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MOVEMENT AND SURVIVAL RATES OF BUTTE CREEK SPRING-RUN CHINOOK SALMON SMOLTS FROM THE SUTTER BYPASS TO THE GOLDEN GATE BRIDGE IN 2015, 2016, AND 2017

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Movement and survival rates of Butte Creek spring-run Chinook salmon smolts from the Sutter Bypass to the Golden Gate Bridge in 2015, 2016 and 2017

June 2019

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SUMMARY

California's Central Valley (CCV) Chinook salmon stocks have declined substantially since the mid-1800s with most of them listed as threatened or endangered, or heavily supplemented by hatcheries. Butte Creek supports the largest population of CCV wild spring-run Chinook, and represents an important component of this ESU. However, little information exists on Butte Creek juvenile mortality during out-migration to the ocean, which is considered a critical phase to the overall population dynamics. We used the high resolution Juvenile Salmon Acoustic Telemetry System (JSATS), and a mark-recapture modeling framework to track the movement and estimate survival of migrating wild Chinook salmon smolts from lower Butte Creek to the Golden Gate Bridge in three distinctly different hydrologic periods (spring of 2015, 2016, and 2017). The fish tagged were a mix of genetically identified spring-run and fall-run Chinook juveniles, which were not visually distinguishable. Our results show that outmigrant smolt survival and receiver detection strongly varies by location and year. The highest survival of these outmigrant juveniles to the Golden Gate Bridge was observed in 2017 which was the wettest year of our study, and survival was extremely low in 2015 and 2016 (0.7% in 2015, 2.0% in 2016, and 10.0% in 2017). We observed that survival and migration varied significantly among years and regions; fish migrated faster and experienced higher survival in 2017 than in 2015 and 2016; fish migrated faster and experienced higher survival in the lower Sacramento River than in the Sutter Bypass, Delta and Bay. We also showed that release date and Delta flow are significantly correlated with survival rates of these outmigrating smolts. These results are largely driven by 2017 data. Indeed, 2017 tagged fish were released a month later than those in 2015 and 2016, and Delta flow and smolt survival were significantly higher than in the previous two years. More tagging years including measurements of more potentially important environmental factors (such as turbidity) are required to robustly identify the influence of various factors on Butte Creek spring-run Chinook outmigrant smolt survival.

INTRODUCTION

Acoustic tags and receivers have become an important and widely used technology allowing for estimating movement and survival rates of juvenile Chinook salmon (*Oncorhynchus tshawytscha*) in California's Central Valley (Michel et al. 2012 & 2015, Perry et al. 2010). While most previous studies have focused on hatchery smolts that are easily tagged and released in large groups, little is known

about the survival and movement rates of the remaining wild salmon in the Central Valley. Managers have been limited to inferring wild salmon survival and movement dynamics from hatchery fish data; a tactic that has been criticized because the two are different in many ways (Kostow 2004). Wild salmon hatch and rear in a completely different environment and face many challenges that hatchery smolts are shielded from (e.g. predation on pre-smolt life stages, high or low flow periods).

Spring-run Chinook were once a major component of the CCV Chinook stock, with annual catches of over a half million fish in the 1880's, and occupied the headwaters of all major Central Valley river systems where natural barriers were absent (Yoshiyama et al. 2001). The large reduction of in-stream habitat that has resulted from human activities, namely the construction of dams that prevented adult access to spawning habitat and the dewatering of stream reaches, as well as the habitat degradation due to mining and reclamation activities, are considered to be the primary cause of these declines (CDFG 1998, Yoshiyama et al. 2001). Today, wild populations of spring-run Chinook salmon thought to be self-sustaining survive only in three tributaries of the Sacramento River: Mill, Deer, and Butte Creeks (Lindley et al. 2004, Figure 1). Spring-run are reported inconsistently in additional Sacramento tributaries, and are supplemented by stray spring-run adults from the Feather River Hatchery. However, these additional stocks are believed to have been hybridizing with fall-run stocks since the 1960's due to constraints on previously separate spatial distributions created by dams (CDFG 1998). As a consequence, since 1999 the Central Valley spring-run Chinook salmon evolutionarily significant unit (ESU) is state and federally listed as threatened (NMFS 1999).

In order to better manage these stocks for future recovery, an understanding of their life history strategies is needed to gain insight into where and how these fish are facing adversity. With new advances in acoustic tagging technology we are now able to study the movement and survival rates of wild spring-run smolts from source tributaries to the Pacific Ocean. In 2013-2014 acoustic tagging studies were implemented in Mill and Battle Creeks, two Central Valley tributaries that support wild spring-run Chinook salmon. Initially, this study did not include Butte Creek, but after working with various state agencies the infrastructure was installed to capture and tag Butte Creek migrating smolts, and in 2015 the acoustic tagging project began. One notable thing about Butte Creek is that there has been extensive restoration of floodplain and river channel habitat in the lower system and in the Sutter Bypass floodplain, which has been suggested to be an important rearing habitat for Butte Creek spring-run salmon (e.g. the Lower Butte Creek Project (LBCP) established in 1997).

OBJECTIVES

Our objective was to tag approximately 200 Butte Creek spring-run Chinook salmon smolts in the Sutter Bypass each year to provide information on downstream migration timing, preferred habitat types, and locations of high mortality in their downstream migration.

This study also provides survival and movement rate estimates of wild spring-run juveniles through the Sutter Bypass, Sacramento River, Sacramento - San Joaquin Delta and San Francisco Bay.

Finally, the results obtained for Butte Creek spring-run smolts are compared to those from the spring-run tagging study performed in Mill Creek during the same years, allowing for a comparison between two wild populations of spring-run juveniles reared in two different habitat types and utilizing different migration corridors to the lower Sacramento River and Delta.

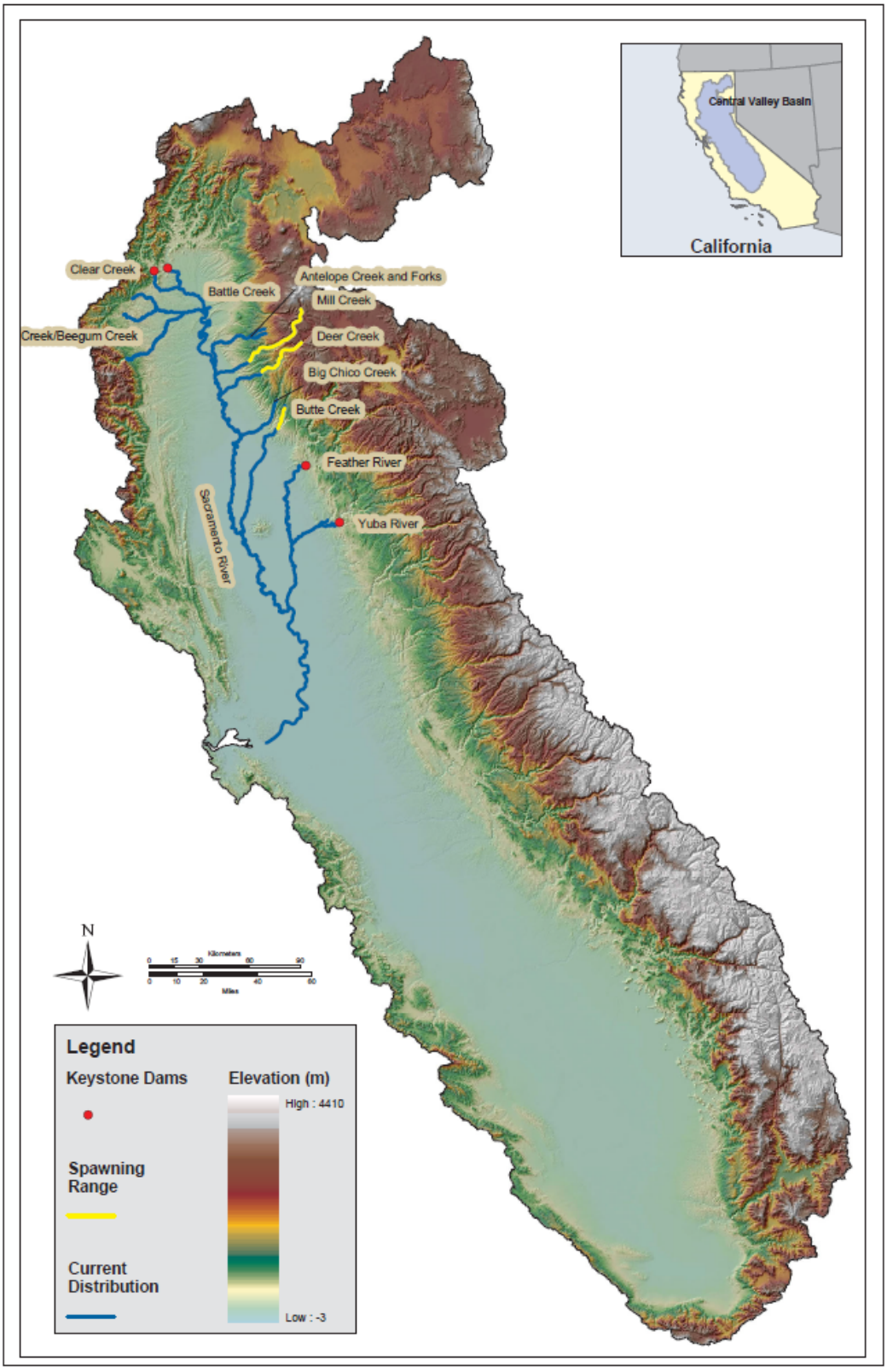

Figure 1. Current distribution of spring-run Chinook salmon as reported by CDFG, 1998.

MATERIALS AND METHODS

Butte Creek spring-run Chinook salmon life history

CCV spring-run Chinook Salmon demonstrate a unique diversity in life history among the California stocks of Chinook Salmon. Specifically, Butte Creek spring-run Chinook Salmon juveniles exhibit a wide variety of rearing and out-migration strategies. Data collected at the Parrot-Phellan Diversion Dam (PPDD; Figure 2, site T-1) by the California Department of Fish and Wildlife (CDFW) between 1995 – 2013 shows a prolonged and variable Butte Creek spring-run juvenile out-migration window. Juvenile out-migration begins with age-1 smolts (also called yearling) migrating from the fall to the following spring, followed by recently emerged fry in late fall/early winter, then age-0 parr in late winter/early spring, and ends with age-0 smolts in late spring (April to June; Figure 3A). Therefore, length-frequency out-migration distributions during the trapping period (usually November to June) show a multi-modal distribution that generally appears to delineate the various juvenile life history strategies (Figure 3B). For this study we are primarily targeting Butte Creek juveniles emigrating during the spring (April-May) at sizes greater than 80mm, therefore the fish we are studying could be age-0 or age-1 smolts and represent only a sample of the life history strategies observed in this population.

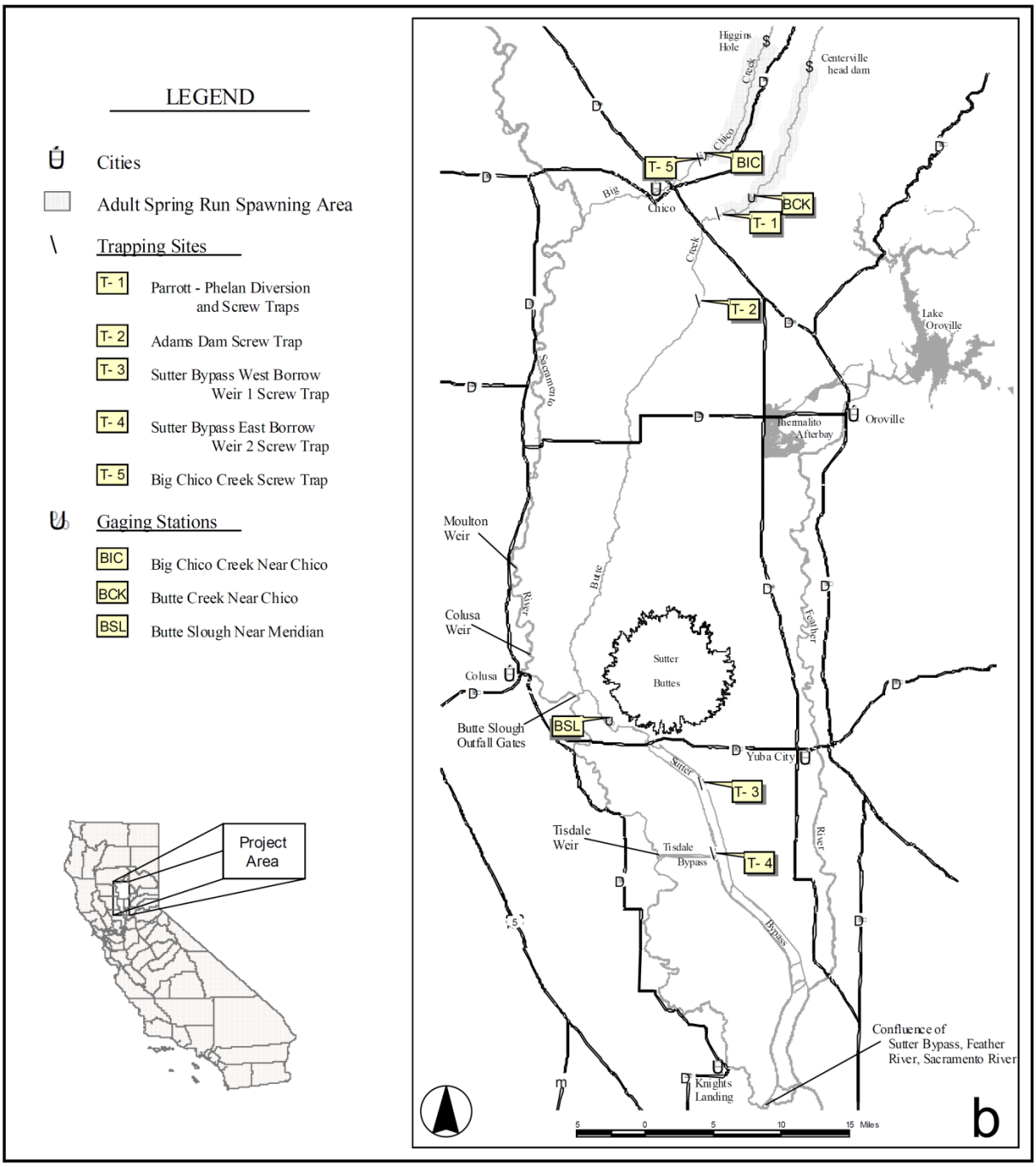

Figure 2. Butte Creek watershed indicating trapping sites (source: Ward and McReynolds, 2004). Note that Weirs 1 and 2 have been accidently mislabeled and are reversed, T-3 = East Borrow Weir 2 and T-4 = West Borrow Weir 1.

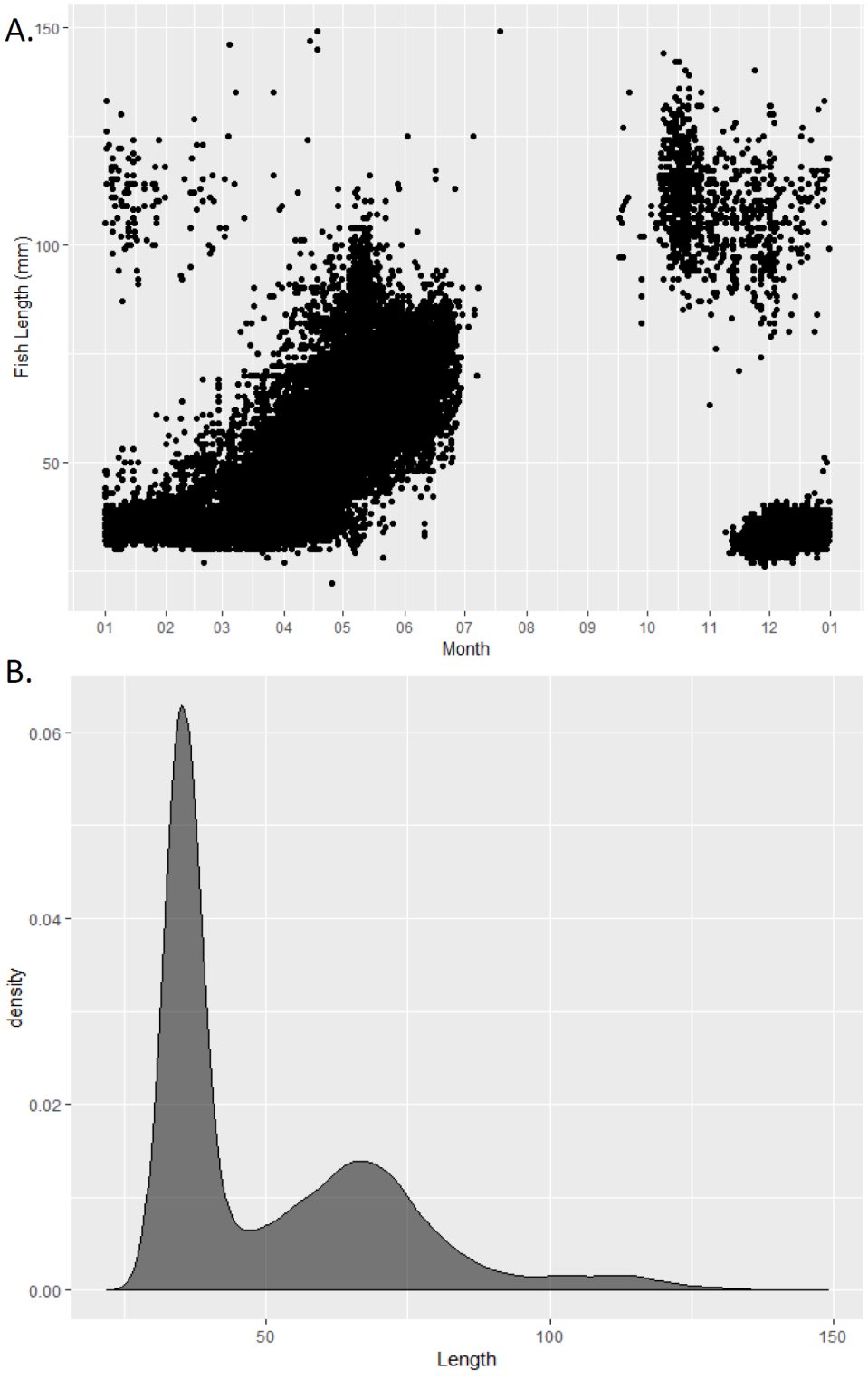

Figure 3. A. Length of fish caught at PPDD rotary screw traps from 1995 to 2004 by CDFW. B. Size density distribution of fish caught at PPDD from 1995 to 2004.

Acoustic tagging experiment

This study uses the Juvenile Salmon Acoustic Telemetry System (JSATS, McMichael et al. 2010; Figure 4A) to track the movement and estimate survival of migrating wild spring-run Chinook smolts from Butte Creek. The JSATS was chosen over other acoustic telemetry systems (e.g. Vemco, HTI) because JSATS tags were the smallest acoustic tag available at the time of the study (0.3g), making it possible to implant tags into migrating young of year Chinook salmon smolts down to ~80mm and 6.0 grams. Other factors which make JSATS tags more favorable include excellent performance under high noise conditions, relatively low cost tags ($200 each) and relatively low cost autonomous receivers ($4000 each). This technology also allows the user to customize the ping rate for each tag making it possible to have pulse intervals between 5 and 60 seconds, which can increase detection efficiency or prolong battery life.

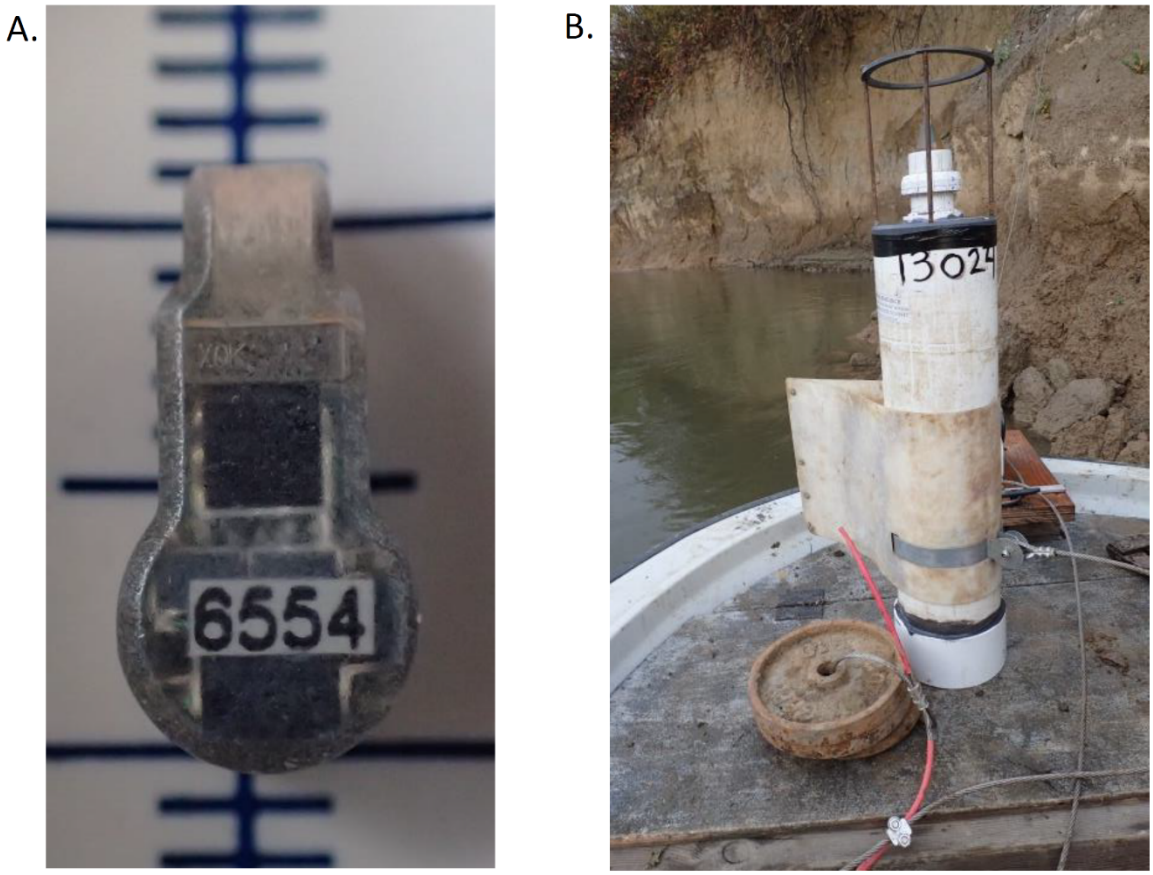

Figure 4. A. ATS model SS300 JSATS tag weighing about 0.3 grams in air. Small scale marks are 1 mm. B. ATS SR3000 JSATS receiver in NOAA custom housing.

Another technological advance in acoustic tracking was the fabrication of a low cost automated receiver to detect JSATS tags (ATS SR3000). We were able to deploy these less expensive receivers at a fraction of the nodes compared to the Vemco array of 300 receivers. The ATS SR3000 receivers are positively-buoyant, self-contained devices with a hydrophone which detects and decodes the signal to produce a unique ID for each tagged fish. A compact flash card stores the files internally and lithium batteries provide a life of up to 100 days. Temperature and tilt angle are also recorded within the receiver every 15 minutes, which can be useful when trouble-shooting receiver performance. The receiver housings have been modified by Arnold Ammann (NMFS) to allow the use of a rechargeable lithium-ion battery to extend the life of the receiver to 120 days (Figure 4B).

Acoustic receivers were deployed throughout the migration pathway for juvenile Chinook salmon from natal tributaries to the Pacific Ocean. Receivers were deployed at all locations initially for winter-run Chinook tracking in January, then re-batteried before wild fish tagging commenced in April. Reaches were selected by spacing the acoustic receivers out every 20-30 river kilometers, as well as focusing on specific entrainment locations such as the Delta Cross Channel and City of Sacramento Water Intake structure. All receivers contained at least 60 day batteries that allowed tracking of migrating smolts through the end of June. All receivers were retrieved 30 days after the last smolt was tagged and data was processed and analyzed by NMFS. The receivers typically secured to a large tree on the bank with ¼" stainless steel cable and fastened by a nico sleeve which crimps the connection. Between 30 and 100ft of cable extended from the tree to the middle of the channel where the receiver deployed. The receiver, outfitted with a fin that keeps the receiver in-line with the current, is then cabled to a 40lb of weight anchor which is also attached to the main cable off the tree. The receivers contain 5lbs of buoyancy which allows them to float underwater without the need for extra floatation. At least 6ft of water depth is required to deploy the receivers so that they remain submerged and hidden from the public.

We used results from a coded-wire tag study conducted on Butte Creek spring-run juveniles from 1996 to 2001 to guide our study design. In that study, fish were trapped at PPDD (Figure 3, site T-1), which is directly downstream of the spring-run Chinook spawning habitat, and were held in net pens for subsequent coded-wire tagging before release. Traps in both canals of the Sutter Bypass (Figure 3, site T-3 and T-4) were installed in order to optimize coded-wire tag recovery. Based on the catch number from both Sutter Bypass Weir 1 and Weir 2 we estimated the number of juveniles that

potentially could have been acoustically tagged (see Table 1) as well as the timing of out-migration. Smolts >80mm were caught in the Sutter Bypass from March to May (see Figure 5).

Table 1. Number of fish >80 mm sampled at Weirs 1 and 2 in the Sutter Bypass per year.

Sampling Year	**Fish > 80 mm**
1996	41
1998	2
1999	111
2000	102

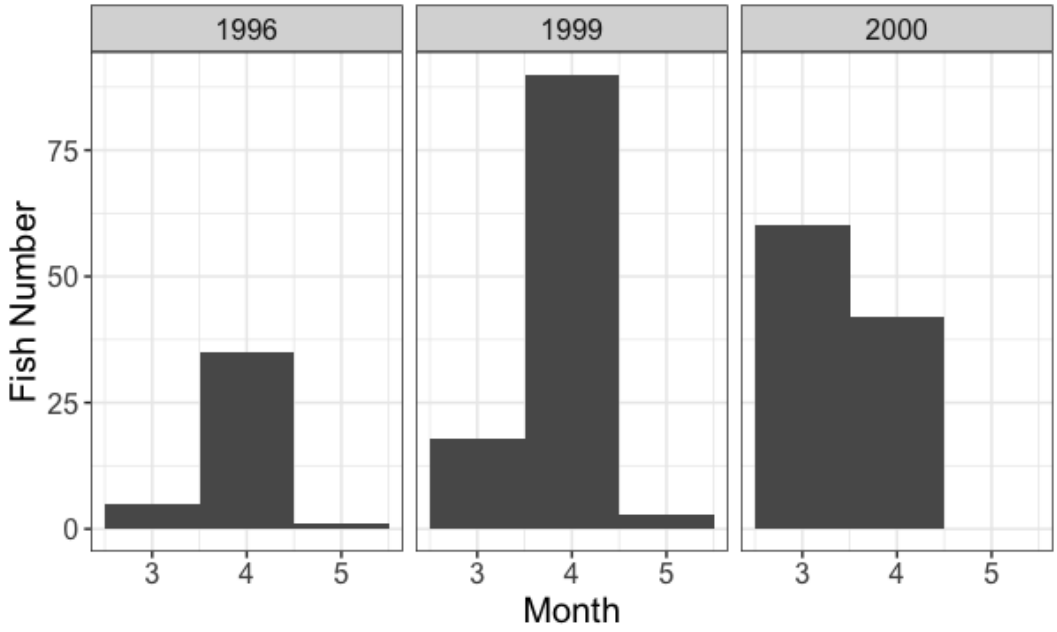

Figure 5. Monthly (March, April, May) catch of smolts >80mm at Weir 1 and 2 in the Sutter Bypass.

Based on these results, we collected fish by using a 2.44-m-diameter rotary screw trap (RST) installed at Weir 2 in the Sutter Bypass with the help of CDFW and DWR (Figure 6). We chose Weir 2 as the trapping site to ensure that fish collected and tagged were actively migrating downstream, since it is relatively low in the Butte Creek system. Additionally, this downstream site ensures that the 30-day

acoustic tag battery life is utilized efficiently, allowing movement through the Sutter Bypass, Sacramento River, Delta and San Francisco Bay to be recorded.

Figure 6. Installation of the rotary screw trap at Weir 2 in the Sutter Bypass.

The RST was operated continuously (24 hours per day), and was emptied of fish each morning. All the salmonids were measured (fork length (FL) in mm), and only Chinook salmon greater than 6g were implanted with an acoustic tag in order to keep the tag:body weight ratio less than 5% (Ammann et al. 2013, Brown et al. 1999). On the river bank adjacent to the RST, a shaded surgery station was used to implant tags before the sun was overhead and temperatures became too warm (Figures 7 and 8). Fish were surgically implanted with acoustic transmitters as described in Appendix A. After surgery, fish were held in holding pens for 12 hours before release at 10pm below weir 2. Genetic tissue samples were collected from all fish tagged for run assignment.

Figure 7. Surgery station set-up at the back of the truck next to Weir 2.

Figure 8. Surgery procedure on a Butte Creek Chinook salmon smolt.

Data analysis

We hypothesized that each fish tagged either exited the study area after completing its migration or died en-route to the Ocean. Along the way, each fish can be detected as it passes locations with receivers with probability p_i at the ith location. Between the ith and ith+1 receiver locations, the fish survives with probability ϕ_i. To estimate these reach-specific survival rates (ϕ_i) and detection probabilities (p_i) we used a spatial form of the Cormack-Jolly-Seber (CJS) model (Cormack 1964, Jolly 1965, Seber 1986), where tag detections at individual receivers were considered as a "mark" and subsequent detections at downstream receivers as a "recapture". The method of maximum-likelihood is used to estimate survival and detection probabilities and 95% confidence intervals for both (Lebreton et al. 1992).

For consistency between study years and because of the low number of fish migrating through the Delta, we selected a subset of receiver locations for the survival analysis, thus creating a total of 9 separate reaches for which survival and detection probability were estimated (Figure 9; Table 2).

Table 2. Study reach locations and length (rkm).

Region	**Reach**	**Distance from ocean (rkm)**	**Reach length (km)**	**Region length (km)**
Sutter Bypass	Weir2_RST – Butte1	249.54 – 249.05	0.49	43.06
Sutter Bypass	Butte1 – Butte2	249.05 – 238.46	10.59	
Sutter Bypass	Butte2 – Butte3	238.46 – 226.46	12	
Sutter Bypass	Butte3 – Butte5	226.46 – 216.98	9.48	
Sutter Bypass	Butte5 – Butte6	216.98 – 206.48	10.5	
Sacramento River	Butte6 – I80_Br	206.48 – 170.74	35.74	54.05
Sacramento River	I80_Br - Freeport	170.74 – 152.43	18.31	
Delta	Freeport – Benicia	152.43 – 52.04	100.39	100.39
Bay	Benicia – GoldenGateE	52.04 – 1.71	50.33	50.33

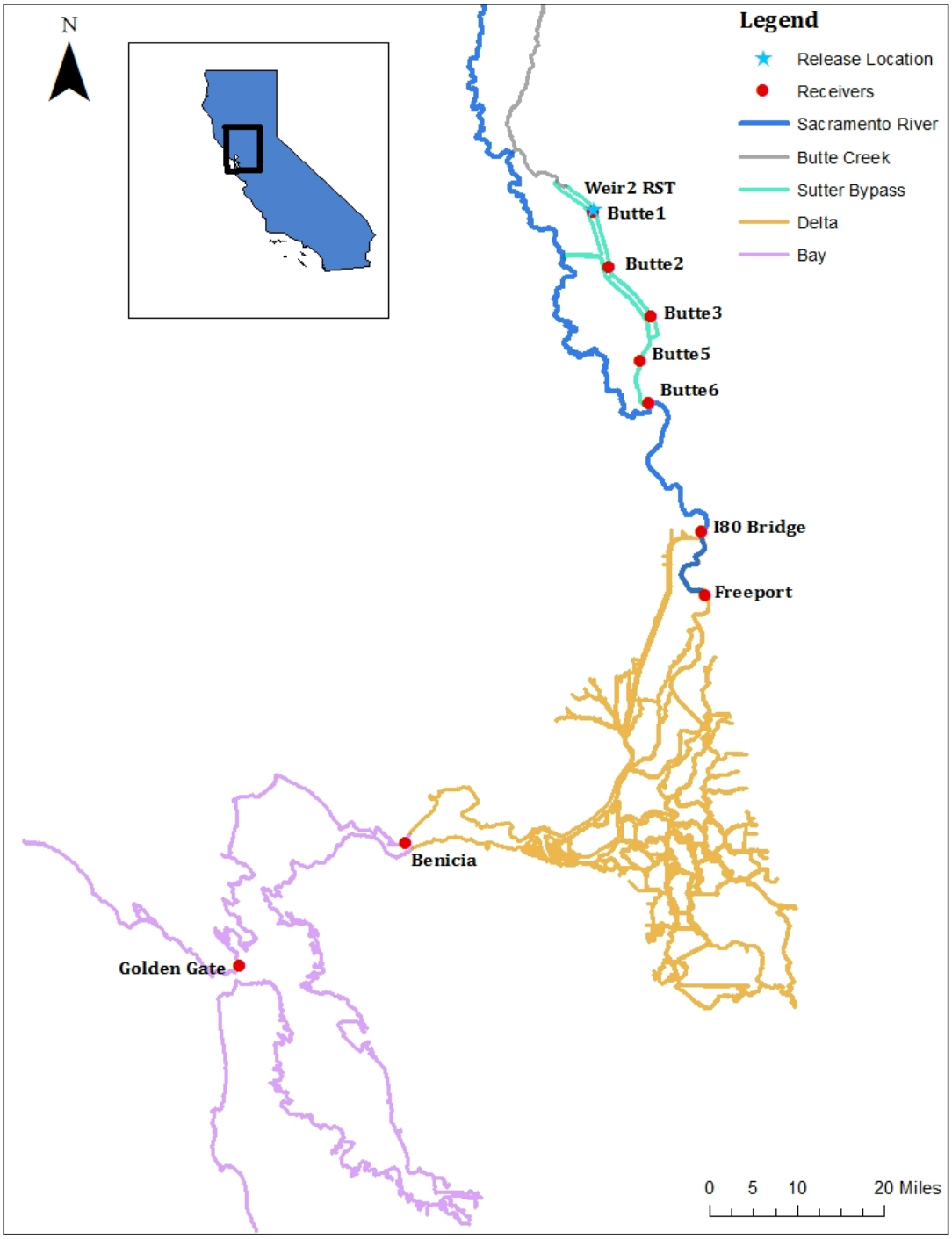

Figure 9. Receivers and release site location map.

Because the length of reaches along the migratory path are not identical, survival estimates were standardized per 10 km in order to allow inter-reach survival comparisons. Finally, regional (Sutter Bypass, Sacramento River, Delta, Bay) and overall (from the release site to the Golden Gate) survival was

also estimated for both years. We used the same methodology described in Cordoleani et al. (2018) to generate these values.

In order to evaluate year and location effects on out-migrating smolt survival and detection probabilities, we compared the constant model (i.e. constant survival and detection rates through space and time) to models including parameters allowing year and/or reach to vary (e.g. *~reach x year*; see Table 4 for list of models). Because it is impossible to measure or estimate all potential factors that influence salmon survival, we hypothesized that the fully parameterized model (full model) that included year and reach as factors would have the best fit to the data and provide us with the best estimates of reach survival by year. We therefore used this model to generate reach-specific, regional, and overall survival estimates.

However, in order to gain a better understanding of the underlying mortality mechanisms, we also looked at regional models that included fish characteristics (e.g. fish length, migration rate, Fulton's condition factor; Table 6), and region-level environmental covariates (e.g. Sutter Bypass flow and water temperature; Table 6). All continuous covariates were standardized by subtracting the mean and dividing by the standard deviation. To be able to partition the influence of each covariate of interest on the survival variability through time, we used the base model ϕ*(~reach)* and included covariates in an additive framework (see Table 7 for list of models). We deliberately excluded the *year* variable from all covariate models because it would have accounted for the majority of interannual variability in survival, and would therefore mask any influence of the individual/environmental covariates and provide no information on mechanisms. However, we compared the ϕ*(~reach + year)* model to the covariates models in order to assess how much interannual variability explained by the *year* variable could be explained by these covariates instead. Once the relative importance of the covariates had been determined from the model selection exercise, we extracted the standardized β parameter coefficients for each important covariate to identify the relationship direction between those covariates and fish survival. These β parameter coefficients allow for comparison of the influence of covariates between models, and can be interpreted as the predicted change in survival for 1 standard deviation increase in the covariate. We used the Akaike's Information Criterion corrected for small sample sizes (AICc) for model selection (Akaike 1973; Burnham and Anderson 2002). We performed this analysis using the RMark package (Laake 2013) within program R (version 3.1.1.; R Development Core Team 2013).

Finally, in order to obtain additional information on the movements of the tagged fish during their out-migration and relate that to their survival, we estimated the average migration rates for the

different regions along the migration pathway. We did this by considering the movement rate of the successful fish between its last detection in one reach to its first detection at the next reach.

RESULTS

In 2015, the RST fished for 11 days between April 6th and April 16th. In that period of time a total of 141 salmon smolts were tagged and released and another 23 undersized juvenile Chinook were captured and released. Because the RST was located below a diversion dam, outflows were subject to sudden increases or decreases depending on agricultural demands. When rice farmers began flooding fields in mid-April the water levels dropped above weir 2 and flows into the RST became very low, preventing the rotary screw trap cone from spinning. As a result, we were forced to end the study prematurely before the target of 200 tagged smolts was met. In 2016 we were able to start tagging on April 14th, and by April 18th 200 Chinook salmon smolts were tagged and released into the Sutter Bypass. In 2017, because of extremely high flow during the months of March and April the tagging was delayed by about a month and we started tagging on May 6th. We tagged 200 smolts from May 6th to May 12th, 190 were released for the survival study and 10 fish were kept for a tag retention study. On average the fish tagged in the Sutter Bypass were slightly larger in 2016 compared to 2015; fish tagged in 2017 were substantially smaller than those tagged in the previous two years (Table 3).

Table 3. Weight (g) and Fork length (mm) of juvenile Chinook salmon captured, tagged and released at the Sutter Bypass RST in 2015, 2016 and 2017. n = sample size; SD = standard deviation.

Year	n	Mean Weight (SD)	Mean Length (SD)
2015	141	13.47 (5.36)	104.74 (12.28)
2016	200	16.24 (4.27)	110.51 (8.60)
2017	190	8.88 (3.14)	93.44 (8.67)

Genetic assignment

The genetic analysis determined that the smolts tagged in the Sutter Bypass were a mix of Central Valley fall-run and spring-run origin. In 2015, 6 smolts were confidently identified as Central Valley fall-run and 124 smolts as Central Valley spring-run, while in 2016 and 2017 a higher proportion of fish tagged were genetically classified as Central Valley fall-run (121 fall-run versus 65 spring-run in 2016 and 151 fall-run versus 30 spring-run in 2017). It also appears that fall-run and spring-run smolts exhibit similar size range (Figure 10). We performed an F-test (var.test function on R) to compare fall-run vs spring-run smolts length variances for each year and found no statistical difference between spring-run and fall-run fish length distributions in 2015 and 2016 (2015 p-value= 0.1489, 2016 p-value= 0.9086), but a significant difference in length distribution in 2017 (p-value= 0.0286). Overall, this indicates that no length cutoff could robustly apply to these two runs every year, and that visual distinction based on length is problematic. Therefore, although not all the fish tagged were spring-run Chinook salmon, because of their overlapping size range and migration timing we assumed that fall-run juveniles collected in this study were a good proxy for the purpose of this study.

Because the rotary screw trap used in this study was located below the Butte Creek fall-run spawning ground it is likely that we caught Butte Creek fall-run smolts outmigrating as well. In addition, because Sacramento River water spilled into the lower Butte Creek watershed several times before the tagging experiment took place it is also possible that some of the tagged fall-run fish originated from another Sacramento River tributary and used the Sutter Bypass as a migratory corridor.

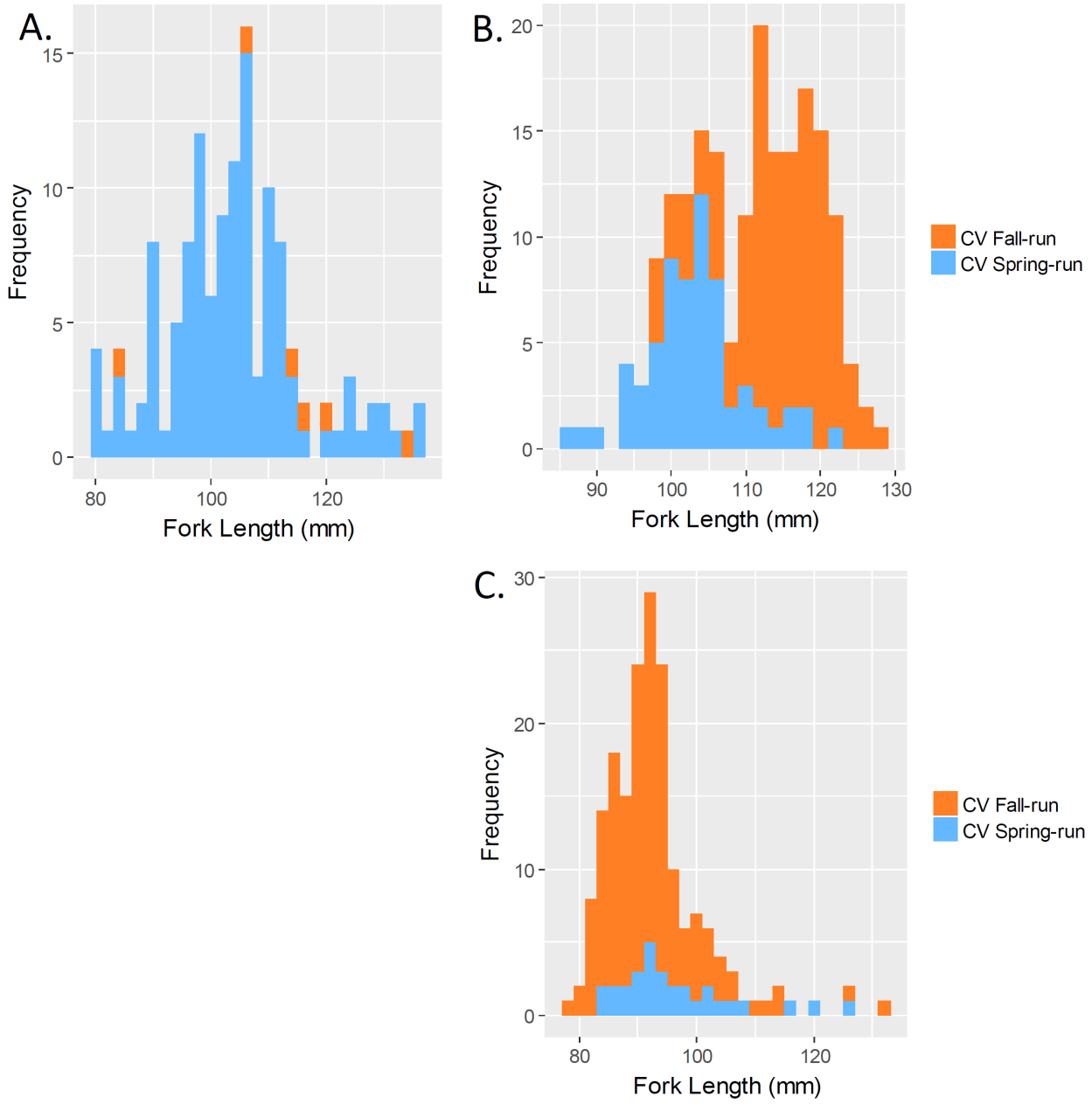

Figure 10.A. 2015, B. 2016 and C. 2017 length frequency histogram of Sutter Bypass tagged fish with genetic distinction. CV = Central Valley.

Hydrological conditions

The hydrological conditions experienced by the migrating smolts changed considerably between the three years of the study. California experienced an extreme drought in water year (WY) 2015 that

was classified as “critical”, while WY 2016 water year was considered “below normal”, and WY 2017 was classified as “wet” by the California Department of Water Resources (DWR; CDEC data).

Overall, flow in each region decreased over time, and as expected, flow was much higher in 2017 than in the two previous years. Flows in the Sacramento River and the Delta exhibited very similar dynamics through time, while Sutter Bypass flow evolved slightly differently, especially in 2017. In the spring of 2015, likely because of very dry winter conditions, the flow recorded in the lower Butte Creek system had already dropped substantially, and tagged smolt experienced very low flow during their migration through the Sutter Bypass, averaging 3.46 m^3s^{-1} (Figure 11, Table 6). While 2016 was not considered as a wet year, a series of rain events, leading to the flooding of the Sutter Bypass, occurred during the CCV spring-run smolt out-migration period. Although the flow decreased throughout the study period it remained substantially above the maximum flow value recorded during the same period in 2015. The 2016 BSL flow averaged 11.78 m^3s^{-1} (Table 6). In 2017, even though Sutter Bypass flow substantially decreased from April to May it was much higher than in 2015 and 2016 with an average of 19.32 m^3s^{-1} during the out-migration period. The same pattern was observed in the Sacramento River and the Delta, and it is also interesting to note that tagged smolts experienced slightly higher flows in the Sacramento River than in the Delta in 2015, while flow in the Delta was higher in 2016 and 2017 (157.69 m^3s^{-1} versus 120.36 m^3s^{-1} in 2015, 388.39 m^3s^{-1} versus 444.65 m^3s^{-1} in 2016, and 1,167.85 m^3s^{-1} versus 1,793.60 m^3s^{-1} in 2017; Figure 11, Table 6).

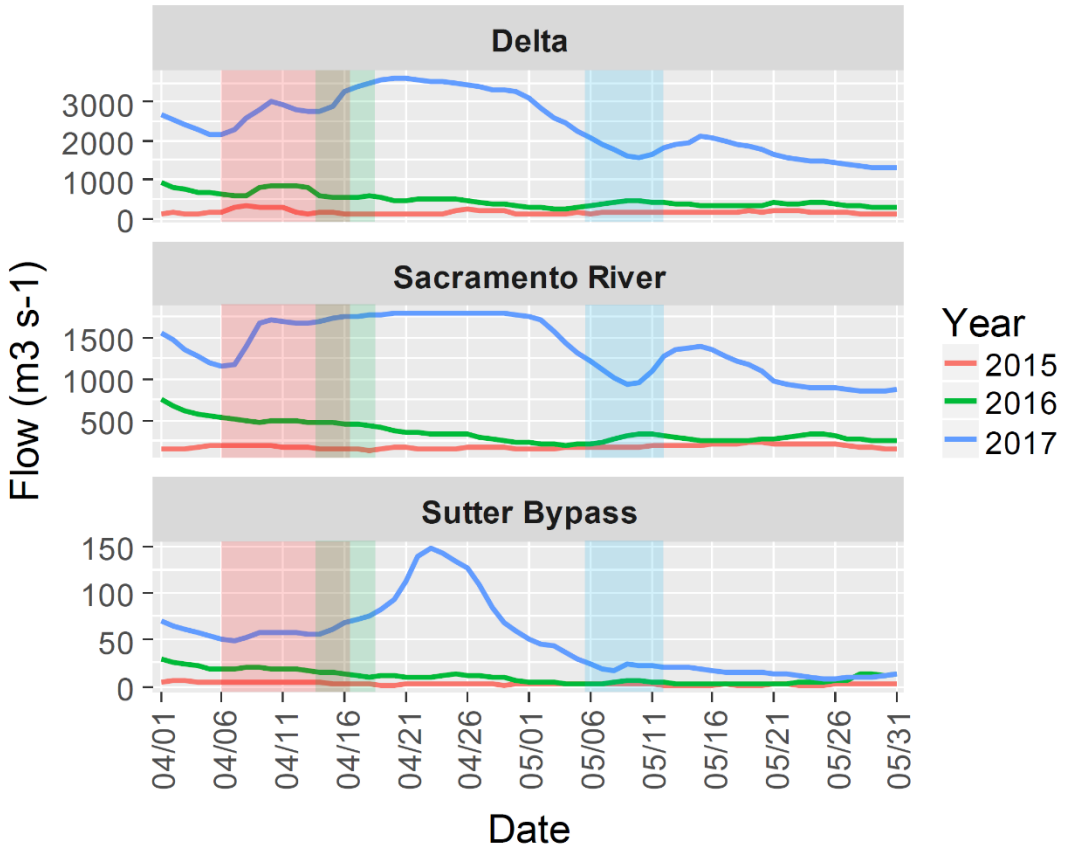

Figure 11. Mean daily flow in April-May of 2015, 2016, and 2017 from the Delta (net Delta outflow data, https://www.water.ca.gov/Programs/Environmental-Services/Compliance-Monitoring-And-Assessment/Dayflow-Data), the Sacramento River (Verona station: http://cdec.water.ca.gov/cgi-progs/stationInfo?station_id=VON), and the Sutter Bypass (Butte Slough near Meridian station: http://cdec.water.ca.gov/cgi-progs/staMeta?station_id=BSL). The shaded rectangles indicate tagging time period for 2015 in red, 2016 in green, and 2017 in blue.

Overall, in each region and for each year, water temperature increased from April to May, but occasionally decreased during the tagging period. Water temperature differences among the three study years reflected a combination of regular seasonal warming and year-to-year variation related to the different hydroclimate years. Specifically, Figure 12 shows that April water temperatures in Sutter Bypass in 2015 and 2016 were very similar, but because sampling started earlier in 2015 the water temperatures experienced by tagged smolts in that year were cooler than those experienced by tagged smolts in 2016 (average temperature ranged from 15.67 °C in 2015 to 17.07 °C in 2016, Table 6). Likewise, smolts tagged and released in May 2017 experienced the warmest Sutter Bypass water temperatures in our three-year study (average temperature of 20.85 °C), and this is consistent with the strong seasonal warming that regularly takes place. On the other hand, it is interesting to note that Sacramento River water temperatures experienced by tagged smolts in spring 2015 were overall the

warmest in our three-year study, and those in 2017 the coolest (average temperature ranged from 19.09 °C in 2015 to 16.07°C in 2016, and 15.29°C in 2017, Table 6). In the Delta, tagged smolts experienced slightly colder water temperatures in 2015 than in the two following years. Additionally, even though water temperatures during the tagging period were warmer in 2017 than in 2016, overall, the average water temperatures when tagged smolts were migrating through the Delta were slightly warmer in 2016 than in 2017 (average temperature ranged from 17.11 °C, 17.87 °C, 17.84 °C, Table 6).

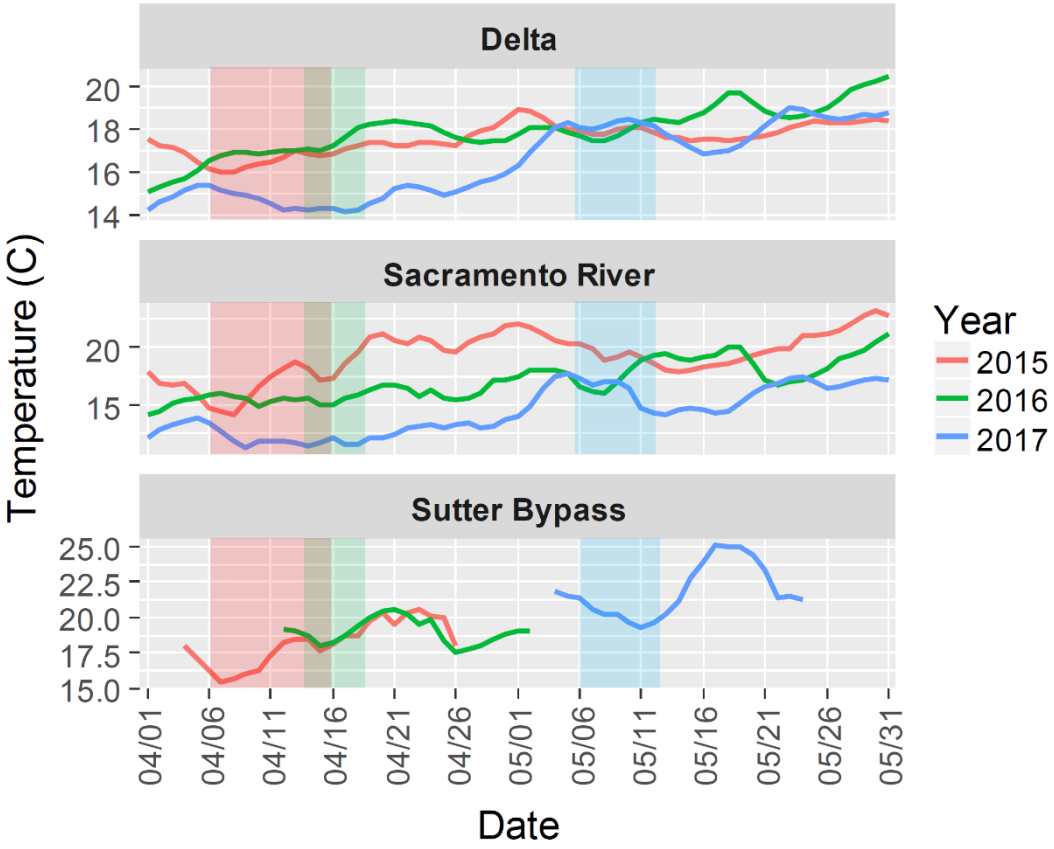

Figure 12. Mean daily water temperature in April-May of 2015, 2016, and 2017 from the Delta (Mallard Island station, http://cdec.water.ca.gov/dynamicapp/staMeta?station_id=MAL), the Sacramento River (Verona station: http://cdec.water.ca.gov/cgi-progs/stationInfo?station_id=VON), and the Sutter Bypass (Butte1 site ATS receiver thermistor in 2015 and 2016, and temperature logger in 2017). The shaded rectangles indicate tagging time period for 2015 in red, 2016 in green, and 2017 in blue.

Fish movement pattern

In 2015, 27 of the 141 tagged fish were detected entering the Sacramento River (19.1%), 14 fish were detected entering the Delta (9.9%) and only 1 fish was detected at the Golden Gate Bridge (0.7%;

Figure 13). In 2016, 71 of the 200 tagged fish were detected entering the Sacramento River (35.5%), 49 fish were detected in the Delta (24.5%) and 4 fish were detected at the Golden Gate Bridge (2%; Figure 13). In 2017, out of the 190 fish tagged 61 were detected exiting the Sutter Bypass (32%), 39 entered the Delta (20%), 29 were detected exiting the Delta (15%), and 21 fish were detected at the Golden Gate Bridge (11%; Figure 13).

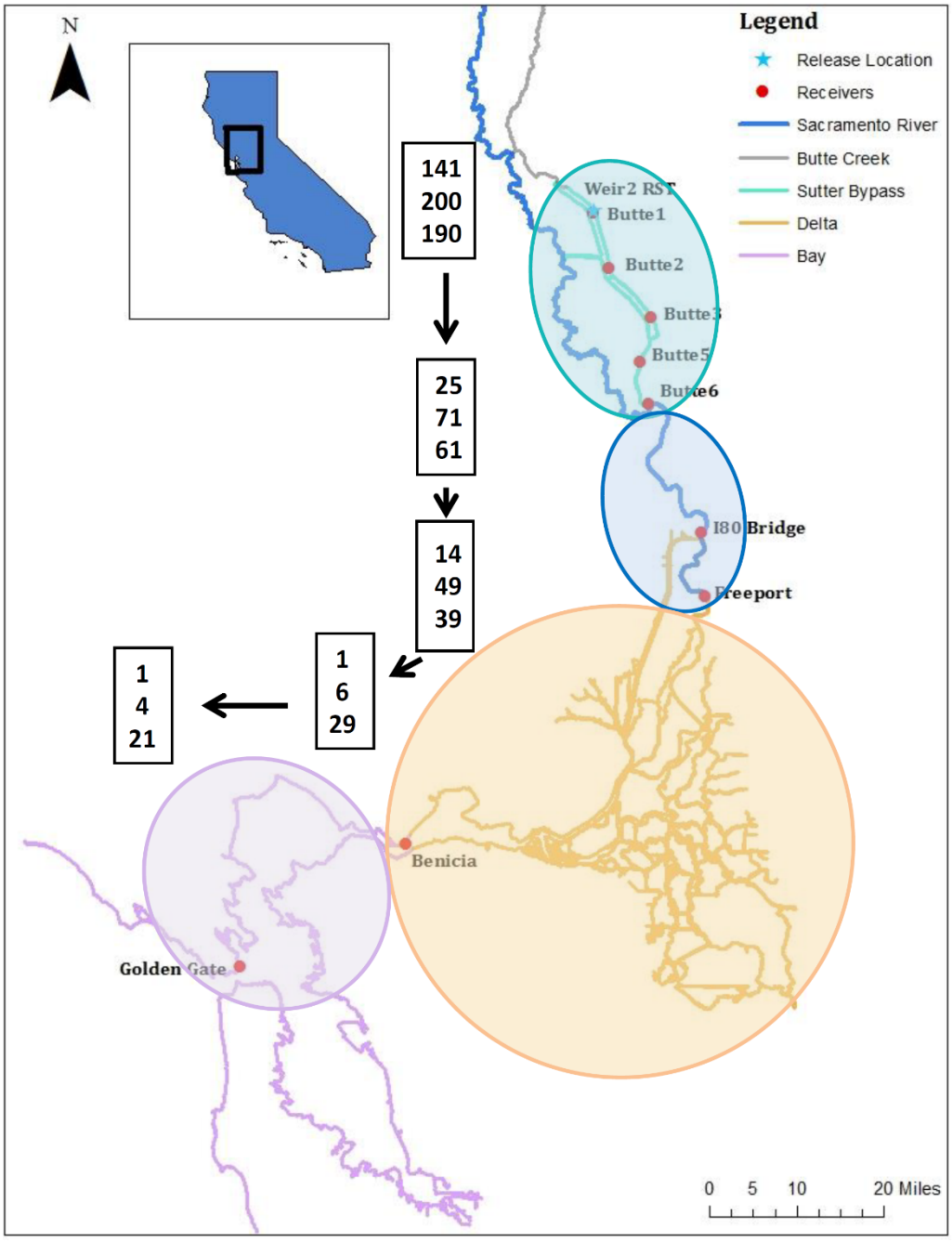

Figure 13. Map of number of tagged fish detected in each region and each year (i.e. from 2015, top number to 2017, bottom number).

Although there was large variability in the movement rates among fish each year, especially in the Sacramento River, most of the smolts tagged moved quickly throughout the migration corridor (Tables 5 and 6, Figure 14). Overall, fish migrated faster in 2017 than in 2016 and 2015, except in the Sutter Bypass where fish migrated faster in 2016 than in 2017. Based on a Tukey's Honest Significant Difference test ("TukeyHSD" function in R), Sutter Bypass migration rates in 2016 and 2017 were significantly higher than in 2015 (p-values < 0.001), and the Sacramento River migration rate in 2017 was significantly higher than in 2016 which was significantly higher than in 2015 (p-values < 0.001). Additionally, for all years, fish migrated significantly faster in the Sacramento River than in the Sutter Bypass, Delta and Bay (p-values < 0.001). We estimated a mean migration rate of 10.24 km/day in the Sutter Bypass and 33.21 km/day in the Sacramento River in 2015 versus estimates of 22.13 km/day and 56.83 km/day respectively in 2016, and 18.94 km/day and 87.05 km/day respectively in 2017 (Table 5). Since only one fish was successfully detected at Benicia and the Golden Gate Bridge in 2015, it was impossible to estimate Delta and Bay travel rate statistics for that year. However, in 2016 and 2017 more fish were detected in those two regions, and we observed a similar increase in movement rate in 2017 compared to 2016. The average movement rate through the Delta and Bay was estimated at 22.48 km/day and 17.49 km/day respectively in 2016, and 35.04 km/day and 27.46 km/day respectively in 2017.

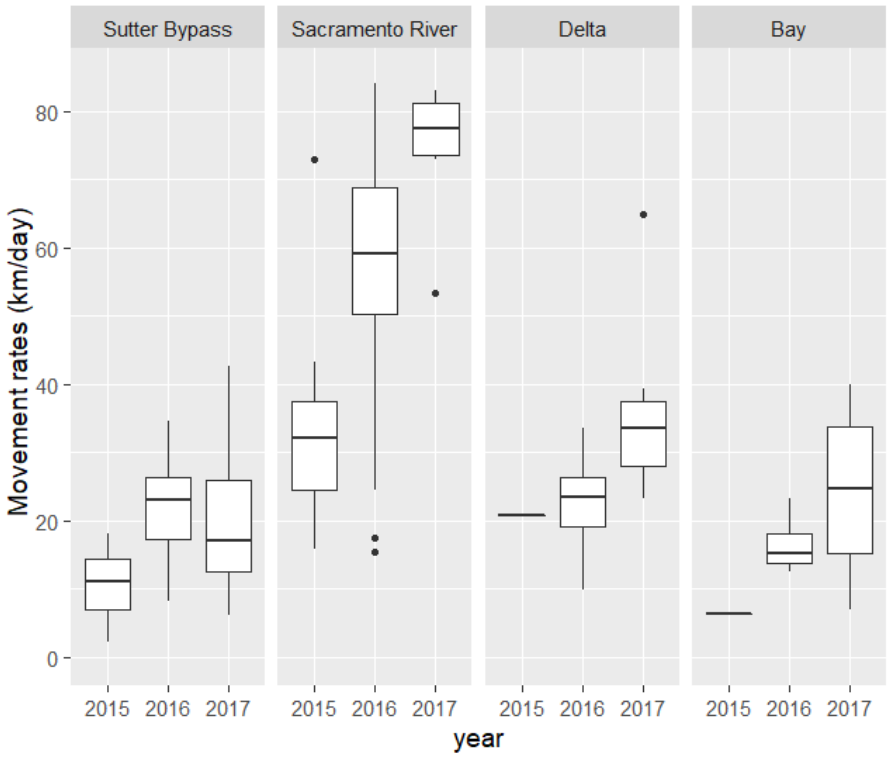

Figure 14. Boxplot of movement rates in kilometers per day (km/day) for 2015, 2016 and 2017. The horizontal bold line represents the median value and the vertical whiskers represent the 95% percentiles. The dots are extreme values.

Fish survival estimate

The full model, supported as the single best model (AICc = 2457.752, and ΔAICc of the second best model greater than 4; Table 4), includes survival as a function of *reach x year* and detection probability as a function of *reach + year*. Therefore, outmigrant smolt survival and receiver detection strongly varies by location and year.

Table 4. Comparison of constant versus year- and/or reach varying survival (ϕ), and detection (p) models for out-migrating Chinook salmon. Npar = number of model parameters; AICc = Akaike's information criterion corrected for small sample size; ΔAICc = difference in AICc score between the given model and the most parsimonious model. Models are ordered from lowest to highest AICc. Lower AICc scores indicate greater relative model parsimony.

Model	Npar	AICc	ΔAICc
ϕ(~reach x year) p(~reach + year)	42	2457.752	0
ϕ(~reach x year) p(~reach x year)	60	2465.771	8.019175
ϕ(~reach + year) p(~reach + year)	24	2474.48	16.72863
ϕ(~reach + year) p(~reach x year)	42	2475.828	18.0761
ϕ(~reach) p(~reach + year)	22	2492.386	34.63411
ϕ(~reach) p(~reach x year)	40	2494.622	36.86999
ϕ(~reach x year) p(~reach)	40	2518.581	60.82939
ϕ(~reach + year)p(~reach)	22	2552.097	94.34541
ϕ(~reach) p(~reach)	20	2569.54	111.7883
ϕ(~reach x year) p(~1)	31	2659.657	201.9056
ϕ(~reach + year) p(~1)	13	2705.729	247.9772
ϕ(~year) p(~reach x year)	33	2719.107	261.3553
ϕ(~reach) p(~1)	11	2722.11	264.358
ϕ(~1) p(~reach x year)	31	2725.694	267.9424
ϕ(~year) p(~reach + year)	15	2808.98	351.2281
ϕ(~1) p(~reach + year)	13	2817.694	359.9425
ϕ(~year) p(~reach)	13	2863.121	405.3697
ϕ (~1) p(~reach)	11	2872.01	414.2581
ϕ(~year) p(~1)	4	3034.43	576.6784
ϕ(~1) p(~1)	2	3041.662	583.9099

We used the full model (i.e. *ϕ(~reach x year) and p(~reach + year)*) to estimate survival per 10km, per region and cumulatively. Overall, survival through the entire migratory corridor (from the release site to the Golden Gate Bridge) was much higher in 2017 than in 2016 and 2015 (10.0 % in 2017 versus 2.0% in 2016 and 0.7% in 2015; Table 5, Figure 15).

At the regional level, survival increased in the Sutter Bypass from 19.1% in 2015 to 35.5% in 2016 and slightly decreased to 35.1% in 2017. In both the Sacramento River and the Delta, survival increased from 2015 to 2017 ranging from 51.8% in 2015 to 79.5% in 2017, and from 7.1% in 2015 to 55.3% in 2017 respectively (Table 5; Figure 15). The 100% survival in the Bay in 2015 is only representative of one fish, however in 2016 and 2017 more fish were detected at the Golden Gate Bridge receivers and survival increased from 66.7% in 2016 to 73.2% in 2017. For all years, the highest regional survival was observed in the lower Sacramento River, except for the 100% survival in the Bay in

2015. Additionally, in 2015 and 2016 the lowest survival estimate was for the Delta region, while in 2017 Delta survival was much higher compared to previous years, as well as Sutter Bypass survival in 2017. It is important to note that the length of each region varies considerably (e.g. the Delta region is about twice as long as the Sutter Bypass and Sacramento River regions; Table 2). Additionally, some survival rate values have large confidence intervals (e.g. 2015 Delta survival, 2016-2017 Bay survival, and 2017 Sacramento River survival) that is due to a combination of low number of fish surviving to the region (e.g. 1 fish survived in the Delta and Bay in 2015), and low receiver detection efficiencies (e.g. p = 0.41 in the Sacramento River in 2017). This detection efficiency reduction could be due to factors such an increased turbidity or an increased distance between fish and receiver locations during temporary flooding.

Table 5. 2015-2017 regional and total percentages of survival and mean migration rates along with their standard deviation (SD). NA = Not Available value.

Year	Region	% Survival ± SE	Mean migration rate (km/day) ± SD
2015	Total	0.7 ± 0.7	NA
	Sutter Bypass	19.1 ± 3.3	10.24 ± 4.61
	Sacramento River	51.8 ± 9.6	33.21 ± 14.31
	Delta	7.1 ± 6.9	NA
	Bay	100 ± 0.0	NA
2016	Total	2.0 ± 1.0	23.04 ± 4.70
	Sutter Bypass	35.5 ± 3.4	22.13 ± 6.21
	Sacramento River	69.0 ± 5.5	56.83 ± 16.26
	Delta	12.2 ± 4.7	22.48 ± 8.03
	Bay	66.7 ± 19.2	16.56 ± 4.72
2017	Total	10.0 ± 2.2	27.53 ± 6.05
	Sutter Bypass	35.2 ± 4.8	18.94 ± 6.87
	Sacramento River	79.5 ± 14.9	87.05 ± 17.31
	Delta	55.3 ± 10.8	35.04 ± 11.38
	Bay	73.2 ± 8.9	23.85 ± 10.82

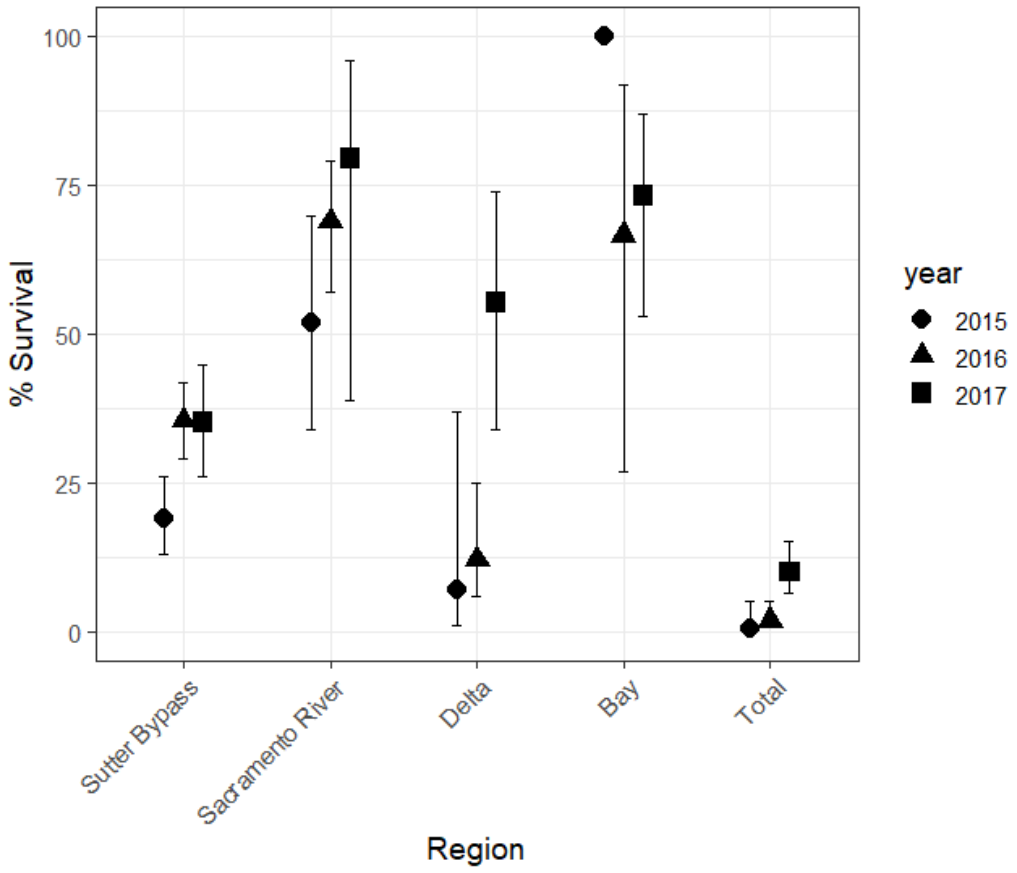

Figure 15. 2015-2017 regional and total survival rates, with their lower and upper 95% confidence limits.

Finally, the per 10km survival rates varied dramatically between reaches within the Sutter Bypass, Sacramento River, Delta and Bay, and some similar survival patterns were observed among years (Figure 16). In the Sutter Bypass, relatively low survival was observed between the release site and the first receiver (Weir2_RST – Butte 1 in Table 2; 26.0% in 2015, 81.5% in 2016, and 51.9% in 2017) and between Butte3 and Butte5 receivers (39.6% in 2015, 65.3% in 2016, and 64.4% in 2017). Survival was higher in the other reaches of the Sutter Bypass, ranging from 72.6% to 93.8% in 2015, 80.3% to 84.6% in 2016, and 73.0% to 89.9% in 2017. In 2015, the Sacramento River survival decreased from the first reach (Butte6 - I80_Br) to the second reach (I80_Br – Freeport), whereas it increased in 2016, and slightly decreased in 2017 (from 91.5% to 87.4% in 2015, from 92.3% to 98.8% in 2016, and from 97.0% to 95.1% in 2017). It is important to note that the large confidence intervals around Butte1 and Freeport survival values is likely due to low receiver detection efficiencies at those receivers. In 2016, survival from Benicia to the Golden Gate Bridge (Golden GateE receiver) was much higher than in the Delta (from Freeport to Benicia), however 2017 survival was quite similar in those two reaches.

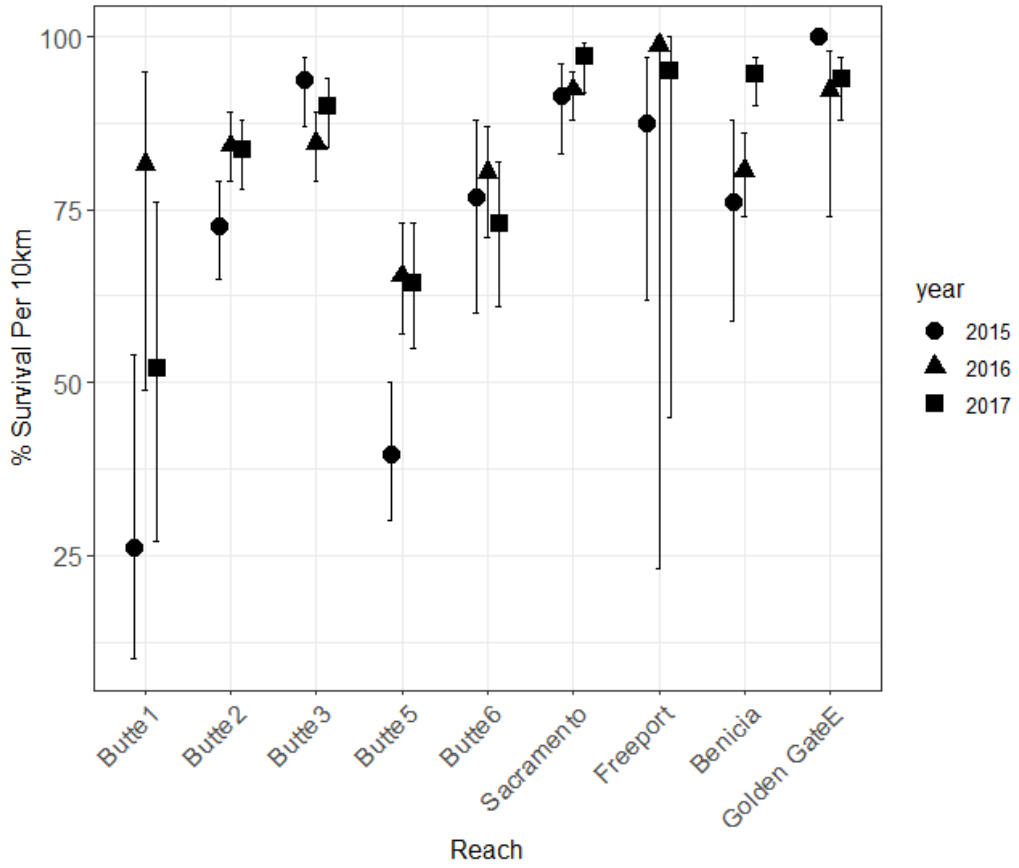

Figure 16. 2015, 2016 and 2017 per 10km survival rate estimates along with their lower and upper 95% confidence limits.

After individually testing the effects of each covariate (Table 6) on regional smolt survival, the *ϕ(~reach + year)* model was selected as the best model, emphasizing the strong year effect on smolts survival (Table 7). A series of models including fish release Julian day, and various environmental covariates were better supported over the base model *ϕ(~reach)*, suggesting that survival is influenced by those covariates. Particularly, models with Delta flow and Julian day seem to have a strong impact on smolt survival (i.e. ΔAICc <4). Both Delta flow and Julian day had a positive effect on survival, which means that higher flow and later release date were correlated with higher survival. The positive relationship with Julian day is counterintuitive but could be explained by the fact that 2017 survival was significantly higher than in 2015 and 2016 and fish were released much later in the season that year. In contrast, the models including Bay travel rate, fish length and condition factor were not better

supported than the base model, suggesting that these covariates had no detectable influence on survival.

Table 6. Individual and region specific covariates used in the regional survival models.

Category	**Covariate**	**Definition**	**2015 value**	**2016 value**	**2017 value**
Individual	Length	Fish fork length	80 – 136 mm	85 – 128 mm	78 – 132 mm
Individual	K	Fish Fulton's condition factor	0.61 – 1.55	0.95 – 1.43	0.91 – 1.27
Individual	Julian day	Fish release date in Julian day	96 – 106	105 – 109	126 – 132
Individual	travel Sutter	Fish migration rate through the Sutter Bypass	2.08 – 18.05 km/day	8.21 – 34.60 km/day	6.18 – 42.64 km/day
Individual	travel Sac River	Fish migration rate through the Sacramento River	15.75 – 72.97 km/day	15.44 – 84.04 km/day	53.29 – 114.54 km/day
Individual	travel Delta	Fish migration rate through the Delta	20.81 km/day	9.85 – 33.43 km/day	23.14 – 64.90 km/day
Individual	travel Bay	Fish migration rate through the Bay	6.29 km/day	12.55 – 23.24 km/day	6.85 – 39.91 km/day
Region specific	flow Sutter	Mean flow at Butte Slough near Meridian during period when tagged fish were detected in the Sutter Bypass	122.23 cfs / 3.46 m^3s^{-1}	415.90 cfs / 11.78 m^3s^{-1}	682.31 cfs / 19.32 m^3s^{-1}
Region specific	flow Sac River	Mean flow at Verona during period when tagged fish were detected in the Sacramento River	5,568.97 cfs / 157.69 m^3s^{-1}	13,715.74 cfs / 388.39 m^3s^{-1}	41,242.10 cfs / 1,167.85 m^3s^{-1}

Category	Covariate	Definition	2015 value	2016 value	2017 value
Region specific	flow Delta	Mean net Delta outflow during period when tagged fish were detected in the Delta	4,250.64 cfs / 120.36 m^3s^{-1}	15,702.67 cfs / 444.65 m^3s^{-1}	63,340.47 cfs / 1,793.60 m^3s^{-1}
Region specific	temp Sutter	Mean temperature near release site during period when tagged fish were detected in the Sutter Bypass	15.67 °C	17.07 °C	20.85 °C
Region specific	temp Sac River	Mean temperature at Verona during period when tagged fish were detected in the Sacramento River	19.09 °C	16.07 °C	15.29 °C
Region specific	temp Delta	Mean temperature at Mallard Island during period when tagged fish were detected in the Delta	17.11 °C	17.87 °C	17.84 °C

Table 7. Comparison of reach + year survival with survival models including individual and region specific covariates described in Table 6. The detection probability (*p*) is a function of reach + year for each model. Npar = number of model parameters; AICc = AIC score corrected for small sample size; ΔAICc = distance from the most parsimonious model. Models are ordered from lowest to highest AICc. Lower AICc scores indicate greater relative model parsimony. β parameter estimates are shown for the covariate models with substantial support (i.e. ΔAICc <4).

Model	**Npar**	**AICc**	**ΔAICc**	β **coefficient**
ϕ(~reach + year) p(~reach + year)	14	1120.513	0	
ϕ(~reach + flow Delta) p(~reach + year)	13	1121.771	1.258113	1.09
ϕ(~reach + Julian day) p(~reach + year)	13	1123.025	2.512213	0.46
ϕ(~reach + travel Delta) p(~reach + year)	13	1127.645	7.132213	
ϕ(~reach + flow Sutter) p(~reach + year)	13	1135.525	15.01181	
ϕ(~reach + flow Sac River) p(~reach + year)	13	1139.070	18.556513	
ϕ(~reach + temp Sutter) p(~reach + year)	13	1139.892	19.379613	
ϕ(~reach + travel Sac River) p(~reach + year)	13	1141.128	20.614613	
ϕ(~reach + temp Sac River) p(~reach + year)	13	1145.371	24.85781	
ϕ(~reach + temp Delta) p(~reach + year)	13	1147.410	26.897013	
ϕ(~reach + travel Sutter) p(~reach + year)	13	1148.714	28.20101	
ϕ(~reach) p(~reach + year)	12	1150.205	29.69244	
ϕ(~reach + travel Bay) p(~reach + year)	13	1150.247	29.73421	
ϕ(~reach + Length) p(~reach + year)	13	1150.767	30.25441	
ϕ(~reach + K) p(~reach + year)	13	1150.796	30.28251	

DISCUSSION

We estimated reach-specific survival and movement rates of wild Central Valley Chinook salmon smolts, using fish tracking data and a sophisticated mark-recapture modelling framework, and investigated the differences/similarities in these rates observed between three different hydrological years. Survival of Chinook salmon smolts tagged in the Sutter Bypass and tracked through their migration corridor was extremely low in 2015 and 2016 (0.7% and 2%, respectively), but significantly higher (especially in the Delta) in 2017 (10.0%). These survival rates are lower than most of the survival

estimates obtained by Michel et al. (2015) for acoustic tagged late-fall run Chinook salmon yearlings (survival per year ranged from 2.8% to 15.7%). This survival is also low in comparison to the 2014 survival found by Faulkner et al. (2017) for populations of wild spring/summer Chinook salmon from the Snake River (a tributary of the Columbia River) migrating through a much longer watershed than in our study (mean survival rate of 34.9% through the entire 910km watershed). However, the fish tracked in these two studies were yearlings and therefore larger in size than the smolts tagged in the Sutter Bypass. This could play a role in the survival difference observed as larger and older fish could be more successful at avoiding predators. Similar to our study, Notch (2017) found very poor survival (0.3%) to the ocean for acoustic-tagged wild caught smolts from Mill Creek, an upper Sacramento River tributary. This suggests that out-migration survival of spring migrating wild Chinook salmon smolts can be very low, and may be a bottleneck to recovery of these populations.

For all years and all regions, except the Bay, survival is correlated with movement rate, with faster migration correlated to higher survival. However, results in the Bay region should be viewed with caution because of the small number of fish detected. The fastest movement and higher survival rates were observed in the lower Sacramento River. Furthermore, smolt survival was found to be significantly influenced by flow in the Delta. One possible mechanism suggested by these results would be that an increase in flow could lead to faster migration, which would in turn lead to higher survival. Overall flow during the study period (i.e. April-May) increased from 2015 to 2017, and migration rates also increased between 2015 and 2017 except in the Sutter Bypass where 2017 migration rates were slightly lower than in 2016. This could be explained by the fact that fish tagged in 2017 were smaller than fish tagged in 2015-2016, due to cooler spring conditions that year, which could lead to lower swimming performance and/or an increased rearing time in the Bypass. Another possible mechanism is that an increase in storm-driven flow lead to an increase in turbidity which could have the potential to reduce spatio-temporal exposure to predation (Gregory and Levings 1998). The large increase in survival observed in 2017 in the Sacramento River and the Delta corroborates with this assumption as spring-run and fall-run smolt out-migration timing overlaps with the Striped Bass spawning season. Adult Striped Bass migrate into the San Joaquin and Sacramento Rivers in large numbers in the spring to spawn and are likely to prey on juvenile outmigrants during that time (Turner 1976; Tucker et al. 2003). Finally, the calendar date at release (i.e. Julian day covariate) also had a significant impact on smolt survival, with higher survival for fish released later in the season. This relationship is counterintuitive since release date in our study correlates with an increase in photoperiod and an overall seasonal warming, and

therefore potentially poorer out-migration conditions. However, this is likely due to higher survivals observed in 2017, a wet year that exhibited cool temperatures, even though fish were tagged a month later that year than in 2015 and 2016. A longer time series including measurements of other potentially important environmental factors (such as turbidity) is required to robustly identify the influence of various individual and environmental factors on Butte Creek spring-run Chinook outmigrant smolt survival.

In the Sutter Bypass there were two reaches with substantially lower survival than the other reaches; from the release site to Butte1 especially in 2015 and 2017, and between receivers Butte3 and Butte5 for all years. These two reaches had the lowest survival per 10 km of all reaches for each year. Common to both these reaches are in-river diversion weir structures; the first located at the start of Weir2_RST – Butte1 reach, and the second located in the middle of Butte3 – Butte5 reach. Studies have shown that Striped Bass (*Morone saxatilis*) and Sacramento Pikeminnow (*Ptychocheilus grandis*) – both considered major predators of juvenile salmon in the CCV – tend to congregate below in-river diversion weirs and are effective at predating on disoriented salmon smolts that pass over these structures (Brown and Moyle 1981; Tucker et al. 2003; Sabal et al. 2016). Various non-native salmon predator species, such as Largemouth Bass (*Micropterus salmoides*), Striped Bass, Channel Catfish (*Ictalurus punctatus*), and native predators, such as Sacramento Pikeminnow have been reported in the lower Butte Creek watershed (ICF Jones & Stokes. 2009). These predators were also caught in the RST during this study in all years.

Finally, the size of the fish tagged as well as their genetic origin varied among years, likely due to the large variability in hydroclimatic conditions observed in each region among years. The larger fish tagged each year could be either spring-run yearling outmigrating quite late in the season, or fall- and spring-run young of the year juveniles that experienced very good rearing conditions above the trapping site (e.g. in the Butte sink). It is important to note those tagged fish belong to one of the multiple life history strategies observed in the Butte Creek spring-run Chinook salmon population, and the results of this study might not be representative of other life history strategies where juveniles outmigrate as fry or parr at a different time of year. Salmon smolts have evolved to outmigrate with spring snowmelt freshets during April and May. However, various human-induced and environmental constraints such as the homogenization of the hydrology due to dams, elevated water temperature associated with dams, and water diversions in the Delta peaking during the spring are now likely diminishing the benefits of

this life history strategy and leading to lower out-migration survival. Given these constraints, earlier out-migration life histories (fry/parr) might exhibit higher relative survival. However, due to their small size, which precludes acoustic tagging, very little is known about these life histories. Studies that aim to quantify the proportion of returning adults with the different out-migration life histories (such as in Sturrock et al. (2015)) would be needed to put the spring smolt out-migration life history studied here in broader context.

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APPENDIX A. NOAA JSATS Wild Chinook Salmon Tagging Protocol

By Jeremy Notch on 1/23/2018

1) Rotary Screw Trap fish collection
    A. The rotary screw trap (RST) will be checked each morning before smolts are tagged
    B. Before smolts are netted, all debris floating on top and inside of the live car will be cleared so that less debris is transferred into holding tank and making it easier to sight fish
    C. Once debris is cleansed, fish will be crowded into the back of the RST with a metal mesh crowder and netted with a long handled dip. The best technique to capture fish is to use two long handled dip nets simultaneously, coming from both sides of the trap and meeting in the middle. A very slow motion will make the fish less wary and easier to capture. The fish will then be transferred to a 5 gallon bucket secured with a screw on lid.
    D. A large cooler (>50 liters) will be filled with water and placed near the surgery station. The captured smolts will be placed inside, with two bubblers running while fish are present
2) Fish Selection Criteria
    A. ATS Juvenile Salmonid Acoustic Telemetry Systems (JSATS) tags weigh 0.30 g in air. The estimated minimum length and weight of juvenile Chinook salmon for surgical tagging should be ~80 mm and > 6.0g (tag weight $\leq$ 5% body weight), respectively.

3)Fish Tagging:
    A. Environmental conditions (Pre- and post-operative anesthesia baths)
        i. Dissolved oxygen (DO): will be measured as milligrams/liter in a pre- and post-tag holding tank, raceway, or other water source during each tag session.
            1. Measurements will be taken using a YSI model 55 DO meter
            2. DO concentrations in pre- and post-tag holding areas should be between 80% and 110% saturation.
        ii. Temperature: will be measured in °C in a pre- and post-tag holding area during each tag session.
            1. Changes in water temperature exceeding 2°C require tempering (Kelsch and Shields 1996). "Tempering" means "to bring to a suitable state by mixing in or adding a usually liquid ingredient". Therefore, prior to exposing fish to a new water source the fish holding temperature and the temperature of the

new water source need to be measured to ensure that the difference between the two water sources is ≤ 2°C. If the temperature difference is > 5°C then water in the container holding fish should be tempered at a rate of 0.5°C h^{-1} until the temperature difference between the two water sources is ≤ 2°C. If the temperature difference is < 5°C, temper at a rate of 1°C h^{-1} until the temperature difference between the two water sources is ≤ 2°C. New source water should be added in small amounts multiple times over the time interval to gradually change the temperature. Once the temperature difference between the two water sources is ≤ 2°C fish can be transferred to the new water source.

B. Equipment setup

i. Tags should be programmed and prepared for implantation.

ii. Disinfect all tags in dilute Nolvasan™, chlorhexidine solution and thoroughly rinse in distilled or de-ionized water using at least a double rinse. Position disinfected tags near the surgery table and do not handle them without gloved hands or the use of instruments.

iii. Prepare surgical table and equipment for use.

1. The surgical station will be clean and wiped down with a solution of disinfectant and surgical instruments will be placed in a disinfectant bath (e.g., dilute Nolvasan™, chlorhexidine solution) before fish handling and surgical procedures.
2. Each table should have 1 Nolvasan™ disinfectant baths and 2 rinse baths
3. Surgical instruments will be transferred to a freshwater rinse bath before surgery
4. Instruments should be rinsed twice and rinse should be changed often to avoid accumulation of disinfectant in rinse water
5. To minimize the chances for pathogen transfer between fish populations, all equipment used for capture, holding, anesthesia, surgery, recovery, and movement of fish during the project will be thoroughly cleaned and disinfected before use with a different fish population or watershed.
6. Soiled gloves should be changed immediately and after handling 10 fish

iv. Setup measuring board and scale

1. Ensure the scale is functioning properly. Scales should be calibrated at the start of the study, checked each week for accuracy, and recalibrated as necessary.
2. Put approximately 1-2 mL of diluted stress coat on the weigh boat and the measuring board.

C. Recovery tanks must be filled with river water and supplied with oxygen just prior to tagging. The concentration of DO in recovery buckets should be between 120 and 150% saturation.

D. Administration of anesthetic: The effectiveness of MS-222 as an anesthetic varies with factors such as temperature, fish density, and individual sensitivity. Adjustments of the anesthesia concentration should be based on the amount of time it takes for a fish to lose equilibrium (induction time).

i. Fill the anesthesia containers with 11.35L of river water. As a suggestion for a starting concentration, add 1.02g of MS-222 dry powder. This will yield an anesthetic concentration of 90 mg/L. Base the daily starting concentration on fish responses during the tagging operation in previous days. Adjust dosage if needed.

ii. Maintain anesthetic concentration of 30 mg/L in the recirculation system. This can be achieved by adding 0.68g of MS-222 dry powder to 22.7L of water.

iii. All anesthetic solutions will be buffered to between pH 7 and 8 using baking soda dissolved in solution. 2.04g baking soda into 11.3L water for anesthesia and 1.4g in 22.7L for maintenance.

iv. Water in all containers (anesthesia and gravity feed) should be changed regularly to minimize dilution of anesthesia water and temperature changes and to ensure you do not run out of water during a procedure.

v. Add a small amount of diluted stress coat for each liter of water in the anesthesia, gravity feed, and recovery containers to protect fish from loss/damage to the slime layer.

vi. Containers should be filled and prepared just prior to tagging to avoid temperature changes.

E. Anesthetizing fish

i. Use a sanctuary net or dip net to hold water to remove one fish from the pre-tag holding source and place directly into an anesthesia bucket. Remove fish from net by hand, taking care not to dilute anesthesia bath with water from the net. Secure the lid as soon as the fish is in the bucket. Start a timer to keep track of how long a fish has been in the anesthesia bucket.

1. Time of sedation for a fish should normally be 1-2 minutes. If loss of equilibrium is greater than 1 minute, reject that fish. If after sedating a few fish, they are consistently losing equilibrium in more or less time than typical, adjust the concentration of the anesthetic (up or down) in 0.5 ml increments of stock MS-222 solution.
2. Remove the lid after one minute to observe the fish for loss of equilibrium. Once the fish loses equilibrium, visually screen the fish for size and health: general condition of eyes, scales and fins, tags, fin clips, fungus, disease, descaling, bloated abdomen, discharge of milt, or any obvious abnormalities. Make sure to keep the fish submerged during this examination. Relay any information to the data recorder.
3. Keep the fish in the water for an additional 30 - 60 sec after it has lost equilibrium.
4. Rejects - If the fish is unacceptable for tagging, place the fish in the bucket labeled Rejects, and relay the information to the data recorder.

ii. Any fish exposed to the initial anesthesia concentration (prior to being removed for weighing and measuring) for more than 5 min will be rejected due to the risk of excessively deep anesthesia and reduced likelihood of successful recovery.

F. Recording fish length and weight

i. Transfer the fish to the scale and weigh the fish to the nearest 0.1 g.

ii. Transfer the fish to the measuring board and measure the fork length to the nearest millimeter (mm).

iii. Data must be vocally relayed to the data recorder. The data recorder should then record this information on the appropriate datasheet and repeat numbers back to avoid any miscommunication.

iv. Any fish that is dropped on the floor during this process must be rejected. A fish dropped on the table during surgery may still be tagged. If a fish is dropped on the floor after it is tagged, remove the tag and reject the fish.

G. Surgical procedures

i. Selected fish will be bathed in cool (< 18°C), aerated water during surgery. Surgery will be performed in as sterile an environment as possible.

ii. Fish will be placed ventral-side up on a surgery cradle made of Microcell foam with a size-specific mold to hold the fish in position. See Figure 6 for general reference of surgical procedures.

iii. Water diffused with a maintenance anesthesia solution (15 mg/L) will be passed through tubing from a container using a submersible pump and will continually flow into a reservoir in the mold where the fish's head will be submerged, gently flushing the anesthetic solution over gill membranes to ensure oxygen and anesthesia are carried to, and metabolic wastes are efficiently moved away from, the gills continuously throughout the procedure.

iv. Using a Sharppoint™ 15° stab point 3.0mm or 5.0mm restricted blade depth scalpel, a 6-7 mm incision will be made parallel to and 2 mm to the side of the ventral midline and anterior to the pelvic girdle.

1. One scalpel blade can be used on about seven fish before it becomes dull. If the blade is pulling roughly or making jagged incisions, it needs to be changed
2. Use blunt tipped forceps or hemostat to open the incision to ensure you did not damage any internal organs or cause excessive bleeding. If you observe damage or think you damaged an organ, do not implant the tag, and reject that fish. Excessive bleeding indicates likely organ damage and should be noted on the datasheet if the surgery continues.

v. A sterilized, individually-coded, tag will be inserted through the incision into the peritoneal cavity of the fish.

vi. The tag will be positioned so it is lying immediately under the incision

1. This positioning will provide a barrier between the suture needle and internal organs. Through time the tag location will naturally move posterior in the fish.
2. The tag should be inserted battery side first with the battery oriented parallel to the incision. As the tag is placed into the peritoneal cavity the battery should be pushed towards the head and the transducer of the tag should be towards the tail.
3. The incision will be closed with two simple sutures using 10.5 mm (NP-1) precision point, 3/8 circle needle with 6/0 Monoswift™ monofilament Poly(glycolide-co-caprolactone) (PGCL 25) synthetic absorbable suture material.
4. To make a stitch, lock the needle (at the end of the suture) in the hemostat so the needle point faces you. Enter the outside edge of the incision on the side farthest from you and exit through the other edge of the incision, pulling the suture perpendicular through the two edges. The needle should enter and exit the skin as close to the edge of the incision as possible without tearing the skin (~ 2 mm from edge of incision). Pull the needle and suture through the skin to leave a tag end of about 2 - 3 cm of suture material protruding from the needle entrance location, then release the needle from the needle drivers. With your non-dominant hand, grasp the long end of the suture material (usually with thumb and forefinger) at or below the needle, and make two forward wraps (i.e., away from your body) around the tip of the needle driver, which should be held in your dominant hand. With the two wraps still around the needle driver, grasp the short tag end of suture material with the needle driver and tighten the stitch by pulling the wraps off the needle driver and pulling both ends of suture material perpendicular to the incision. On the first knot, the dominant hand holding the needle driver should pull toward your body and the non-dominant hand should pull away from your body. Tighten the suture lightly, just so the edges of the incision meet, but do not overlap, pucker, or bulge the edges of the incision. The second knot is the same as the first, but in

reverse order. On the second knot, grasp the long end of suture material with your non-dominant hand, make two reverse wraps (i.e., toward you body) around the end of the needle driver, grasp the short end of suture with the needle driver, and tighten the stitch. This time, the knot should be tightened by pulling your dominant hand (holding the needle drivers) away from you and your non-dominant hand toward you. The second knot can be slightly tighter than the first, again taking care not to overlap, pucker, or bulge the edges of the incision. This completes one knot. Cut the suture with the hemostat or scissors, leaving ends approximately 2 mm in length.

5. After surgery is complete, use a pair of sharp scissors to clip a small piece (1cm^2) of tissue off the upper caudal fin. The fin clip should be small enough that it will not affect the swimming performance of the tagged smolt. Transfer the tissue sample to a piece of blotter paper and store in a envelope labeled with Date, fish ID, watershed, fish length and weight. Place in a warm area to dry.
6. Transfer fish to recovery tank as soon as possible.
7. .Each individual suture (one packet) can be used on 5 fish. Disinfect the suture material and the attached suture needle in the sanitizing solution used for instruments.

vii. Fish will then be placed into an aerated bucket so that individuals could be tracked while recovering from anesthesia and surgery.

1. Fish shall be considered recovered when it regains equilibrium and swims normally.
2. The time of recovery shall be recorded for each fish.
3. Transfer recovered fish into holding tank of fresh water.

viii. Between surgeries, the surgeon should replace the tools that were just used into the disinfectant bath. Each surgeon will have at least two (2) sets of surgical instruments to rotate through to ensure that tools get a thorough soaking in disinfectant for between uses (10 min minimum contact time with disinfectant). Each surgery station will have two trays of diluted Nolvasan™ and one of distilled water. Once disinfected in Novalsan™ solution, rinse the tools thoroughly with distilled or de-ionized water and ensure that the scalpel blade and suture are ready to use on the next fish. Organic

debris in the disinfectant bath reduces its effectiveness, so be sure to change the bath regularly. If necessary, replace the scalpel blade.

H. Post-operative recovery

i. transport to release location

1. When all fish in a recovery bucket have spent a minimum of 10 minutes in the bucket (exposed to high DO concentration) and regained equilibrium, transfer the bucket to the post-tag holding container (tank, raceway, or river area that has a constant flow of river water).

ii. timed release

1. The post-tag holding period must be consistent across the different tag sessions and release. If the tagging operation is not completed by the scheduled time, the release timing must be adjusted to accommodate the minimum post-tag holding period. Post-surgery holding time should be no shorter than 10 hours.
2. Tagged fish will be transferred to the release pen by pouring the 5-gallon recovery bucket into the pen. No dip net will be used to move the fish from recovery bucket to release pen.
3. Releases will be performed at least 1 hour after sunset to reduce predation potential during the corpuscular period. At target time range of 9 – 10pm will be used depending on when the fish were tagged, giving them at least 10 hours to recover before release.