Title: Movement and survival of wild Chinook salmon smolts from Butte Creek during their outmigration to the ocean: comparison of a dry versus wet year

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Abstract

California's Central Valley (CCV) Chinook Salmon (*Oncorhynchus tshawytscha*) stocks have declined substantially since the mid-1800s with most listed as threatened or endangered, or heavily supplemented by hatcheries. As the largest population of CCV wild spring-run Chinook Salmon, Butte Creek fish are an important source for promoting life history diversity in the CCV Chinook Salmon community. However, little information exists on Butte Creek juvenile mortality during out-migration to the ocean, which is considered a critical phase in the overall population dynamics. We used the Juvenile Salmon Acoustic Telemetry System (JSATS) to track the movement of individual fish, and a mark-recapture modeling framework to estimate survival of migrating wild Chinook Salmon smolts from lower Butte Creek to ocean entry at the Golden Gate Bridge. Survival and migration varied significantly among years; in 2015, a dry year, Chinook Salmon smolts migrated slower throughout their migratory corridor and exhibited lower survival than in a wetter year (2016), and among locations; fish migrated faster and experienced higher survival in the lower Sacramento River than in the Sutter Bypass and the Delta. Our data suggests that higher flow at release and larger fish lengths both resulted in increased survival. Our findings have shed light on a critical phase of the wild spring-run juvenile Chinook Salmon dynamics and could help inform future restoration and management projects that would improve the survival and abundance of the CCV spring-run Chinook Salmon populations.

Introduction

Balancing human demands for water with maintenance of a functioning ecosystem capable of supporting healthy Chinook Salmon populations has become a central challenge facing natural resource managers in California's Central Valley (CCV). Here, four runs of Chinook Salmon (*Oncorhynchus tshawytscha*) have evolved distinct life histories to capitalize on the diversity of habitat available in CCV rivers and streams. The runs are named according to the season in which the adults return to fresh water: fall, late-fall, winter, and spring (Healey 1991). Similar to many large West Coast rivers, Chinook Salmon stocks from the CCV have declined substantially since the mid-1800s, mainly due to the construction of large dams and habitat degradation (Yoshiyama 2001). Spring-run Chinook Salmon were once a major component of CCV Chinook Salmon runs and occupied the headwaters of all major CCV river systems where natural barriers were absent (Williams 2006). Now, self-sustaining spring-run populations survive only in three tributaries of the Sacramento River: Mill, Deer and Butte Creeks (Lindley et al. 2004). Spring-run are reported inconsistently in additional Sacramento River tributaries and are supplemented by stray spring-run adults from the Feather River Hatchery (Yoshiyama 2001). However, these additional stocks are believed to have been hybridizing with fall-run stocks since the 1960s due to spatial constrictions on previously separate spawning distributions created by dams (CDFG 1998). As a consequence of these various stressors, since 1999 the CCV spring-run Chinook Salmon evolutionarily significant unit (ESU) is state and federally listed as threatened (U. S. Office of the Federal Register 1999).

One of the fundamental objectives for managing spring-run populations for future recovery is ensuring that we are supporting and managing for the full range of life history diversity within the ESU (Beechie et al. 2006). Indeed, spring-run Chinook Salmon populations demonstrate unique juvenile rearing plasticity characterized by a wide range of size, timing, and age at which they out-migrate from their natal tributaries to the ocean (e.g., sub-yearling fry and smolt, yearling; CDFG 1998). Such life history diversity has been suggested to convey a stabilizing portfolio effect by providing each population the ability to buffer environmental changes due to anthropogenic forcing or climate, ultimately increasing the resiliency of the entire community (Hilborn et al. 2003; Greene et al. 2010, Schindler et al. 2010). As the largest population of CCV spring-run Chinook Salmon, Butte Creek fish are an important source for promoting diversity in the CCV Chinook Salmon community and have been the focus of considerable investment in the form of population monitoring and restoration efforts. Several restoration actions were implemented in the early 1990s by various state and federal agencies in coordination with water interests and local stakeholders (e.g. CALFED and the U.S. Fish and Wildlife Service's Final Restoration Plan for the Anadromous Fish Restoration Program (AFRP)) in order to restore and maintain CCV spring-run Chinook Salmon populations on a long-term basis. The Lower Butte Creek Project (LBCP), for instance, was established in 1997 to improve passage for protected fish species while maintaining the viability of commercial agriculture, private wetlands, government lands, and other habitats (ICF Jones & Stokes 2009). Although increases in returning Butte Creek spring-run Chinook adults have been observed in recent years, the success of those management efforts on enhancing juvenile survival and maintaining population life history diversity has yet to be determined.

Juvenile mortality during out-migration to the ocean is considered a critical phase to overall population dynamics (Healy 1991; Williams 2006). Tagging and tracking juvenile Chinook Salmon from their freshwater rearing habitats and through riverine systems and into the marine environment can help determine survival rates and identify locations where juvenile mortality is greatest during downstream migration. Acoustic tagging technology has become a well-established tool in estimating movement and survival rates of CCV Chinook Salmon juveniles (Perry et al. 2010; Michel et al. 2013, 2015). While these studies have mainly focused on hatchery smolts that are easily captured, tagged and released in large groups, little is known about the survival and movement of the remaining wild spring-run Chinook Salmon populations. Assessing juvenile mortality of wild spring-run Chinook Salmon is challenging in part due to the small size of these populations and the difficulty in capturing them during their out-migration. However, utilizing survival data from hatchery stocks as a surrogate for wild salmon survival dynamics is often 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 in their early life that hatchery smolts are able to avoid due to hatchery management and release practices (e.g. predation, water quality). In this paper we detail an acoustic tagging study implemented in lower Butte Creek and extending to the Golden Gate Bridge, aimed at assessing the movement and survival rates of the largest population of wild CCV spring-run Chinook Salmon smolts during their out-migration to the ocean. We were particularly interested in evaluating potential dissimilarities between survival through the Sutter Bypass; a floodplain which has been suggested to be important rearing habitat for juvenile Chinook Salmon (Garman 2013), and the lower Sacramento-San Joaquin River Delta, which is considered a strongly degraded habitat (Nichols et al. 1986). Moreover, previous studies have demonstrated that CCV juvenile out-migration survival can vary strongly among years due to various anthropogenic and environmental factors (Baker and Morhardt 2001; Brandes and McLain 2001; Michel et al. 2015). Therefore, we compared fish movement and locations of high mortality during out-migration for a hydrologically dry year (2015) versus a hydrologically wetter year (2016). We finally discuss the implications of our results on the long-term dynamics of the Butte Creek population and the implementation of future recovery actions.

<A> Methods

Study site.— Butte Creek is a tributary of the Sacramento River that originates at Humboldt Mountain on the western slopes of the Cascade Range at an elevation of more than 2,100 meters (Figure 1). The Butte Creek watershed encompasses an area of about 2,900 square kilometers and is connected to the Sacramento River at two locations, the Butte Slough Outfall Gates (BSOG) and the downstream end of the Sutter Bypass, a remnant flood basin habitat (Garman 2013). Butte Creek historically entered the Sacramento River at the BSOG, but is now diverted away from the Sacramento River for 40 kilometers into the Sutter Bypass

(Figure 1). This bypass is composed of two canals as well as the East-West Diversion weir which is used to control the flow of water going into the east and west side canals of the bypass. Several weirs along both canals divert water for agricultural or managed wetland uses (ICF Jones & Stokes 2009). During high flow conditions, water from the Sacramento River flows into the bypass through Moulton, Colusa and Tisdale weirs in order to prevent flooding of downstream areas.

Once juvenile salmon exit the Sutter Bypass and enter the Sacramento River above the town of Verona, they migrate downstream through the lower Sacramento River, Sacramento-San Joaquin Delta and San Francisco Bay before entering the Pacific Ocean. In a wet year fish could also cross the Sacramento River at the base of the Sutter Bypass and enter the Yolo Bypass through Fremont Weir, however no water from the Sacramento River spilled into the Yolo Bypass during 2015 and 2016 tagging period. The entire migration corridor considered for this study encompasses 249 river kilometers (rkm) from the release site in the Sutter Bypass to the Golden Gate Bridge.

Freshwater life history.— CCV spring-run Chinook Salmon demonstrate a unique diversity in life-history among the stocks of California Chinook Salmon. Adult spring-run Chinook Salmon ascend un-damned tributaries to elevations between 300 -1,500 meters when the spring freshet allows access, and hold in deep pools over summer before spawning in the fall. CCV spring-run juveniles emerge from the gravel between November and March, depending on water temperatures, and spend 3 to 15 months in fresh water before emigrating to the ocean (CDFG 1998). Spring-run Chinook Salmon juveniles exhibit a wide variety of rearing and out-migration strategies. They can either migrate out of the spawning habitat soon after emergence as fry during high flows in the winter, rear in their natal habitat and out-migrate as smolts during the spring, or remain in the stream for an entire year and out-migrate the following fall, winter, or spring as yearlings (CDFG 1998). Juveniles out-migrating from Butte Creek are assumed to be a mix of fry and smolts, with very few remaining in Butte Creek as yearlings (Clint Garman, California Department of Fish and Wildlife, Personal Communication). Smolt emigration peaks in April and May, but can extend from February through June (Ward et al. 2004a, 2004b, 2004c).

Acoustic tagging and receivers.— We used the Juvenile Salmon Acoustic Telemetry System (JSATS; McMichael et al. 2010) to track the movements and estimate survival of migrating wild spring-run Chinook Salmon smolts from Butte Creek. The transmitters (tags) were manufactured by Advanced Telemetry Systems (ATS), JSATS model SS300, with a tag weight in air of 300 mg and size of 10.7 x 5.0 x 2.8 mm. These tags emit a uniquely coded signal at 416.7 kHz at a pulse rate of about 5 seconds, and have an expected life of 32 days at these settings. The JSATS tag we used weighed 300 mg which allowed us to tag juvenile Chinook Salmon that weighed at least 6.0 g (approximate fork length = 80 mm) which resulted in tag burdens ≤5%. Laboratory studies comparing growth and survival between acoustically tagged and untagged juvenile salmon have suggested that tag burdens of less than 5% do not significantly affect acoustically tagged fish compared to untagged controls (Ammann et al. 2013; Brown et al. 2010).

To detect the presence of tagged fish we deployed acoustic receivers at several sites beginning at the capture/release site and ending at the Golden Gate Bridge (Figure 1). We used a combination of receivers manufactured by ATS, Teknologic and Lotek Wireless. The number of receivers deployed at each location varied from one to five depending on the channel width. Reaches were defined by receiver locations and varied from 0.5 to 100 rkm in length (Table 1). Each year we deployed all receivers prior to release of tagged fish then recovered and downloaded data at the end of June.

We collected fish using a 2.44 m diameter rotary screw trap (RST) installed at Weir 2 in the Sutter Bypass. 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 ensured that the 30 day acoustic tag battery life was utilized efficiently, allowing movement through the Sutter Bypass, Sacramento River, Delta and San Francisco Bay to be recorded. The RST was operated continuously (24 hours per day), and was emptied of fish each morning. All salmonids were measured (fork length (FL) in mm) and fish > 80 mm were implanted with an acoustic tag.

On the river bank adjacent to the RST, we set up a shaded work station to surgically implant tags before the sun was overhead and temperatures became too warm. The same surgeon implanted tags into the coelom of the fish for both years of the study. Fish were anesthetized (using 90 mg/l tricaine methanesulfonate), weighed, measured, photographed, then placed ventral side up in a padded V-channel. During surgery we irrigated the fish's gills with water containing a maintenance dose of anesthetic (30 mg/l). We made an incision on the ventral side of the fish between the pelvic girdle and pectoral fins with a Sharpoint 3 mm 15° stabbing blade scalpel. The incision was 6–8 mm long and 3 mm off the ventral midline. We inserted the tag into the coelom and oriented it so the tag transducer was posterior. We closed the incision with a single suture of 6-0 Polydioxanone absorbable monofilament and tied with a double-wrapped square knot (i.e. surgeon's knot). We placed tagged fish into a recovery bucket and monitored until they resumed their normal swimming behavior. After surgery, we held fish in holding pens just below Weir 2 for 12 hours before release at 22:00 hours (Pacific Standard Time), primarily to ensure the fish were fully recovered, but also because juvenile salmon tend to migrate at night (Chapman et al. 2013).

We also collected tissue samples from all tagged fish to identify their origin by using Genetic Stock Identification (GSI; Clemento et al. 2014). For each fish, we calculated the posterior probability that it originated from a given stock, and assigned the fish to the stock with highest posterior probability. Based on Satterthwaite et al. (2014) and communication with John C. Garza (NMFS-SWFSC), we considered assignments of fish with a maximum posterior probability exceeding 75% as robust stock assignments for this study. We did not assign a stock to fish with posterior probability less than 75%. The genetic analysis was performed at the Southwest Fisheries Science Center in Santa Cruz, CA.

Data analysis.— Tagged fish either completed their migration out of the study reaches or completed a partial migration and died before exiting the detection arrays. We used a spatial form of the Cormack-Jolly-Seber model (CJS; Cormack 1964; Jolly 1965; Seber 1986) to estimate reach-specific survival rates (ϕ_i) and detection probability (p_i). We considered the initial tag location as a "mark" and subsequent detections at downstream receivers as a "recapture". We used the method of maximum-likelihood to estimate survival and detection probabilities along with their 95% confidence intervals (Lebreton et al. 1992).

For consistency between tagging 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 (Table 1; Figure 1). Furthermore, because the length of reaches along the migratory path is not identical, we standardized survival estimates per 10 km in order to allow inter-reach survival comparisons. Finally, we estimated regional (Sutter Bypass, Sacramento River, Delta and Bay) and overall (from the release site to the Golden Gate Bridge) survival for both years, using methodology described in Michel et al. (2015).

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 * year*; see Table A1 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 models that included fish characteristics (i.e. fish length and Fulton's condition factor (K)), and environmental variables (i.e. Sutter Bypass flow and water temperature at release). We used flow data from Butte Slough near Meridian (CDEC station BSL, http://cdec.water.ca.gov/cgi-progs/stationInfo?station_id=BSL) located downstream of BSOG (closest flow gauge to the Sutter Bypass release site), and temperature data from the Butte1 acoustic receivers (post calibrated at the Southwest Fisheries Science Center, Santa Cruz, CA). 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 3 for list of models). We deliberately excluded the *year* variable from all covariate models because the inclusion of this variable would have accounted for the majority of interannual variability in survival, and therefore masking any influence of the individual/environmental covariates and providing 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 covariates had been determined from the model selection exercise, we extracted the standardized β parameter coefficients for these covariates 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 fish between its last detection in one reach to its first detection at the next reach.

<A> Results

In 2015, we deployed the RST on April 1st and tagged fished for 11 days between April 6th and April 16th. In that period of time we tagged and released a total of 141 smolts. In 2016 we started tagging on April 14th, and were able to tag and release our target of 200 juveniles by April 18th. In 2015 the mean fork length was 104.75 mm and the mean weight was 13.47 g, whereas in 2016 the average fish tagged was 110.02 mm and 16.68 g (Table 2).

<B> Genetic assignment

The genetic analysis suggests the smolts tagged in the Sutter Bypass were a mix of CCV fall-run and spring-run origin. In 2015, 6 smolts were confidently identified as CCV fall-run fish and 124 smolts as CCV spring-run fish while in 2016 a higher proportion of fish tagged were genetically classified as CCV fall-run fish (121 fall-run versus 65 spring-run; Table 2). It also appears that, although fall-run smolts were slightly larger in both years, fall-run and spring-run smolt exhibit similar size range (Table 2; Figure A1). We performed an F-test (var.test function in R) to compare fall-run versus spring-run smolt length variances for each year and found no statistical difference between spring-run and fall-run fish length distributions (2015 p-value= 0.1489, 2016 p-value= 0.9086). This implies that no length cutoff could be robustly applied to these two runs, 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 were a good proxy for the purpose of this study.

The rotary screw trap used in this study was located below Butte Creek fall-run spawning habitat, it is therefore likely that many of the captured fall-run smolts were wild Butte Creek fall-run Chinook Salmon. In addition, because Sacramento River water spilled into the lower Butte Creek watershed via Moulton, Colusa and Tisdale Weirs several times before the tagging experiment took place, it is also possible that some of the tagged fall-run fish originated from the mainstem Sacramento River or another tributary and used the Sutter Bypass as a migratory corridor.

<B> Hydrological conditions

The 2015 water year, California experienced an extreme drought that was classified as “critical”, while the 2016 water year was considered “below normal” by the California Department of Water Resources (DWR; CDEC data). 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. Therefore, the hydrological conditions experienced by the migrating smolts changed considerably between the two years of the study. 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 stayed very low during the entire study period, averaging 4.03 m^3s^{-1} at BSL (Figure 2A). In 2016 we tagged and released fish after a flood event, and 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 12.91 m^3s^{-1}. The same pattern was observed in the Sacramento River reach, with an average flow of 160.29 m^3s^{-1} in 2015 and 381.53 m^3s^{-1} in 2016 (CDEC station at Verona, http://cdec.water.ca.gov/cgi-progs/stationInfo?station_id=VON; Figure 2A).

In 2015, water temperatures in the Sutter Bypass and the Sacramento River increased throughout the tagging experiment (Figure 2B). Water temperature at the Butte1 receiver peaked at 18.5°C during the tagging period, then kept increasing and reached 21°C by the end of April. Similarly, water temperature in the Sacramento River increased from 14°C to 22°C during the month of April 2015 (CDEC station at Verona, http://cdec.water.ca.gov/cgi-progs/stationInfo?station_id=VON). In 2016, the Sutter Bypass water temperature, during the tagging period, varied between 18°C and 19.5°C. The peak water temperature at the Butte1 receiver was 21°C on April 21, 2016. The Sacramento River water temperature in 2016 slowly increased throughout the month of April but never exceeded 18°C.

<B> Fish movement

In 2015, 27 of the 141 tagged fish (19.1%) were detected entering the Sacramento River, 14 fish (9.9%) were detected entering the Delta and only 1 fish (0.7%) was detected at the Golden Gate Bridge. In 2016, 71 of the 200 tagged fish (35.5%) were detected entering the Sacramento River, 49 fish (24.5%) were detected in the Delta and 4 fish (2%) were detected at the Golden Gate Bridge. Although some variability in movement rates among fish was observed each year, especially in the Sacramento River, most of the tagged smolts moved quickly throughout the migration corridor (Figure 3). On average, it took fish 6 days in 2015 versus 2 days in 2016 to transit the Sutter Bypass, and 2 days in 2015 versus 1 day in 2016 to transit the Sacramento River (Table 4). The single fish that survived to the Golden Gate Bridge in 2015 migrated through the Delta in less than 5 days and migrated from the release site to the Pacific

Ocean in 27 days. In 2016, it took an average of 5 days to migrate through the Delta, and 18 days to migrate from release site to the ocean (Table 4).

Tagged fish migration rates were higher in the Sacramento River compared to the Sutter Bypass and Delta in both years (Figure 3; Table 4). Based on a Tukey test (TukeyHSD function in R), migration rate in 2016 was significantly higher than in 2015 in the Sacramento River and the Sutter Bypass (Sutter Bypass p-value < 0.001, and Sacramento River p-value < 0.001); migration rates were significantly higher in the Sacramento River compared to the Sutter Bypass in both years (2015 p-value = 0.0, and 2016 p-value = 0.0). We calculated a mean migration rate of 10.24 kilometers per day (km d^{-1}) in the Sutter Bypass and 33.21 km d^{-1} in the Sacramento River in 2015 versus estimates of 22.13 km d^{-1} and 56.83 km d^{-1} respectively in 2016 (Table 4). Since only one fish was successfully detected at Benicia (the Delta exit location) and the Golden Gate Bridge in 2015, it was not possible to estimate Delta and Bay travel rate statistics for that year. However, more fish were detected in 2016 and the average movement rate through the Delta was estimated at 22.48 km d^{-1}.

<B> Survival estimates

The full model, strongly supported as the single best model (AICc = 1383.726, and ΔAICc of the second best model greater than 8; Table A1), includes survival as a function of *reach * year*, and a constant detection probability. This suggests that outmigrant smolt survival varies by location and year. Additionally, although the best model supported a constant detection probability, the spatially-explicit models (i.e. *p(~reach))* suggested that detection rates throughout the migratory corridor were consistently high, ranging from 0.851 to 1. For all model exercises presented in this paper, detection probability was therefore set to be constant through space and time, and was estimated to be 0.993.

After including individual and environmental variables in the analysis, the ϕ*(~reach + year)* model was selected as the best model, emphasizing the strong year effect on smolts survival (Table 3). The Sutter Bypass flow at release covariate model was substantially better supported (ΔAICc > 3) over the base model ϕ*(~reach)*. Furthermore, it shared similar support (ΔAICc < 3) to the ϕ*(~reach +* year) model (which benefitted from a free parameter), suggesting that the flow model explained much of the variation in interannual survival. The model including fish length also had substantial support over the base model (ΔAICc < 6), and suggested a positive influence of fish length on survival. However, the models including water temperature at release and condition factor (K) were not better supported than the base model, suggesting that these covariates had no detectable influence on survival.

We used the full model (i.e. ϕ(*~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 better in 2016 than in 2015 (3.0% versus 0.7%; Table 4). At the regional level comparing 2015 to 2016, survival increased in the Sutter Bypass from 19.1% to 35.5%, in the Sacramento River from 51.8% to 69.0%, and in the Delta from 7.1% to 12.2% (Figure 4; Table 4). For both years, the highest regional survival was observed in the lower Sacramento River, while the lowest estimate was for the Delta region. However, the length of each region varied considerably (the Delta region is about twice as long as the Sutter Bypass and Sacramento River regions; Table 1), and survival often decreases proportionally with increasing region length.

Per 10km survival rates varied dramatically between reaches within the Sutter Bypass, Sacramento River and Delta, and some similar survival patterns were observed among years (Figure 5). In the Sutter Bypass, relatively low survival was observed between the release site and the first receiver (Weir2_RST – Butte 1 in Table 1; 27.1% in 2015) and between Butte3 and Butte5 receivers (39.3% in 2015 and 65.1% in 2016). Survival was higher in the other reaches of the Sutter Bypass, ranging from 72.5% to 94.0% in 2015 and 79.8% to 84.7% in 2016. In the Sacramento River for 2015, survival decreased from the first reach (Butte6 - I80_Br) to the second reach (I80_Br – Freeport), whereas it increased in 2016 (91.9% and 82.5% in 2015, and 92.6% and 95.1% in 2016). Survival in the Delta was lower than in the Sacramento River for both years (76.8% in 2015 and 81.1% in 2016). Finally, due to the low number of tagged fish surviving to the Golden Gate Bridge (n=1 in 2015, and n=4 in 2016) the 2015 survival rate in the San Francisco Bay could not be estimated, and the 2016 San Francisco Bay survival rate should be used for discussion purpose only.

<A> Discussion

This is the first study to investigate the survival and migration rates of wild Butte Creek spring-run Chinook Salmon smolts during their out-migration to the Pacific Ocean. The acoustic telemetry system used in this study had high detection probabilities greater than 85% at all receiver locations. The mark-recapture models provided estimates of survival at fine spatial scales during a dry and wet water year. We showed that Chinook Salmon smolts migrated faster throughout their migratory corridor in 2016 (wet year) than in 2015 (dry year). This difference is likely due to higher flow velocities, both in the Sutter Bypass and in the Sacramento River in 2016 compared to 2015. The mean migration rate to the ocean (Golden Gate Bridge) was 33.7 km d^{-1} for 2016 which is faster than total mean migration rate for Sacramento River late-fall Chinook Salmon (14.3-23.5 km d^{-1}, 2007-2009) reported by Michel et al (2013).

Survival to the ocean was also higher in 2016 than in 2015 (0.7% in 2015 and 3.0% in 2016; Table 4). However, 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 2015 and 2016 survivals found by Faulkner et al. (2016; 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 38.3% in 2015 and 33.0% in 2016 through the entire 910km watershed). However, the fish tracked in these two studies were larger in size than the fish tagged in the Sutter Bypass, and we have shown that fish length influences out-migrating fish survival. 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.

In the Sutter Bypass there were two reaches with substantially lower survival than the other reaches; from the release site to Butte1 during 2015, and between receivers Butte3 and Butte5 in both years. These two reaches had the lowest survival per 10 km of all reaches in 2015, and the Butte3 – Butte5 reach had the lowest survival per 10 km of all reaches in 2016. Common to both these reaches are in-river diversion weir structures; at the start of Weir2_RST – Butte1 reach and 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 weir 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 both years. If predators are generally concentrated below these diversion weirs, and furthermore if their concentration was enhanced during the low flow conditions in 2015, this may explain the lower survival of juvenile Chinook Salmon in these two reaches.

Similarly, predation could play an important role in the Sacramento River and Delta reaches as spring-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). The increase in survival observed in 2016 in the Sutter Bypass and the Sacramento River corroborates with the assumption that an increase in flow induces an increase of fish transport as well as a potential increase in turbidity, which could both reduce spatio-temporal exposure to predation (Gregory and Levings 1998; Michel et al. 2013 and references therein). The higher flow observed in the Sacramento River in comparison to the Sutter Bypass could explain the relatively higher survival and faster migration rate observed in this region.

On the contrary, the relatively lower survival and slower migration rates observed in the Delta could be explained by the complex network of natural and man-made tidally-influenced channels that salmon smolts need to navigate on their journey to the ocean, increasing their exposure to potential predators (Nichols et al. 1986). Perry et al. (2010) demonstrated that survival through the Delta was dependent on the fish route selection, which depends strongly on natural flow conditions and the amount of water exported for the state and federal water project. Poor Delta water quality has also been suggested to influence out-migrating Chinook Salmon smolts survival by decreasing their swimming performance, and presumably their predator evasion capabilities (Lehman et al. 2017).

It is important to note that our study focused on a single rearing and out-migration life history strategy where spring- and fall-run juveniles leave the tributaries as smolts. The results of this study might not be representative of other life history strategies where juveniles out-migrate as fry, parr and yearlings. Smolts evolved to out-migrate 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 smolt out-migration life history studied here in broader context.

Our results have strong implications for the management of threatened CCV spring-run Chinook Salmon populations. Butte Creek currently supports the most abundant population of spring-run Chinook Salmon in the CCV and is a key component for the diversity and viability of the spring-run stock. The Sutter Bypass has been designated by NOAA Fisheries as a critical habitat for CCV spring-run Chinook Salmon and is considered an important rearing habitat and migratory corridor (Johnson and Lindley 2016). Therefore, to clearly identify the effects of fish characteristics and environmental variables in relation to juvenile movement and survival, a longer time series with increased sample size is necessary. Moreover, further investigation on salmon predation, especially at in-river structures, and improved water quality monitoring in the Sutter Bypass (i.e. water temperature, flow and turbidity along the Bypass) are critical to clearly assess the reasons for low survival in some of the reaches. This type of information will help target restoration and management projects on specific areas within the Sutter Bypass that could improve spring-run juvenile survival and ultimately lead to increased abundances of adults returning to spawn in Butte Creek. This information could also benefit other runs of CCV Chinook Salmon which use the lower Butte Creek system as a nursery and migratory corridor when accessible, and would ultimately promote CCV salmon stock diversity and stability.

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Table 1. Study reach location, distance from Golden Gate (rkm) and length (km).

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	12.00	
Sutter Bypass	Butte3 – Butte5	226.46 – 216.98	9.48	
Sutter Bypass	Butte5 – Butte6	216.98 – 206.48	10.50	
Sacramento River	Butte6 – I80 Bridge	206.48 – 170.74	35.74	54.05
Sacramento River	I80 Bridge - Freeport	170.74 – 152.43	18.31	
Delta	Freeport – Benicia	152.43 – 52.04	100.39	100.39
Bay	Benicia – Golden Gate	52.04 – 0.80	51.24	51.24

Table 2. Weight (g) and Fork length (mm) of juvenile Chinook Salmon captured, tagged and released at the Sutter Bypass RST in 2015 and 2016. Group assignment is shown only for fish with genetic stock assignment posterior probability exceeding 75%. n = sample size; SD = standard deviation.

Year	**Group**	**n**	**Mean Weight (SD)**	**Mean (SD)/Min/Max Length**		
2015	CV fall-run	6		112.67 (16.85)	84	135
	CV spring-run	125		104.00 (11.73)	80	136
	All	141	13.47 (5.36)	104.75 (12.28)		
2016	CV fall-run	121		114.60 (6.82)	98	128
	CV spring-run	65		103.51 (6.88)	85	122
	All	200	16.68 (7.68)	110.02 (10.93)		

Table 3. Comparison of ~*reach + year* survival model versus models including *reach* and individual/environmental covariates (fish length, condition factor (*K*), Sutter Bypass flow and water temperature at release). The detection probability (*p*) is constant for each model. Npar = number of model parameters; AICc = AIC score corrected for small sample size; ΔAICc = distance from the most parsimonious model; w = Akaike weights. Models are ordered from lowest to highest AICc. Lower AICc scores indicate greater relative model parsimony. β parameter estimates are shown for the two covariate models with substantial support over the reach only model.

Model	**Npar**	**AICc**	**ΔAICc**	β **coefficient**
ϕ *(~reach + year) p(~1)*	11	1394.074	0	
ϕ *(~reach + ReleaseFlow) p(~1)*	11	1396.929	2.85	0.24
ϕ *(~reach + Fish Length) p(~1)*	11	1402.226	8.15	0.17
ϕ *(~reach + ReleaseTemp) p(~1)*	11	1404.477	10.40	
ϕ *(~reach) p(~1)*	10	1405.719	11.64	
ϕ *(~reach + K) p(~1)*	11	1406.765	12.69	

Table 4. Overall and per region percent survival, mean migration rate (km d^{-1}) and mean migration time (d), along with their standard error (SE) and standard deviation (SD), for juvenile Chinook Salmon tagged each year. NA = Not Applicable.

Year	Region	% Survival ± SE	Mean migration rate (km d^{-1}) ± SD	Mean migration time (d) ± SD
2015	All	0.7 ± 0.7	NA	NA
	Sutter Bypass	19.1 ± 3.3	10.24 ± 4.61	5.75 ± 4.28
	Sacramento River	51.8 ± 9.6	33.21 ±14.31	1.88 ± 0.73
	Delta	7.1 ± 6.9	NA	NA
2016	All	3.0 ± 1.2	33.69 ± 15.32	18.44 ± 3.93
	Sutter Bypass	35.5 ± 3.4	22.13 ± 6.21	2.15 ± 0.81
	Sacramento River	69.0 ± 5.5	56.83 ± 16.26	1.09 ± 0.57

Figure captions

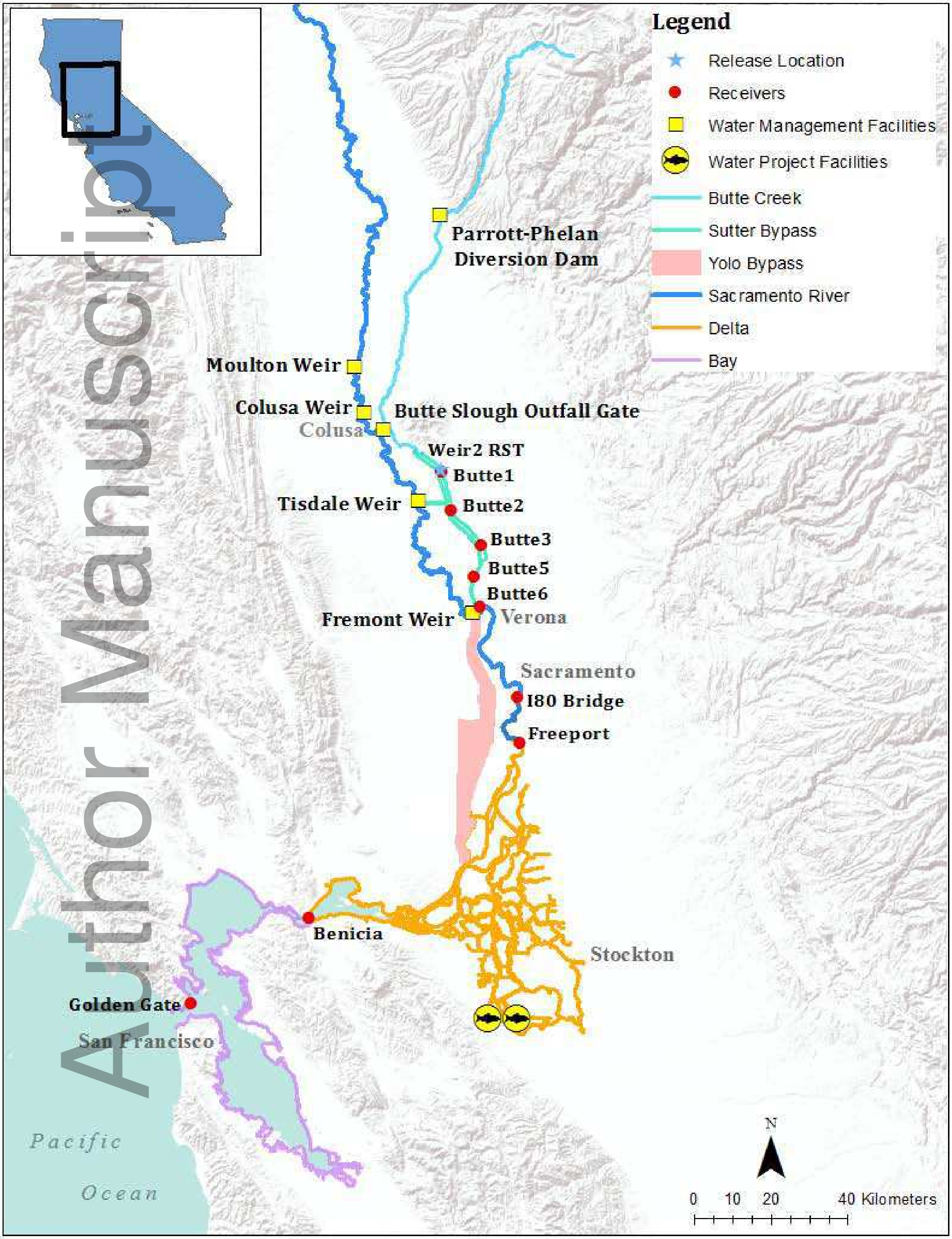
Figure 1. Map of the California's Central Valley showing the different regions considered in the study, the release and receivers location.

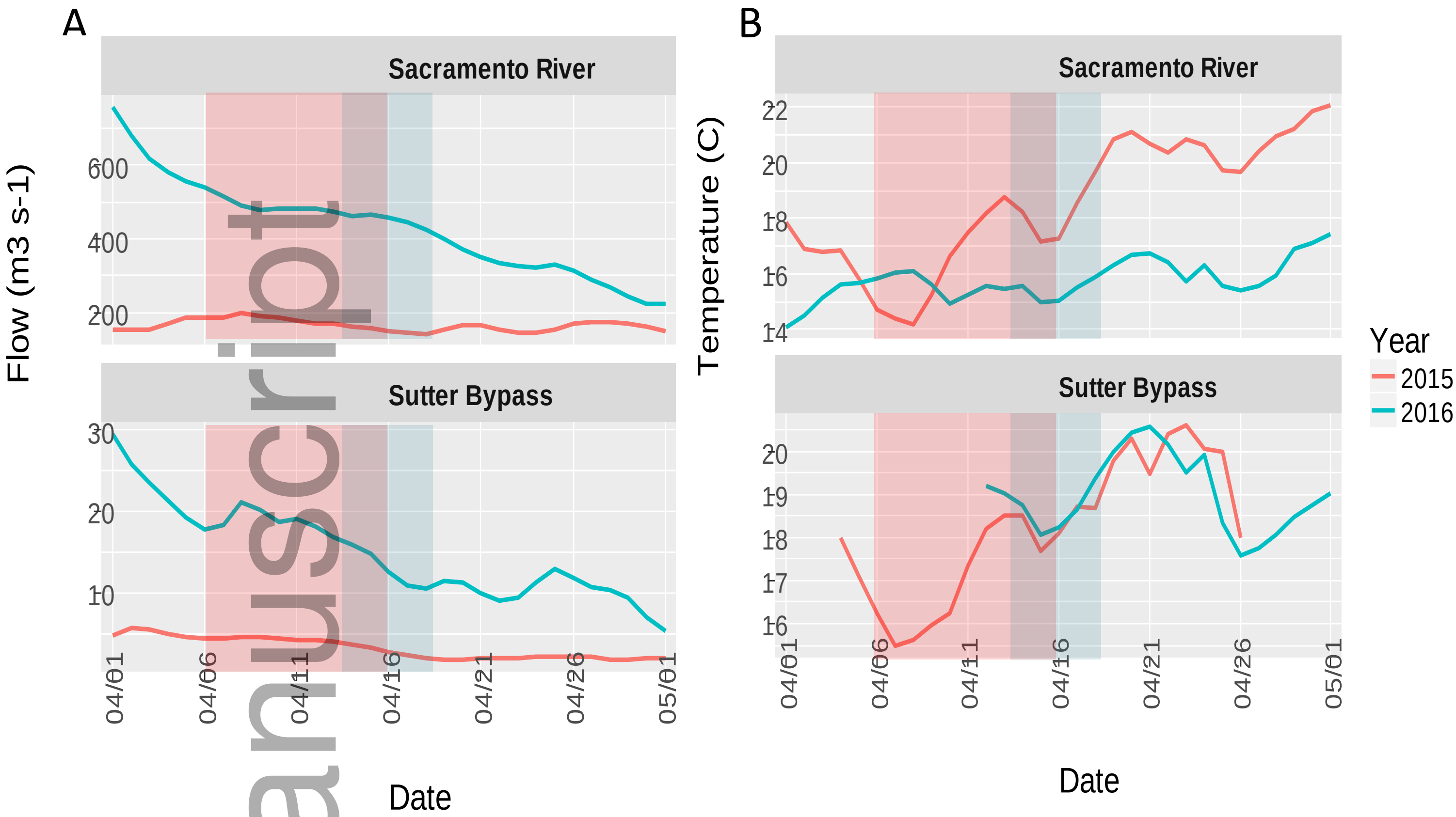
Figure 2. A. Mean daily flow in April of 2015 and 2016 from the Sacramento River (Verona station: http://cdec.water.ca.gov/cgi-progs/stationInfo?station_id=VON), and Sutter Bypass (BSL station: http://cdec.water.ca.gov/cgi-progs/staMeta?station_id=BSL). B. Mean daily water temperature during April 2015 and 2016 from the Sacramento River (Verona station: http://cdec.water.ca.gov/cgi-progs/stationInfo?station_id=VON), and Sutter Bypass (Butte1 site, ATS receiver thermistor). The shaded rectangles indicate tagging and release time period in Sutter Bypass for 2015 in red and 2016 in blue.

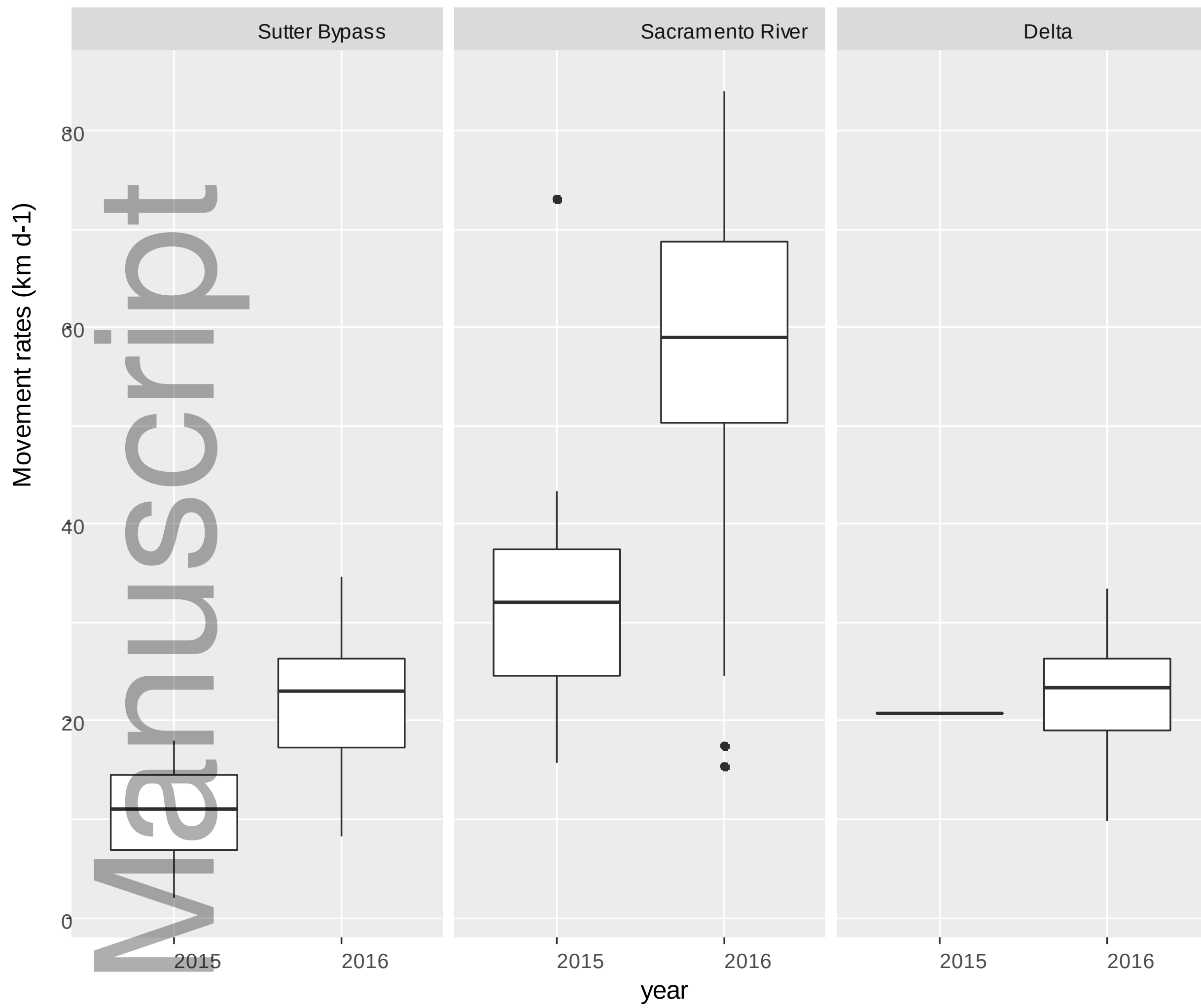
Figure 3. Boxplot of per year region movement rates (km d^{-1}). The horizontal bold line represents the median value and the vertical whiskers represent the 95% percentiles. The dots are extreme values.

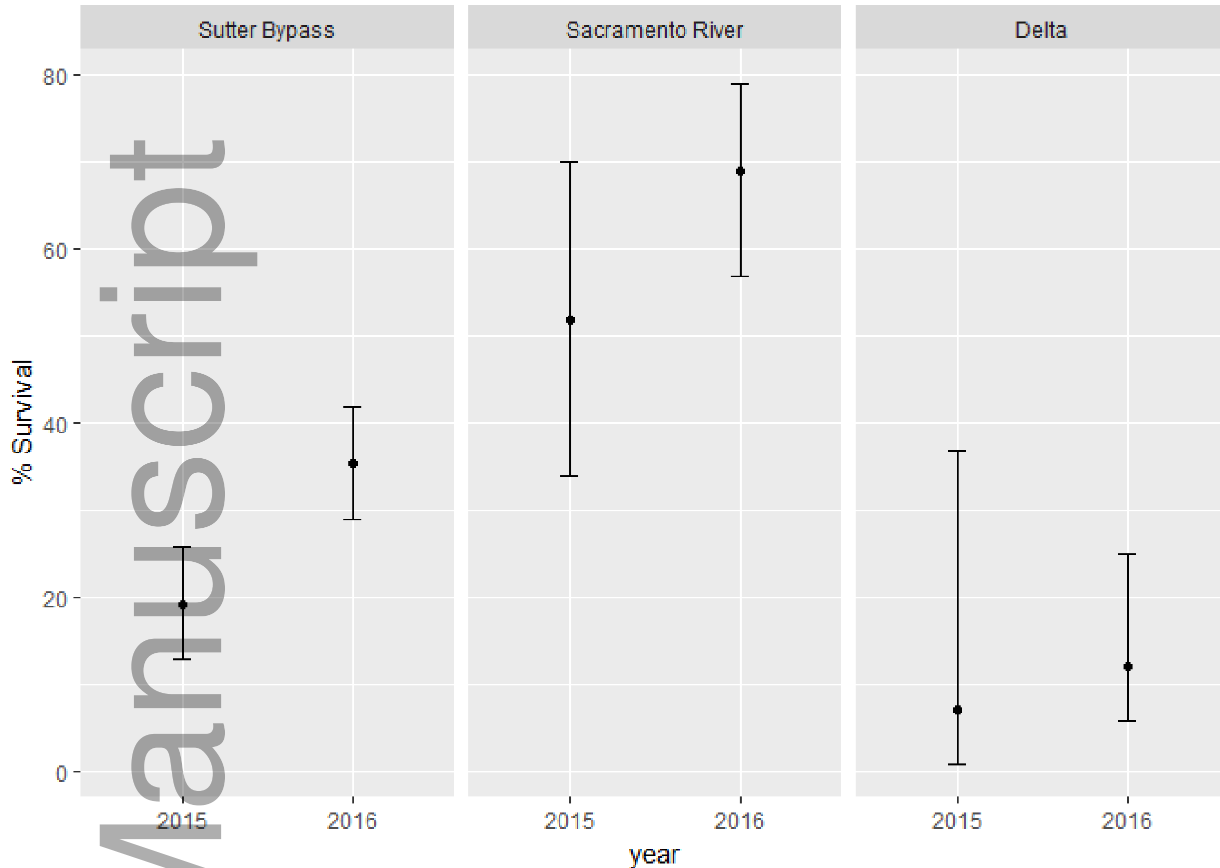
Figure 4. 2015 and 2016 region survival rates with their lower and upper 95% confidence limits.

Figure 5. 2015 and 2016 reach specific per 10km survival rate estimates along with their lower and upper 95% confidence limits.

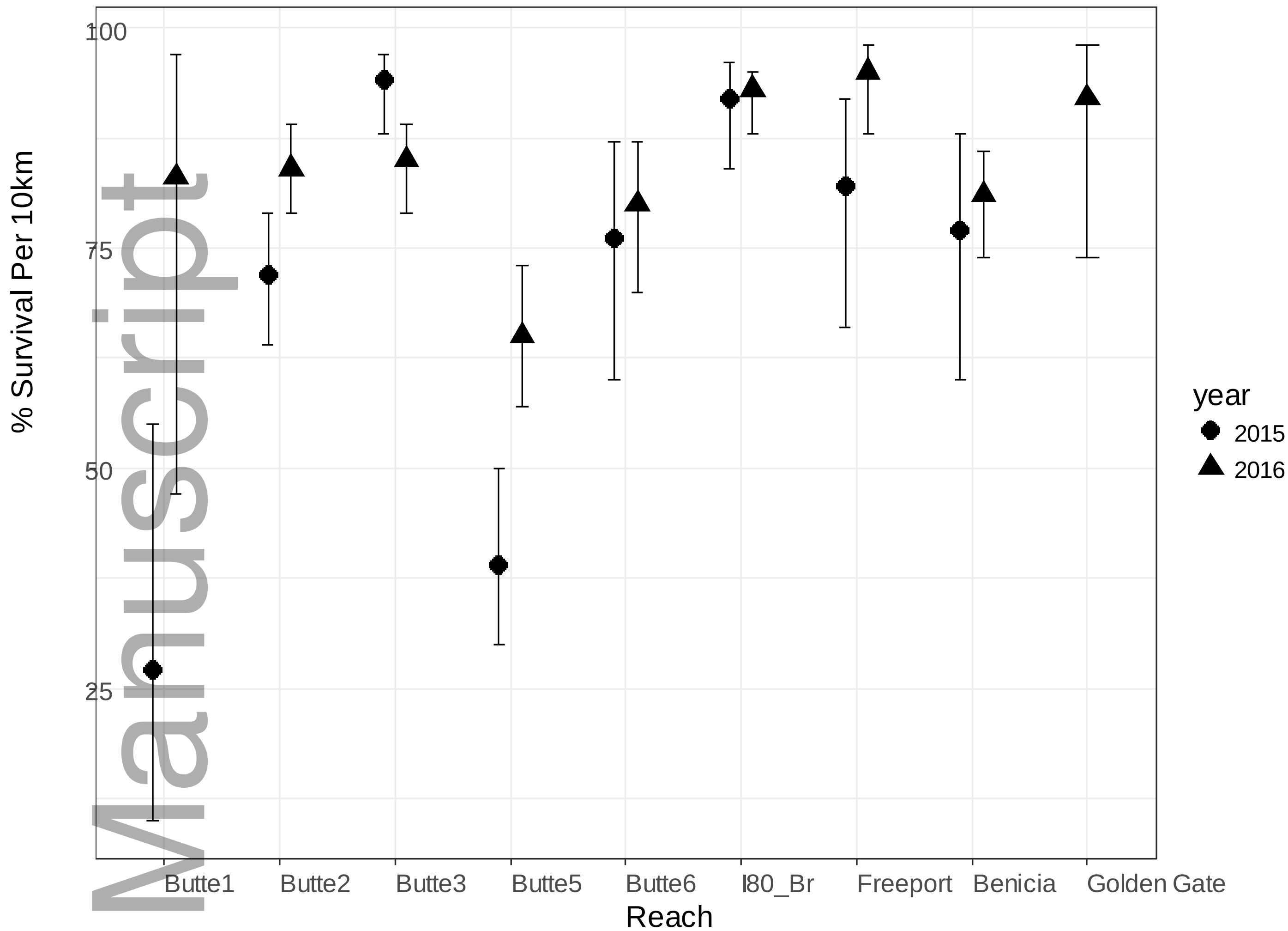

Legend
Release Location
Receivers
Water Management Facilities
Water Project Facilities
Butte Creek
Sutter Bypass
Yolo Bypass
Sacramento River
Delta
Bay
Parrott-Phelan
Diversion Dam
Moulton Weir
Colusa Weir
Colusa
Butte Slough Outfall Gate
Weir2 RST
Butte1
Tisdale Weir
Butte2
Butte3
Butte5
Butte6
Fremont Weir
Verona
Sacramento
I80 Bridge
Freeport
Benicia
Stockton
Golden Gate
San Francisco
Pacific
Ocean
N
0 10 20 40 Kilometers


A
B
Sacramento River
Sutter Bypass
Flow (m3 s-1)
600
400
200
30
20
10
Temperature (C)
22
20
18
16
14
20
19
18
17
16
04/01
04/06
04/11
04/16
04/21
04/26
05/01
Date
Year
2015
2016


Sutter Bypass
Sacramento River
Delta
Movement rates (km d-1)
80
60
40
20
0
2015
2016
2015
2016
2015
2016
year



Sutter Bypass
Sacramento River
Delta
80
60
40
20
0
% Survival
2015
2016
year



100
75
50
25
% Survival Per 10km
Butte1
Butte2
Butte3
Butte5
Butte6
I80_Br
Freeport
Benicia
Golden Gate
Reach
year
2015
2016