m, and 13014 163m (Figure 59). The mean detection range for this trial was as follows for each receiver; 13024 31m, 18002 15m, 16006 49m, 13064 53m, 19030 44m, and 13014 79m.

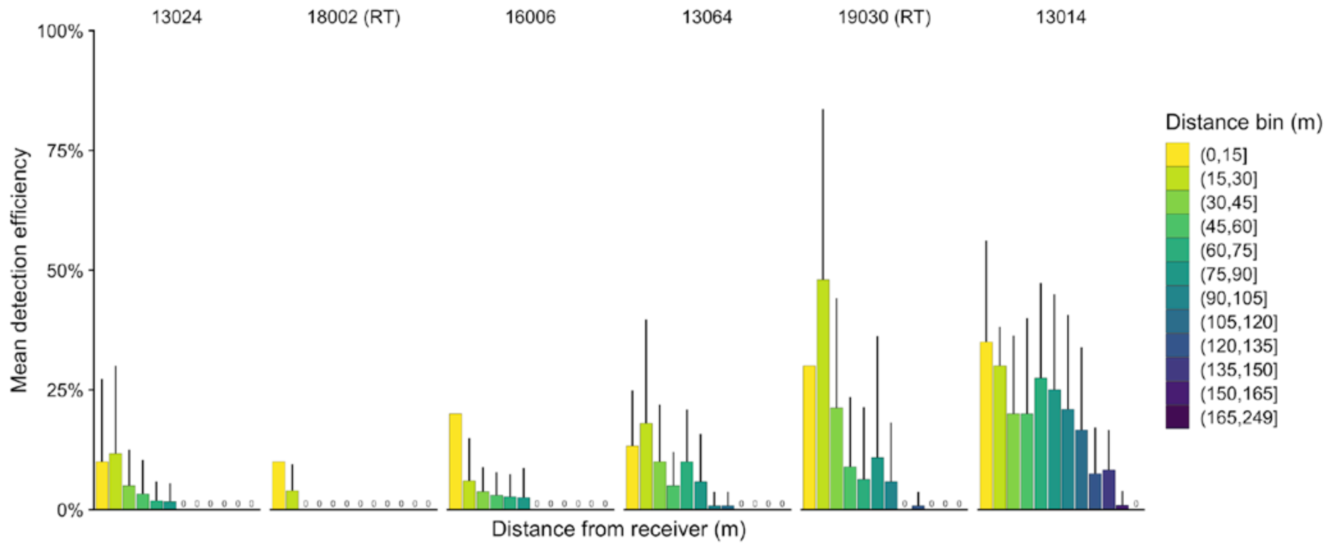

Figure 59. Detection efficiency (proportion of detections heard out of all available to be heard) binned by tag distance from receiver for Butte Bridge detection efficiency trial in October 2019. Detection efficiency data is displayed per receiver (receiver names shown above plots). Receivers with "(RT)" suffix are real-time receivers, all others are autonomous.

While the handheld GPS unit for tracking tags was set to record every second, it was inconsistent in successfully recording a waypoint at this frequency. This was likely due to the majority of the drifts taking place adjacent to the bridge fenders and under the bridge itself which likely impeded GPS reception. To get the most accurate drifts possible we interpolated a waypoint every second in between each recorded waypoint. Figure 60 shows each receiver location, the drift trajectory, and where the detections for each receiver occurred.

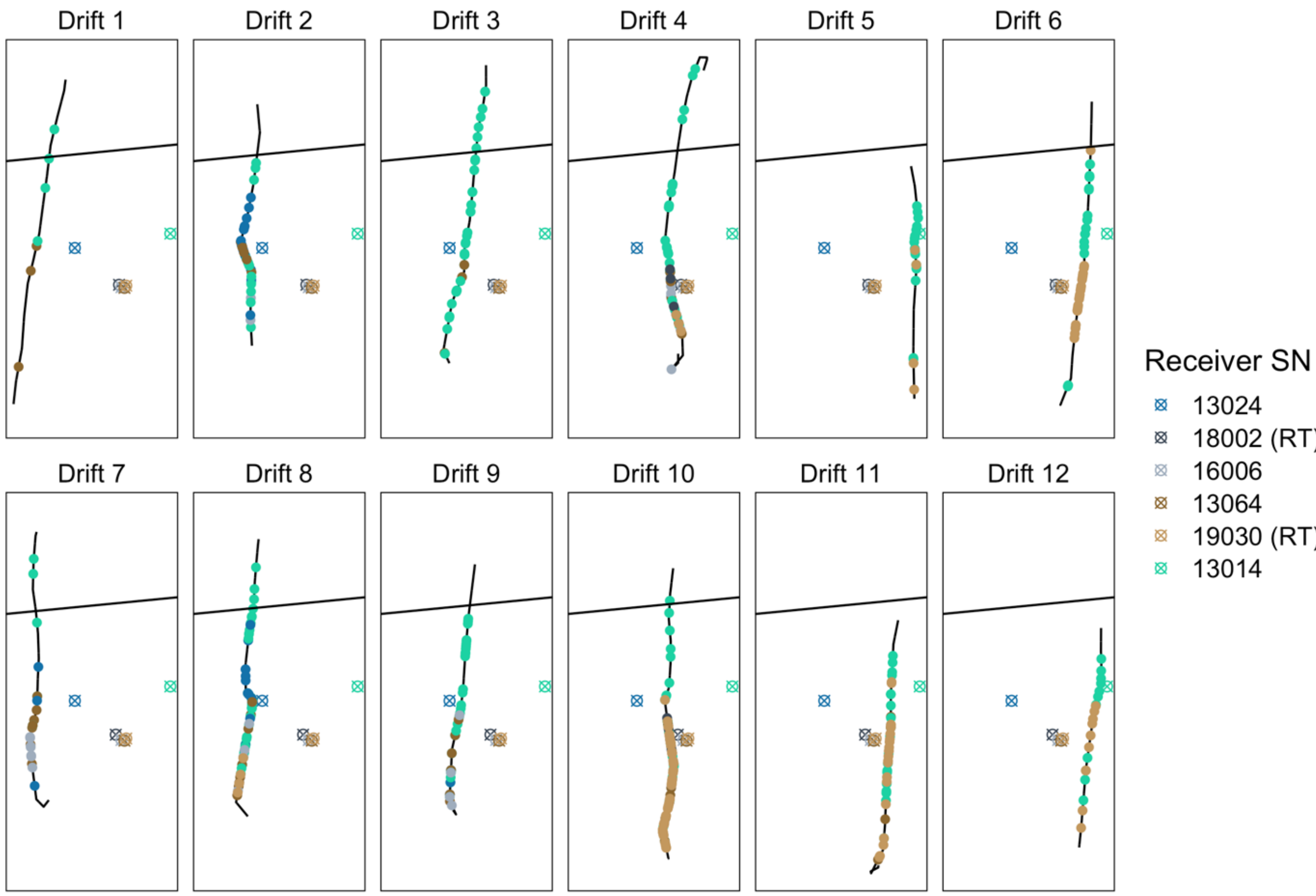

Figure 60. Tag drifts with detections by receiver for Butte Bridge detection efficiency trial in October 2019. Crossed circles represent receivers (color coded by receiver), and solid points represent detected tag transmissions (color coded by the receiver that detected it). The black horizontal line represents the location of the main bridge, while the vertical black line represents the track of the drift, during which tags were continuously transmitting.

Detection efficiencies presented here represent the number of acoustic tag transmissions detected by a receiver as a proportion of the total number of acoustic transmissions emitted by a tag. Putting this into the context of detecting live fish, only three to four transmissions (depending on the detection filter used) need to be detected at all receivers combined for a fish to be officially ‘detected’ at a receiver location. The poor detection efficiencies presented here are therefore not exactly representative of the probability that a fish gets detected at a receiver location, but certainly the two are very related. In other words, fish detection probability is higher than tag transmission detection probability presented here. Future analyses will incorporate this fish detection element into the assessment of detection efficiencies at a receiver location.

3.9. Real-time analytics, data sharing, and website development

3.9.1. Real-time analytics and data sharing

During the 2019 study year, the real-time website (https://calfishtrack.github.io/real-time/index.html) hosted the detection, movement, and survival analytics for 14 different telemetry studies, including the studies covered by this report. Analytics were generated and hosted in real-time, with an approximate two-hour delay between fish detections and when they appeared on the website. The real-time receiver array provided continuous coverage of key locations for these 14 telemetry studies, including:

- Single array at Butte City
- Dual array at City of Sacramento
- Dual array at Georgiana Slough as well as on the mainstem Sacramento River just downstream of Georgiana Slough
- Single array at Middle River near Highway 4
- Single array at Old River near Highway 4
- Single array at Central Valley Project salvage tanks (maintained by UC Davis)
- Dual array at Benicia Bridge

In addition, intermittent coverage was provided at additional locations maintained by UC Davis, including:

- Clifton Court Forebay radial gates and intake canal

Copies of some of the study detection webpages from the 2019 study year are included in the appendix of this report (Section 7.3).

Data sharing was successfully implemented as of June 14, 2018, with real-time filtered detection data hosted and shared to the general public via NOAA's ERDDAP data server. As described in the Methods section, detection data on ERDDAP can be accessed either by direct download from the ERDDAP website (https://oceanview.pfeg.noaa.gov/erddap/tabledap/FEDcalFishTrack.html), or via R programming language using the Rerddap package (more details on this in the next section).

3.9.2. Website/analytics development

The real-time website, and analytics it hosts, were frequently updated and refined during the course of the 2019 study year. The majority of updates occurred during the spring period, when the majority of fish were tagged and released. Major updates are summarized below, per different webpage category:

- Study detection webpages:
    - Addition of a link within each study detection webpage that downloads a PDF of that study's ITAG Telemetry Study From. This document describes all the relevant study details and project leader contact information.
    - Addition of a table describing routing probability at the Georgiana Slough junction with the Sacramento River, as estimated by a multistate mark-recapture model. Survival and detection probabilities for all upstream reaches are also provided in this table.

In addition to these developments on previously existing webpages, new webpages were added to the website. These include:

- Autonomous receiver's webpage: describes the locations and deployment history of autonomous JSAT receiver locations via a dynamic map which depicts the location of all currently deployed receivers managed by UCSC and SWFSC. Tables feature searching and sorting capabilities and include all past and current autonomous receiver deployments from all members of ITAG, dating back to 9/1/2017.
- Download data webpage: dedicated to describing how to download data from two distinct datasets, both hosted on NOAA's ERDDAP data server: 1) preliminary filtered real-time detection data, updated hourly, and 2) quality-controlled autonomous and real-time detection data, updated quarterly. The webpage also describes two ways for downloading data from each dataset:
    - Direct download via ERDDAP's website: (https://oceanview.pfeg.noaa.gov/erddap/tabledap/FEDcalFishTrack.html for real-time preliminary detection data, and https://oceanview.pfeg.noaa.gov/erddap/tabledap/FED_JSATS_detects.html for quality-controlled historic JSAT detection data).
    - Download directly into R programming software via the "Rerddap" package, using the ERDDAP dataset IDs for the two datasets ("FEDcalFishTrack" for the real-time preliminary detection data, and "FED_JSATS" for the quality-controlled historic JSAT detection data). Example R code is provided on the download webpage (https://calfishtrack.github.io/real-time/pageRealtime_download.html) to demonstrate how to access these datasets via R programming software, as well as download user-defined subsets of the datasets.
- Archived studies webpages: provides historic detection webpages from past seasons, which have been archived to allow for quick reference to preliminary survival and movement data. These can be accessed via a drop-down menu on the right-hand side of the tabs at the top of the website.

4. Discussion

The 2019 water year was one of the wettest on record in California, resulting in above average flows in the Sacramento River and its tributaries during periods of juvenile Chinook salmon outmigration, which likely led to higher survival rates compared to previous years. Overall, outmigration survival to the Pacific Ocean was higher than average for most study populations. Hatchery releases of juvenile salmon either coincided with a large storm event or occurred during residual high flows from previous storm events, which provided optimum outmigration conditions to navigate the riverine and estuarine environments, potentially resulting in lower temporal exposure to predator fish. The one exception was low survival of tagged Chinook salmon smolts from the Sutter Bypass, which occurred later in the spring as a result of prolonged inundation of the Sutter Bypass. This resulted in elevated water temperatures and was likely confounded with higher predation rates downstream of release location, as higher water temperatures typically result in higher predation rates (Michel et al. 2020).

Winter-run Chinook salmon smolts were released into the Sacramento River after a severe winter storm, which caused high tributary flows and resulted in the Sacramento River reaching flood stage. After 650 acoustic-tagged winter-run smolts were released with the hatchery production group on February 14, 2019 at Caldwell Park in Redding, 266 tagged smolts were detected upstream of the Fremont Weir between February 17–April 21, 2019. During this time, the Sacramento River crested over Fremont Weir and flooded the Yolo Bypass, allowing smolts to take an alternate migration route through the Yolo Bypass and avoid much of the lower Sacramento River and Delta. Detections of tagged smolts at Knights Landing and above Fremont Weir indicate that fish started arriving around the Yolo Bypass on February 14th, with a peak arrival date of February 26th (Figure 15). This coincided with the Sacramento River spilling over the Fremont Weir into the Yolo Bypass, with a river height of 9.75m (32 ft) being sustained for 22 days. In total, 104 fish were detected upstream of the Fremont Weir and not detected downstream in the Sacramento River, which likely means those fish entered the Yolo Bypass. Of those 104 fish, 44 were detected near the confluence of the Yolo Bypass and Sacramento River at Rio Vista. The acoustic receiver array to appropriately measure the proportion of fish that used the Yolo Bypass, and their ensuing survival, was not in place in the 2019 year. We have therefore adapted our regional and reach-specific survival estimates to encompass the larger region across which two alternative routes exist (spanning Fremont Weir to Chipps Island), thereby not introducing bias into our regional survival estimates.

The hatchery production of late fall-run Chinook salmon smolts were released relatively early in the fall compared to previous years, creating challenges in obtaining tags as well as rearranging staff schedules in order to complete the work. Because of the early release, the acoustic tag order was not shipped in time, which resulted in the need to borrow tags from CDFW. However, the borrowed tags were over a year old and appear to have had compromised battery life, according to a tag life study we conducted (Section 3.6.1). In this study, we selected a 5% random sample of 23 tags to examine battery life - 16 model SS300 and 7 model SS400 tags. At the end of the battery life study, 3 (19%) model SS300 and 2 (29%) model SS400 tags died before their warranty life of 52 and 78 days, respectively. Scaling these to the number of study fish tagged, the potential for tag failure is a concern, which would bias survival estimates low. This could partly explain why survival of late fall-run Chinook salmon smolts was relatively low compared to previous years, especially in downstream reaches within the Delta and Bay where some of the lowest survival rates were observed. These reaches would have coincided with the timing of tag failures, which were most common after 30 days, although many fish appear to have died or completed outmigration before this date. In total, 10 fish were known to still remain in the system 30 days after release.

Overall, detection efficiencies in the upper and lower Sacramento River were relatively low due to high water throughout the winter and spring. This led to uncertainty in survival estimates at many locations, and resulted in the removal of many sites in the reach-specific survival analysis. Downstream of the lower Sacramento River detection efficiencies generally improved. When high flows are channelized through the Sacramento River, water velocities are greatly increased and the receivers stationed underwater are severely impaired. While the flotation of the receiver maintains its upright position in the water column, the swaying created by high water velocities created challenging conditions for the hydrophone to detect passing tags. This same phenomenon was apparent in a USGS study (C.

Vallee, USGS, *pers. comm.*), which found that detection efficiencies were better for stationary receivers mounted on a piling compared to anchored receivers, which have inherent floatation and can sway in the current. As a result, future mounting style modifications may be necessary, as the uncertainty in survival estimates created by high flow conditions can lead to large spatial or temporal gaps in data coverage.

Starting in 2021, tagging operations will be moved upstream from the Sutter Bypass into the Butte Sink to enable the tagging of wild Sutter Bypass smolts under less stressful water conditions. Because the Sutter Bypass is frequently inundated by the Sacramento River during high water conditions, tagging operations are dependent on water levels to drop in the bypass before a rotary screw trap can be safely and effectively deployed to capture fish. Sometimes this does not occur until late in the spring, when water temperatures are relatively warm. To avoid this situation in the future, capturing wild smolts with a seine net in the Butte Sink, which is upstream of the flood zone, will allow smolts to be tagged earlier in the spring when water conditions are better suited for handling and conducting surgeries. Utilizing this location will also allow for further examination into the different migration pathways smolts may utilize upon entering the Sutter Bypass (east versus west channel), as well as identifying the proportion of fish exiting Butte Creek via Butte Slough Outfall Gates and entering the Sacramento River near Colusa.

Further analysis of the data and results presented here are warranted. The research team is in the process of developing the capability to adjust survival estimates to account for premature tag failure. While several other studies have successfully implemented this capability, many tags in this study not only died prematurely, but also operated intermittently up to that point. This added complexity significantly complicated our ability to adequately adapt the methods used by other studies to allow for these adjustments to survival estimates. As such, survival estimates presented for the late fall-, fall-, and hatchery spring-run Chinook salmon populations in this report are likely biased low, as they do not currently have any corrections for premature tag failure (for which there is evidence of in those studies). Also, as the collection of study years and study groups continues to grow as a part of this research program, synthesis efforts will become increasingly important and valuable. Particular synthesis efforts that UCSC has started include: 1) an effort to explore the survival differences and similarities between wild and hatchery-origin smolts, 2) the impacts of different environmental covariates on spring season outmigrating smolt survival in the Sacramento River (an effort similar to the late fall-run analysis produced by Henderson et al. 2019), 3) an exploration of survival nonlinearities with respect to important environmental covariates in the Delta (such as water temperature and flow), and 4) an effort to utilize the XT model (Anderson et al., 2005) to determine the importance of distance traveled versus migration time on survival, with an interest in how this may vary between populations and hydrologic conditions. In conclusion, the dataset being generated by this program will be invaluable in answering pressing management questions, and we hope to continue forging the necessary collaborations to ensuring data are easily accessible and interpreted.

5. Disclaimer

Reference to trade names does not imply endorsement by the U.S. Government or the Department of Commerce.

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7. Appendix

7.1. Manuscripts in review

- Michel et al. *in review* at Ecosphere

7.2. Published work

- Notch et al. 2020. Environmental Biology of Fishes

7.3. Real-time website pages for WY2019 Acoustic Tagged fish groups

7.1. Manuscripts in review

Ecological nonlinearities inform the design of functional flows for imperiled fish in a highly modified river

Running head: Salmon survival informs functional flows

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ABSTRACT

Water is a fundamental resource in freshwater ecosystems, and streamflow plays a pivotal role in driving riverine ecology and biodiversity. In highly modified rivers, ecologically functional flows -managed hydrographs that are meant to reproduce the primary components of the natural, unimpaired hydrograph- are touted as a potential way forward to restore ecological functions of a river, while also balancing human water needs. One of the major challenges in implementing functional flows will be establishing the shape and magnitude of the managed hydrograph so as to optimize improvements to the ecosystem, given the limited resources. Identifying the shape of the flow–biology relationship is thus critical for determining the environmental consequences of water withdrawal or flow regulation.

In California's Central Valley, studies have found that increased streamflow can improve survival of imperiled juvenile salmon populations during their oceanward migration. Yet, these studies have not explored the potential nonlinearities between flow and survival. This gives resource managers the difficult task of designing functional flows without clear guidance on flow targets. We used an information theoretic approach to analyze migration survival data from 2,436 acoustic-tagged juvenile Chinook salmon from studies spanning a range of differing water years (2013-2019) to extract actionable information on the flow-survival relationship. This relationship was best described by a step function, with three flow thresholds that we defined as *minimum* (4,259 cfs), *historic mean* (10,712 cfs), and *high* (22,872 cfs). Survival varied by flow threshold: 3.0% below *minimum*, 18.9% between *minimum* and *historic mean*, 50.8% between *historic mean* and *high*, and 35.3% above *high*.

We used these thresholds in a hypothetical functional flow implementation over the same years, and compared predicted cohort migration survival between actual and hypothetical hydrographs. Functional flows using these thresholds lead to modeled increases in annual cohort migration survival of between 55% and 132% without any additions to the water budget, and increases from 79% to 330% with a modest addition to the water budget. These quantitative estimates of the biological consequences of different flow thresholds provide resource managers with critical information for designing optimal flow regimes in California's highly constrained water management arena.

INTRODUCTION

In rivers, natural flow regimes are directly linked with ecological processes that govern the life history of aquatic organisms, and are a major determinant of biodiversity (Bunn and Arthington, 2002). Identifying the shapes of flow–ecology relationships is therefore critical for determining the biological consequences of water withdrawal or flow regulation on the ecosystem, and to establish well-informed water management rules and recommendations (Rosenfeld, 2017). Water resource use and development in watersheds has altered natural flow regimes, which in turn has altered riverine ecosystems, and is generally acknowledged to have considerable negative impacts on native biota (Pringle et al., 2000). As water resources become increasingly overtaxed due to population growth and climate change (Tanaka et al., 2006; Palmer et al., 2008), the task of balancing human and ecosystem needs will become more urgent and politically charged (Arthington et al., 2018). More than ever, objective, science-based approaches are needed for informing the development of water resource allocation targets (Petts 2009).

Few freshwater systems illustrate the management challenges of balancing environmental resources with the restoration of a collapsing ecosystem better than California's Central Valley (CCV) watershed. Here, water is heavily regulated as it supports a multi-billion dollar agricultural economy as well as tens of millions of urban and suburban water users (Speir et al., 2015). The ecosystem is vastly different than it was historically, with many native fish populations diminishing, and increasingly extreme climatic events impacting water availability (Hanak and Lund, 2012). Researchers at the nonpartisan Public Policy Institute of California have suggested that restoration of native fish populations and general ecosystem health in the CCV is unattainable under the current regulatory status quo (Mount et al., 2019). These same authors propose that ecosystem-based management of the CCV is a potential way forward. Two key changes would be the adoption of ecologically functional flows (Yarnell et al., 2015, 2020) and an ecosystem water budget. Functional flows are managed hydrographs that are meant to reproduce the primary components of the natural, unimpaired hydrograph so as to restore related geomorphic, biogeochemical, or ecological functions, while also balancing human water needs. An ecosystem water budget is essentially a “water right” for the environment: a set amount of water than can be allocated as resource managers see fit to improve the condition of the ecosystem. If these two key changes were implemented throughout the CCV, one of the major challenges will be establishing the shape and magnitude of the managed hydrograph so as to optimize improvements to the ecosystem, given a fixed water budget. A key part of this challenge is predicting the biotic responses to different flow targets.

In the CCV, hydrologic infrastructure and water management have strongly modified the hydrograph of most river systems, including the Sacramento River, resulting in reduced winter and spring discharges (Brown and Bauer 2010). The spring rainfall and snowmelt recession is a critical facet of the CCV Mediterranean-type flow regime, and alterations to this hydrograph strongly affect riverine species which have evolved to use high spring flows resulting from winter and spring rain-fed and snowmelt runoff (Yarnell et al., 2010). Among them, CCV Chinook salmon (*Oncorhynchus tshawytscha*) populations have been particularly impacted by water management infrastructure and altered flow regimes (Kimmerer, 2008; Yoshiyama et al., 1998). Of the five historic Chinook salmon populations in the CCV, one has been extirpated, one is listed as endangered, one is listed as threatened, and the other two are listed as “Species of Concern” under the Endangered Species Act (ESA).

One of the primary biological impacts of the water management infrastructure and altered flow regimes in the CCV is the low flow driven reduction in spring outmigration (i.e., seaward) survival of juvenile salmon (Henderson et al., 2019; Kjelson et al., 1981; Michel et al., 2015; Notch et al., 2020). Importantly, the survival bottleneck at this life stage has significant repercussions throughout the Chinook salmon lifecycle (Michel, 2019). Therefore, one vital aspect for implementation of functional flows in the CCV is to assess how they will impact juvenile Chinook salmon during their outmigration to the Pacific Ocean.

To date, studies have found strong, positive linear relationships between survival and flow in CCV rivers. However, when environmental resources are also commercially important for competing needs, this creates a problem: how to allocate limited resources if the only guidance managers have is that more is better for the population or ecosystem process in question? This difficulty often results from the statistical techniques commonly used by ecologists, which by design only reveal linear relationships between population or ecosystem processes and the environment. Yet these relationships are rarely linear in reality (Hunsinker et al., 2016; Rosenfeld, 2017), and these nonlinearities can play a critical role in the population or ecosystem dynamics. Several studies have shown that non-linear responses of ecosystems to environmental resource changes could initiate catastrophic regime shifts and local population extinction events (Scheffer et al., 2001). Therefore, it is important to explore possible nonlinearities between environmental resources and ecosystem processes, with the particular objective of finding information that is more actionable to resource managers. This is especially pertinent to Pacific salmon stocks that are often found in the middle of constrained resource management arenas (Munsch et al., 2020).

We investigated the link between flow variations in the Sacramento River, the primary Chinook salmon river in the CCV watershed, and outmigration survival of juvenile Chinook salmon. We also evaluated hypothetical outmigration survival rates in the context of alternative hydrographs. We addressed the following questions: (1) Is there evidence of nonlinearity in the flow-survival relationship in the Sacramento River? (2) If so, how can knowledge of the nonlinear relationship be used to enact ecologically functional flows that benefit juvenile Chinook salmon? Finally, we weigh the efficacy of two different hypothetical functional flow regimes on increasing population-level Chinook salmon outmigration survival rates.

METHODS

Study Area

The Sacramento River is the largest river in California, and supports the second largest population complex of Chinook salmon on the U.S. West Coast. However, the Sacramento River has been severely altered from its historic state, with major dams constructed throughout its watershed, extensive water diversions in place for municipal, industrial, and agricultural uses, and diking for flood control and land reclamation. Shasta Reservoir, and its downstream forebay Keswick Reservoir, are key components in the interface between human alterations and the ecosystem in the Sacramento River. These reservoirs block passage to historic salmonid spawning and rearing habitat upstream, and also regulate downstream flow. During all months, the large majority of streamflow in the Sacramento River is regulated by these reservoirs, which alters the seasonal patterns of the natural hydrograph, including the homogenization and reduction of flows during some critical salmon rearing and migration periods (Brown and Bauer 2010).

All of the juvenile winter-run Chinook salmon (*ESA endangered status*), significant portions of the juvenile spring-run Chinook salmon (*ESA threatened status*), and juvenile fall/late-fall run Chinook salmon (*ESA species of concern*) must navigate a portion of the Sacramento River with several large-scale, and hundreds of small-scale, water diversions. In the late spring, when a large portion of these juveniles outmigrate, natural seasonal reductions in tributary inputs coincide with increases in water diversions; the cumulative impacts of which result in incrementally lower flows in the more downstream reaches, until the confluence with the Feather River, the largest tributary of the Sacramento River (Fig. 1). We presume that detrimental impacts of low flows are primarily expressed in this region, where flows in the late spring are often the lowest of the year. In addition, flows in this region are considerably lower relative to the portions of the Sacramento River upstream and downstream, both of which are not characteristic of historic conditions. We define this middle region (hereafter "region of interest") as extending from the last major tributary before the Feather River on the upper end - the confluence with Deer Creek (Tehama County, river kilometer [rkm – distance from the Pacific Ocean by way of river] 425) to just upstream of the Feather River confluence on the lower end (Sutter County, rkm 215; Fig. 2). The survival rate of acoustic tagged juvenile Chinook salmon in certain portions of this section are the lowest on the Sacramento River (Michel et al., 2015, Notch et al., 2020).

Study Fish and Season

The large majority of juvenile Chinook salmon in the Sacramento River rear and outmigrate during the winter or spring months (Fisher, 1994). Historically, these seasons typically provided adequate flows and cool water temperatures to allow for juveniles to rear in, and transit through, downstream regions. At present, episodic flows are only occasionally adequate for outmigration or off-channel rearing in most years, primarily due to reservoir water storage for use in the summer months, after the outmigration window (Sturrock et al., 2019). In the winter and early spring, flows increase in the downstream direction from Keswick to Wilkins Slough until mid-April (Fig. 1), driven by tributary inflows that greatly exceed diversions. After mid-April, there is an inversion in this pattern, and flows are substantially lower at Wilkins Slough compared to Keswick (Fig. 1), resulting from cumulative diversions greatly exceeding tributary inflows during the irrigation season. It is during this same mid- to late-spring period, after the inversion, that the majority of natural-origin juvenile salmon outmigrate through this region (Fig. 1). Moreover, most CCV juvenile Chinook salmon hatchery releases peak in spring (Huber and Carlson, 2015), and their outmigration survival rates are also highly sensitive to flow rates (Henderson et al., 2019).

Acoustic telemetry studies investigating the survival and movement of juvenile salmon in the Sacramento River have proliferated in recent years (Cordoleani et al., 2018; Michel et al., 2015; Notch et al., 2020). We compiled all the available spring period (March 15th to June 15st) acoustic tagging data for the Sacramento River, and selected fish that were released upstream of region of interest (above rkm 425): 3,402 in total. Finally, of those fish, only fish that were known to have entered the region of interest played a large role in parameterization of the flow-survival relationship explored in this analysis; fish that did not appear to survive to the region of interest played a less important, but non-zero, role given that they may have survived to, but were not detected entering, the region. The number of fish that were known to enter the region of interest amounted to 2,436 acoustic tagged fish from 6 different years, including wild and hatchery fish, and fish from three of the four Sacramento River Chinook salmon runs (Table 1).

Acoustic Telemetry

Wild fish were collected using rotary screw traps deployed in the Sacramento River and Mill Creek, while hatchery fish were collected from hatchery raceways. Fish were tagged using similar methods across years and populations as described by Deters et al. (2010). Acoustic tags were surgically implanted into the coelomic cavity of the anesthetized fish and closed using 1 or 2 interrupted sutures, depending on tag model. Wild fish were allowed to recover in a net pen for approximately 12 hours post-surgery and released on site after sunset. Hatchery fish were allowed to recover for up to 24 hours post-surgery and released on-site, or trucked to a release location using an aerated hatchery transport tanker.

All fish were tagged and tracked using the Juvenile Salmon Acoustic Telemetry System (McMichael et al., 2010). The transmissions from the tags were detected and the unique tag number recorded by autonomous receivers from different manufacturers (ATS, Teknologic, or Lotek Wireless). All receiver locations had two or more receivers to maximize detection probability. In an effort to reduce the tag burden in study fish, a maximum 5% tag-to-fish weight ratio was observed. This allowed for fish as small as 75 mm to be tagged and released. Fish tagged ranged from 75 to 120 mm fork length (mean 86.8, sd 5.8).

CJS model

We used the Cormack-Jolly-Seber (CJS) model for live recaptures within Program MARK (White and Burnham, 1999) using the “RMark” package (Laake, 2013) in R statistical software (vers. 3.6.1; R core team, 2019) to estimate survival as well as to assess the fit of different flow relationships with survival. For species that express an obligate migratory behavior such as

Chinook salmon, a spatial form of the CJS model can be used, in which recaptures (i.e., tagged fish detected downstream from release) occur along a migratory corridor. The model determines if a fish not detected at a given receiver location was ever detected at any receiver downstream of that specific receiver, thus enabling calculation of maximum-likelihood estimates for detection probability of all receiver locations (p), survival (Φ), and 95% confidence intervals for both (Lebreton et al., 1992).

If a predator consumes an acoustic-tagged salmon and swims downstream past the next receiver location, the CJS model would incorrectly assign that fish as having survived the reach in which it was consumed. In order to minimize this occurrence, we applied a predator filter to the detection data. Chinook salmon express obligate anadromy and do not typically travel upstream (i.e., against current) once migration has begun; any movements in the upstream direction are likely predator movements. We therefore used the entirety of detection data available in the Sacramento River for each year (>12 receiver locations per year) to truncate the detection history of each fish to only include detections leading up to the first upstream movement, if one occurred.

We then subset the remaining detection data to only include receiver locations that bookend the region of interest. After release, the first receiver location was at the Deer Creek confluence, at the upstream end of the region of interest. The second receiver location was considered to be just upstream of the Feather River confluence, and therefore, the reach between these receiver locations encompassed the entire region of interest (Fig. 2). We also included additional receiver locations further downstream in the detection history to allow for an estimation of detection probability at the Feather River confluence location. However, during high flow events, such as in 2017 and 2019, a portion of the Sacramento River spilled into a flood bypass located just downstream of the Feather River confluence receiver location (Fig. 2). Since this introduced a secondary migration route, we used a combination of receivers at the end of the bypass (located at Liberty Island, Solano County) and receivers in the mainstem Sacramento River (located at City of Sacramento, Sacramento County) to create a synthetic recapture event in the detection history, ensuring both potential routes were covered. These data were only included in the analysis to better estimate detection probability at the end of the region of interest. Finally, we also used two downstream receiver locations to further improve detection probability estimation, one at Benicia Bridge (Contra Costa County, rkm 52) and at the Golden Gate, the entrance to the Pacific Ocean (rkm 1).

Flow-survival relationship

Each fish was assigned a value equal to the mean flow over the entire travel time from passing the Deer Creek confluence to first detection at the Feather River confluence. For fish not detected at the Feather River confluence (either due to mortality upstream, or imperfect detection probability), we imputed travel time by creating probability density functions (p.d.f.'s) from all known travel times for each tagging group (i.e., rows in Table 1) using kernel density estimation ("density" function in R statistical software). We then imputed travel time by randomly selecting a point along the p.d.f. for that fish's tagging group. We used flow values from the United States Geological Survey's (USGS) Sacramento River at Wilkins Slough gauging station (USGS station number 11390500). This location was nearest to the downstream end of the region of interest, and represented the minimum flows that fish would experience during the late spring period (April 15th and later) (Fig. 1).

We created an initial CJS model by grouping fish based on 5% quantile bins of the flows they experienced. These survival groups, parameterized in the model by dummy variables, were allowed to only impact survival estimates of the region of interest (i.e., reach 2: Deer Creek confluence to Feather River confluence, Φ_{reach2}).

To explore non-linearity in the flow-survival relationship, we employed different survival modeling structures. We created multiple CJS models that allowed the relationship between flow and survival to take linear, log-linear, polynomial, cubic spline curve, and threshold (i.e., step function) forms. We used flow values for individual fish as individual covariates in the first 4 model types, and as a grouping variable (dummy variable) for the threshold model. For all models, detection probability was allowed to vary by receiver location and tagging group.

We included both fish origin (hatchery or wild) and fork length as individual covariates in preliminary survival models to account for potential sources of variation in survival other than flow. Covariates that lead to an improvement in model fit were included in all flow survival models.

As part of the threshold form, we explored the potential for multiple thresholds in the flow-survival relationship. We bounded the potential values for the single threshold models by the 5 and 95% quantile limits of the flow data, and allowed values to vary at 100 cfs increments. We tested for multiple thresholds by adding additional thresholds which were allowed to vary along the same sequence as the single threshold models. All flow bins created between a quantile boundary and a threshold, or between two thresholds, were required to have a minimum of 100 fish from two separate tagging years (minimum 200 fish total), or we increased its upper boundary by 100 cfs until the requirement was met. We did this to ensure the survival estimate for any flow bin group was not overly influenced by a single year. In addition, models containing multiple flow thresholds had a secondary constraint that thresholds must be at least 1000 cfs apart. Because the model was based on user-defined flow thresholds, while the other functional forms were fitted by the model, there were thousands of threshold models included in the final model selection, while only a few models representing the other functional forms.

For all models, we only allowed survival in the region of interest (reach 2: Deer Creek confluence to Feather River confluence, Φ_{reach2}) to be parametrized as a function of flow.

The model structure for the linear and log-linear flow relationships are as follows (equations 1, 2):

(1) $\text{Logit}(\Phi_{reach2}) = \beta_0 + \beta_1[Flow]$

(2) $\text{Logit}(\Phi_{reach2}) = \beta_0 + \beta_1[\log(Flow)]$

The model structure for the polynomial flow relationships (using 4th order polynomial as an example, equation 3):

(3) $\text{Logit}(\Phi_{reach2}) = \beta_0 + \beta_1[Flow] + \beta_2[Flow^2] + \beta_3[Flow^3] + \beta_4[Flow^4]$

The model structure for the threshold flow relationships (using 2 threshold model as an example, equation 4):

(4) $\text{Logit}(\Phi_{reach2}) = \beta 0 + \beta 1[Dummy\ variable\ if\ flows > f_1] + \beta 2[Dummy\ variable\ if\ flows \leq f_1\ \&\ flows > f_2] + \beta 3[Dummy\ variable\ if\ flows \leq f_2]$

where f_1 and f_2 represent the flow threshold values.

The model structure for the cubic spline flow relationship (equation 5):

(5) $$\text{Logit}(\Phi_{reach2}) = \begin{cases} \beta 0_1 + \beta 1_1[Flow] + \beta 2_1[Flow^2] + \beta 3_1[Flow^3],\ Flow \in [Flow_0, Flow_1], \\ \beta 0_2 + \beta 1_2[Flow] + \beta 2_2[Flow^2] + \beta 3_2[Flow^3],\ Flow \in [Flow_1, Flow_2],\ \ldots.. \\ \beta 0_n + \beta 1_n[Flow] + \beta 2_n[Flow^2] + \beta 3_n[Flow^3],\ Flow \in [Flow_{n-1}, Flow_n], \end{cases}$$

where n is degrees of freedom.

We used model selection to find the most parsimonious model. In general, cubic spline, polynomial, and threshold models fit data increasingly better than linear models as more degrees of freedom are added. However, because increasing model complexity tends to decrease a model's relevance to out of sample data, we used Bayesian Information Criterion (BIC) to balance between model complexity and goodness of fit. We tested a minimum of three models of each model type (i.e., spline, polynomial, threshold), starting with the least complex. For each model type, we added degrees of freedom until there was no longer a decrease in BIC by more than 2 points. This objectively set the bounds for this model selection exercise, beyond the initial three models. For example, if the lowest BIC of all triple threshold models (4 degrees of freedom) was more than 2 BIC points higher than the lowest BIC of all the double threshold models (3 degrees of freedom), we ended the threshold analysis and did not run quadruple threshold models. We also tested a "full" model for comparison – which included no flow terms, was fully parameterized: allowing for survival to vary by reach and by fish tagging group (i.e., rows in Table 1).

Functional flow scenarios and theoretical survival improvements

Where we found strong evidence of a non-linear flow-survival relationship, we assessed different management strategies that could use this information to improve cohort outmigration survival of salmon in the Sacramento River. We generated two hypothetical implementations of functional flows during the spring period for the study years (2013-2019). The first implementation scenario allowed for sustained flows that would result in the highest survival rates based on the non-linear flow-survival relationship. Sustained flows were centered around the average date of peak spring juvenile salmon outmigration (April 19th, based on 2005-2019 expanded juvenile salmon capture data from USFWS's Red Bluff rotary screw traps, https://www.fws.gov/redbluff/rbdd_biweekly_final.html), and scheduled to last as long as possible given the water budget. The second scenario represented an adaptive management implementation of functional flows: following a substantial increase in catch rates at the Red Bluff rotary screw traps, flows were temporarily increased (for 4 days) to the levels that would to result in the highest survival rates based on the non-linear flow-survival relationship. The maximum number of 4-day "pulse" flows were enacted given the available water budget. Days with substantial increases in catch rates at the rotary screw traps are proximate estimates of periods of peak outmigration of juvenile salmon, and we estimated these days to be when both (1) total expanded catch exceeded 10,000 juvenile salmon, and (2) the increase was more than one standard deviation over the mean from the previous 10 days. Finally, we used two water budgets for these scenarios: a realized water budget (which consisted of the totality of water released from Keswick Dam during the spring of each year), and an ecosystem water budget, which added 150 thousand-acre-feet (TAF) to the status-quo water budget each year.

We used the expanded combined daily catch of all runs of Chinook salmon for determining peak outmigration triggers. Expansion factors were based on capture efficiency trials operated by USFWS Red Bluff Office, and the resulting expanded total catch numbers represent the total number of fish passing the screw trap at Red Bluff. The rotary screw traps are 38 river kilometers upstream of the region of interest, and therefore approximately represents the daily number of fish entering the region of interest during their outmigration. The screw traps are operated continuously, except during the passage of significant numbers of hatchery fish or during storm conditions (B. Poytress, UFSWS, *pers. comm.*). As a result, some spring sampling days are missing from our study period. Furthermore, some days of significant hatchery fish catches were also removed from the dataset; these days were identified as days when expanded daily catch total surpassed 80,000 fish.

To estimate the realized water budget, we multiplied the sum of the mean daily flow estimates (cfs) from March 15th to June 15th from the Keswick Dam gauge (USGS station number 11370500) by 1.983×10^{-3} to convert to volume (TAF). To benefit outmigrating salmon, the non-linear flow-survival targets from the most parsimonious CJS model would need to be realized at the Wilkins Slough gauge, so we estimated a daily net change between Keswick Dam and Wilkins Slough. This approximates the net difference between water inputs (tributaries) and water exports (water diversions) between the Keswick Dam and Wilkins Slough at a daily time step. Finally, all functional flow implementation scenarios had three important regulatory constraints: (1) minimum Keswick flows of 3,250 cfs (*National Marine Fisheries Service 2009 Biological Opinion and Conference Opinion on the Long-Term Operations of the Central Valley Project and State Water Project: NMFS 2009 BiOp*), (2) maximum Keswick flow reduction rate of 15% per day *(U.S. Bureau of Reclamation 2008 Central Valley Project Biological Assessment*), and (3) no alteration to any daily Keswick releases that were deemed to be for flood control (>20,000 cfs).

We then modeled the impact of the different flow implementation scenarios on cohort outmigration survival of spring-outmigrating juvenile Chinook salmon. We used parametric bootstrapping, where the pertinent logit-transformed survival distribution from the CJS model (given flow levels at Wilkins Slough for that day) were resampled corresponding to the expanded daily total catch at the Red Bluff screw traps. We estimated the mean logit-scale survival from the totality of samples across all days of the spring-period, and then re-scaled (inverse-logit transform). For missing daily values, we imputed catch using a linear interpolation of the time-series. Finally, to provide a baseline for assessing the potential survival gains of each scenario, we estimated the cohort outmigration survival for the *status-quo* (using the observed spring hydrograph in the years 2013-2019).

RESULTS

We found strong evidence of non-linearity in the flow-survival relationship (CJS model with grouping based on 5% quantile flow bins, Fig. 3). Survival was positively related to flow for values up to 10,000 cfs, followed by a sharp increase in survival near 10,000 cfs, at which point survival asymptotes at approximately 50%.

Out of 724,567 models we tested, the triple threshold models were the most parsimonious, with 12 that were within 2 BIC points of the top model (Table S1). We estimated survival parameters and threshold values (4,259, 10,712, and 22,872 cfs) from these 12 models using model averaging. The threshold models were substantially better supported than any of the other model types tested (ΔBIC > 29). Furthermore, these threshold models, as well as all polynomial and spline models, were better supported than the linear, log-linear, and full models (ΔBIC > 146), indicating strong support of a nonlinear flow-survival relationship. Full models including fish length and origin (wild or hatchery) parameters did not increase parsimony, and therefore these parameters were not included in flow survival models (Table S1).

In order to better understand model fit across the range of potential flow thresholds, for each flow value tested in the threshold models, we estimated the mean BIC of all models that included that flow value as one of its thresholds (Fig. 4). With similar results to the model selection exercise, models with flow thresholds around 4,259, 10,712, and 22,872 cfs had strong support (i.e., lower mean BIC). We labeled these "*minimum*" (4,259 cfs), "*historic mean*"

(10,712 cfs), and "*high*" (22,872 cfs). The *historic mean* threshold had highest support of the three thresholds (Fig. 4). Few fish experienced flow values between approximately 14,000 and 21,000 cfs (Fig. 5), and therefore model fit did not vary significantly with thresholds found in this range.

We used model averaged parameter estimates to predict survival for the range of flow values (Fig. 6). There was a 6.3 fold increase in survival from flows below 4,259 cfs (0.03), to flows between 4,259 and 10,712 cfs (0.189). There was a 2.7 fold increase in survival from flows between 4,259 and 10,712 cfs, to flows above 10,712 cfs (0.508). Overall, there was a 16.9 fold increase in survival from flow below 4,259, to flows above 10,712 cfs. Finally, survival decreased above the 22,872 cfs threshold to 0.353. Survival was significantly different between groups, with non-overlapping 95% confidence intervals. The 22,872 cfs threshold may be an artifact of lower detection efficiencies associated with fish utilizing additional high flow migration routes which have with less receiver coverage.

We compared modeled cohort outmigration survival rates among five different water release scenarios for five water years with the modeled survival rates for actual flows (Fig. 7). Water years 2013 (Dry), 2014 and 2015 (Critical), and 2016 and 2018 (Below Normal) represent three classes of water supply scarcity in the Sacramento River Basin (http://cdec.water.ca.gov/reportapp/javareports?name=WSIHIST). For Dry year 2013 and Below Normal years 2016 and 2018, the three alternative scenarios using the available water budget resulted in survival rate increases ranging from 55 to 98%, while the scenarios with an additional 150 TAF resulted in survival rates increases ranging from 79 to 119%.

For Critical years 2014 and 2015, the realized water budgets were not sufficient to allow for the alternative release scenarios, beyond just maintaining flows above the low flow threshold for as long as possible (resulting in survival rate increases of 83 and 132%, respectively). Scenarios using an additional 150 TAF resulted in survival rate increases ranging from 130 to 330%.

DISCUSSION

Streamflow is a master variable in stream ecology, influencing biological and physical habitat characteristics, and if not managed properly, flow alteration can be a serious threat to freshwater ecosystems. Yet, water management decisions continue to be poorly informed by environmental research (Davies et al, 2014; Horne et al., 2016). In the Sacramento River Basin, surface water demands exceed supplies in all but the wettest years (Grantham and Viers, 2014), and there is a pressing need to optimally allocate those limited resources to meet management objectives, including ecosystem benefits. We identified threshold responses in salmon outmigration survival across a range of observed instream flow rates. These relationships are valuable tools for updating water management practices aimed at balancing competing demands. Applying our *minimum* threshold (4,259 cfs) as a lower critical flow boundary for functional flows could result in a 6.3 fold increase in outmigration survival. Flows above the *historic mean* threshold (10,712 cfs) could provide an additional 2.7 fold increase in survival. This threshold could be enacted when the resources are available, especially if coordinated with hatchery releases or peak wild salmon migration periods. All else being equal, these survival gains could result in concomitant increases in adult escapement. These modeled survival benefits justify the need to identify ways to exceed these flow thresholds more consistently and for longer periods during the spring months.

High flows promote favorable outmigration conditions for Chinook salmon juveniles, resulting in increased survival to the ocean (Connor et al., 2003; Smith et al., 2003). We identified an optimal threshold of 10,712 cfs, which we labeled *historic mean*, as it is similar to the long-term average of natural spring flow conditions under which Chinook salmon have evolved in this system (Fig. 1). Outmigrating juveniles move at higher speeds with higher flow (Berggren and Filardo, 1993), limiting their exposure time to predators and other hazards. Movement speeds and survival rates of wild Chinook salmon juveniles in this section of the river are strongly correlated (Notch et al., 2020). Additionally, high flows typically increase water turbidity, which may aid juveniles in evading predators (Gregory and Levings, 1998). Flow levels above the *historic mean* threshold represent normal spring time flows under natural runoff and streamflow conditions up until approximately May 15th (Fig. 1). Yet, from 1993 and 2019 such flows were only achieved in 37% of days during the April 15 – May 15 peak outmigration period, and only 10% of days in below average water years (Fig. 8), and were even less likely to occur later in the spring (Fig. 9). In late spring (after approximately April 15), tributary accretions subside and demand for agricultural water deliveries increase dramatically, a combination that creates progressively diminished instream flow in downstream reaches (Fig.1). Sturrock et al. (2019) found that under current water management regimes, the low flows and high water temperatures that occur in the late spring are selective forces against the later-migrating smolt juvenile life history type (>75mm fork length [FL]). Ultimately, the implementation of ecologically functional flows above the 10,712 cfs threshold could be a powerful tool to restore functional parts of the natural flow regime during critical periods of the salmon life history.

The mechanism driving the lower flow threshold (4,259 cfs) is unclear. Anecdotal observations indicate that under certain low flow conditions, sections of the Sacramento River may have increased habitat heterogeneity, in particular with regards to pools and riffles where predator ambush habitat is likely created (Michel, *pers. obs.*). Flow influences other important environmental variables, such as water temperature, that might also have nonlinear relationships with survival. Because temperature and flow are highly correlated (flow and temperature experienced for these fish as measured at Wilkins Slough had a Pearson's correlation coefficient of 0.93) and flow is the most persistent driver of survival in the CCV (Henderson et al., 2019, Notch et al., 2020), we did not include temperature in this analysis. At very low flows during the latter end of the spring period, water temperature in the lower Sacramento River can approach the thermal tolerance of juvenile Chinook salmon. Under the lower flow threshold conditions, mean water temperature was 19.9º C (0.5 SD) at the Wilkins Slough gauge. At this temperature, salmon health and vulnerability to predation can be affected and ultimately lead to lowered survival (Lehman et al., 2017, Marine et al., 2004, Michel et al., 2020, Miller et al., 2014). During most years, spring outmigration flows are above the lower threshold, and these unfavorable conditions are usually only observed during years of drought (e.g., 1994, 2013-2015; Fig. 9). However, in recent years, spring flows below this lower threshold have occurred in years of near average precipitation (i.e. 2016, 2018; Fig. 9), likely resulting from a complex suite of factors, including reservoir management strategies for conserving cold water for endangered winter-run Chinook salmon, and increasing water deliveries for out of stream uses during the summer months.

Of the models we tested, the threshold models had strongest support, possibly because they allow for a sharp transition between survival levels as a result of a small changes in flow across some ecologically important value. For example, exceeding a given threshold can lead to river bank overflow, which activates seasonal floodplains, providing juvenile salmon an alternative downstream migration route. This is the hypothesized mechanism for the *high* threshold (22,872 cfs): Tisdale Weir, within the area of interest, overtops at approximately this flow value, allowing fish to enter the Sutter Bypass. Survival decreased at flows above this threshold, suggesting that fish utilizing this alternate route experienced decreased survival compared to fish remaining in the Sacramento River. While flood bypasses are generally considered to be high quality rearing habitat for juvenile salmon (Sommer et al., 2001), there is little known about the relative survival of fish utilizing these habitats. The detection efficiency of fish utilizing the bypass route is likely lower, however, which could be a confounding driver of the *high* threshold.

The modeled functional flow scenarios indicated that substantial gains over the *status quo* were possible by leveraging the thresholds we identified. These flow scenarios lead to increases in annual outmigration survival ranging between 57% and 130% without additions to the water budget, and increases ranging from 79% to 330% with a modest 150 TAF addition to the water budget (Fig. 7). There were no clear and consistent differences in survival between the historic peak migration pulse flow scenario and the 4-day adaptive pulse flow scenario, whether with the realized water budget or with the additional environmental water budget. We included an additional scenario where flows mimicked the *status quo* hydrograph, but flows were not allowed to dip below the minimum threshold, which alone led to substantial gains in survival in the Critical Dry water years 2014 and 2015 (Fig. 7). Adaptive functional flow scenarios may be preferable to a single-pulse, fixed calendar date scenario in ways not measured in this study. For example, the adaptive implementation will be more responsive to hydrologic or biotic nuances of a given year, and promote more diversity in outmigration timing.

Our analysis is consistent with many studies concluding that flow is a strong driver for Chinook salmon smolt spring outmigration survival. This period of time coincides with peak hatchery releases and peak natural-origin outmigration of fall-run Chinook salmon, the stock that supports an important commercial and recreational fishery, as well as peak outmigration of ESA threatened wild spring-run Chinook salmon smolts from Sacramento River tributaries. Spring-run Chinook salmon populations spawn at high elevations and therefore experience slower growth rates and delayed outmigration timing compared to other Chinook salmon populations spawning in the rivers on the valley floor, making them particularly vulnerable to late spring low flows. Further, these late outmigrants are subject to asynchronous flow conditions between natal streams (when their initial downstream migration is triggered by snow melt or spring freshets in the tributary) and the mainstem Sacramento River, where they experience periods of low managed flows. Restoring the functionality of the spring flow regime during wild smolt outmigration is a critical step towards promoting sustainable fisheries (Jager and Rose, 2003), as well as restoring a threatened population of salmon.

Other CCV native fish species may require different flow conditions during the spring, potentially creating water management conflicts. For example, high flows and cold water from dam releases may have detrimental impacts on threatened green sturgeon (*Acipenser medirostris*) in the Sacramento River (Zarri et al., 2019). Similarly, endangered winter-run Chinook salmon rely on cold water released from Shasta Reservoir during egg development in the summer, which is contingent on water operations that allow sufficient cold water availability in Shasta Reservoir for the summer months (Martin et al., 2017). Increasing spring flows for the benefit of fall-run and threatened spring-run Chinook salmon requires carefully balancing the needs of other protected species in the Sacramento River.

Our study focused on the flow-survival relationship for the smolt outmigration life-history, as it was based on acoustically tagged fish, and tag size constraints precluding the tagging of smaller juveniles. However, other juvenile life-history types, namely fry and parr (approximately <55mm, and 55 to 75mm FL, respectively), are important contributors to CCV Chinook salmon populations (Sturrock et al., 2019). While higher winter and spring flows also benefit fry and parr life histories (Sturrock et al., 2015, 2019) the flow thresholds defined in this study are for smolt outmigration and are likely not directly compatible with fry and parr life histories, which need flows appropriate for rearing. In general, targeting ecologically functional flows that mimic the shape of the historic hydrograph under which these fish evolved should also benefit these other life histories and promote life history diversity.

Our study identifies key thresholds in the flow-survival relationships that can help water and fisheries managers evaluate trade-offs associated with different water management options that are, by law, supposed to balance in-stream and out-of-stream management objectives. We recommend that future studies attempt flow experiments to verify that migrating salmon would benefit as predicted from managed flow augmentation (such as pulse flows). It is likely that such pulse flows will engendered larger survival gains than predicted here: flow pulses are known to promote juvenile Chinook salmon to initiate their downstream migration (Sykes et al., 2009), allowing a larger portion of the population to take advantage of the associated improvements in survival. Courter et al. (2016) used managed flow releases in the Yakima River, Washington, to show the positive impact of increased flow on Chinook salmon smolt survival, which was then used to implement a minimum flow target. Experimental pulse flows may also help decouple the mechanisms driving increased survival, because increased flows through reservoir releases may not affect temperature and turbidity the same as storm-related flow increases. Ultimately, functional flows in CCV should include a spring pulse flow component that mimics the characteristics of spring freshets and snowmelt events of a natural hydrograph. These will benefit outmigrating smolts and also engender many other benefits to the ecosystem (Kiernan et al., 2012, Poff et al., 1997).

This is timely research as the frequency of drought events is predicted to increase in the CCV, creating additional stress to already vulnerable salmon populations (Yates et al., 2008). Munsch et al. (2019) showed a truncation of fish size and outmigration timing of juvenile Chinook salmon from the Sacramento River during warmer springs, which could lead to lower ocean survival. This highlights the influence of climate change on salmon species phenology and dynamics and the need for new flow management policies that include the potential impacts of future climate warming. In the Sacramento River, finding functional flows that could simulate ecologically critical aspects of the natural spring hydrograph, especially in increasingly common dry water years, is a critical step in ensuring the resiliency of juvenile Chinook salmon and other native fish species into the 21st century.

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Table 1. Wild and hatchery tagged fish groups included in our analysis from 2013 to 2019. Release locations are further described in Fig. 2. Genetic population assignments made using protocols outlined in Clemento et al. (2011).

Population	Origin	Year	Release Dates	Release Location	N	Genetic Population Origin
Mill Creek	Wild	2013	Mid-April to mid-May	MCRT	48	74% CCV fall-run 26% CCV spring-run
Coleman	Hatchery	2013	Mid-April	CNFH	285	100% CCV fall-run
Mill Creek	Wild	2015	Mid-April to mid-May	MCRT	110	44% CCV fall-run 56% CCV spring-run
Coleman	Hatchery	2016	Early-April to late-April	CNFH	540	100% CCV fall-run
Mill Creek	Wild	2017	Mid-April to late-April	MCRT	24	100% CCV fall-run
Coleman	Hatchery	2017	Early-April to late-April	CNFH	370	100% CCV fall-run
Sacramento River	Wild†	2017	June 6	RBDD	33	100% CCV fall-run
Sacramento River	Wild†	2018	Early-May to early-June	RBDD	207	100% CCV fall-run
Livingston Stone	Hatchery	2019	March 26	NFBC	199	100% Sacramento winter-run
Coleman	Hatchery	2019	April 11	CNFH	140	100% CCV fall-run
Coleman	Hatchery	2019	Late-May	RBDD	480	100% CCV fall-run
TOTAL		**2013-2019**	**Late-March to early-June**		**2436**	

†Fish captured in rotary screw traps in the Sacramento River and tagged were assumed to be wild, although some hatchery fish may have been misidentified and incidentally tagged.

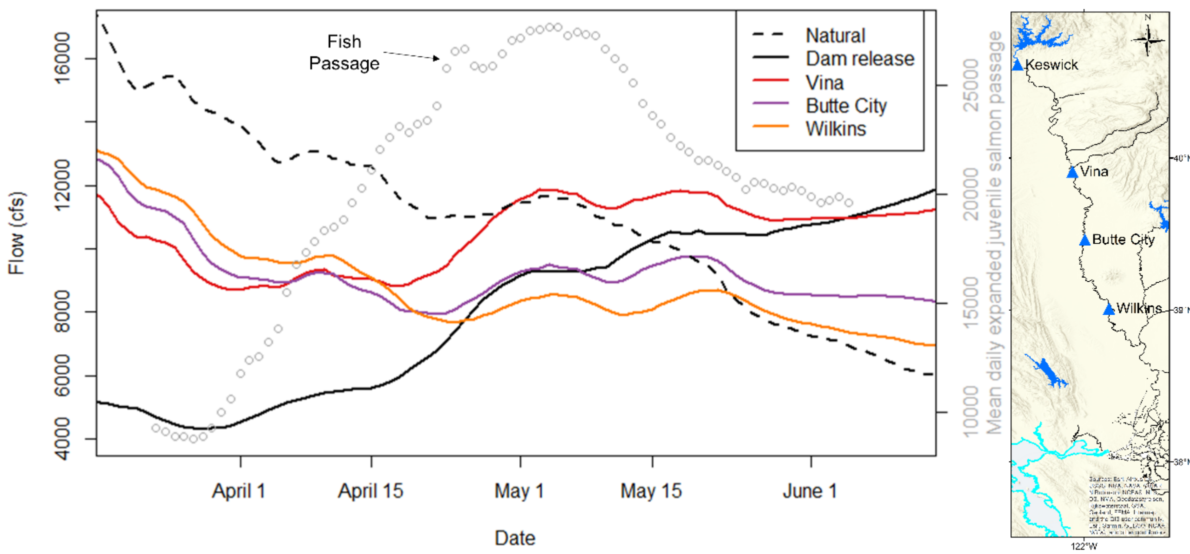

Fig. 1. Mean daily Sacramento River hydrographs for the spring period from 2000-2019, excluding those classified as wet (2006, 2011, 2017, 2019: http://cdec.water.ca.gov/reportapp/javareports?name=WSIHIST), mean daily natural hydrograph (dashed line), and mean daily expanded juvenile salmon passage (primarily natural-origin) (grey points, data from USFWS Red Bluff rotary screw traps, 38 km upstream of the region of interest). Flow levels (in cfs) are plotted through time at several gauges along the river, starting from Keswick gauge ("dam release": USGS station number 11370500) on the upstream end to Wilkins Slough gauge (USGS station number 11390500) on the downstream end (color legend inset has gauges listed in order from upstream to downstream). The mean daily natural flow regime is the sum of the "full natural flow" statistic on the California Data Exchange Center (http://cdec.water.ca.gov) for the Bend Bridge (BND) gauging station, along with the daily flow from Mill Creek (USGS 11381500) and Deer Creek (USGS 11383500) gauges, both located upstream of major diversions. It is therefore representative of the estimated full natural flow entering the region of interest. A 10-day moving average smoothing has been applied to all

hydrographs and fish passage data. All stream gauges are operated by either USGS, US Bureau of Reclamation, or California Department of Water Resources.

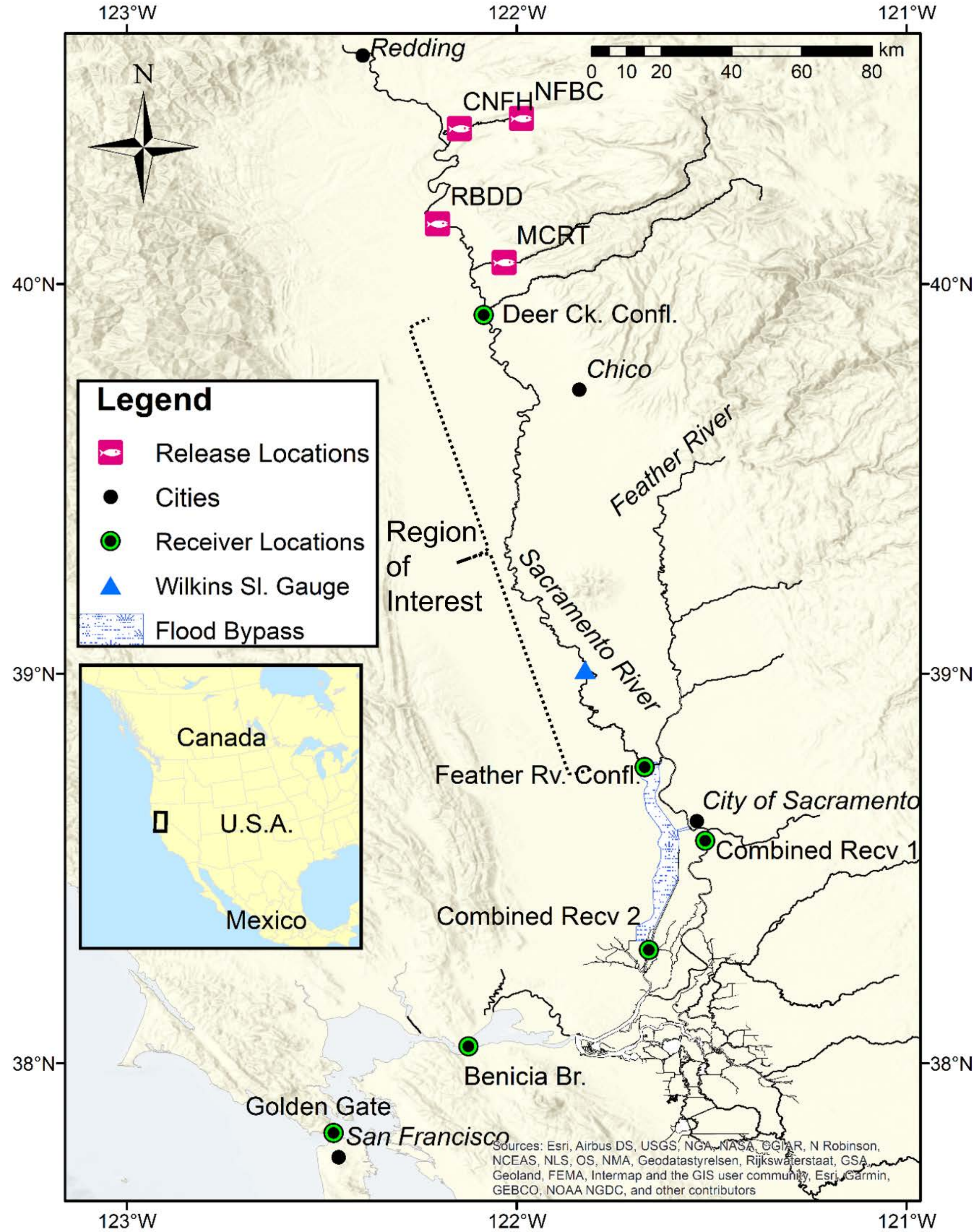

Fig. 2. Study area, release locations, and receiver locations. Region of interest spans from the confluence with Deer Creek to the confluence with Feather River. Release location abbreviations

are: CNFH: Coleman National Fish Hatchery, NFBC: North Fork Battle Creek, RBDD: Red Bluff Diversion Dam, MCRT: Mill Creek rotary screw trap.

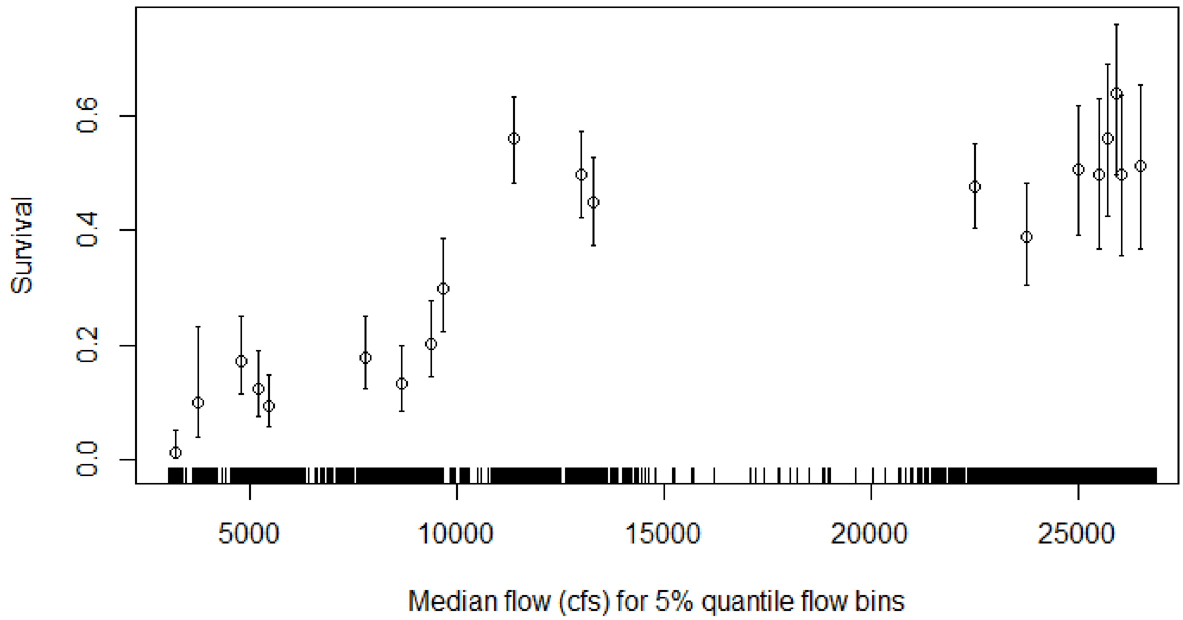

Figure 3. Survival as a function of flow. Survival estimates (circles) with 95% confidence intervals (bars) for groups at 5% quantile bins of experienced flow, plotted at the median value of bins (in cfs) on the x-axis. Flow experienced per fish is indicated by vertical tick marks on x-axis.

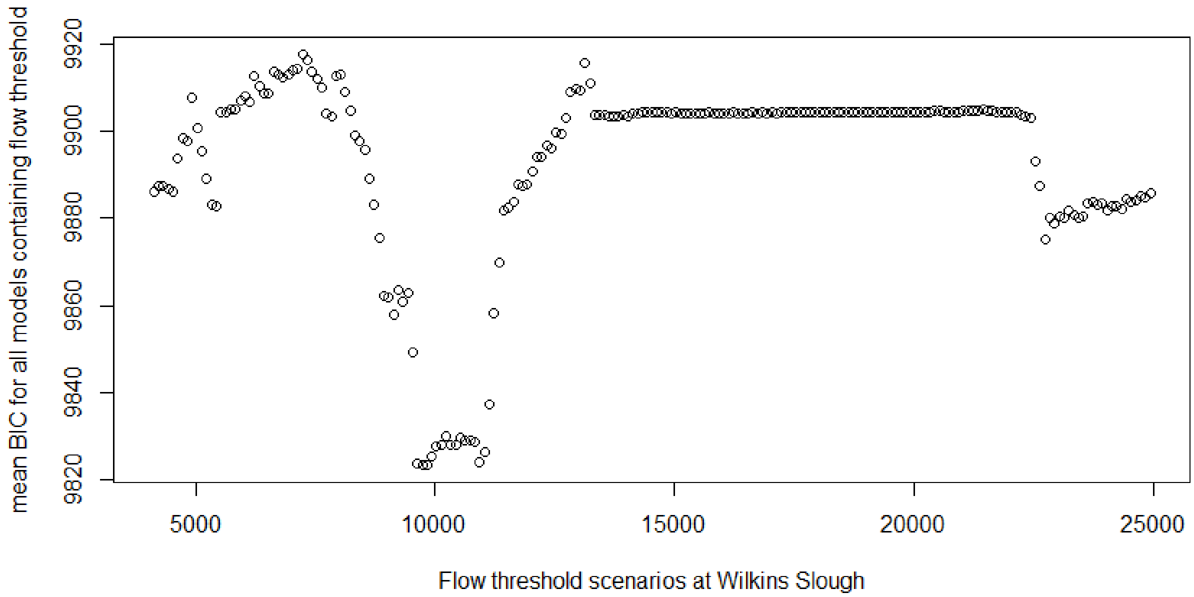

Figure 4. Mean BIC scores per threshold value as a function of flow. A lower BIC value indicates a stronger supported model.

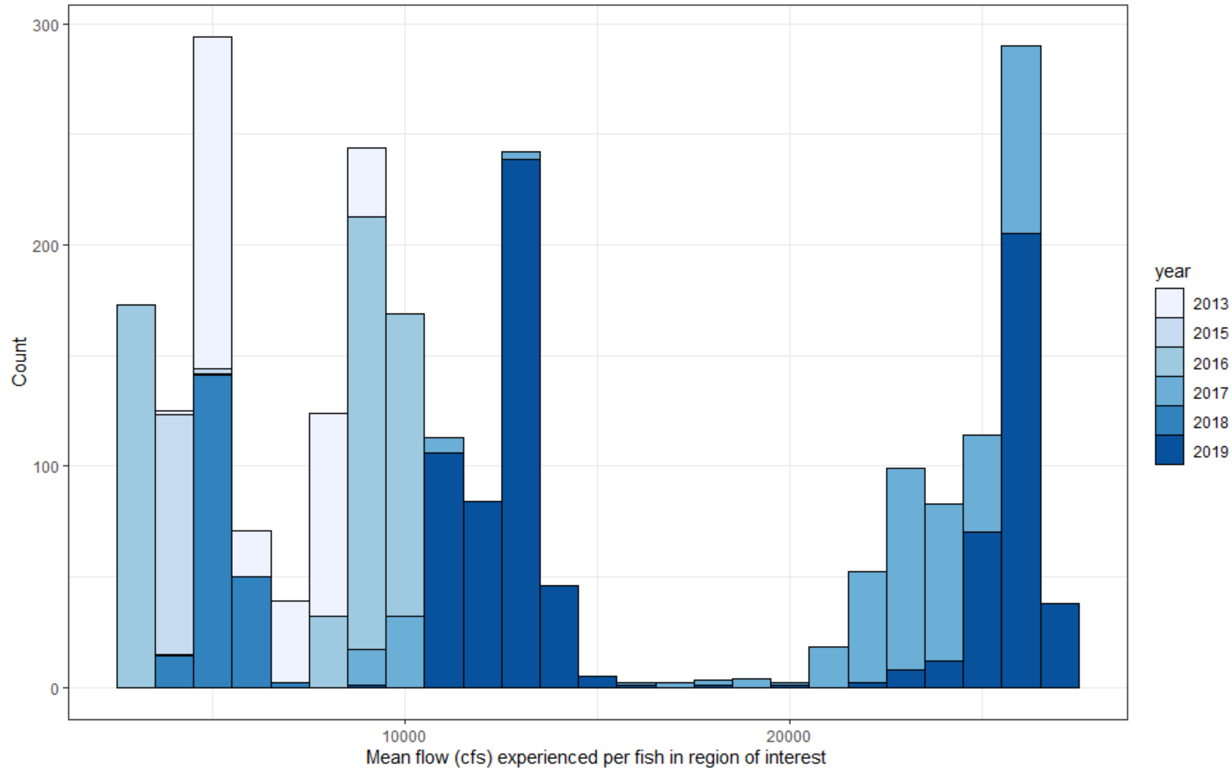

Figure 5. Frequency of flow values used in analysis by year. Values are mean flow (cfs - as measured at Wilkins Slough gauge), both empirical and imputed, for all fish. Flow bin sizes are 1000 cfs, and bar colors indicate the relative number of fish by year for each flow bin.

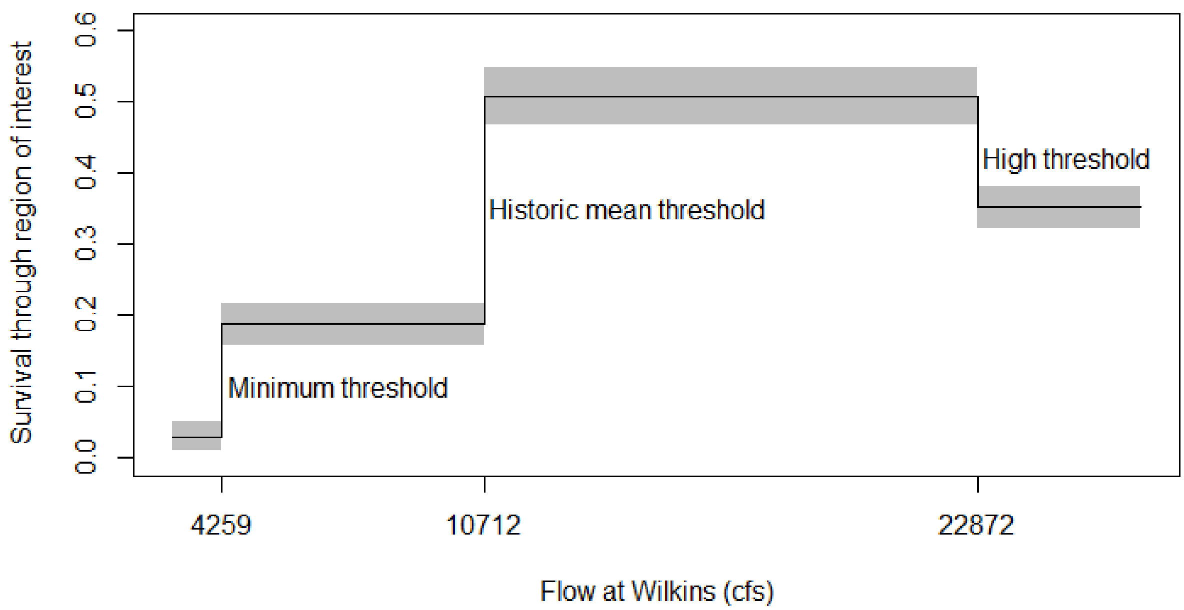

Figure 6. Thresholds of predicted survival as a function of flow. Predictions are based on the model averaged parameters from the most parsimonious triple threshold models, with mean thresholds at 4,259 cfs, 10,712 cfs, and 22,872 cfs, with 95% confidence intervals (grey fill). Flow averaged from Wilkins Slough gauge through the region of interest (confluence with Deer Creek to confluence with Feather River).

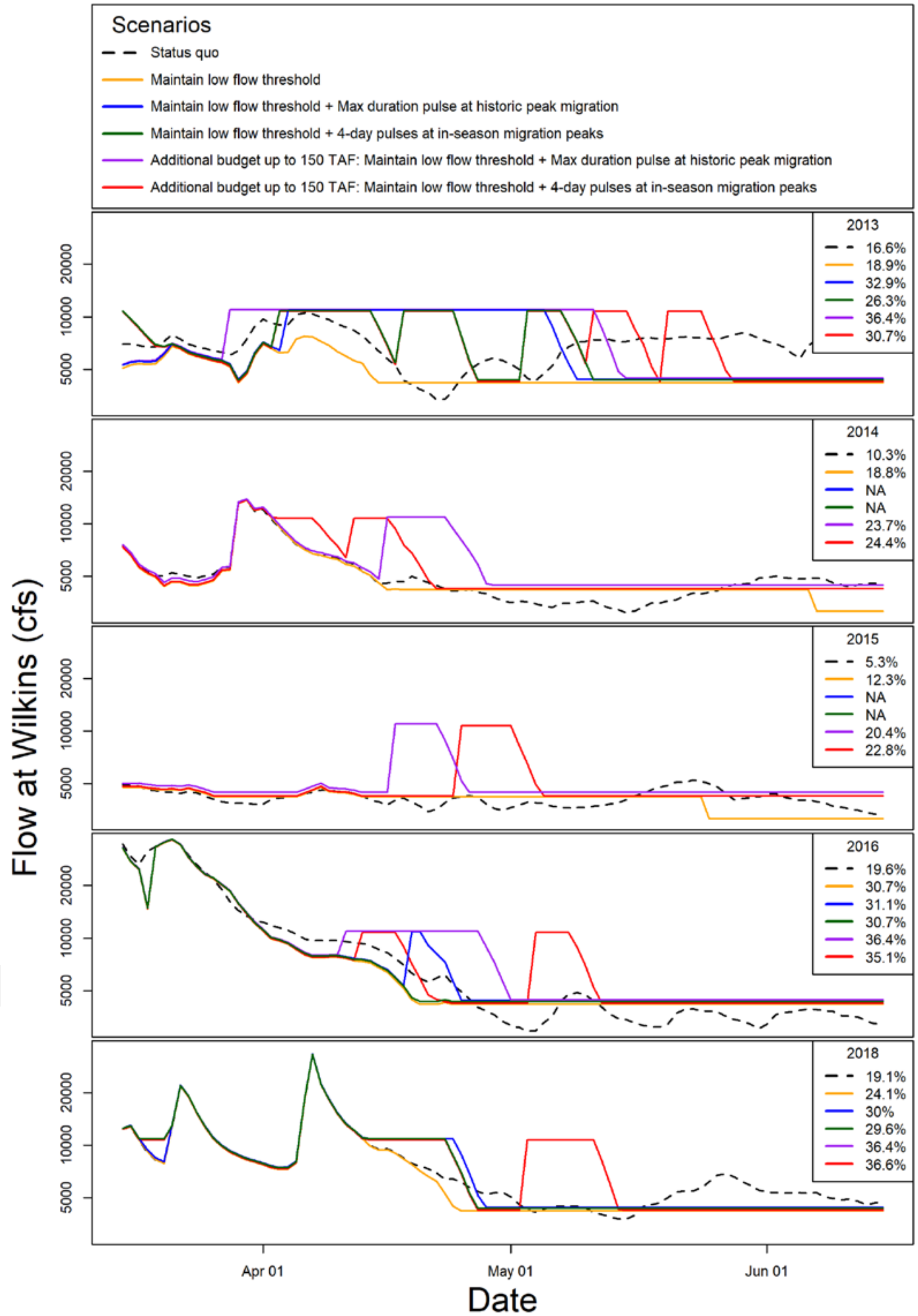

Figure 7. Alternative flow scenario hydographs using the flow survival nonlinearities found in this study. Predicted cohort spring outmigration survival based on flow scenarios and daily fish passage at Red Bluff rotary screw traps are depicted in figure legends. Scenarios for 2017 and 2019 water

years are not depicted, as wet conditions in those years precluded the need for functional flows. In the critically dry years of 2014 and 2015, functional flows were not possible based on actual water budget ("NA" for respective survival estimates in legend).

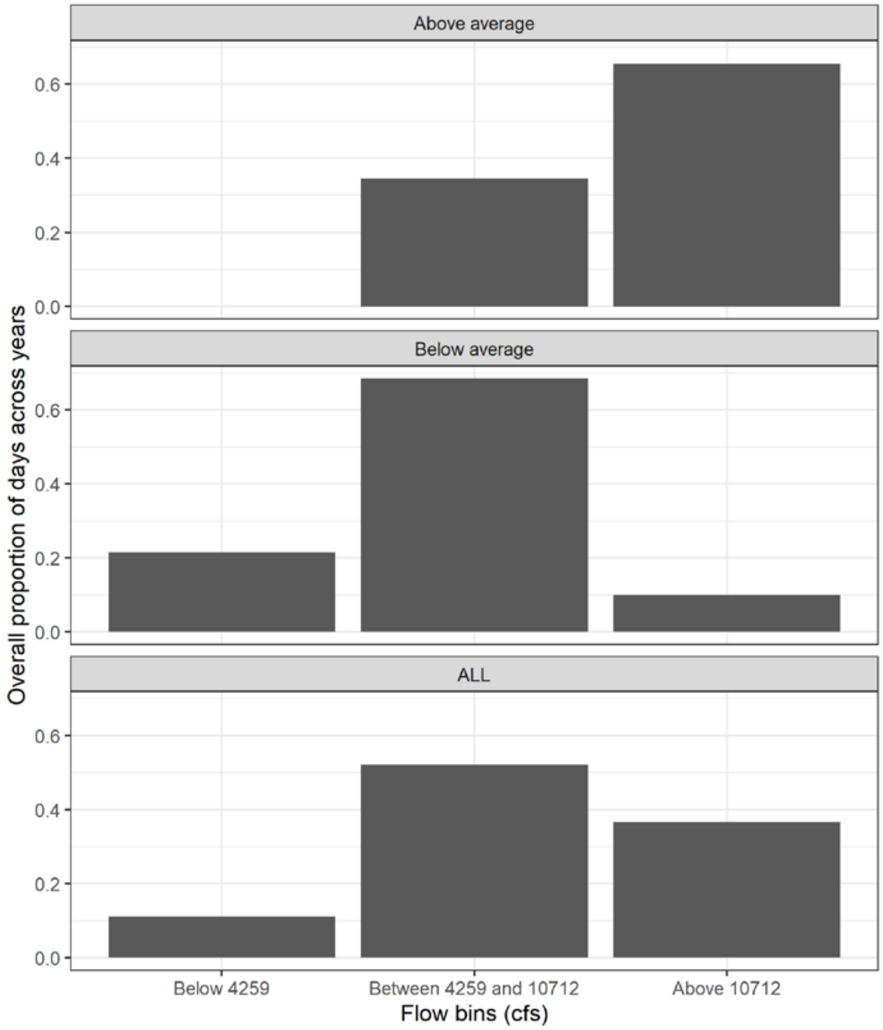

Fig. 8. Proportion of daily flows at Wilkins Slough that fall below, between, or above the two lower flow thresholds from April 15th to May 15th period from 1993 to 2019, split out by above average (i.e., "Wet" and "Above normal") and below average (i.e., "Below normal", "Dry", and "Critically dry") water years, according to the Water Year Hydrologic Classification Index for the Sacramento Valley (http://cdec.water.ca.gov/reportapp/javareports?name=WSIHIST).

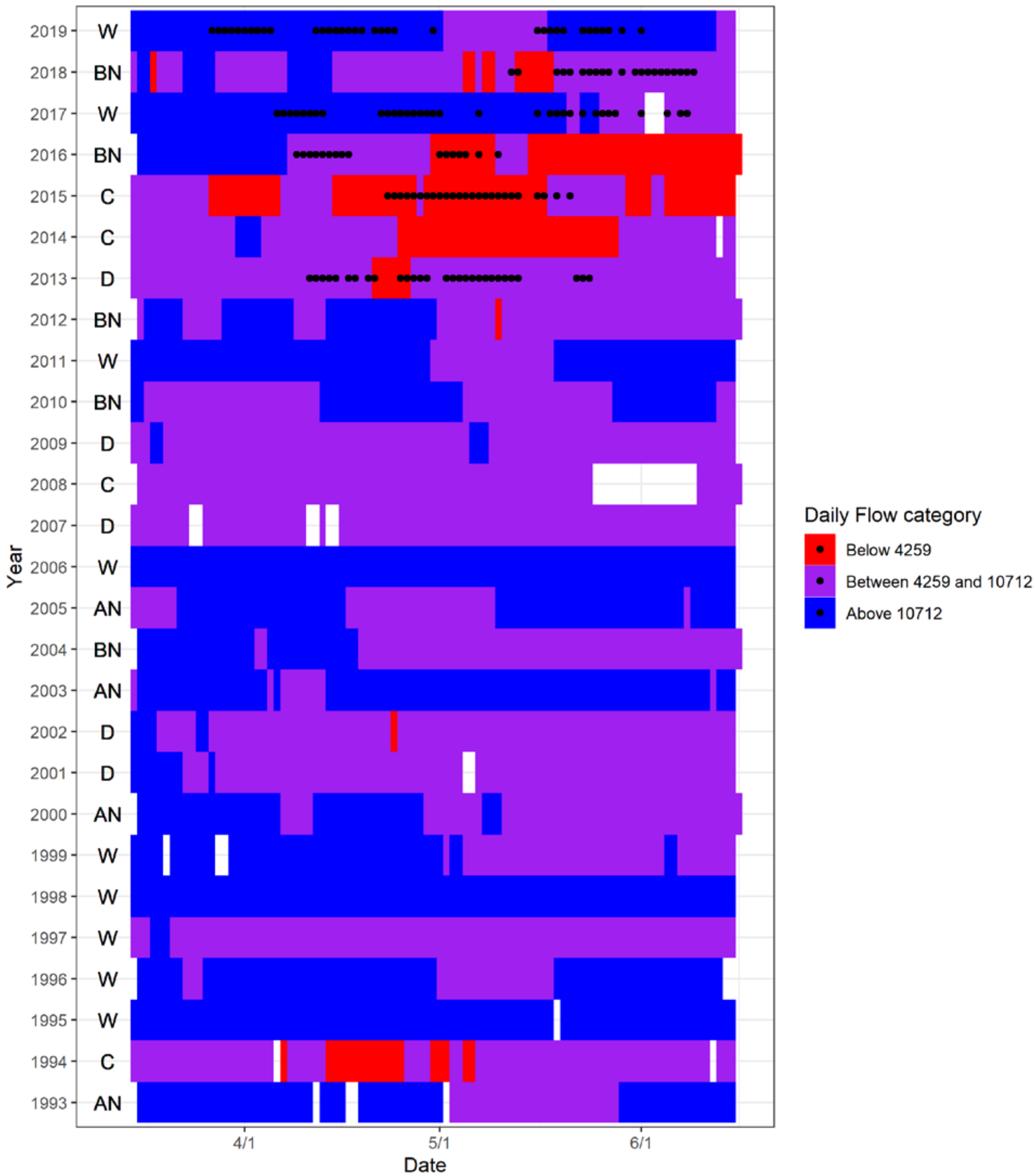

Fig. 9. Classification of flow values into the below 4,259 cfs, between 4,259 cfs and 10,712 cfs, and above 10,712 cfs categories for each day of the spring outmigration period (March 15th to June 15th) for the years 1993 to 2019. Flow values are as measured at USGS Wilkins Slough gauging station on the Sacramento River. Non-colored areas correspond to missing flow data. Black points represent

days when acoustic tagged fish were entering the region of interest. Text within box indicates the Water Year Hydrologic Classification Index for the Sacramento Valley (http://cdec.water.ca.gov/reportapp/javareports?name=WSIHIST); year type codes are W – wet, AN – above normal, BN, below normal, D – dry, and C – critically dry.

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7.2. Published work

Outmigration survival of wild Chinook salmon smolts through the Sacramento River during historic drought and high water conditions

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Abstract Populations of wild spring-run Chinook salmon in California's Central Valley, once numbering in the millions, have dramatically declined to record low numbers. Dam construction, habitat degradation, and altered flow regimes have all contributed to depress populations, which currently persist in only a few tributaries to the Sacramento River. Mill Creek (Tehama County) continues to support these threatened fish, and contains some of the most pristine spawning and rearing habitat available in the Central Valley. Despite this pristine habitat, the number of Chinook salmon returning to spawn has declined to record low numbers, likely due to poor outmigration survival rates. From 2013 to 2017, 334 smolts were captured and acoustic tagged while outmigrating from Mill Creek, allowing for movement and survival rates to be tracked over 250 km through the Sacramento River. During this study California experienced both a historic drought and record rainfall, resulting in dramatic fluctuations in year-to-year river flow and water temperature. Cumulative survival of tagged smolts from Mill Creek through the Sacramento River was 9.5% (±1.6) during the study, with relatively low survival during historic drought conditions in 2015 (4.9% ± 1.6) followed by increased survival during high flows in 2017 (42.3% ± 9.1). Survival in Mill Creek and the Sacramento River was modeled over a range of flow values, which indicated that higher flows in each region result in increased survival rates. Survival estimates gathered in this study can help focus management and restoration actions over a relatively long migration corridor to specific regions of low survival, and provide guidance for management actions in the Sacramento River aimed at restoring populations of threatened Central Valley spring-run Chinook salmon.

Keywords Acoustic telemetry · Salmon survival · Sacramento River · Chinook salmon · Biotelemetry · Central Valley

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Introduction

Wild stocks of spring-run Chinook salmon (*Oncorhynchus tshawytscha*) were abundant in all rivers draining into California's Central Valley (CCV) prior to dam construction, with population estimates of over two million spawning adults (Yoshiyama et al. 1998). Many of these populations have since been extirpated, due in large part to the loss of 47% of historic spawning and rearing habitat behind large impassable dams (Yoshiyama et al. 2001). For the past few decades, annual run sizes of remaining populations have been around 1% of the estimated historic average (Yoshiyama et al. 2001; Williams et al. 2016). The remaining populations of wild spring-run Chinook salmon in the CCV are isolated to just a few tributaries to the Sacramento River, with self-supporting populations limited to Deer, Mill and Butte Creeks (NMFS 2014). In these tributaries, access to pristine spawning and rearing habitat persists, and spatial segregation restricts inter-breeding with hatchery-origin fall-run Chinook salmon. Despite the pristine spawning and rearing habitat, these populations have declined severely, and in 1999 the CCV spring-run Chinook salmon Evolutionary Significant Unit was listed as threatened under the federal *Endangered Species Act*.

The downstream migration of smolts to the ocean is considered a highly vulnerable phase in the Pacific salmon life cycle, accounting for a high proportion of mortality over a short window of time (Healey 1991; Bradford 1995; Rechisky et al. 2012; Clark et al. 2016). It is presumed that the declining populations of wild salmon in the CCV are a result of the modified river and estuary environment that has reduced rearing potential (Sommer et al. 2001), increased predation risks (Grossman 2016), and limited available natural riparian habitat (Moyle et al. 2007). Increased predation risks are due to non-native species introductions and altered flow and temperature regimes in the Sacramento River and Delta that together have increased the vulnerability of juvenile salmon to both native and non-native predators (Nobriga 2007; Cavallo et al. 2012). Without significant habitat improvements in the river and estuary environments, as well as improved instream flows, the negative effects of altered outmigration habitats on CCV Chinook salmon smolts will likely intensify as the climate in California becomes more extreme as a consequence of anthropogenic climate change (Yates et al. 2008).

Extant populations of CCV spring-run Chinook salmon exhibit diverse life-history strategies characterized by large variations in size, timing, and age during outmigration from natal tributaries. One strategy is characterized by prolonged tributary rearing until the onset of smoltification, followed by rapid outmigration through the riverine and estuarine environments to the ocean during late spring (Johnson and Merrick 2012). Compared to other populations of CCV Chinook salmon, tributary spring-run Chinook salmon juveniles have slow growth rates and delayed outmigration timing resulting from low water temperatures in high elevation rearing habitat (Johnson and Merrick 2012). This delay in growth and outmigration timing often results in exposure to low flows and elevated water temperatures in the mainstem Sacramento River, which is largely diverted during the spring for agricultural water uses.

Water storage in Shasta Reservoir and surface water diversions downstream have significantly altered the hydrograph of the Sacramento River, primarily by reducing peak flows during the winter and spring and truncating the recession limb of spring snowmelt events (SWRCB 2017). Historically these flow events triggered smolt outmigration to the ocean, but today smolts experience increasingly diminished stream flow during the spring because of the cumulative impacts of water diversions. Water releases from Shasta Dam are tightly managed to meet a variety of objectives that include deliveries for State and Federal water projects, managing salinity levels in the Delta, and preserving coldwater in Shasta Reservoir to protect incubating endangered winter-run Chinook salmon eggs below the dam. As a result, median flows in the Sacramento River during March and April are less than 50% of unimpaired flow (SWRCB 2017), which can lead to decreased turbidity levels and elevated water temperatures, both of which have negative impacts on smolt survival (Becker 1971; Gregory 1993; Baker et al. 1995; Cavallo et al. 2012).

Several studies have focused on hatchery smolt survival in the CCV, with all finding low outmigration survival rates to the ocean compared to studies conducted in the Columbia and Fraser rivers in the Pacific Northwest region of the United States and Canada (Brandes and McLain 2001; Welch et al. 2008; Buchanan et al. 2013; Michel et al. 2015). However, insufficient data exists on the survival rates of wild Chinook salmon smolts in the CCV, primarily due to the difficulty in capturing these rare fish. Wild salmon smolts out-migrate to the ocean across many weeks during the spring compared to hatchery-origin salmon (Sturrock et al. 2019), which are typically released in a few large groups. Inferring survival rates for wild smolts based on acoustic tagged hatchery salmon can be misleading due to differences in fish size, behavior, fitness, and environmental conditions encountered while outmigrating. Thus, understanding the movement and survival rates of wild smolts across contrasting water year types is needed to devise effective management strategies for recovering wild spring-run Chinook salmon populations.

In this study, we measured the movement and survival rates of acoustic tagged wild Chinook salmon smolts from Mill Creek, a tributary to the upper Sacramento River which supports some of the last remaining wild spring-run Chinook salmon in the CCV. Utilizing detection data from an extensive network of acoustic receivers, we calculated the movement and survival rates of acoustic tagged juvenile salmon at fine spatial scales throughout Mill Creek and the Sacramento River. We used data collected over five consecutive years (2013–2017) to estimate survival and movement rates over a range of environmental conditions. Most notably, three consecutive years of drought followed by an extremely wet year provided us with insight into the relationship between environmental conditions and outmigration survival of wild salmon smolts in the CCV.

Methods

Study area

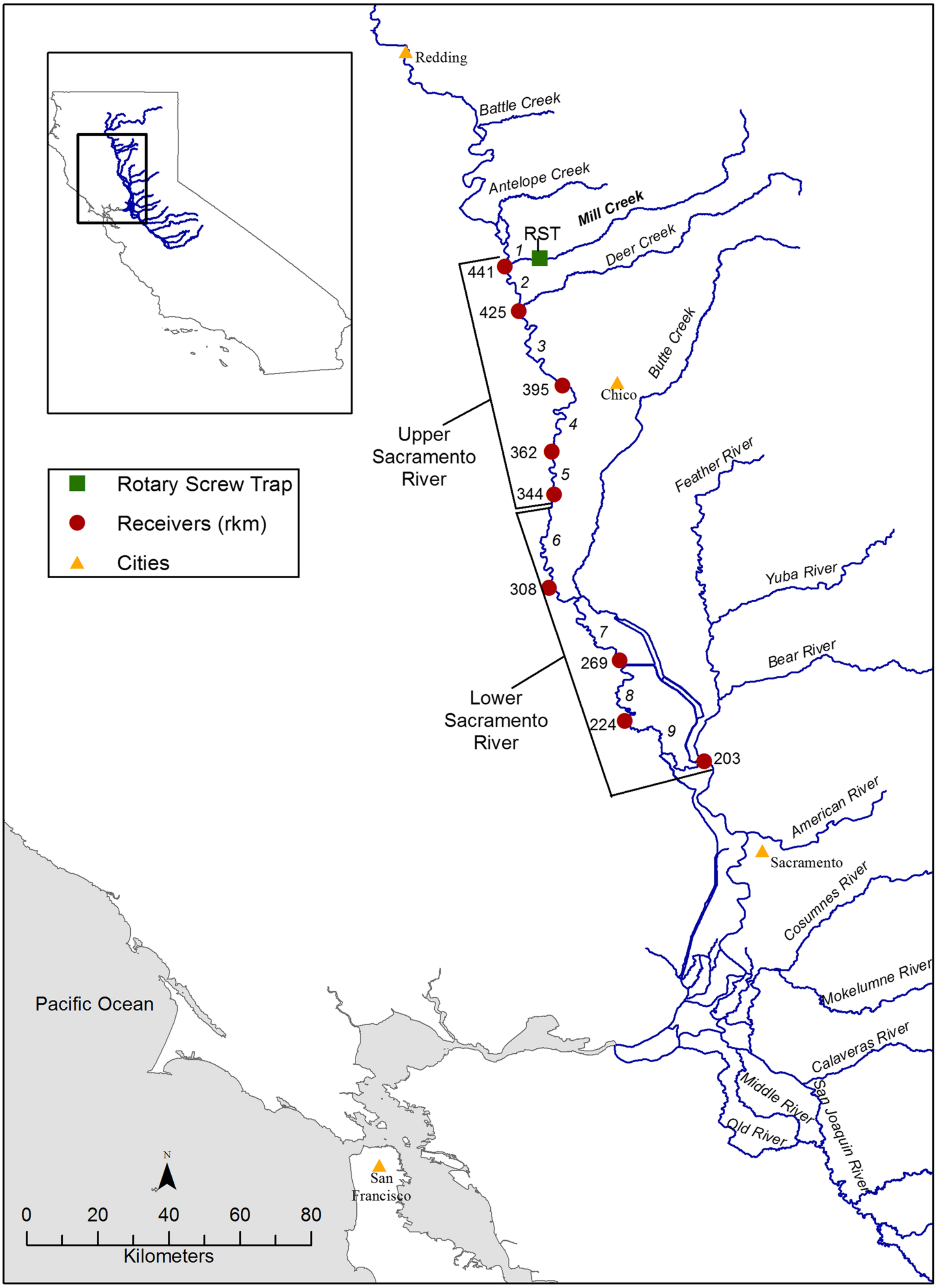
Originating in Lassen National Park, Mill Creek flows south-west through protected land in Lassen National Forest and into a remote canyon with limited public access. Mill Creek is 100 km long and originates at 2000 m in elevation, providing salmon and steelhead access to some of the highest elevation anadromous fish spawning habitat in the United States. Upon reaching the valley floor, water from Mill Creek is diverted from April through October for agricultural purposes behind two small dams, both of which provide anadromous fish upstream access with fish ladders. This study focuses on the movement and survival rates of wild juvenile salmon smolts captured, tagged and released below the upstream diversion dam on Mill Creek and extends downstream to the lower Sacramento River (Fig. 1).

Mill Creek joins the Sacramento River, the largest river in California draining an area of 70,000 km^2, at river kilometer 441 (distance upstream from ocean - rkm). The Sacramento River begins at Shasta Dam near the northern end of the CCV, and flows for 289 rkm downstream of Mill Creek before transitioning into the Sacramento-San Joaquin River Delta, which transitions into the San Francisco Estuary and finally the Pacific Ocean at the Golden Gate Bridge. The Sacramento River has two distinct regions, noted as the upper (rkm 441–344) and lower (rkm 344–203) Sacramento River in this study (Fig. 1). The upper Sacramento River is in a relatively natural state, containing expansive gravel bars, riparian habitat and large woody debris, whereas the lower Sacramento River is highly modified for agricultural purposes and channelized by levees. The Sacramento River is impacted in both regions by water diversions, which divert increasingly more water in lower reaches to supply neighboring agricultural fields.

Fish collection and tagging

Approximately 10 km upstream from the Sacramento River and directly below the upper diversion dam on Mill Creek, a rotary screw trap (RST) was used to capture migrating salmon smolts. The location is below much of the juvenile rearing habitat for spring-run Chinook salmon, and the smolts captured here are more likely to be actively migrating downstream to the ocean. The 1.5 m diameter RST was deployed in early April each year and operated continuously until catch rates diminished due to cessation in outmigration as a result of elevated water temperatures and decreasing flows (typically late May to early June). The trap was checked daily for juvenile salmon, which were netted and placed in holding buckets before being weighed to the nearest tenth of a gram and measured to the nearest mm of caudal fork length. All salmon of appropriate size were anesthetized in MS-222 buffered with 120 mg·L^{-1} sodium bicarbonate prior to surgery the morning of capture, which involved implanting acoustic transmitters (tags) into the coelomic cavity of the anesthetized fish (Deters et al. 2010). Fish were selected to prevent tag weight from exceeding 5% of the fish's body weight, which previous research has found to be an acceptable level of burden in survival studies (Brown et al. 2010; Ammann et al. 2013). This guideline suggested that smolts as small as 6 g and 80 mm fork length could be acoustic tagged with the transmitter used in this study without significant negative effects.

During 2013–2014, fish were released in Mill Creek below the RST approximately 1 h after recovery from anesthesia. Because these smolts were actively migrating, releasing them soon after recovery was considered the best option to avoid additional stress and disruption of their migratory inclination. Beginning in 2015, we modified the release procedure after low survival rates



Redding
Battle Creek
Antelope Creek
Mill Creek
RST
Deer Creek
Butte Creek
Chico
Upper Sacramento River
Lower Sacramento River
Feather River
Yuba River
Bear River
American River
Sacramento
Cosumnes River
Mokelumne River
Calaveras River
Middle River
Old River
San Joaquin River
Pacific Ocean
San Francisco
441
425
395
362
344
308
269
224
203
1
2
3
4
5
6
7
8
9
Rotary Screw Trap
Receivers (rkm)
Cities
N
0
20
40
60
80
Kilometers

◀ **Fig. 1** Location of each region used for this study (Mill Creek, upper Sacramento River, lower Sacramento River). Red dots indicate the location of an acoustic receiver, numbers next to red dots indicate the river kilometer, numbers between red dots indicate the reach number, and the green square indicates the tagging and release site in Mill Creek. The second diversion dam in Mill Creek is located between the RST and the first red dot

were observed within Mill Creek in 2014, and employed an automated release cage for the remainder of the study. This floating device (30 cm wide × 60 cm high × 50 cm long) fabricated of aluminum panels with 0.2 cm diameter holes allowed smolts to rest in shade throughout the day before a battery powered door opened at 22:00, and potentially reduced the risk of predation while out-migrating at night. The release cage also allowed us to observe the behavior of tagged smolts over a period of time, which a recent study suggests becomes normal after 24 h post-surgery (Singer et al. 2019). All tagged fish in this study appeared to be in good condition, and no mortalities were observed prior to release, however, the change in release strategy could potentially have influenced survival rates after the release cage was used in 2015.

Due to the tag-related restrictions in fish size, smolts used for this study are representative of the larger size class out-migrating from Mill Creek during the spring. The historic median size (1995–2010) of juveniles captured in the RST during the study period was 68 mm, with the tagging size threshold of 80 mm representing the 80th percentile (Johnson and Merrick 2012). As a result, the smolts in this study may exhibit different migration characteristics and survival rates compared to the smaller size classes of juveniles out-migrating from Mill Creek during the same time period.

Acoustic telemetry

We used the Juvenile Salmon Acoustic Telemetry System (JSATS) to track survival and movement rates of juvenile Chinook salmon (McMichael et al. 2010). The JSATS uses tags that emit a unique ID at 416.7 kHz. Tags were programmed to transmit at a five second interval, enabling the tag to function for a minimum of 27 days. The tags used in 2013 were Lotek Wireless model L-AMT-1.416 with a weight in air of 280 mg and dimensions of 10.5 mm long × 5.2 mm high × 3.0 mm wide. Tags used in 2014–2017 were Advanced Telemetry Systems (ATS) model SS300 with a weight in air of 300 mg and dimensions of 10.7 mm long × 5.0 mm high × 2.8 mm wide. The transmissions from the tags were detected and recorded by autonomous receivers from different manufacturers (ATS, Teknologic, and Lotek Wireless). Most receiver locations had two receivers to maximize detection probability.

Each year over 140 acoustic receivers were deployed throughout the migration pathway for juvenile Chinook salmon from Mill Creek to the Pacific Ocean; however for the purposes of this study, receivers from the Delta and San Francisco Bay were excluded, and the focus area was from release at Mill Creek to the lower Sacramento River at the Feather River confluence. Within Mill Creek, the upper Sacramento River and lower Sacramento River, smaller reaches were separated within each region (Fig. 1). Reaches were selected by dividing relatively long segments of river into smaller sections (20–30 km), which allowed movement and survival rates to be analyzed at smaller distances and indicated specific areas of low survival rates over time. The receivers were left in place for 30 days after the last smolt was tagged and released each year.

Data analysis

To estimate reach, regional, and cumulative survival, we used a Cormack-Jolly-Seber (CJS) model for live recaptures (Cormack 1964; Jolly 1965; Seber 1982) using program MARK (White and Burnham 1999) within the RMark package (Laake and Rexstad 2013) in R statistical software, version 3.3.0 (R Core Team 2016). A spatial adaptation of the CJS model works well for juvenile Chinook salmon which tend to exhibit a strict downstream movement behavior once smoltification has begun (Healey 1991). This behavior is advantageous for acoustic telemetry studies in riverine environments due to the linear nature of these systems, which require the fish to pass through specific reaches. As the tagged fish were migrating toward the ocean, we assumed that if no detections were recorded downstream of its last detection, the fish died between its last detection and the next downstream receiver. In addition, we assumed tags remained inside the fish for the duration of the study and were not expelled, as previous research shows tag shedding does not occur for at least 10 days (Notch 2017), which is after fish would have transited the study area.

When calculating survival rates, we also considered detection probability of the receivers (probability of detecting a passing acoustic tag), which can introduce error under certain environmental conditions. The noise caused by high water flows can impair receiver efficiency, increasing the likelihood of fish passing undetected, and contributing to overall uncertainty. To calibrate these estimates, the CJS model takes into account fish detected at downstream receivers to estimate the proportion of fish that were detected while moving past the upstream receiver's location, and then uses maximum-likelihood estimates for detection probability of all monitoring locations (p), all apparent survival estimates (Φ), and 95% confidence intervals for both (Lebreton et al. 1992). With the exception of 2015, we had relatively small sample sizes throughout this study, which led to increasing uncertainty in survival estimates from upstream to downstream, as fewer fish remained in the system.

Cumulative survival

To calculate cumulative survival within each region and through the study area, the raw (un-standardized) reach-specific survival estimates were multiplied within the region of interest. To account for the propagation of error, standard errors of the cumulative products of survival were calculated using the deltamethod.special function within the RMark package (Seber 1982; Powell 2007). This function requires the variance-covariance matrix for the cumulative survival estimates, and approximates the standard errors for the cumulative products of survival using a first-order Taylor approximation.

Regional survival

To calculate the regional survival rates, we simplified the pathway by using three reaches (regions) for the model; Mill Creek (reach 1, rkm 450–441), the upper Sacramento River (reach 2–5, rkm 441–344) and the lower Sacramento River (reach 6–9, rkm 344–203). We chose these regions based on their distinct habitat types and flow values resulting from water diversions that remove increasingly more water in lower reaches. We created a capture history matrix by assigning a 1 to fish detected within each region or farther downstream, and a 0 to fish not detected at the end of each region or farther downstream. Within the reach specific and regional survival analysis, we first estimated survival rates using a fully-parameterized survival and detection probability model that included no environmental covariates.

Reach-specific survival

Reach-specific survival estimates were calculated using all nine reaches in the study from Mill Creek through the upper and lower Sacramento River (rkm 450–203). We standardized survival rates per 10 km in order to compare estimates among reaches of varying distances (hereafter referred to as survival rates). We created a capture history matrix for all tagged fish by compiling detections at each receiver site into a 1 (detection) or 0 (no detection), allowing the CJS model to calculate survival rates and detection efficiencies for each reach within each year. Survival estimates in the final reach were generated by compiling detections in reaches downstream of the study area, which allowed for the estimation of detection probability at the final receiver line. The resulting survival rates represent the mean estimates for each reach or region, plus and minus the standard error.

Covariate survival

Several covariates were considered in an effort to determine which individual and environmental factors were most influential in regional smolt survival. We chose covariates that are believed to be strong drivers of smolt survival: streamflow (Raymond 1968; Connor et al. 2003; Tiffan et al. 2009), water temperature (Baker et al. 1995; Sykes et al. 2009), turbidity (Gregory 1993; Gregory and Levings 1998) and fish size (Munsch et al. 2019). Specifically, we considered Mill Creek flow at fish release [cubic feet per second (CFS)], Mill Creek temperature at fish release (degrees Celsius), upper Sacramento River flow (CFS), lower Sacramento River flow (CFS), lower Sacramento River temperature (degrees Celsius), lower Sacramento River turbidity (Nephelometric Turbidity Unit (NTU)), and fish length (mm). We used environmental data from state and federal streamflow gauges, and assigned specific values to each fish according to the time they entered each region. For individual fish that were not detected entering the upper Sacramento River region but detected further downstream, we estimated entry time by adding the average Mill Creek travel time estimate to the release time. For individual fish that were not detected entering the lower Sacramento River region but detected farther downstream, we estimated the entry time as the average upper Sacramento River travel time added to the actual or estimated entry time into the upper Sacramento River region. We assessed the influence of individual and environmental covariates factors on survival by allowing each fish to have its own set of covariate estimates based on the in-situ water conditions encountered in each region.

We included all covariates in a suite of survival models using every possible combination of environmental and individual covariates, which we then compared to other non-covariate survival models: a null model (constant survival through space and time) and a base model (reach). We compared models for fit using Akaike's Information Criterion, with a correction for small sample sizes (AICc) (Akaike 1981). This criterion ranks each model by assigning a score according to how accurate the model is relative to the given data, and penalizes models with many parameters. To determine the rank of the different models, we used the difference in AICc score relative to the top model (ΔAICc). For models with ΔAICc <2, we selected the model with the fewest parameters as the best model (Burnham and Anderson 2002). If more than one model was selected using this procedure, we used model averaging to estimate model parameters and standard errors (Burnham and Anderson 2002).

In total, we used 256 models in the survival analysis, testing all possible combination of reach plus individual and environmental covariates. Within program MARK, survival was modeled as a function of reach length and a number of individual and environmental parameters (Eq. 1), while detection efficiency varied by reach and year. One parameter coefficient (β) for each environmental and individual variable quantifies the linear relationship between that variable and survival. By standardizing the environmental and individual covariates (subtracting the mean value from each raw data point and dividing by the standard deviation), resulting *standardized* beta coefficients offer a straightforward interpretation across different models and environmental covariates. For a change in one standard deviation of the environmental variable, survival will change by the amount specified by that model's standardized beta coefficient. Eq. 1 shows the formulation of the survival model used:

$$\begin{aligned}\text{Logit}\,(\Phi) = \beta_0 + \beta_1[\textit{Reach Length}] \\ + \beta_2[\textit{Env.Variable 1}] + [\ldots] \\ + \beta_{(V+1)}[\textit{Env.Variable V}]\end{aligned} \tag{1}$$

where β_0 is the intercept, and V is the number of environmental covariates in any given model.

Once we selected the top covariate model, we predicted the effects of covariates on survival across the range of values observed during this study in each study region using model parameter estimates. This analysis allowed for an interpretation of the effect that each covariate may have on survival across a range of environmental conditions. The survival predictions are also bounded by 95% confidence intervals, which increase at the upper values of environmental parameters as a result of the small sample size experiencing those conditions.

Results

We tagged a total of 334 smolts during five years (2013–2017), with inter-annual variation in the sample sizes and forks lengths. The mean tagged fish fork length ranged from 83.5 mm to 86.9 mm and varied significantly among years ($P = 0.02$). Fish weight was more consistent, ranging from 6.7 g to 7.7 g, which did not vary significantly among years ($P = 0.24$). Sample sizes of tagged smolts were relatively small for years 2014, 2016 and 2017 ($n = 23$–36; Table 1) due to limited numbers of juvenile salmon present in Mill Creek (likely due to low numbers of spawning adult salmon the prior year). Additionally, many captured fish were not tagged due to the ≥80 mm and 6 g minimum tagging size threshold.

Due to severe drought conditions in three of the five years of this study (2013, 2014, 2015), study-period flows were lower and water temperatures higher in Mill Creek during drought years relative to the 20 year average (Fig. 2). Mill Creek flows increased considerably in 2016–2017 resulting from above average snowpack in

Table 1 Sample size, weight and length for smolts tagged and released each year

Year	Sample Size	Fork Length ± SD (mm)	Weight ± SD (g)
2013	59	84.2 ± 11.4	7.3 ± 3.3
2014	36	83.5 ± 2.9	6.7 ± 0.9
2015	186	86.9 ± 6.2	7.4 ± 2.1
2016	23	85.7 ± 4.0	7.7 ± 1.1
2017	30	86.1 ± 4.4	7.4 ± 1.3
ALL	334	85.9 ± 7.1	7.4 ± 2.1

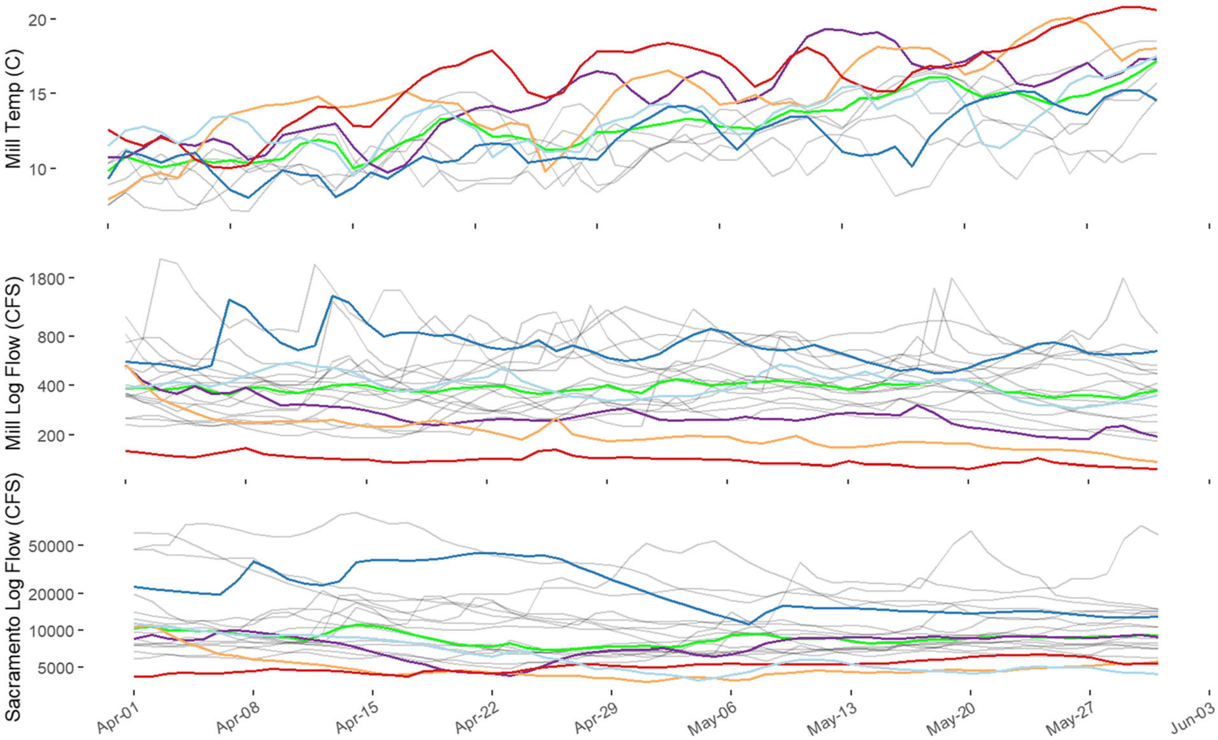


Fig. 2 Mill Creek temperature (top), flow (middle), and Sacramento River flow at Butte City (bottom) from 1998 to 2017 (grey lines). The green line is the 20 year median, purple line is 2013, orange line is 2014, red line is 2015, light blue line is 2016, and dark blue line is 2017

both years and record rainfall in 2017. Drought conditions also influenced Sacramento River flows during this study, with four of the five years (2013–2016) having considerably lower flows compared to the 20-year average (Fig. 2). In addition, water diversions for agricultural practices coinciding with this study further reduced Sacramento River flows in lower reaches. Sacramento River flows increased in 2017 relative to the 20-year average, resulting from an extremely wet winter and spring.

Cumulative survival

Fish exhibited variable cumulative survival from Mill Creek through the Sacramento River, ranging from 0% in 2016 to 42.3% (±9.1) in 2017 (Table 2), with a mean survival of 9.5% (±1.6). With the exception of 2016, cumulative survival through the upper Sacramento River ranged from 73.3% (±6.1) in 2017 to 27.9% (±3.8) in 2015, and cumulative survival through the lower Sacramento River ranged from 61.3% (±7.9) in 2017 to 15.3% (±4.5) in 2015.

Regional survival

Region specific survival rates were relatively consistent among years in the upper and lower Sacramento River, but varied annually within Mill Creek (Fig. 3). Survival rates in Mill Creek ranged from 88.1% (± 3.0) in 2017 to 62.1% (±3.1) in 2015. With the exception of 2016, survival rates in the upper Sacramento River ranged from 96.5% (± 0.9) in 2017 to 86% (± 1.4) in 2015, and survival rates in the lower Sacramento ranged from 98.1% (± 0.7) in 2017 to 92.0% (± 2.3) in 2015. The small sample size in 2016 did not allow for the calculation of survival estimates in the Sacramento River that year.

Reach-specific survival

Reach specific survival rates averaged among all years followed a similar pattern to the regional survival rate. The lowest survival rates were observed in Mill Creek (reach 1; 67.9% ± 2.6), followed by the highest survival rates in the first upper Sacramento River reach (reach 2; 97.5% ± 0.9), and progressively lower survival rates in

Table 2 Survival rates (per 10 km) and cumulative survival for each study region per year, including cumulative survival through all regions. Survival rates and cumulative survival in Mill Creek are the same because the reach length is 10 km

Year	Region	Survival Rates (SE)	Cumulative Survival (SE)
2013	Mill Creek	0.78 (0.03)	0.78 (0.03)
	Upper River	0.93 (0.01)	0.57 (0.06)
	Lower River	0.96 (0.01)	0.42 (0.07)
	All		0.17 (0.05)
2014	Mill Creek	0.65 (0.05)	0.65 (0.05)
	Upper River	0.87 (0.02)	0.32 (0.07)
	Lower River	0.93 (0.03)	0.18 (0.07)
	All		0.03 (0.03)
2015	Mill Creek	0.62 (0.03)	0.62 (0.03)
	Upper River	0.86 (0.01)	0.28 (0.04)
	Lower River	0.92 (0.02)	0.15 (0.05)
	All		0.05 (0.02)
2016	Mill Creek	0.67 (0.07)	0.67 (0.07)
	Upper River	0.00	0.00
	Lower River	0.00	0.00
	All	0.00	0.00
2017	Mill Creek	0.88 (0.03)	0.88 (0.03)
	Upper River	0.97 (0.01)	0.73 (0.06)
	Lower River	0.98 (0.01)	0.61 (0.08)
	All		0.42 (0.09)

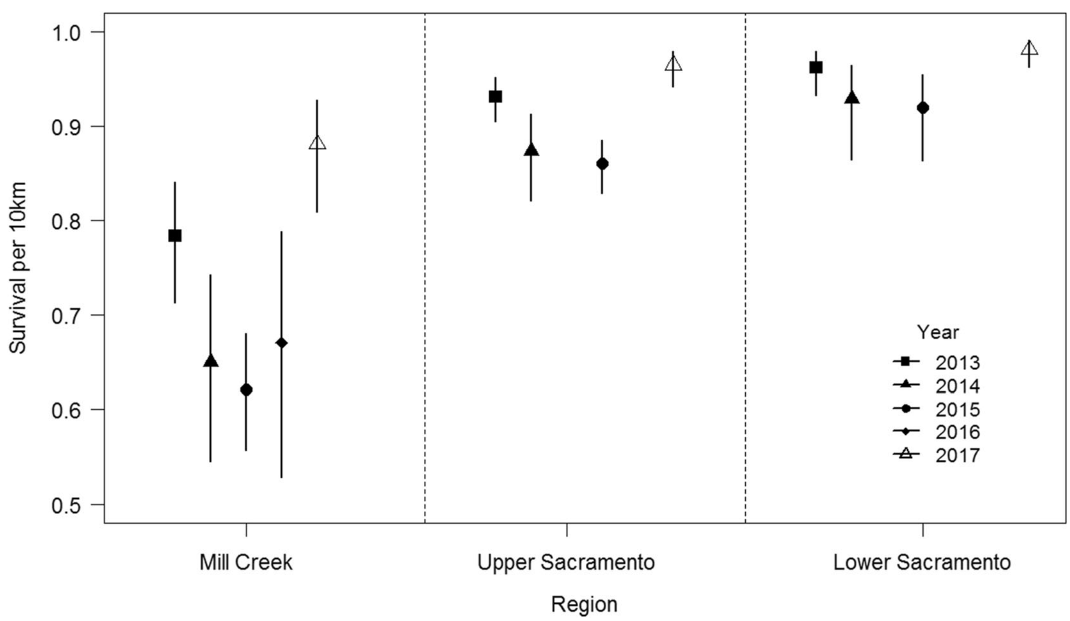


Fig. 3 Standardized regional survival rates (per 10 km) for each region during all study years. Error bars represent the upper and lower 95% confidence intervals. In 2016 no tagged smolts survived through the upper and lower Sacramento River

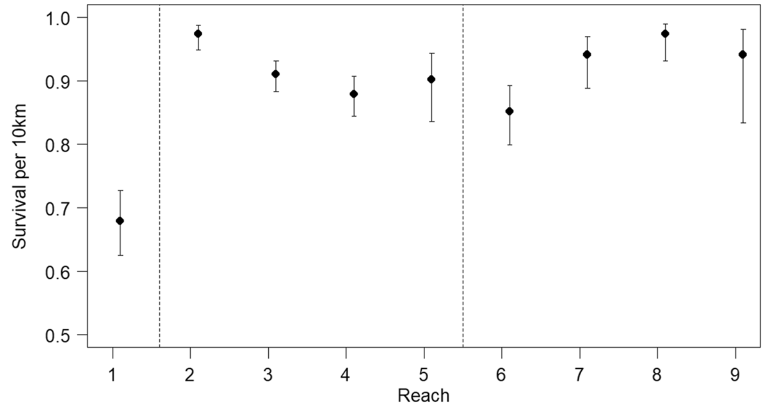


Fig. 4 Standardized survival rates (per 10 km) averaged across all five years for each study reach. The dotted lines represent breaks between each region (Mill Creek, upper Sacramento River, lower Sacramento River). Error bars represent upper and lower 95% confidence intervals

downstream reaches (reaches 3 to 6) with the lowest rates observed in the beginning of the lower Sacramento River (reach 6; 85.2 ± 2.3). Survival rates increased further downstream in the lower Sacramento River (reach 8; 97.4% ± 1.3) and remained relatively high through the end of the study region (reach 9; 94.2% ± 3.3) (Fig. 4).

Covariate survival

In the regional analysis of survival as a function of individual and environmental covariates, the top two models suggest that flow in all regions (Mill Creek, upper Sacramento River, lower Sacramento River) as well as temperature in Mill Creek were a better model fit

Table 3 Beta estimates (standard errors) of covariates included in mark recapture models with a ΔAICc <2. The selected top models with the least parameters are in bold

Covariate	Mode 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8	Model 9	Model 10	Base Model	Null Model
Intercept	**0.861**	0.863	0.862	**0.847**	0.864	0.848	0.861	0.863	0.862	0.861		
	(0.12)	(0.12)	(0.12)	**(0.12)**	(0.12)	(0.12)	(0.12)	(0.12)	(0.12)	(0.12)		
Mill Creek	**0.406**	0.278	0.4		0.274		0.406	0.278	0.4	0.406		
Flow	**(0.17)**	(0.19)	(0.17)		(0.19)		(0.17)	(0.19)	(0.17)	(0.17)		
Mill Creek		−0.2		**−0.329**	−0.2	−0.325		−0.2				
Temp		(0.15)		**(0.13)**	(0.15)	(0.13)		(0.15)				
Upper Sac	**0.597**	0.597	0.593	**0.601**	0.593	0.596	0.597	0.597	0.593	0.597		
Flow	**(0.15)**	(0.15)	(0.15)	**(0.15)**	(0.15)	(0.15)	(0.15)	(0.15)	(0.15)	(0.15)		
Lower Sac	**0.763**	0.763	0.767	**0.763**	0.767	0.767	0.652	0.652	0.664	0.82		
Flow	**(0.25)**	(0.25)	(0.24)	**(0.25)**	(0.24)	(0.24)	(0.25)	(0.25)	(0.25)	(0.27)		
Lower Sac							−0.204	−0.204	−0.191			
Temp							(0.23)	(0.23)	(0.22)			
Lower Sac										−0.096		
Turbidity										(0.21)		
Fish Length			−0.103		−0.106	−0.108			−0.101			
(mm)			(0.08)		(0.08)	(0.08)			(0.08)			
Survival Covariates	**4**	5	5	**4**	6	5	5	6	6	5	0	0
Parameters	**39**	40	40	**39**	41	40	40	41	41	40	36	31
ΔAICc	**0**	0.39	0.49	**0.75**	0.83	1.16	1.36	1.75	1.94	1.98	35.8	135.2

than the null model (constant survival) and base model (reach). These models were among the 10 best supported models <2 ΔAICc points, and contained the least number of parameters (Table 3). Model averaging was used to compute standardized beta coefficients for each model, revealing the importance of flow and temperature in smolt survival. Increasing flow in all regions was correlated with higher survival rates through those regions, and increasing water temperature in Mill Creek was correlated with lower survival rates through Mill Creek (Fig. 5).

To explore the relationship between fish movement speed and reach-specific survival, survival rates were transformed using a logit link function and plotted against movement speed at each receiver location per year. Fish movement speeds were correlated with survival rates in all reaches (pseudo R^2 value = 0.66), with slower movement speeds correlated with lower survival rates and faster movement speeds correlated with higher survival rates (Fig. 6). The slowest movement speeds were observed in Mill Creek (16.3 km/day ±14.7 S.D), followed by the highest movement speeds in the first upper Sacramento River reach (70 km/day ±16 S.D), and the slowest movement speeds in reach 4 of the upper Sacramento River (49.6 km/day ±11.6 S.D). Movement speeds increased below reach 6 in the lower Sacramento River, and obtained a maximum in reach 8 in the lower Sacramento River (81 km/day ±7 S.D).

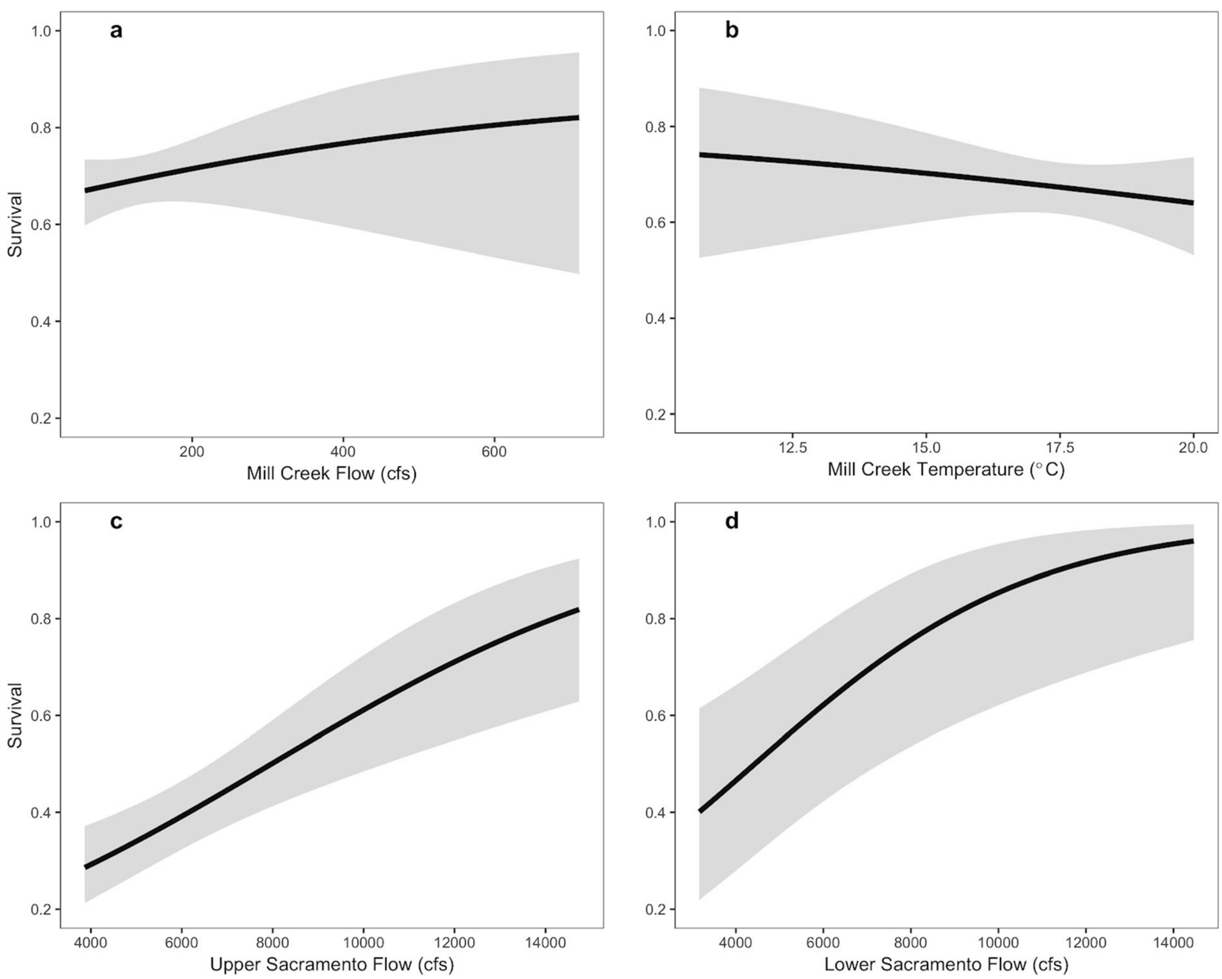


Fig. 5 Predicted survival through Mill Creek (a, b), the upper Sacramento River (c) and lower Sacramento River (d) in relation to flow and temperature values recorded during the study. Survival predictions were plotted using model averaged estimates from the top two covariate models, and back transformed using the logit link function which constrains survival between 0 and 1. Shaded areas represent the 95% confidence intervals around the survival estimates

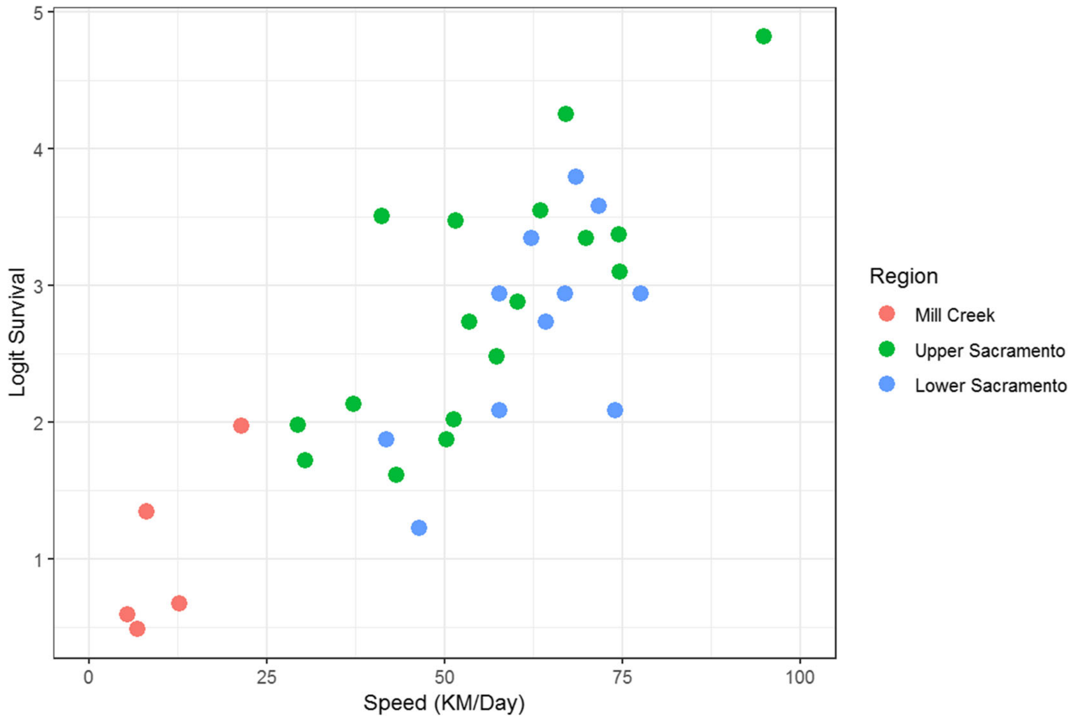


Fig. 6 Standardized reach specific survival rates transformed using a logit link function plotted against movement speed (kilometers per day). The points represent specific reaches within each region where fish survived to allow for movement and survival estimates to be calculated. (beta regression, pseudo R^2 value = 0.66)

Discussion

This study provides the first estimates of wild spring-run Chinook salmon smolt survival through Mill Creek and the Sacramento River during the spring, encompassing both critically dry and wet years. Overall survival estimates were relatively low compared to other telemetry studies conducted in the Sacramento River (Michel et al. 2015; Cordoleani et al. 2018), and were most likely influenced by three consecutive years of drought during the study. Flows in Mill Creek during the drought years (2013, 2014, 2015) were considerably lower and water temperatures higher than the 20 year average (Fig. 2). In addition, Sacramento River flows in the drought years were considerably lower than the 20 year average, and remained low in 2016 when flow conditions improved in Mill Creek. Flows in Mill Creek and the Sacramento River were well above the 20 year average in the 2017 outmigration period when California experienced its wettest winter and spring on record, and 2017 had the highest outmigration survival rates observed during this study through all regions (Fig. 3).

Fish tagged during this study were relatively large compared to the mean size of juveniles captured in the Mill Creek RST, but coincided with peak juvenile outmigration timing (Johnson and Merrick 2012). While smolts make up a small proportion of the overall catch, studies have shown they can have outsized contributions to adult spawning populations in some years (Sturrock et al. 2015). During dry years, warmer than average conditions lead to elevated stream temperature which results in higher growth rates and early onset of smoltification (Beckman et al. 1998). During the drought year of 2015 this was found to be true, with higher numbers of smolts captured earlier in the spring. However, during most years smolts rearing in Mill Creek take longer to grow and outmigrate compared to juveniles in other CCV streams (Whitton et al. 2011) due to the high elevation spawning and rearing habitat. This results in delayed outmigration timing that often coincides with increased water diversions, and likely creates unfavorable outmigration conditions.

Survival rates in Mill Creek were relatively low compared to reaches in the upper and lower Sacramento River. Overall, 68% of the 334 tagged smolts appeared to have survived their outmigration through the lower nine kilometers of Mill Creek and entered the Sacramento River. These survival estimates are influenced in large part by the spring of 2015, when only 62% of the 186 smolts survived to the Sacramento River. During 2015, Mill Creek experienced extremely low flows resulting from the drought and an exceptionally low snowpack. The low flows were further exacerbated by agricultural water diversions which removed approximately 50% of the stream flow from lower Mill Creek. The remaining flow was insufficient for migrating salmon smolts, as suggested by the low survival rates in relation to stream flow in Mill Creek (Fig. 5).

Stream flow in rivers manipulated by agricultural practices can be a strong driver of smolt survival, as was documented on Idaho's Snake River where increased flows downstream of large dams resulted in higher survival rates for juvenile Chinook salmon migrating to the ocean (Connor et al. 2003). In the Sacramento River, flow was found to be the top covariate in predicting outmigration survival of hatchery late-fall Chinook salmon, with years of high flow resulting in a three-fold increase in outmigration survival through the river (Henderson et al. 2018; Friedman et al. 2019). In addition to flow, higher water velocities can lead to improved smolt survival rates, likely because it promotes rapid downstream migration which reduces the exposure time to predators (Tiffan et al. 2009). In the upper and lower Sacramento River, faster movement speeds were associated with higher survival rates during this study (Fig. 6), which is likely attributed to higher water velocities during periods of high flow which help move fish quickly through the system.

Conversely, during drought conditions low stream flows can negatively impact smolt movement speeds (Zabel et al. 1998; Smith et al. 2002). One potential explanation for the relatively low survival rates in Mill Creek compared to other reaches in the Sacramento River is the slower movement speeds observed there (Fig. 6). Movement rates were between 8 and 19 km•day^{-1} in Mill Creek compared to 40–80 km•day^{-1} in the Sacramento River. The relatively slow smolt movement speeds through Mill Creek increases exposure time to potential risks such as predation and the effects of water diversions, which can both significantly impact survival; water diversions reduce flow and diminish cover, resulting in increased predator densities (Mussen et al. 2012). Movement rates improved in Mill Creek during years of higher flow (2016 and 2017), increasing from 8 to 10 km•day^{-1} to >20 km•day^{-1}, and corresponded with higher survival rates [62% in 2015 with exceptionally low flow (mean = 72 cfs), and 88% in 2017 with high flow (mean = 620 cfs)].

Drought conditions also result in elevated water temperature, which impairs smolt swimming performance (Lehman et al. 2017), and increases metabolic demand in predator fish, potentially leading to higher predation rates on juvenile Chinook salmon. Low flows resulting from drought conditions may also increase the likelihood of smolt encounters with predator fish, and clear water resulting from impaired run-off below large dams may increase the risk of predation on juvenile Chinook salmon (Gregory 1993). Additional compounding stressors include anthropogenic structures in Mill Creek and the Sacramento River such as water diversion infrastructure, bridge pilings, rock revetment, and wing dams which increase the effectiveness of ambush predators (Sabal et al. 2016). These structures create unnatural locations where predators can lie and wait, striking naïve juvenile salmon that are potentially disoriented after swimming through these obstacles, as they pass by (Brown and Moyle 1981; Sabal et al. 2016). Striped bass have been found to be effective ambush predators (Tucker et al. 2002) and are estimated to significantly impact juvenile Chinook salmon populations (Lindley and Mohr 2003). In addition, the long migration distances for Mill Creek smolts result in longer exposure times to predators, which may lead to significant mortality (Anderson et al. 2005).

California's variable climate can result in multiple years of drought followed by exceptional rainfall. This occurred during the 2017 water year, when California experienced unprecedented rainfall, elevating stream flows in all, and flooding in some, CCV rivers. The high flows resulted in favorable conditions for out-migrating smolts, and survival rates in the Sacramento River greatly improved compared to the previous four years of the study (Fig. 3). In total, 42.3% (±9.1) of the smolts tagged in Mill Creek survived through the Sacramento River in 2017, increasing from an average survival of 9.9% (±3.2) during the previous four study years (2013–2016). A similar increase in survival was observed in hatchery late fall-run Chinook salmon smolts across dry and wet years in the Sacramento River, when 3% survived to the Golden Gate during years of relatively low flow (2007–2010), followed by an increase in survival to 15% during a wet year with high river flows (2011) (Michel et al. 2015). While these high spring flow events are relatively uncommon in the regulated CCV system, they significantly increase survival rates of out-migrating salmon smolts.

The results from this study have implications for future restoration and management actions for threatened and endangered populations of wild Chinook salmon in the CCV. Smolts that out-migrate relatively late in the spring experienced very low survival rates during years of low flows, most likely as a result of flow-mediated predation during drought conditions (2013–2015) and substantial water diversions in the Sacramento River (2013–2016). Survival decreased with lower flows and higher water temperatures, and during drought conditions a large proportion of smolts perished within Mill Creek or shortly after migrating into the Sacramento River. Supplying enough water instream for smolts during their critical migration window can lead to higher outmigration survival, as well as increased returns of spawning adults (Raymond 1968; Berggren and Filardo 1993; Giorgi et al. 1997; Michel 2018). To accomplish this goal, managers need to consider trade-offs between stream flows for agriculture and fisheries needs, with an emphasis on maintaining adequate stream flows during critical stages of the salmon life cycle. Further, there are additional benefits from synchronizing managed flow increases on the Sacramento River with natural flow events occurring in the natal tributaries. As the few wild salmon populations in the CCV remain threatened and endangered, understanding how habitat and environmental conditions influence their survival is critical to support effective recovery planning.

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7.3. Real-time website pages for WY2019 Acoustic Tagged fish groups

CalFishTrack

Central Valley Enhanced Acoustic Tagging Project

Hatchery-origin late-fall run Chinook salmon

2018-2019 Season (PROVISIONAL DATA)

Project Status

PROJECT IS COMPLETE, ALL TAGS ARE NO LONGER ACTIVE

Telemetry Study Template for this study can be found here (https://github.com/CalFishTrack/real-time/blob/master/data/Telemetry_Study_Summary_NOAA_CNFH_late-fall-run.pdf?raw=true)

Code

```
## Project has begun, see tagging details below:
```

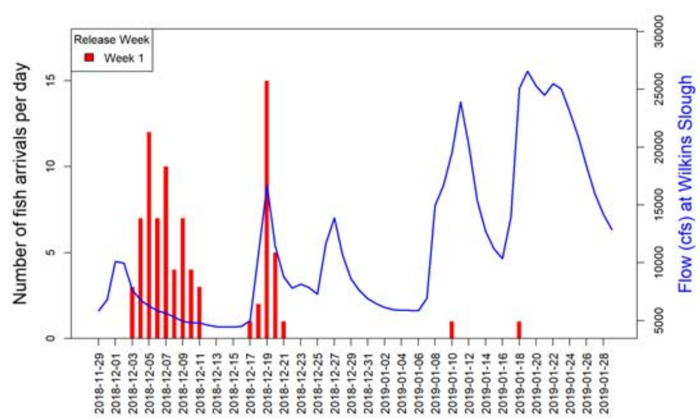
Release	First_release_time	Last_release_time	Number_fish_released	Release_location	Release_rkm	Mean_length	Mean_weig
Week 1	2018-11-29 08:00:00	2018-11-30 09:15:00	440	BattleCk_CNFH	517.344	141.9	34

Real-time Fish Detections

Data current as of 2020-04-07 15:00:00. All times in Pacific Standard Time.

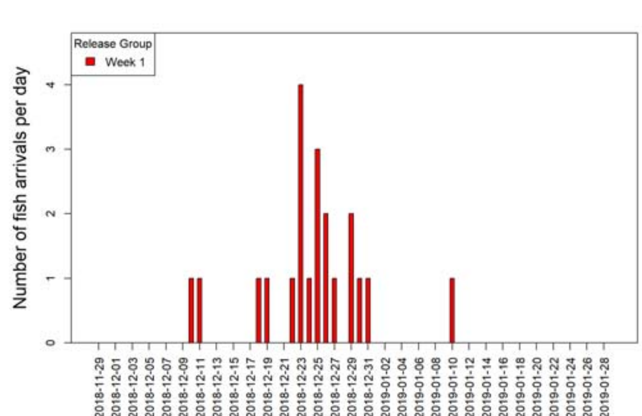
Detections at Tower Bridge (downtown Sacramento) versus Sacramento River flows at Wilkins Slough

Code



Detections at Benicia Bridge

Code



Central Valley Enhanced

Acoustic Tagging Project

Hatchery-origin late-fall run Chinook salmon

Minimum survival to Tower Bridge (using CJS survival model)

Code

Release Week	Survival (%)	SE	95% lower C.I.	95% upper C.I.	Detection efficiency (%)
ALL	21.7	2	18.1	25.9	86.9
Week 1	21.7	2	18.1	25.9	NA

Reach-specific survival and probability of entering Georgiana Slough

Code

Measure	Estimate	SE	95% lower C.I.	95% upper C.I.
Survival from release to TowerBridge	22.9	2.0	19.1	27.1
Survival from TowerBridge to I80-50_Br	100.0	0.0	94.9	100.0
% arrived from I80-50_Br to Georgiana Slough confluence (not survival because fish may have taken Sutter/Steam)	43.9	5.0	34.4	53.8
Detection probability at TowerBridge	82.5	4.0	73.3	89.0
Detection probability at I80-50_Br	83.5	3.9	74.4	89.8
Detection probability at Blw_Georgiana	92.6	5.0	74.8	98.1
Detection probability at Georgiana Slough	100.0	0.0	100.0	100.0
Routing probability into Georgiana Slough (Conditional on fish arriving to junction)	34.0	7.1	21.6	49.0

Minimum survival to Benicia Bridge East Span (using CJS survival model)

Code

Release Group	Survival (%)	SE	95% lower C.I.	95% upper C.I.	Detection efficiency (%)
ALL	4.9	1.1	3.2	7.4	83.3
Week 1	4.9	1.1	3.2	7.4	83.3

Detections statistics at all realtime receivers

Code

Detections for all releases combined

general_location	First_arrival	Mean_arrival	Last_arrival	Fish_count	Percent_arrived	rkm
TowerBridge	2018-12-03 13:21:27	2018-12-11 16:42:13	2019-01-18 18:02:18	83	18.86	172.000
I80-50_Br	2018-12-03 14:00:13	2018-12-11 21:17:02	2019-01-18 18:37:17	84	19.09	170.748
Georgiana_Slough1	2018-12-06 06:45:52	2018-12-14 14:42:10	2018-12-21 05:58:48	15	3.41	119.208
Sac_BlwGeorgiana	2018-12-04 20:46:20	2018-12-19 11:35:41	2019-01-11 23:24:47	28	6.36	119.058
Georgiana_Slough2	2018-12-07 22:21:13	2018-12-16 15:07:31	2018-12-21 06:28:28	11	2.50	118.758
Sac_BlwGeorgiana2	2018-12-04 21:10:00	2018-12-18 12:42:11	2019-01-11 23:41:16	28	6.36	118.398
Benicia_east	2018-12-10 20:28:58	2018-12-25 04:16:00	2019-01-10 18:28:19	18	4.09	52.240
Benicia_west	2018-12-11 22:27:30	2018-12-24 21:21:55	2019-01-01 07:51:14	18	4.09	52.040

Central Valley Enhanced

Acoustic Tagging Project

Hatchery-origin late-fall run Chinook salmon

CalFishTrack

Central Valley Enhanced Acoustic Tagging Project

Hatchery-origin winter-run Chinook salmon

2018-2019 Season (PROVISIONAL DATA)

Project Status

PROJECT IS COMPLETE, ALL TAGS ARE NO LONGER ACTIVE

Telemetry Study Template for this study can be found here (https://github.com/CalFishTrack/real-time/blob/master/data/Telemetry_Study_Summary_NOAA_LSNFH_Winter-run.pdf?raw=true)

Code

```
## Project began on 2019-02-14 18:30:00, see tagging details below:
```

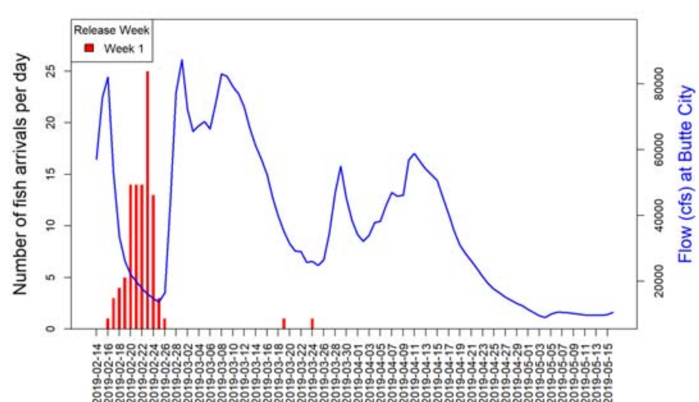
Release	First_release_time	Last_release_time	Number_fish_released	Release_location	Release_rkm	Mean_length	Mean_weig
Week 1	2019-02-14 18:30:00	2019-02-14 18:30:00	650	Caldwell Park_Rel	551.288	93.9	

Real-time Fish Detections

Data current as of 2020-04-07 15:00:00. All times in Pacific Standard Time.

Detections at Butte City Bridge versus Sacramento River flows at Butte City

Code



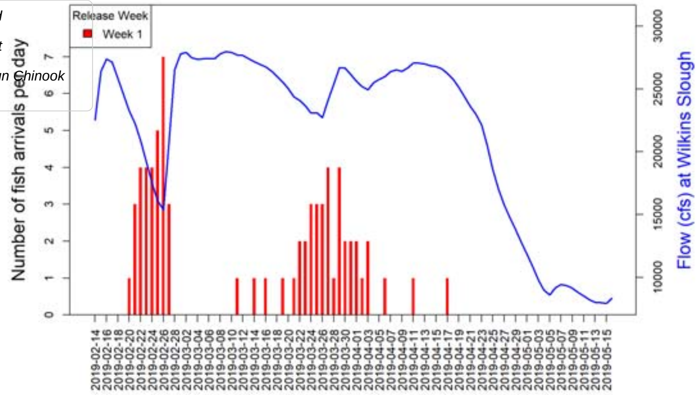
Detections at Tower Bridge (downtown Sacramento) versus Sacramento River flows at Wilkins Slough

Code

Central Valley Enhanced

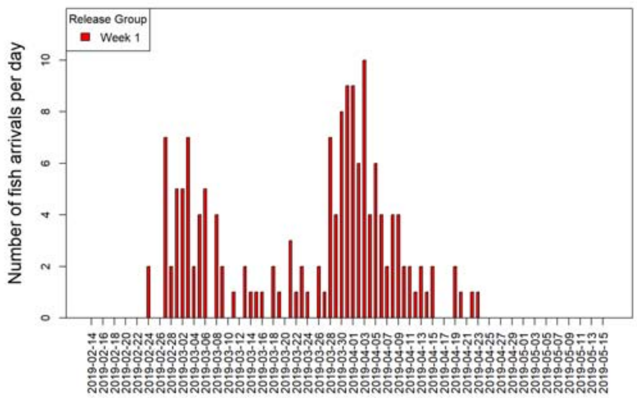
Acoustic Tagging Project

Hatchery-origin winter-run Chinook salmon



Detections at Benicia Bridge

Code



Minimum survival to Tower Bridge (using CJS survival model)

If Yolo Bypass Weirs are overtopping during migration, fish may have taken that route, and therefore this is a minimum estimate of survival

Code

Release Week	Survival (%)	SE	95% lower C.I.	95% upper C.I.	Detection efficiency (%)
ALL	21.8	2.4	17.6	26.8	49.4
Week 1	21.8	2.4	17.6	26.8	NA

Reach-specific survival and probability of entering Georgiana Slough

Code

Measure	Estimate	SE	95% lower C.I.	95% upper C.I.
Survival from release to Butte City	64.0	7.8	47.7	77.5
Survival from Butte City to TowerBridge (minimum estimate since fish may have taken Yolo Bypass)	43.3	6.3	31.6	55.7
Survival from TowerBridge to I80-50_Br	83.1	7.4	63.7	93.2
% arrived from I80-50_Br to Georgiana Slough confluence (not survival because fish may have taken Sutter/Steam)	76.4	6.7	60.9	87.1
Detection probability at Butte City	23.8	3.5	17.6	31.4
Detection probability at TowerBridge	38.9	4.3	30.8	47.7
Detection probability at I80-50_Br	51.5	5.0	41.8	61.1
Detection probability at Blw_Georgiana	56.2	6.2	44.0	67.8
Detection probability at Georgiana Slough	94.7	5.1	70.6	99.3
Routing probability into Georgiana Slough (Conditional on fish arriving to junction)	17.5	3.7	11.5	25.9

Minimum survival to Benicia Bridge East Span (using CJS survival model)

Central Valley Enhanced Acoustic Tagging Project Hatchery-origin winter-run Chinook salmon

Code

Release Group	Survival (%)	SE	95% lower C.I.	95% upper C.I.	Detection efficiency (%)
ALL	24.5	1.7	21.3	28	84.3
Week 1	24.5	1.7	21.3	28	84.3

Detections statistics at all realtime receivers

Code

Detections for all releases combined

general_location	First_arrival	Mean_arrival	Last_arrival	Fish_count	Percent_arrived	rkm
ButteBrRT	2019-02-16 21:30:15	2019-02-22 18:51:46	2019-03-24 11:57:49	99	15.23	344.108
TowerBridge	2019-02-20 23:57:58	2019-03-13 21:41:21	2019-04-17 01:48:42	70	10.77	172.000
I80-50_Br	2019-02-20 03:41:36	2019-03-14 02:43:41	2019-04-17 02:08:01	77	11.85	170.748
Georgiana_Slough1	2019-02-20 22:25:23	2019-03-14 08:14:07	2019-04-03 23:49:33	19	2.92	119.208
Sac_BlwGeorgiana	2019-02-21 15:50:22	2019-03-17 14:04:43	2019-04-17 12:30:48	53	8.15	119.058
Georgiana_Slough2	2019-02-20 22:33:47	2019-03-14 05:35:38	2019-04-03 23:58:16	19	2.92	118.758
Sac_BlwGeorgiana2	2019-02-20 15:48:15	2019-03-17 03:25:37	2019-04-11 19:12:35	64	9.85	118.398
Benicia_east	2019-02-24 11:29:12	2019-03-24 21:18:39	2019-04-22 21:43:15	134	20.62	52.240
Benicia_west	2019-02-24 16:24:13	2019-03-25 00:23:13	2019-04-23 08:53:06	140	21.54	52.040

Detections for Week 1 release groups

general_location	First_arrival	Mean_arrival	Last_arrival	Fish_count	Percent_arrived	rkm
ButteBrRT	2019-02-16 21:30:15	2019-02-22 18:51:46	2019-03-24 11:57:49	99	15.23	344.108
TowerBridge	2019-02-20 23:57:58	2019-03-13 21:41:21	2019-04-17 01:48:42	70	10.77	172.000
I80-50_Br	2019-02-20 03:41:36	2019-03-14 02:43:41	2019-04-17 02:08:01	77	11.85	170.748
Georgiana_Slough1	2019-02-20 22:25:23	2019-03-14 08:14:07	2019-04-03 23:49:33	19	2.92	119.208
Sac_BlwGeorgiana	2019-02-21 15:50:22	2019-03-17 14:04:43	2019-04-17 12:30:48	53	8.15	119.058
Georgiana_Slough2	2019-02-20 22:33:47	2019-03-14 05:35:38	2019-04-03 23:58:16	19	2.92	118.758
Sac_BlwGeorgiana2	2019-02-20 15:48:15	2019-03-17 03:25:37	2019-04-11 19:12:35	64	9.85	118.398
Benicia_east	2019-02-24 11:29:12	2019-03-24 21:18:39	2019-04-22 21:43:15	134	20.62	52.240
Benicia_west	2019-02-24 16:24:13	2019-03-25 00:23:13	2019-04-23 08:53:06	140	21.54	52.040

CalFishTrack

Central Valley Enhanced Acoustic Tagging Project

Deer Creek wild steelhead

2018-2019 FALL Season (PROVISIONAL DATA)

Project Status

PROJECT IS COMPLETE, ALL TAGS ARE NO LONGER ACTIVE

Telemetry Study Template for this study can be found here (https://github.com/CalFishTrack/real-time/blob/master/data/Telemetry_Study_Summary_Deer_Creek_Steelhead_Smolt.pdf?raw=true)

Code

```
## Project has begun, see tagging details below:
```

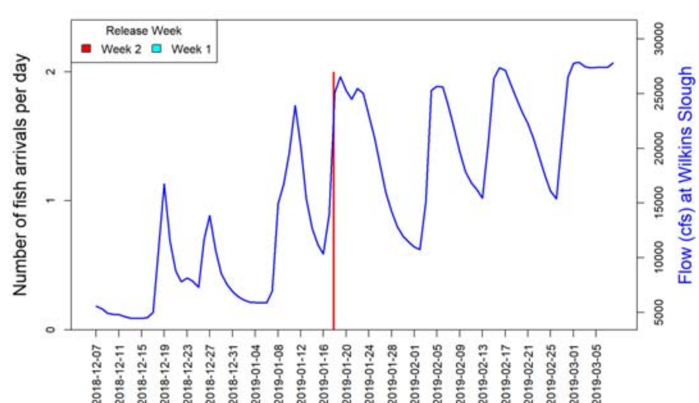
Release	First_release_time	Last_release_time	Number_fish_released	Release_location	Release_rkm	Mean_length	Mean_weig
Week 1	2018-11-24 10:15:00	2018-11-24 10:15:00	1	DeerCkRST	441.728	172.0	64
Week 2	2018-12-05 11:09:00	2018-12-08 10:40:00	6	DeerCkRST	441.728	229.5	133

Real-time Fish Detections

Data current as of 2020-04-07 15:00:00. All times in Pacific Standard Time.

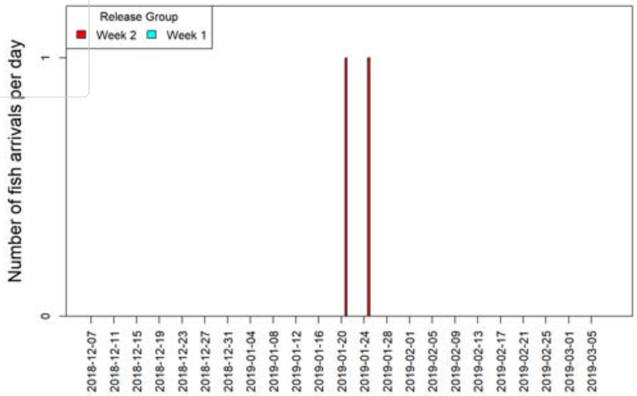
Detections at Tower Bridge (downtown Sacramento) versus Sacramento River flows at Wilkins Slough

Code



Detections at Benicia Bridge

Code



Minimum survival to Tower Bridge (using CJS survival model)

Code

Release Week	Survival (%)	SE	95% lower C.I.	95% upper C.I.	Detection efficiency (%)
ALL	28.6	17.1	7.2	67.3	100
Week 1	0.0	0.0	0.0	0.0	NA
Week 2	33.3	19.2	8.4	73.2	NA

Reach-specific survival and probability of entering Georgiana Slough

Code

[1] "Too few detections: routing probability cannot be estimated"

Minimum survival to Benicia Bridge East Span (using CJS survival model)

Code

Release Group	Survival (%)	SE	95% lower C.I.	95% upper C.I.	Detection efficiency (%)
ALL	28.6	17.1	7.2	67.3	100
Week 1	0.0	0.0	0.0	0.0	NA
Week 2	33.3	19.2	8.4	73.2	NA

Detections statistics at all realtime receivers

Code

Detections for all releases combined

general_location	First_arrival	Mean_arrival	Last_arrival	Fish_count	Percent_arrived	rkm
TowerBridge	2019-01-18 09:01:04	2019-01-18 14:11:11	2019-01-18 19:21:18	2	28.57	172.000
I80-50_Br	2019-01-18 19:47:06	2019-01-18 19:47:06	2019-01-18 19:47:06	1	14.29	170.748
Sac_BlwGeorgiana	2019-01-19 02:46:34	2019-01-19 02:46:34	2019-01-19 02:46:34	1	14.29	119.058
Sac_BlwGeorgiana2	2019-01-19 02:56:49	2019-01-19 07:09:36	2019-01-19 11:22:23	2	28.57	118.398
Benicia_east	2019-01-22 02:27:58	2019-01-24 00:50:46	2019-01-25 23:13:34	2	28.57	52.240
Benicia_west	2019-01-21 20:36:52	2019-01-23 21:56:47	2019-01-25 23:16:42	2	28.57	52.040

Code

Central Valley Enhanced

Acoustic Tagging Project

Deer Creek wild steelhead

2018-2019 FALL Season (PROVISIONAL DATA)

Project Status

Real-time Fish Detections

CalFishTrack

Central Valley Enhanced Acoustic Tagging Project

Sacramento River Green Sturgeon

2018-2019 Season (PROVISIONAL DATA)

Project Status

PROJECT IS COMPLETE, ALL TAGS ARE NO LONGER ACTIVE

Telemetry Study Template for this study can be found here (https://github.com/CalFishTrack/real-time/blob/master/data/Telemetry_Study_Summary_Sac_River_Green_Sturgeon.pdf?raw=true)

Code

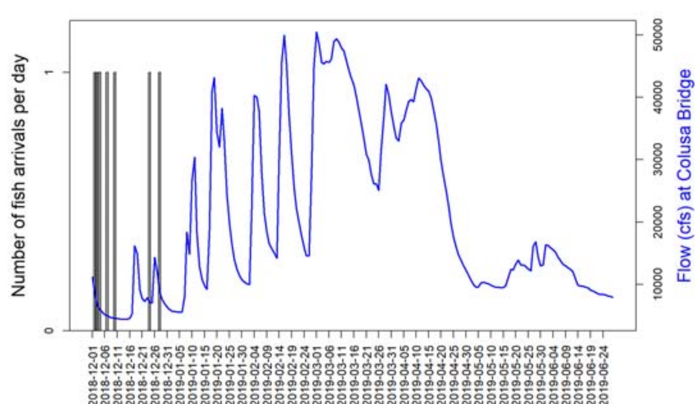
Release_time	Number_fish_released	Release_location	Release_rkm	Total_length	Weight
2018-10-04 22:54:00	1	Bank Robber	452.5	207	44.4
2018-10-05 10:30:00	1	RBDD Release	461.0	180	28.3
2018-10-08 12:34:00	1	RBDD Release	461.0	177	28.6
2018-10-10 20:55:00	1	Hunters Resort	450.3	254	69.2
2018-10-16 22:00:00	1	Hunters Resort	450.3	234	64.2
2018-10-17 23:48:00	1	Upper Woodson	421.4	266	93.8
2018-10-31 23:59:00	1	Altube Island	460.0	266	87.7
2018-11-14 22:21:00	2	Woodsen	421.4	281	104.5

Real-time Fish Detections

Data current as of 2020-04-07 15:00:00. All times in Pacific Standard Time.

Detections at Tower Bridge (downtown Sacramento) versus Sacramento River flows at Colusa Bridge

Code



Detections statistics at all realtime receivers

Code

general_location	First_arrival	Fish_count	Percent_arrived	rkm

Central Valley Enhanced Acoustic Tagging Project Sacramento River Green Sturgeon

general_location	First_arrival	Fish_count	Percent_arrived	rkm
TowerBridge	2018-12-02 21:39:28	7	77.78	172.000
I80-50_Br	2018-12-02 22:17:33	6	66.67	170.748
Sac_BlwGeorgiana	2018-12-06 23:08:34	5	55.56	119.058
Sac_BlwGeorgiana2	2018-12-06 23:26:14	6	66.67	118.398

CalFishTrack

Central Valley Enhanced Acoustic Tagging Project

Butte Creek wild spring-run Chinook salmon

2018-2019 Season (PROVISIONAL DATA)

Project Status

PROJECT IS COMPLETE, ALL TAGS ARE NO LONGER ACTIVE

Telemetry Study Template for this study can be found here (https://github.com/CalFishTrack/real-time/blob/master/data/Telemetry_Study_Summary_Butte%20Creek_2019.pdf?raw=true)

Code

```
## Project began on 2019-05-05 21:00:00, see tagging details below:
```

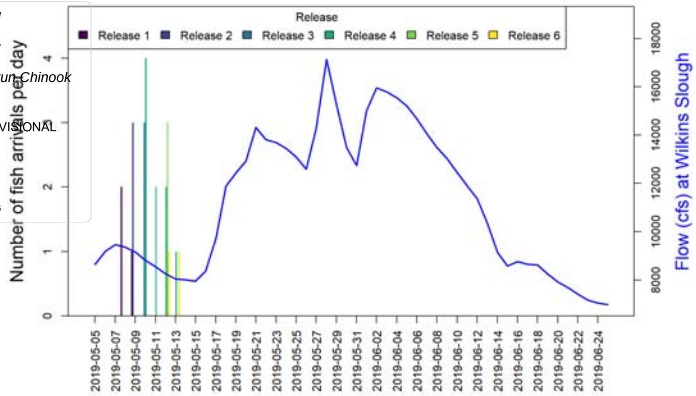
Release	Release time	Number_fish_released	Release_location	Release_rkm	Mean_length	Mean_weight	First_release
Release 1	2019-05-05 21:00:00	32	SutterBypass Weir2 RST	249.541	93.2	8.7	NULL
Release 2	2019-05-06 21:00:00	29	SutterBypass Weir2 RST	249.541	93.5	8.7	NULL
Release 3	2019-05-07 21:00:00	37	SutterBypass Weir2 RST	249.541	90.7	8.0	NULL
Release 4	2019-05-08 21:00:00	36	SutterBypass Weir2 RST	249.541	90.5	7.9	NULL
Release 5	2019-05-09 21:00:00	40	SutterBypass_Weir2_RST_Rel	249.541	91.7	8.3	NULL
Release 6	2019-05-10 21:00:00	31	SutterBypass_Weir2_RST_Rel	249.541	91.8	8.3	NULL

Real-time Fish Detections

Data current as of 2020-04-07 15:00:00. All times in Pacific Standard Time.

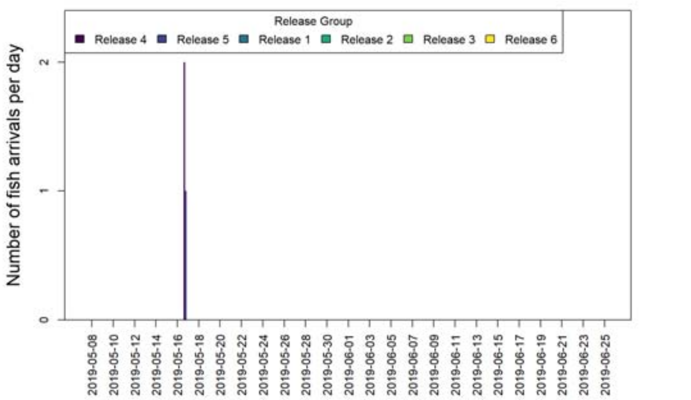
Detections at Tower Bridge (downtown Sacramento) versus Sacramento River flows at Wilkins Slough

Code



Detections at Benicia Bridge

Code



Minimum survival to Tower Bridge (using CJS survival model)

If Yolo Bypass Weirs are overtopping during migration, fish may have taken that route, and therefore this is a minimum estimate of survival

Code

Release	Survival (%)	SE	95% lower C.I.	95% upper C.I.	Detection efficiency (%)
ALL	16.2	2.8	11.5	22.4	69.2
Release 1	17.0	7.1	7.1	35.5	NA
Release 2	10.3	5.7	3.4	27.6	NA
Release 3	21.3	7.5	10.2	39.3	NA
Release 4	30.2	8.3	16.6	48.5	NA
Release 5	7.5	4.2	2.4	20.8	NA
Release 6	9.7	5.3	3.2	26.1	NA

Reach-specific survival and probability of entering Georgiana Slough

Code

Measure	Estimate	SE	95% lower C.I.	95% upper C.I.
Survival from release to Tower Bridge (minimum estimate since fish may have taken Yolo Bypass)	16.3	2.7	11.7	22.2
Survival from TowerBridge to I80-50_Br	97.5	10.6	0.9	100.0
% arrived from I80-50_Br to Georgiana Slough confluence (not survival because fish may have taken Sutter/Steam)	46.2	9.8	28.4	65.0
Detection probability at TowerBridge	69.0	8.6	50.3	83.0
Detection probability at I80-50_Br	80.0	10.3	53.0	93.4
Detection probability at Blw_Georgiana	84.6	10.0	54.9	96.1
Detection probability at Georgiana Slough	100.0	0.0	38.3	100.0
Routing probability into Georgiana Slough (Conditional on fish arriving to junction)	13.3	8.8	3.4	40.5

Central Valley Enhanced

Acoustic Tagging Project

Butte Creek wild spring-run Chinook salmon

2018-2019 Season (PROVISIONAL DATA)

Project Status

Real-time Fish Detections

Minimum survival to Benicia Bridge East Span (using CJS survival model)

Code

Release Group	Survival (%)	SE	95% lower C.I.	95% upper C.I.	Detection efficiency (%)
ALL	1.5	0.8	0.5	4.4	100
Release 1	0.0	0.0	0.0	0.0	NA
Release 2	0.0	0.0	0.0	0.0	NA
Release 3	0.0	0.0	0.0	0.0	NA
Release 4	5.6	3.8	1.4	19.7	NA
Release 5	2.5	2.5	0.4	15.7	NA
Release 6	0.0	0.0	0.0	0.0	NA

Detections statistics at all realtime receivers

Code

Detections for all releases combined

general_location	First_arrival	Mean_arrival	Last_arrival	Fish_count	Percent_arrived	rkm
TowerBridge	2019-05-08 07:46:45	2019-05-11 01:16:39	2019-05-13 20:54:10	23	11.22	172.000
I80-50_Br	2019-05-08 05:36:12	2019-05-10 21:33:03	2019-05-14 22:20:49	26	12.68	170.748
Georgiana_Slough1	2019-05-10 23:24:06	2019-05-11 23:17:19	2019-05-12 23:10:32	2	0.98	119.208
Sac_BlwGeorgiana	2019-05-09 07:48:43	2019-05-12 01:24:58	2019-05-13 19:25:02	11	5.37	119.058
Georgiana_Slough2	2019-05-10 23:39:09	2019-05-11 23:30:44	2019-05-12 23:22:19	2	0.98	118.758
Sac_BlwGeorgiana2	2019-05-09 07:58:26	2019-05-12 02:07:47	2019-05-13 19:37:10	13	6.34	118.398
Benicia_east	2019-05-17 07:04:08	2019-05-17 07:47:16	2019-05-17 08:15:15	3	1.46	52.240
Benicia_west	2019-05-17 07:08:08	2019-05-17 07:55:31	2019-05-17 08:28:20	3	1.46	52.040

Code

Central Valley Enhanced

Acoustic Tagging Project

Butte Creek wild spring-run Chinook salmon

2018-2019 Season (PROVISIONAL DATA)

Project Status

Real-time Fish Detections

Central Valley Enhanced

Acoustic Tagging Project

Hatchery-origin Battle Creek winter-run Chinook salmon

CalFishTrack

Central Valley Enhanced Acoustic Tagging Project

Hatchery-origin Battle Creek winter-run Chinook salmon

2018-2019 Season (PROVISIONAL DATA)

Project Status

PROJECT IS COMPLETE, ALL TAGS ARE NO LONGER ACTIVE

Telemetry Study Template for this study can be found here (https://github.com/CalFishTrack/real-time/blob/master/data/Telemetry_Study_Summary_WCS_BattleCreekReintro.pdf?raw=true)

Code

```
## Project began on 2019-03-26 09:30:00, see tagging details below:
```

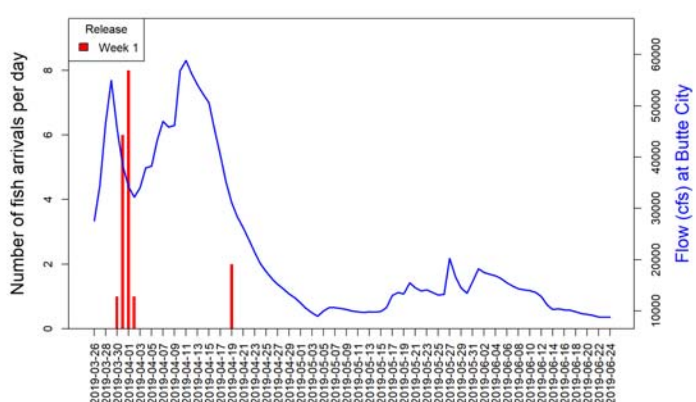
Release	First_release_time	Last_release_time	Number_fish_released	Release_location	Release_rkm	Mean_length	Mean_weig
Week 1	2019-03-26 09:30:00	2019-03-26 09:30:00	500	NF Battle Creek	536.234	88.5	7

Real-time Fish Detections

Data current as of 2020-04-07 15:00:00. All times in Pacific Standard Time.

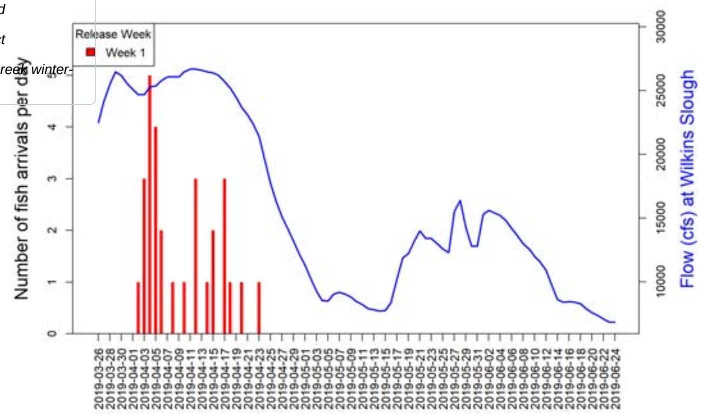
Detections at Butte City Bridge versus Sacramento River flows at Butte City

Code



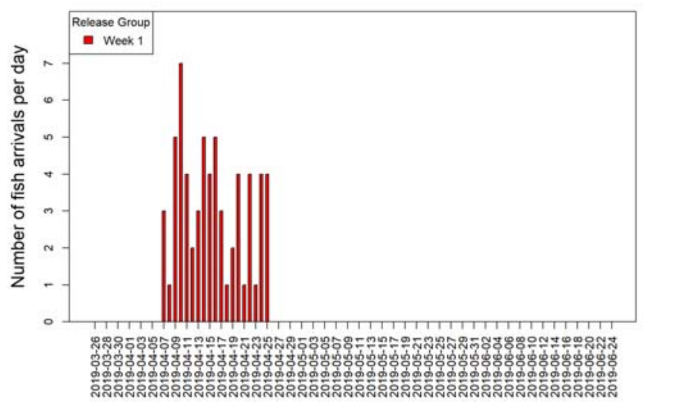
Detections at Tower Bridge (downtown Sacramento) versus Sacramento River flows at Wilkins Slough

Code



Detections at Benicia Bridge

Code



Minimum survival to Tower Bridge (using CJS survival model)

If Yolo Bypass Weirs are overtopping during migration, fish may have taken that route, and therefore this is a minimum estimate of survival

Code

Release Week	Survival (%)	SE	95% lower C.I.	95% upper C.I.	Detection efficiency (%)
ALL	18.5	4	11.8	27.7	31.4
Week 1	18.5	4	11.8	27.7	NA

Reach-specific survival and probability of entering Georgiana Slough

Code

Measure	Estimate	SE	95% lower C.I.	95% upper C.I.
Survival from release to Butte City	49.8	16.1	21.9	77.9
Survival from Butte City to TowerBridge (minimum estimate since fish may have taken Yolo Bypass)	44.7	15.6	19.0	73.6
Survival from TowerBridge to I80-50_Br	94.2	16.3	4.3	100.0
% arrived from I80-50_Br to Georgiana Slough confluence (not survival because fish may have taken Sutter/Steam)	65.4	11.6	40.9	83.8
Detection probability at Butte City	7.2	2.8	3.3	15.2
Detection probability at TowerBridge	26.0	5.1	17.3	37.2
Detection probability at I80-50_Br	33.3	6.2	22.4	46.4
Detection probability at Blw_Georgiana	40.7	9.5	24.2	59.7
Detection probability at Georgiana Slough	100.0	0.0	88.7	100.0
Routing probability into Georgiana Slough (Conditional on fish arriving to junction)	32.1	6.5	20.8	45.9

Central Valley Enhanced

Acoustic Tagging Project

Hatchery-origin Battle Creek winter-run Chinook salmon

Minimum survival to Benicia Bridge East Span (using CJS survival model)

Code

Release Group	Survival (%)	SE	95% lower C.I.	95% upper C.I.	Detection efficiency (%)
ALL	12.8	1.5	10.1	16	89.3
Week 1	12.8	1.5	10.1	16	89.3

Detections statistics at all realtime receivers

Code

Detections for all releases combined

general_location	First_arrival	Mean_arrival	Last_arrival	Fish_count	Percent_arrived	rkm
ButteBrRT	2019-03-30 04:36:57	2019-04-03 01:07:00	2019-04-19 07:10:55	18	3.6	344.108
TowerBridge	2019-04-02 21:20:43	2019-04-09 19:56:08	2019-04-23 14:10:22	29	5.8	172.000
I80-50_Br	2019-04-02 04:22:35	2019-04-12 08:05:47	2019-04-28 18:21:53	35	7.0	170.748
Georgiana_Slough1	2019-04-03 07:13:19	2019-04-09 22:26:49	2019-04-20 15:32:02	22	4.4	119.208
Sac_BlwGeorgiana	2019-04-03 19:56:03	2019-04-15 01:03:57	2019-04-26 02:45:37	19	3.8	119.058
Georgiana_Slough2	2019-04-03 07:23:30	2019-04-09 18:59:28	2019-04-20 15:15:20	16	3.2	118.758
Sac_BlwGeorgiana2	2019-04-03 10:21:17	2019-04-12 05:22:17	2019-04-23 02:33:25	27	5.4	118.398
Benicia_east	2019-04-07 20:45:00	2019-04-15 10:21:50	2019-04-25 12:14:51	57	11.4	52.240
Benicia_west	2019-04-07 20:51:22	2019-04-16 03:48:51	2019-04-25 12:19:18	56	11.2	52.040

Code

Central Valley Enhanced

Acoustic Tagging Project

Hatchery-origin Battle Creek winter-run Chinook salmon

Central Valley Enhanced

Acoustic Tagging Project

Hatchery-origin Battle Creek winter-run Chinook salmon

CalFishTrack

Central Valley Enhanced Acoustic Tagging Project

Feather River Hatchery Spring-run Chinook salmon

2018-2019 Season (PROVISIONAL DATA)

Project Status

PROJECT IS COMPLETE, ALL TAGS ARE NO LONGER ACTIVE

Telemetry Study Template for this study can be found here (https://github.com/CalFishTrack/real-time/blob/master/data/Telemetry_Study_Summary_NOAA_Feather_Hatchery_Spring-run.pdf?raw=true)

Code

```
## Project began on 2019-04-22 09:00:00, see tagging details below:
```

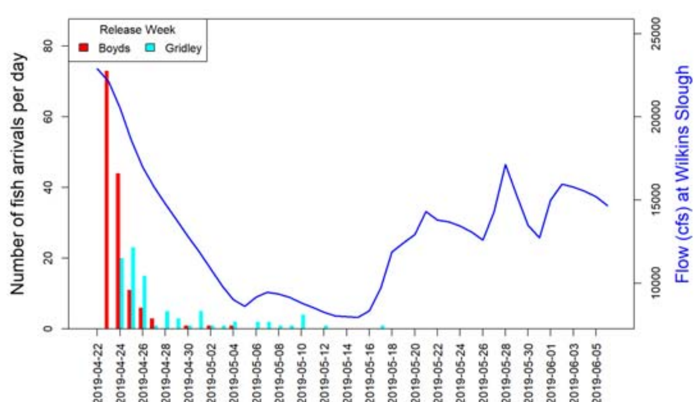
Release	First_release_time	Last_release_time	Number_fish_released	Release_location	Release_rkm	Mean_length	Mean_weig
Boyds	2019-04-22 12:45:00	2019-04-22 12:45:00	300	FR_Boyds_Rel	240.755	89.6	8
Gridley	2019-04-22 09:00:00	2019-04-22 09:00:00	300	FR_Gridley_Rel	287.387	89.8	8

Real-time Fish Detections

Data current as of 2020-04-07 15:00:00. All times in Pacific Standard Time.

Detections at Tower Bridge (downtown Sacramento) versus Sacramento River flows at Wilkins Slough

Code



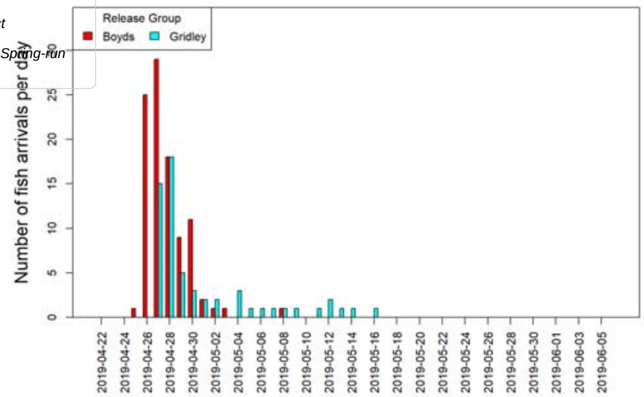
Detections at Benicia Bridge

Code

Central Valley Enhanced

Acoustic Tagging Project

Feather River Hatchery Spring-run Chinook salmon



Minimum survival to Tower Bridge (using CJS survival model)

If Yolo Bypass Weirs are overtopping during migration, fish may have taken that route, and therefore this is a minimum estimate of survival

Code

Release Week	Survival (%)	SE	95% lower C.I.	95% upper C.I.	Detection efficiency (%)
ALL	48.1	2.1	44.0	52.3	79.3
Boyds	59.3	2.9	53.4	64.9	NA
Gridley	37.0	2.9	31.5	42.7	NA

Reach-specific survival and probability of entering Georgiana Slough

Code

Measure	Estimate	SE	95% lower C.I.	95% upper C.I.
Survival from release to Tower Bridge (minimum estimate since fish may have taken Yolo Bypass)	50.2	2.1	46.2	54.2
Survival from TowerBridge to I80-50_Br	100.0	0.0	97.5	100.0
% arrived from I80-50_Br to Georgiana Slough confluence (not survival because fish may have taken Sutter/Steam)	80.4	2.4	75.4	84.6
Detection probability at TowerBridge	76.0	2.5	70.8	80.6
Detection probability at I80-50_Br	85.0	2.1	80.4	88.7
Detection probability at Blw_Georgiana	89.4	2.2	84.1	93.0
Detection probability at Georgiana Slough	100.0	0.0	95.6	100.0
Routing probability into Georgiana Slough (Conditional on fish arriving to junction)	17.8	2.5	13.4	23.1

Minimum survival to Benicia Bridge East Span (using CJS survival model)

Code

Release Group	Survival (%)	SE	95% lower C.I.	95% upper C.I.	Detection efficiency (%)
ALL	26.2	1.8	22.8	29.8	99.4
Boyds	32.7	2.7	27.6	38.2	NA
Gridley	19.7	2.3	15.6	24.6	NA

Detections statistics at all realtime receivers

Code

Detections for all releases combined

general_location	First_arrival	Mean_arrival	Last_arrival	Fish_count	Percent_arrived	rkm
TowerBridge	2019-04-23 11:04:15	2019-04-25 23:25:51	2019-05-17 20:51:39	229	38.17	172.000
I80-50_Br	2019-04-23 11:33:19	2019-04-25 20:23:24	2019-05-17 21:25:57	256	42.67	170.748

Central Valley Enhanced

Acoustic Tagging Project

Feather River Hatchery Spring-run Chinook salmon

general_location	First_arrival	Mean_arrival	Last_arrival	Fish_count	Percent_arrived	rkm
Georgiana_Slough1	2019-04-24 04:09:28	2019-04-26 09:48:04	2019-05-08 03:39:01	43	7.17	119.208
Sac_BlwGeorgiana	2019-04-24 01:14:31	2019-04-26 14:19:42	2019-05-18 13:13:29	178	29.67	119.058
Georgiana_Slough2	2019-04-24 04:17:22	2019-04-26 09:58:09	2019-05-08 03:53:16	43	7.17	118.758
Sac_BlwGeorgiana2	2019-04-24 01:24:41	2019-04-26 12:33:12	2019-05-18 13:25:50	188	31.33	118.398
Benicia_east	2019-04-25 14:19:57	2019-04-29 09:19:22	2019-05-16 04:44:49	156	26.00	52.240
Benicia_west	2019-04-25 14:42:53	2019-04-29 09:57:04	2019-05-16 04:46:21	157	26.17	52.040

Code

Central Valley Enhanced

Acoustic Tagging Project

Feather River Hatchery Spring-run Chinook salmon

CalFishTrack

Central Valley Enhanced Acoustic Tagging Project

Hatchery-origin San Joaquin spring-run Chinook salmon

2018-2019 Season (PROVISIONAL DATA)

Project Status

PROJECT IS COMPLETE, ALL TAGS ARE NO LONGER ACTIVE

Telemetry Study Template for this study can be found here (https://github.com/CalFishTrack/real-time/blob/master/data/Telemetry_Study_Summary_San_Joaquin.pdf?raw=true)

Code

```
## Project began on 2019-02-28 17:55:00, see tagging details below:
```

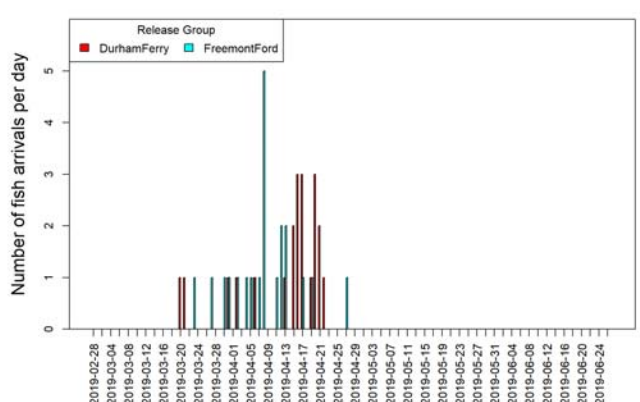
Release	First_release_time	Last_release_time	Number_fish_released	Release_location	Release_rkm	Mean_length	Mean_
DurhamFerry	2019-03-12 20:41:00	2019-03-12 20:41:00	354	DurhamFerry	183.78	80.6	
FreemontFord	2019-02-28 17:55:00	2019-02-28 17:55:00	347	FreemontFord	270.93	80.0	

Real-time Fish Detections

Data current as of 2020-04-07 15:00:00. All times in Pacific Standard Time.

Detections at Benicia Bridge

Code



Central Valley Enhanced

Acoustic Tagging Project

Hatchery-origin San Joaquin spring-run Chinook salmon

Minimum survival to Benicia Bridge East Span (using CJS survival model)

Code

Release Group	Survival (%)	SE	95% lower C.I.	95% upper C.I.	Detection efficiency (%)
ALL	6.1	0.9	4.6	8.2	97.7
DurhamFerry	5.9	1.3	3.9	8.9	NA
FreemontFord	6.3	1.3	4.2	9.4	NA

Detections statistics at all realtime receivers

Code

Detections for all releases combined

general_location	First_arrival	Mean_arrival	Last_arrival	Fish_count	Percent_arrived	rkm
SJ_Hills_Ferry	2019-03-08 06:20:58	2019-03-10 17:27:03	2019-03-14 04:27:14	18	2.57	257.000
Old River	2019-03-30 23:48:44	2019-04-11 21:37:00	2019-04-19 12:27:35	20	2.85	153.001
MiddleRiver	2019-03-21 00:29:58	2019-03-31 19:48:16	2019-04-08 10:51:52	3	0.43	150.000
CVP_Tank	2019-03-24 17:55:48	2019-04-09 19:21:50	2019-04-20 19:18:39	6	0.86	144.531
CVP_UpStream_TrashRack	2019-03-15 01:59:05	2019-04-07 23:05:38	2019-04-20 18:21:59	37	5.28	144.531
Clifton_Court_RadGates	2019-03-14 00:09:00	2019-03-31 00:44:51	2019-04-20 15:40:20	35	4.99	142.721
Clifton_Court_SWP	2019-03-14 07:35:22	2019-03-27 09:08:20	2019-04-16 10:42:17	37	5.28	142.721
Benicia_east	2019-03-20 19:26:59	2019-04-11 00:40:25	2019-04-27 15:39:16	42	5.99	52.240
Benicia_west	2019-03-20 19:31:57	2019-04-10 23:16:14	2019-04-27 15:42:43	43	6.13	52.040

Code

CalFishTrack

Central Valley Enhanced Acoustic Tagging Project

Hatchery-origin acclimation paired release fall-run Chinook salmon

2018-2019 Season (PROVISIONAL DATA)

Project Status

PROJECT IS COMPLETE, ALL TAGS ARE NO LONGER ACTIVE

Telemetry Study Template for this study can be found here (https://github.com/CalFishTrack/real-time/blob/master/data/Telemetry_Study_Summary_Coleman_Hatchery_FCS_Paired_Net_Pen.pdf?raw=true)

Code

```
## Project began on 2019-04-11 15:00:00, see tagging details below:
```

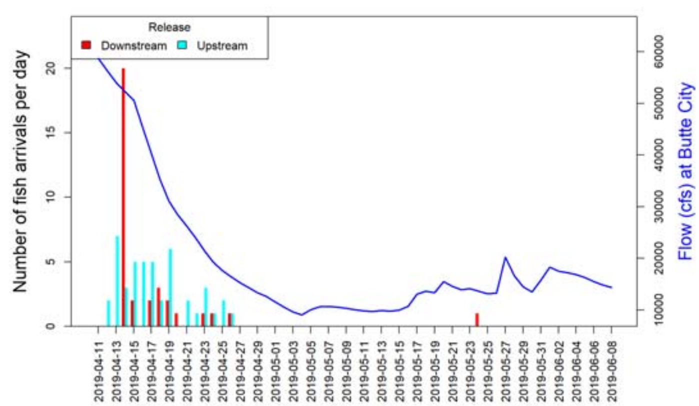
Release	First_release_time	Last_release_time	Number_fish_released	Release_location	Release_rkm	Mean_length	Mean_w
Downstream	2019-04-13 17:00:00	2019-04-13 17:00:00	301	ScottysLanding	410.512	84.2	
Upstream	2019-04-11 15:00:00	2019-04-11 15:00:00	300	BattleCkColeman	534.366	83.9	

Real-time Fish Detections

Data current as of 2020-04-07 15:00:00. All times in Pacific Standard Time.

Detections at Butte City Bridge versus Sacramento River flows at Butte City

Code



Detections at Tower Bridge (downtown Sacramento) versus Sacramento River flows at Wilkins Slough

Code

Central Valley Enhanced

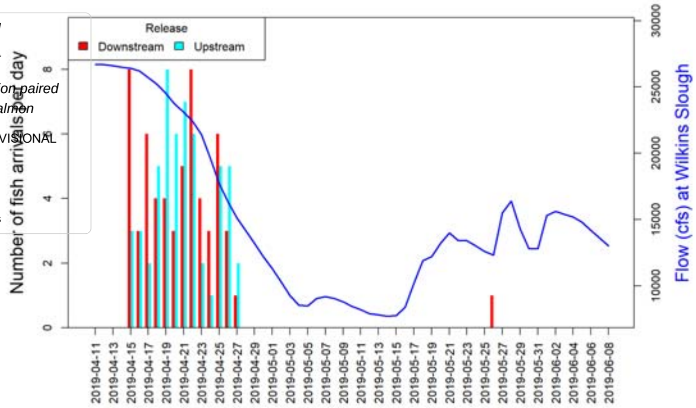
Acoustic Tagging Project

Hatchery-origin acclimation paired release fall-run Chinook salmon

2018-2019 Season (PROVISIONAL DATA)

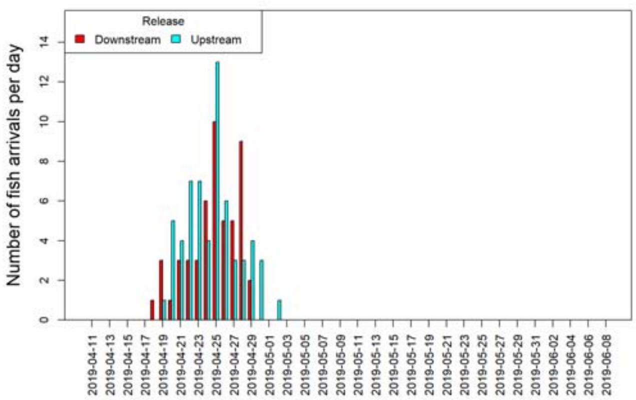
Project Status

Real-time Fish Detections



Detections at Benicia Bridge

Code



Minimum survival to Tower Bridge (using CJS survival model)

If Yolo Bypass Weirs are overtopping during migration, fish may have taken that route, and therefore this is a minimum estimate of survival

Code

Release	Survival (%)	SE	95% lower C.I.	95% upper C.I.	Detection efficiency (%)
ALL	28.6	2.0	24.8	32.7	66.4
Downstream	25.9	2.7	20.9	31.7	NA
Upstream	31.2	2.9	25.8	37.1	NA

Reach-specific survival and probability of entering Georgiana Slough

Code

Measure	Estimate	SE	95% lower C.I.	95% upper C.I.
Survival from release to Butte City	71.7	9.3	50.9	86.1
Survival from Butte City to TowerBridge (minimum estimate since fish may have taken Yolo Bypass)	40.1	5.6	29.7	51.4
Survival from TowerBridge to I80-50_Br	100.0	0.0	0.0	100.0
% arrived from I80-50_Br to Georgiana Slough confluence (not survival because fish may have taken Sutter/Steam)	72.1	3.6	64.6	78.5
Detection probability at Butte City	18.3	3.0	13.2	24.9
Detection probability at TowerBridge	66.0	3.7	58.4	72.8
Detection probability at I80-50_Br	77.6	3.3	70.4	83.4
Detection probability at Blw_Georgiana	90.5	3.0	82.8	95.0
Detection probability at Georgiana Slough	100.0	0.0	92.3	100.0
Routing probability into Georgiana Slough (Conditional on fish arriving to junction)	19.3	3.5	13.3	27.2

Minimum survival to Benicia Bridge East Span (using CJS survival model)

Code

Release Group	Survival (%)	SE	95% lower C.I.	95% upper C.I.	Detection efficiency (%)
ALL	18.7	1.6	15.7	22.0	96.3
Downstream	17.0	2.2	13.1	21.6	NA
Upstream	20.3	2.3	16.2	25.3	NA

Detections statistics at all realtime receivers

Code

Detections for all releases combined

general_location	First_arrival	Mean_arrival	Last_arrival	Fish_count	Percent_arrived	rkm
ButteBrRT	2019-04-12 21:41:34	2019-04-17 16:38:29	2019-05-24 22:09:04	79	13.14	344.108
TowerBridge	2019-04-15 00:30:13	2019-04-21 09:51:31	2019-05-26 21:43:56	114	18.97	172.000
I80-50_Br	2019-04-15 01:02:19	2019-04-21 06:58:41	2019-05-26 22:23:36	134	22.30	170.748
Georgiana_Slough1	2019-04-15 22:11:06	2019-04-21 14:52:50	2019-04-28 02:18:54	24	3.99	119.208
Sac_BlwGeorgiana	2019-04-16 04:30:57	2019-04-22 06:07:28	2019-05-27 14:37:23	91	15.14	119.058
Georgiana_Slough2	2019-04-15 22:18:38	2019-04-21 15:04:08	2019-04-28 02:36:37	24	3.99	118.758
Sac_BlwGeorgiana2	2019-04-16 04:39:20	2019-04-22 01:02:37	2019-05-27 14:44:12	95	15.81	118.398
Benicia_east	2019-04-19 01:10:29	2019-04-25 03:49:46	2019-05-02 06:19:28	108	17.97	52.240
Benicia_west	2019-04-18 16:47:05	2019-04-25 04:32:02	2019-05-02 06:24:24	109	18.14	52.040

Detections for Downstream release groups

general_location	First_arrival	Mean_arrival	Last_arrival	Fish_count	Percent_arrived	rkm
ButteBrRT	2019-04-14 00:25:27	2019-04-17 12:49:01	2019-05-24 22:09:04	34	11.30	344.108
TowerBridge	2019-04-15 16:01:22	2019-04-21 11:13:32	2019-05-26 21:43:56	59	19.60	172.000
I80-50_Br	2019-04-15 19:15:24	2019-04-21 12:22:53	2019-05-26 22:23:36	60	19.93	170.748
Georgiana_Slough1	2019-04-16 12:09:11	2019-04-22 11:49:47	2019-04-27 09:11:41	7	2.33	119.208
Sac_BlwGeorgiana	2019-04-16 04:30:57	2019-04-22 12:03:08	2019-05-27 14:37:23	44	14.62	119.058
Georgiana_Slough2	2019-04-16 12:16:55	2019-04-22 12:00:38	2019-04-27 09:23:19	7	2.33	118.758
Sac_BlwGeorgiana2	2019-04-16 04:39:20	2019-04-22 04:25:57	2019-05-27 14:44:12	48	15.95	118.398
Benicia_east	2019-04-19 01:10:29	2019-04-25 08:01:33	2019-04-29 15:18:37	47	15.61	52.240
Benicia_west	2019-04-18 16:47:05	2019-04-25 07:29:55	2019-04-29 15:21:34	49	16.28	52.040

Detections for Upstream release groups

general_location	First_arrival	Mean_arrival	Last_arrival	Fish_count	Percent_arrived	rkm
ButteBrRT	2019-04-12 21:41:34	2019-04-17 19:31:51	2019-04-26 14:22:50	45	15.00	344.108
TowerBridge	2019-04-15 00:30:13	2019-04-21 08:23:32	2019-04-27 08:57:03	55	18.33	172.000
I80-50_Br	2019-04-15 01:02:19	2019-04-21 02:35:50	2019-04-28 18:18:41	74	24.67	170.748
Georgiana_Slough1	2019-04-15 22:11:06	2019-04-21 06:15:16	2019-04-28 02:18:54	17	5.67	119.208
Sac_BlwGeorgiana	2019-04-16 08:02:03	2019-04-22 00:34:30	2019-04-29 09:02:56	47	15.67	119.058
Georgiana_Slough2	2019-04-15 22:18:38	2019-04-21 06:26:45	2019-04-28 02:36:37	17	5.67	118.758

Central Valley Enhanced

Acoustic Tagging Project

Hatchery-origin acclimation paired release fall-run Chinook salmon

2018-2019 Season (PROVISIONAL DATA)

Project Status

Real-time Fish Detections

general_location	First_arrival	Mean_arrival	Last_arrival	Fish_count	Percent_arrived	rkm
Sac_BlwGeorgiana2	2019-04-16 08:10:30	2019-04-21 21:34:57	2019-04-29 09:13:10	47	15.67	118.398
Benicia_east	2019-04-19 19:31:49	2019-04-25 00:35:46	2019-05-02 06:19:28	61	20.33	52.240
Benicia_west	2019-04-19 19:38:26	2019-04-25 02:06:45	2019-05-02 06:24:24	60	20.00	52.040

Code

CalFishTrack

Central Valley Enhanced Acoustic Tagging Project

Yolo Bypass released Hatchery-origin Chinook salmon

2018-2019 Season (PROVISIONAL DATA)

Project Status

PROJECT IS COMPLETE, ALL TAGS ARE NO LONGER ACTIVE

Telemetry Study Template for this study can be found here (https://github.com/CalFishTrack/real-time/blob/master/data/Telemetry_Study_Summary_RiceProject.pdf?raw=true)

Code

```
## Project began on 2019-04-25 20:00:00, see tagging details below:
```

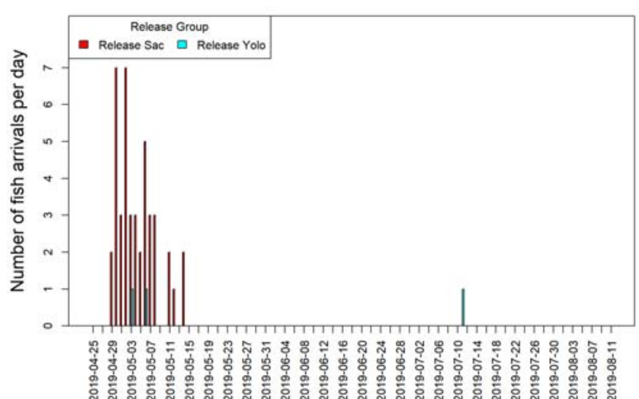
Release	First_release_time	Last_release_time	Number_fish_released	Release_location	Release_rkm	Mean_length	Mean_weig
Release Sac	2019-04-26 20:00:00	2019-04-26 20:00:00	245	SacElkLanding	207.738	82.1	6
Release Yolo	2019-04-25 20:00:00	2019-04-26 20:00:00	480	YB_ToeDrain_I5	159.500	82.9	7

Real-time Fish Detections

Data current as of 2020-04-07 15:00:00. All times in Pacific Standard Time.

Detections at Benicia Bridge

Code



Central Valley Enhanced Acoustic Tagging Project

Yolo Bypass released Hatchery-origin Chinook salmon

Minimum survival to Benicia Bridge East Span (using CJS survival model)

Code

Release Group	Survival (%)	SE	95% lower C.I.	95% upper C.I.	Detection efficiency (%)
ALL	6.4	0.9	4.8	8.4	95.6
Release Sac	17.6	2.4	13.3	22.9	NA
Release Yolo	0.6	0.4	0.2	1.9	NA

Detections statistics at all realtime receivers

Code

Detections for all releases combined

general_location	First_arrival	Mean_arrival	Last_arrival	Fish_count	Percent_arrived	rkm
TowerBridge	2019-04-26 23:27:03	2019-04-27 19:24:49	2019-05-16 22:29:53	191	26.34	172.000
I80-50_Br	2019-04-26 23:58:33	2019-04-27 22:33:51	2019-05-16 23:02:05	186	25.66	170.748
Georgiana_Slough1	2019-04-27 15:13:10	2019-04-30 22:07:24	2019-05-12 21:12:44	21	2.90	119.208
Sac_BlwGeorgiana	2019-04-27 11:33:46	2019-04-30 15:06:28	2019-05-21 05:18:24	85	11.72	119.058
Georgiana_Slough2	2019-04-27 16:20:37	2019-04-30 22:42:23	2019-05-12 21:24:42	21	2.90	118.758
Sac_BlwGeorgiana2	2019-04-27 11:41:53	2019-04-30 14:14:52	2019-05-21 04:52:00	92	12.69	118.398
Benicia_east	2019-04-29 02:53:12	2019-05-04 21:11:05	2019-05-14 17:28:14	44	6.07	52.240
Benicia_west	2019-04-29 02:57:28	2019-05-06 06:24:53	2019-07-11 01:28:23	45	6.21	52.040

Code

CalFishTrack

Central Valley Enhanced Acoustic Tagging Project

Hatchery-origin fall-run Chinook salmon May Release

2018-2019 Season (PROVISIONAL DATA)

Project Status

PROJECT IS COMPLETE, ALL TAGS ARE NO LONGER ACTIVE

Telemetry Study Template for this study can be found here (https://github.com/CalFishTrack/real-time/blob/master/data/Telemetry_Study_Summary_MayPulseFlow.pdf?raw=true)

Code

```
## Project began on 2019-05-16 10:00:00, see tagging details below:
```

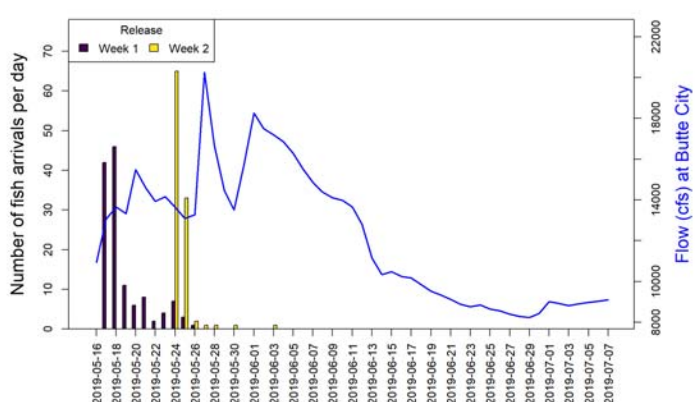
Release	First_release_time	Last_release_time	Number_fish_released	Release_location	Release_rkm	Mean_length	Mean_weig
Week 1	2019-05-16 10:00:00	2019-05-16 10:00:00	250	RBDD_Rel	461.579	92.0	9
Week 2	2019-05-23 10:00:00	2019-05-23 10:00:00	250	RBDD_Rel	461.579	93.4	9

Real-time Fish Detections

Data current as of 2020-04-07 15:00:00. All times in Pacific Standard Time.

Detections at Butte City Bridge versus Sacramento River flows at Butte City

Code



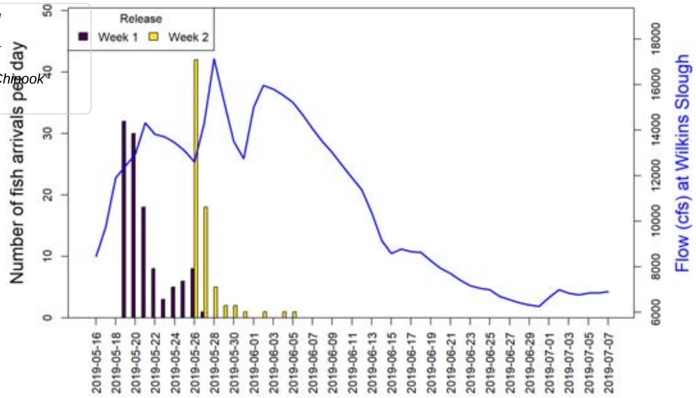
Detections at Tower Bridge (downtown Sacramento) versus Sacramento River flows at Wilkins Slough

Code

Central Valley Enhanced

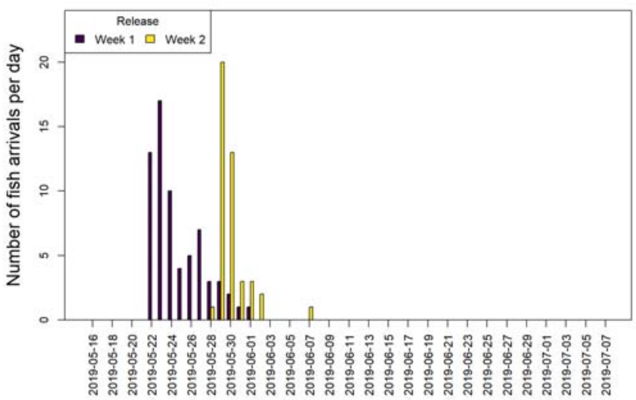
Acoustic Tagging Project

Hatchery-origin fall-run Chinook salmon May Release



Detections at Benicia Bridge

Code



Minimum survival to Tower Bridge (using CJS survival model)

If Yolo Bypass Weirs are overtopping during migration, fish may have taken that route, and therefore this is a minimum estimate of survival

Code

Release	Survival (%)	SE	95% lower C.I.	95% upper C.I.	Detection efficiency (%)
ALL	45.5	2.3	41.0	50.1	80.9
Week 1	52.3	3.3	45.9	58.7	NA
Week 2	38.7	3.2	32.6	45.2	NA

Reach-specific survival and probability of entering Georgiana Slough

Code

Measure	Estimate	SE	95% lower C.I.	95% upper C.I.
Survival from release to Tower Bridge (minimum estimate since fish may have taken Yolo Bypass)	45.9	2.3	41.6	50.4
Survival from TowerBridge to I80-50_Br	97.3	2.0	89.1	99.4
% arrived from I80-50_Br to Georgiana Slough confluence (not survival because fish may have taken Sutter/Steam)	78.7	3.0	72.3	84.0
Detection probability at TowerBridge	80.1	2.7	74.2	84.9
Detection probability at I80-50_Br	84.1	2.8	77.9	88.8
Detection probability at Blw_Georgiana	85.2	3.0	78.4	90.2
Detection probability at Georgiana Slough	100.0	0.0	94.5	100.0
Routing probability into Georgiana Slough (Conditional on fish arriving to junction)	19.3	3.0	14.1	25.8

Minimum survival to Benicia Bridge East Span (using CJS survival model)

Code

Central Valley Enhanced Acoustic Tagging Project Hatchery-origin fall-run Chinook salmon May Release

Release Group	Survival (%)	SE	95% lower C.I.	95% upper C.I.	Detection efficiency (%)
ALL	21.8	1.8	18.4	25.6	99.1
Week 1	26.4	2.8	21.3	32.2	NA
Week 2	17.2	2.4	13.0	22.4	NA

Detections statistics at all realtime receivers

Code

Detections for all releases combined

general_location	First_arrival	Mean_arrival	Last_arrival	Fish_count	Percent_arrived	rkm
ButteBrRT	2019-05-17 11:33:22	2019-05-21 21:45:22	2019-06-03 12:17:55	234	46.8	344.108
TowerBridge	2019-05-19 11:31:19	2019-05-23 22:39:24	2019-06-05 11:04:46	184	36.8	172.000
I80-50_Br	2019-05-19 11:44:40	2019-05-24 00:58:54	2019-05-30 06:45:12	188	37.6	170.748
Georgiana_Slough1	2019-05-20 06:34:16	2019-05-24 19:22:46	2019-05-29 00:09:55	35	7.0	119.208
Sac_BlwGeorgiana	2019-05-20 00:45:03	2019-05-25 01:49:44	2019-06-06 00:27:06	121	24.2	119.058
Georgiana_Slough2	2019-05-20 06:43:36	2019-05-24 19:34:00	2019-05-29 00:17:34	35	7.0	118.758
Sac_BlwGeorgiana2	2019-05-20 00:56:51	2019-05-25 03:30:48	2019-06-06 00:39:11	142	28.4	118.398
Benicia_east	2019-05-22 06:58:29	2019-05-27 05:55:54	2019-06-07 08:13:07	108	21.6	52.240
Benicia_west	2019-05-22 07:01:05	2019-05-27 04:59:43	2019-06-07 08:17:08	106	21.2	52.040

Detections for Week 1 release groups

general_location	First_arrival	Mean_arrival	Last_arrival	Fish_count	Percent_arrived	rkm
ButteBrRT	2019-05-17 11:33:22	2019-05-19 07:18:12	2019-05-26 05:50:44	130	52.0	344.108
TowerBridge	2019-05-19 11:31:19	2019-05-21 14:05:29	2019-05-27 06:33:10	111	44.4	172.000
I80-50_Br	2019-05-19 11:44:40	2019-05-21 20:42:23	2019-05-29 18:43:54	111	44.4	170.748
Georgiana_Slough1	2019-05-20 06:34:16	2019-05-22 04:13:58	2019-05-28 04:11:51	19	7.6	119.208
Sac_BlwGeorgiana	2019-05-20 00:45:03	2019-05-22 15:35:40	2019-05-30 09:42:52	70	28.0	119.058
Georgiana_Slough2	2019-05-20 06:43:36	2019-05-22 04:24:58	2019-05-28 04:19:47	19	7.6	118.758
Sac_BlwGeorgiana2	2019-05-20 00:56:51	2019-05-22 16:21:22	2019-05-30 09:51:10	79	31.6	118.398
Benicia_east	2019-05-22 06:58:29	2019-05-25 03:17:36	2019-06-01 07:39:20	66	26.4	52.240
Benicia_west	2019-05-22 07:01:05	2019-05-25 03:21:25	2019-06-01 07:45:30	66	26.4	52.040

Detections for Week 2 release groups

general_location	First_arrival	Mean_arrival	Last_arrival	Fish_count	Percent_arrived	rkm
ButteBrRT	2019-05-24 10:38:05	2019-05-25 03:49:20	2019-06-03 12:17:55	104	41.6	344.108
TowerBridge	2019-05-26 07:55:31	2019-05-27 12:40:00	2019-06-05 11:04:46	73	29.2	172.000
I80-50_Br	2019-05-26 08:25:09	2019-05-27 04:20:21	2019-05-30 06:45:12	77	30.8	170.748
Georgiana_Slough1	2019-05-26 22:02:28	2019-05-27 22:21:59	2019-05-29 00:09:55	16	6.4	119.208
Sac_BlwGeorgiana	2019-05-27 01:52:08	2019-05-28 09:45:31	2019-06-06 00:27:06	51	20.4	119.058
Georgiana_Slough2	2019-05-26 22:16:01	2019-05-27 22:33:28	2019-05-29 00:17:34	16	6.4	118.758
Sac_BlwGeorgiana2	2019-05-27 02:04:38	2019-05-28 05:41:40	2019-06-06 00:39:11	63	25.2	118.398
Benicia_east	2019-05-28 13:14:13	2019-05-30 13:30:21	2019-06-07 08:13:07	42	16.8	52.240
Benicia_west	2019-05-28 13:16:40	2019-05-30 14:53:55	2019-06-07 08:17:08	40	16.0	52.040

Code

Central Valley Enhanced

Acoustic Tagging Project

Hatchery-origin fall-run Chinook salmon May Release

Central Valley Enhanced
Acoustic Tagging Project
Deer Creek wild steelhead

CalFishTrack

Central Valley Enhanced Acoustic Tagging Project

Deer Creek wild steelhead

2018-2019 SPRING Season (PROVISIONAL DATA)

Project Status

PROJECT IS COMPLETE, ALL TAGS ARE NO LONGER ACTIVE

Telemetry Study Template for this study can be found here (https://github.com/CalFishTrack/real-time/blob/master/data/Telemetry_Study_Summary_Deer_Creek_Steelhead_Smolt.pdf?raw=true)

Code

```
## Project began on 2019-04-16 11:07:00, see tagging details below:
```

Release	First_release_time	Last_release_time	Number_fish_released	Release_location	Release_rkm	Mean_length	Mean_weig
Week 1	2019-04-16 11:07:00	2019-04-17 10:20:00	3	DeerCkRST	441.728	221.7	112
Week 2	2019-04-24 10:46:00	2019-04-27 10:20:00	11	DeerCkRST	441.728	220.5	106
Week 3	2019-04-28 10:19:00	2019-05-04 09:59:00	15	DeerCkRST	441.728	214.9	105
Week 4	2019-05-06 11:16:00	2019-05-11 10:05:00	21	DeerCkRST	441.728	204.0	92
Week 5	2019-05-15 09:30:00	2019-05-17 10:00:00	6	DeerCkRST	441.728	195.5	78
Week 6	2019-05-21 10:30:00	2019-05-23 10:13:00	2	DeerCkRST	441.728	227.0	132
Week 7	2019-05-31 10:30:00	2019-05-31 10:49:00	4	DeerCkRST	441.728	235.0	118
Week 8	2019-06-07 10:01:00	2019-06-07 10:08:00	2	DeerCkRST	441.728	229.0	123

Real-time Fish Detections

Data current as of 2020-04-07 15:00:00. All times in Pacific Standard Time.

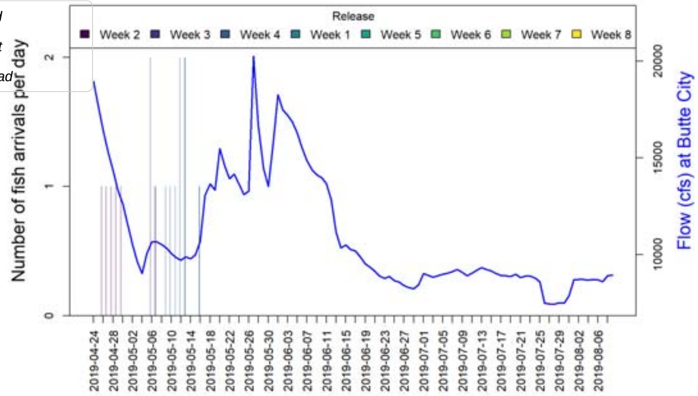
Detections at Butte City Bridge versus Sacramento River flows at Butte City

Code

Central Valley Enhanced

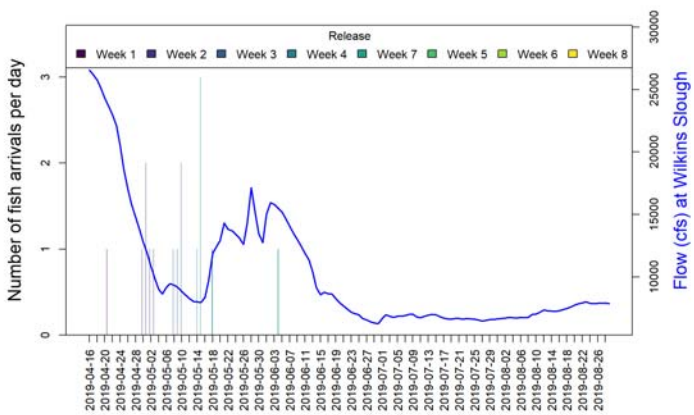
Acoustic Tagging Project

Deer Creek wild steelhead



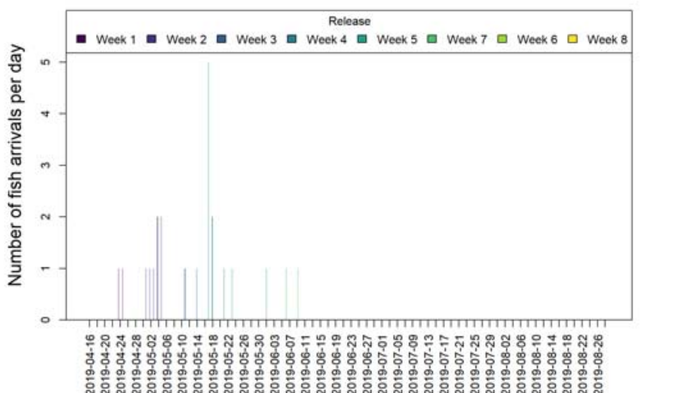
Detections at Tower Bridge (downtown Sacramento) versus Sacramento River flows at Wilkins Slough

Code



Detections at Benicia Bridge

Code



Minimum survival to Tower Bridge (using CJS survival model)

If Yolo Bypass Weirs are overtopping during migration, fish may have taken that route, and therefore this is a minimum estimate of survival

Code

Release	Survival (%)	SE	95% lower C.I.	95% upper C.I.	Detection efficiency (%)
ALL	45.5	8.1	30.6	61.2	55
Week 1	93.9	44.6	0.0	100.0	NA
Week 2	78.5	21.1	24.0	97.7	NA
Week 3	37.6	17.7	12.1	72.5	NA
Week 4	38.1	10.6	20.3	59.8	NA

Central Valley Enhanced
Acoustic Tagging Project
Deer Creek wild steelhead

Release	Survival (%)	SE	95% lower C.I.	95% upper C.I.	Detection efficiency (%)
Week 5	50.0	20.4	16.8	83.2	NA
Week 6	0.0	0.0	0.0	0.0	NA
Week 7	25.0	21.7	3.4	76.2	NA
Week 8	0.0	0.0	0.0	0.0	NA

Reach-specific survival and probability of entering Georgiana Slough

Code

Measure	Estimate	SE	95% lower C.I.	95% upper C.I.
Survival from release to Tower Bridge (minimum estimate since fish may have taken Yolo Bypass)	49.7	6.8	36.8	62.7
Survival from TowerBridge to I80-50_Br	100.0	0.0	83.0	100.0
% arrived from I80-50_Br to Georgiana Slough confluence (not survival because fish may have taken Sutter/Steam)	71.0	9.4	50.0	85.8
Detection probability at TowerBridge	50.3	9.2	32.9	67.6
Detection probability at I80-50_Br	62.9	9.2	44.0	78.5
Detection probability at Blw_Georgiana	62.5	12.1	37.7	82.1
Detection probability at Georgiana Slough	100.0	0.0	68.1	100.0
Routing probability into Georgiana Slough (Conditional on fish arriving to junction)	22.1	8.8	9.5	43.6

Minimum survival to Benicia Bridge East Span (using CJS survival model)

Code

Release Group	Survival (%)	SE	95% lower C.I.	95% upper C.I.	Detection efficiency (%)
ALL	36.5	6.1	25.5	49.0	85.7
Week 1	66.7	27.2	15.4	95.7	NA
Week 2	63.6	14.5	33.9	85.7	NA
Week 3	13.3	8.8	3.4	40.5	NA
Week 4	38.9	10.9	20.6	60.9	NA
Week 5	36.1	21.0	8.7	77.1	NA
Week 6	0.0	0.0	0.0	0.0	NA
Week 7	50.0	25.0	12.3	87.7	NA
Week 8	0.0	0.0	0.0	0.0	NA

Detections statistics at all realtime receivers

Code

Detections for all releases combined

general_location	First_arrival	Mean_arrival	Last_arrival	Fish_count	Percent_arrived	rkm
ButteBrRT	2019-04-26 23:17:28	2019-05-07 01:38:43	2019-05-16 23:31:06	16	25.00	344.108
TowerBridge	2019-04-21 20:26:14	2019-05-09 16:36:30	2019-06-04 08:04:13	16	25.00	172.000
I80-50_Br	2019-04-22 11:28:01	2019-05-12 12:40:26	2019-06-04 08:21:17	20	31.25	170.748
Georgiana_Slough1	2019-05-10 04:11:45	2019-05-22 11:16:31	2019-06-05 20:52:28	5	7.81	119.208
Sac_BlwGeorgiana	2019-04-30 18:54:27	2019-05-12 08:47:56	2019-05-21 06:28:51	11	17.19	119.058
Georgiana_Slough2	2019-05-10 04:20:09	2019-05-22 11:27:16	2019-06-05 21:03:57	5	7.81	118.758
Sac_BlwGeorgiana2	2019-04-22 09:54:36	2019-05-11 10:20:38	2019-06-04 20:44:30	16	25.00	118.398
Benicia_east	2019-04-24 12:26:45	2019-05-14 05:34:26	2019-06-09 11:37:38	20	31.25	52.240
Benicia_west	2019-04-24 12:54:37	2019-05-12 22:53:03	2019-06-09 11:38:50	21	32.81	52.040

Detections for Week 1 release groups

general_location	First_arrival	Mean_arrival	Last_arrival	Fish_count	Percent_arrived	rkm

general_location	First_arrival	Mean_arrival	Last_arrival	Fish_count	Percent_arrived	rkm
TowerBridge	2019-04-21 20:26:14	2019-04-21 20:26:14	2019-04-21 20:26:14	1	33.33	172.000
I80-50_Br	2019-04-22 11:28:01	2019-04-22 11:28:01	2019-04-22 11:28:01	1	33.33	170.748
Sac_BlwGeorgiana2	2019-04-22 09:54:36	2019-04-22 16:43:58	2019-04-22 23:33:21	2	66.67	118.398
Benicia_east	2019-04-24 12:26:45	2019-04-25 00:59:34	2019-04-25 13:32:23	2	66.67	52.240
Benicia_west	2019-04-24 12:54:37	2019-04-25 01:15:59	2019-04-25 13:37:21	2	66.67	52.040

Detections for Week 2 release groups

general_location	First_arrival	Mean_arrival	Last_arrival	Fish_count	Percent_arrived	rkm
ButteBrRT	2019-04-26 23:17:28	2019-04-28 14:59:28	2019-04-30 10:08:14	5	45.45	344.108
TowerBridge	2019-04-30 04:53:50	2019-05-01 21:45:38	2019-05-03 06:24:34	5	45.45	172.000
I80-50_Br	2019-04-29 13:18:31	2019-05-01 06:10:02	2019-05-02 13:40:50	5	45.45	170.748
Sac_BlwGeorgiana	2019-04-30 18:54:27	2019-05-02 06:54:47	2019-05-03 20:13:12	3	27.27	119.058
Sac_BlwGeorgiana2	2019-04-30 19:04:41	2019-05-02 07:05:07	2019-05-03 20:25:33	3	27.27	118.398
Benicia_east	2019-05-01 18:30:23	2019-05-03 23:30:27	2019-05-05 10:31:40	6	54.55	52.240
Benicia_west	2019-05-01 18:32:43	2019-05-04 05:12:07	2019-05-05 22:50:10	7	63.64	52.040

Detections for Week 3 release groups

general_location	First_arrival	Mean_arrival	Last_arrival	Fish_count	Percent_arrived	rkm
ButteBrRT	2019-05-06 08:19:41	2019-05-06 15:13:02	2019-05-07 00:04:38	3	20.00	344.108
TowerBridge	2019-05-08 21:27:35	2019-05-09 18:58:26	2019-05-10 14:38:46	4	26.67	172.000
I80-50_Br	2019-05-08 22:01:57	2019-05-09 12:50:13	2019-05-10 03:38:30	2	13.33	170.748
Georgiana_Slough1	2019-05-10 04:11:45	2019-05-10 19:28:09	2019-05-11 10:44:34	2	13.33	119.208
Sac_BlwGeorgiana	2019-05-09 13:48:35	2019-05-09 13:48:35	2019-05-09 13:48:35	1	6.67	119.058
Georgiana_Slough2	2019-05-10 04:20:09	2019-05-10 19:37:00	2019-05-11 10:53:52	2	13.33	118.758
Sac_BlwGeorgiana2	2019-05-09 14:02:04	2019-05-09 14:02:04	2019-05-09 14:02:04	1	6.67	118.398
Benicia_east	2019-05-11 15:08:33	2019-05-13 03:14:21	2019-05-14 15:20:09	2	13.33	52.240
Benicia_west	2019-05-11 15:15:29	2019-05-13 03:19:47	2019-05-14 15:24:06	2	13.33	52.040

Detections for Week 4 release groups

general_location	First_arrival	Mean_arrival	Last_arrival	Fish_count	Percent_arrived	rkm
ButteBrRT	2019-05-09 11:47:05	2019-05-12 12:12:53	2019-05-16 23:31:06	8	38.10	344.108
TowerBridge	2019-05-14 02:25:03	2019-05-15 20:06:20	2019-05-18 23:24:47	5	23.81	172.000
I80-50_Br	2019-05-14 02:55:57	2019-05-15 11:50:55	2019-05-18 23:51:49	8	38.10	170.748
Sac_BlwGeorgiana	2019-05-13 23:54:26	2019-05-16 09:17:35	2019-05-19 12:23:06	6	28.57	119.058
Sac_BlwGeorgiana2	2019-05-12 17:46:03	2019-05-15 11:40:17	2019-05-19 12:33:44	8	38.10	118.398
Benicia_east	2019-05-17 09:18:49	2019-05-18 09:02:29	2019-05-21 08:50:16	6	28.57	52.240
Benicia_west	2019-05-17 04:28:23	2019-05-17 19:20:22	2019-05-18 08:32:13	7	33.33	52.040

Detections for Week 5 release groups

general_location	First_arrival	Mean_arrival	Last_arrival	Fish_count	Percent_arrived	rkm
I80-50_Br	2019-05-20 16:57:53	2019-05-24 11:27:10	2019-05-28 17:03:27	3	50.00	170.748
Georgiana_Slough1	2019-05-24 12:31:33	2019-05-26 22:16:55	2019-05-29 08:02:17	2	33.33	119.208

Central Valley Enhanced
Acoustic Tagging Project
Deer Creek wild steelhead

general_location	First_arrival	Mean_arrival	Last_arrival	Fish_count	Percent_arrived	rkm
Sac_BlwGeorgiana	2019-05-21 06:28:51	2019-05-21 06:28:51	2019-05-21 06:28:51	1	16.67	119.058
Georgiana_Slough2	2019-05-24 12:51:23	2019-05-26 22:29:11	2019-05-29 08:07:00	2	33.33	118.758
Sac_BlwGeorgiana2	2019-05-21 06:37:57	2019-05-21 06:37:57	2019-05-21 06:37:57	1	16.67	118.398
Benicia_east	2019-05-23 12:26:48	2019-05-28 02:26:07	2019-06-01 16:25:26	2	33.33	52.240
Benicia_west	2019-05-23 12:39:26	2019-05-23 12:39:26	2019-05-23 12:39:26	1	16.67	52.040

No detections for Week 6 release group yet

Detections for Week 7 release groups

general_location	First_arrival	Mean_arrival	Last_arrival	Fish_count	Percent_arrived	rkm
TowerBridge	2019-06-04 08:04:13	2019-06-04 08:04:13	2019-06-04 08:04:13	1	25	172.000
I80-50_Br	2019-06-04 08:21:17	2019-06-04 08:21:17	2019-06-04 08:21:17	1	25	170.748
Georgiana_Slough1	2019-06-05 20:52:28	2019-06-05 20:52:28	2019-06-05 20:52:28	1	25	119.208
Georgiana_Slough2	2019-06-05 21:03:57	2019-06-05 21:03:57	2019-06-05 21:03:57	1	25	118.758
Sac_BlwGeorgiana2	2019-06-04 20:44:30	2019-06-04 20:44:30	2019-06-04 20:44:30	1	25	118.398
Benicia_east	2019-06-06 11:13:34	2019-06-07 23:25:36	2019-06-09 11:37:38	2	50	52.240
Benicia_west	2019-06-06 11:17:02	2019-06-07 23:27:56	2019-06-09 11:38:50	2	50	52.040

No detections for Week 8 release group yet

Code

CalFishTrack

Central Valley Enhanced Acoustic Tagging Project

Mill Creek wild steelhead

2018-2019 Season (PROVISIONAL DATA)

Project Status

PROJECT IS COMPLETE, ALL TAGS ARE NO LONGER ACTIVE

Telemetry Study Template for this study can be found here (https://github.com/CalFishTrack/real-time/blob/master/data/Telemetry_Study_Summary_Mill_Creek_Steelhead_Smolt.pdf?raw=true)

Code

```
## Project began on 2019-05-05 12:57:00, see tagging details below:
```

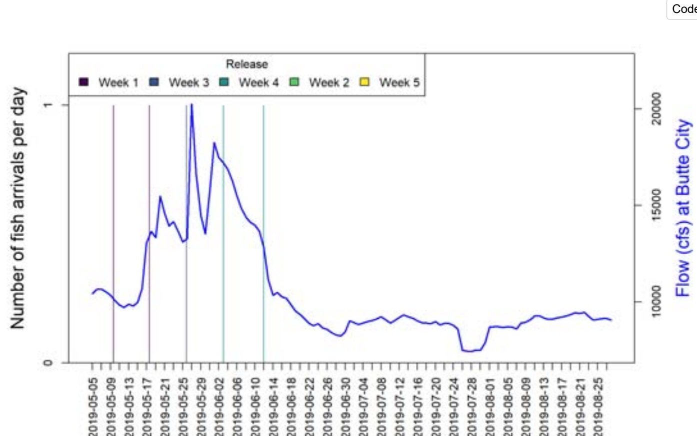
Release	First_release_time	Last_release_time	Number_fish_released	Release_location	Release_rkm	Mean_length	Mean_weig
Week 1	2019-05-05 12:57:00	2019-05-09 13:51:00	5	MillCkRST	450.703	197.8	82
Week 2	2019-05-13 11:30:00	2019-05-14 10:40:00	2	MillCkRST	450.703	178.0	67
Week 3	2019-05-24 12:25:00	2019-05-24 12:25:00	1	MillCkRST	450.703	199.0	79
Week 4	2019-05-30 14:35:00	2019-05-30 14:53:00	4	MillCkRST	450.703	206.2	92
Week 5	2019-06-05 13:45:00	2019-06-05 13:45:00	1	MillCkRST	450.703	146.0	38

Real-time Fish Detections

Data current as of 2020-04-07 15:00:00. All times in Pacific Standard Time.

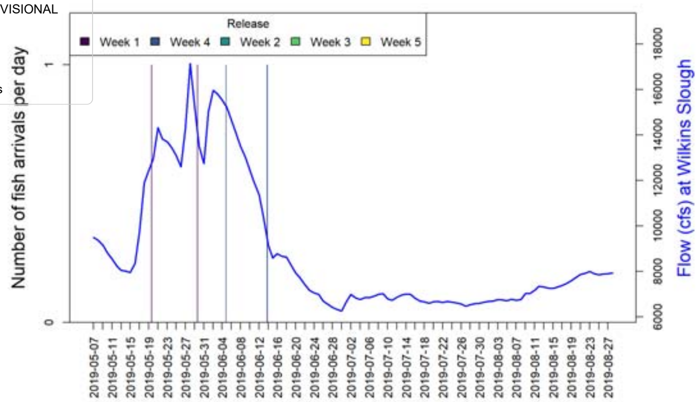
Detections at Butte City Bridge versus Sacramento River flows at Butte City

Code



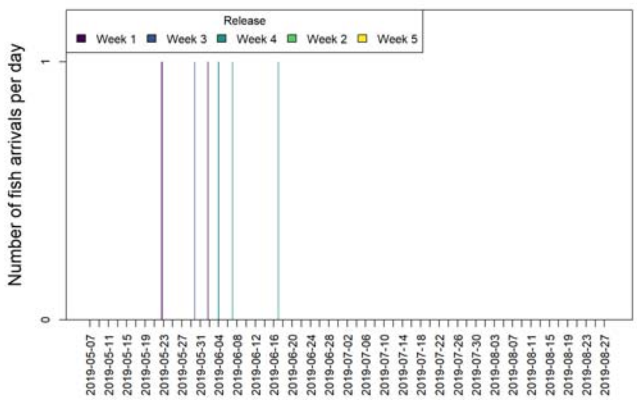
Detections at Tower Bridge (downtown Sacramento) versus Sacramento River flows at Wilkins Slough

Code



Detections at Benicia Bridge

Code



Minimum survival to Tower Bridge (using CJS survival model)

If Yolo Bypass Weirs are overtopping during migration, fish may have taken that route, and therefore this is a minimum estimate of survival

Code

Release	Survival (%)	SE	95% lower C.I.	95% upper C.I.	Detection efficiency (%)
ALL	41.0	14.9	17.3	69.9	75
Week 1	40.0	21.9	10.0	80.0	NA
Week 2	0.0	0.0	0.0	0.0	NA
Week 3	0.0	0.0	0.0	0.0	NA
Week 4	83.3	26.8	10.2	99.5	NA
Week 5	0.0	0.0	0.0	0.0	NA

Reach-specific survival and probability of entering Georgiana Slough

Code

Measure	Estimate	SE	95% lower C.I.	95% upper C.I.
Survival from release to Tower Bridge (minimum estimate since fish may have taken Yolo Bypass)	38.6	13.6	17.0	65.9
Survival from TowerBridge to I80-50_Br	100.0	0.0	61.9	100.0
% arrived from I80-50_Br to Georgiana Slough confluence (not survival because fish may have taken Sutter/Steam)	100.0	0.0	67.2	100.0
Detection probability at TowerBridge	79.7	18.1	30.4	97.2
Detection probability at I80-50_Br	79.7	18.1	30.4	97.2
Detection probability at Blw_Georgiana	49.7	25.0	12.2	87.5

Central Valley Enhanced
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Measure	Estimate	SE	95% lower C.I.	95% upper C.I.
Detection probability at Georgiana Slough	100.0	0.0	14.7	100.0
Routing probability into Georgiana Slough (Conditional on fish arriving to junction)	19.9	17.8	2.7	69.0

Minimum survival to Benicia Bridge East Span (using CJS survival model)

Code

Release Group	Survival (%)	SE	95% lower C.I.	95% upper C.I.	Detection efficiency (%)
ALL	46.2	13.8	22.4	71.8	66.7
Week 1	40.0	21.9	10.0	80.0	NA
Week 2	0.0	0.0	0.0	0.0	NA
Week 3	100.0	0.0	100.0	100.0	NA
Week 4	75.0	21.7	23.8	96.6	NA
Week 5	0.0	0.0	0.0	0.0	NA

Detections statistics at all realtime receivers

Code

Detections for all releases combined

general_location	First_arrival	Mean_arrival	Last_arrival	Fish_count	Percent_arrived	rkm
ButteBrRT	2019-05-10 01:30:07	2019-05-26 15:42:30	2019-06-12 02:05:14	5	38.46	344.108
TowerBridge	2019-05-20 18:39:44	2019-06-02 12:44:30	2019-06-14 13:38:24	4	30.77	172.000
I80-50_Br	2019-05-20 18:56:15	2019-05-31 05:26:38	2019-06-05 21:21:41	4	30.77	170.748
Georgiana_Slough1	2019-06-05 17:47:16	2019-06-05 17:47:16	2019-06-05 17:47:16	1	7.69	119.208
Sac_BlwGeorgiana	2019-05-31 15:44:44	2019-06-03 12:10:19	2019-06-06 08:35:55	2	15.38	119.058
Georgiana_Slough2	2019-06-05 17:56:17	2019-06-05 17:56:17	2019-06-05 17:56:17	1	7.69	118.758
Sac_BlwGeorgiana2	2019-05-21 09:30:52	2019-06-02 02:58:25	2019-06-15 07:27:16	3	23.08	118.398
Benicia_east	2019-05-23 07:28:12	2019-06-04 23:45:46	2019-06-17 08:28:32	4	30.77	52.240
Benicia_west	2019-05-23 07:29:21	2019-06-04 00:12:59	2019-06-17 08:30:45	6	46.15	52.040

Detections for Week 1 release groups

general_location	First_arrival	Mean_arrival	Last_arrival	Fish_count	Percent_arrived	rkm
ButteBrRT	2019-05-10 01:30:07	2019-05-14 07:58:22	2019-05-18 14:26:37	2	40	344.108
TowerBridge	2019-05-20 18:39:44	2019-05-25 20:15:52	2019-05-30 21:52:00	2	40	172.000
I80-50_Br	2019-05-20 18:56:15	2019-05-25 20:42:59	2019-05-30 22:29:43	2	40	170.748
Sac_BlwGeorgiana	2019-05-31 15:44:44	2019-05-31 15:44:44	2019-05-31 15:44:44	1	20	119.058
Sac_BlwGeorgiana2	2019-05-21 09:30:52	2019-05-26 12:44:00	2019-05-31 15:57:09	2	40	118.398
Benicia_east	2019-05-23 07:28:12	2019-05-28 12:37:27	2019-06-02 17:46:42	2	40	52.240
Benicia_west	2019-05-23 07:29:21	2019-05-28 12:40:47	2019-06-02 17:52:14	2	40	52.040

No detections for Week 2 release group yet

Detections for Week 3 release groups

general_location	First_arrival	Mean_arrival	Last_arrival	Fish_count	Percent_arrived	rkm
ButteBrRT	2019-05-26 19:58:16	2019-05-26 19:58:16	2019-05-26 19:58:16	1	100	344.108
Benicia_west	2019-05-30 17:04:42	2019-05-30 17:04:42	2019-05-30 17:04:42	1	100	52.040

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Detections for Week 4 release groups

general_location	First_arrival	Mean_arrival	Last_arrival	Fish_count	Percent_arrived	rkm
ButteBrRT	2019-06-03 16:32:19	2019-06-07 21:18:46	2019-06-12 02:05:14	2	50	344.108
TowerBridge	2019-06-05 20:47:55	2019-06-10 05:13:09	2019-06-14 13:38:24	2	50	172.000
I80-50_Br	2019-06-05 06:58:56	2019-06-05 14:10:18	2019-06-05 21:21:41	2	50	170.748
Georgiana_Slough1	2019-06-05 17:47:16	2019-06-05 17:47:16	2019-06-05 17:47:16	1	25	119.208
Sac_BlwGeorgiana	2019-06-06 08:35:55	2019-06-06 08:35:55	2019-06-06 08:35:55	1	25	119.058
Georgiana_Slough2	2019-06-05 17:56:17	2019-06-05 17:56:17	2019-06-05 17:56:17	1	25	118.758
Sac_BlwGeorgiana2	2019-06-15 07:27:16	2019-06-15 07:27:16	2019-06-15 07:27:16	1	25	118.398
Benicia_east	2019-06-07 13:19:39	2019-06-12 10:54:05	2019-06-17 08:28:32	2	50	52.240
Benicia_west	2019-06-04 08:53:05	2019-06-09 18:17:12	2019-06-17 08:30:45	3	75	52.040

No detections for Week 5 release group yet

Code

CalFishTrack

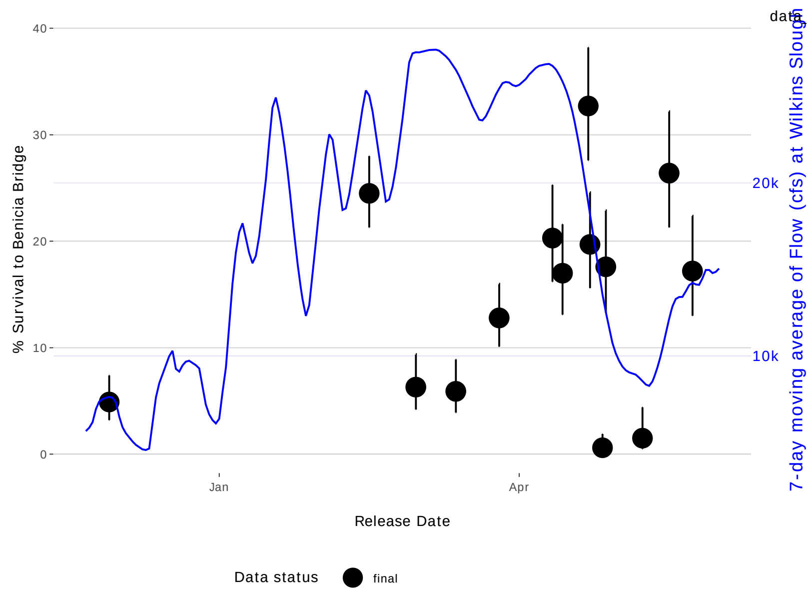
Water Year 2019 Survival Summary

ALL WATER YEAR 2019 STUDIES ARE COMPLETE.

Survival to Benicia for all major Chinook salmon tagging efforts (n > 100)

Code

Data current as of 2020-04-07 15:00:00. All times in Pacific Standard Time.



Hover cursor over points to see release group.