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Spring-run Juvenile Survival and Travel Time Model

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Acknowledgments

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Acronyms and Abbreviations

Term	Definition
°C	degrees Celsius
AIC	Aikake information criteria
ATS	Advanced Telemetry System
BT-SPAS	Bayesian Temporally Stratified Population Analysis System
CDFW	California Department of Fish and Wildlife
CJS	Cormack-Jolly-Seber
CV	coefficient of variation
Delta	Sacramento–San Joaquin River Delta
DWR	California Department of Water Resources
ITAG	Interagency Telemetry Advisory Group
JPE	juvenile production estimate

Term	Definition
JSATS	Juvenile Salmon Acoustic Telemetry System
LOOCV	leave-one-out cross validation
LOOIC	leave-one-out cross-validation information criterion
RL	receiver location
RST	rotary screw trap
spring-run	spring-run Chinook salmon

1 Overview

As part of forecast model to predict a spring-run Chinook salmon (*Oncorhynchus tshawytscha*) (spring-run) juvenile production estimate (JPE), a submodel was required to predict juvenile migration survival from rotary screw trap (RST) locations on spring-run tributaries to the Sacramento–San Joaquin River Delta (Delta) entry (Figure 1). The model we developed uses fish detection data from acoustic telemetry studies to estimate smolt survival rates for juveniles migrating through the Sacramento River from the upper Sacramento and its tributaries (Battle Creek, Clear Creek, Mill Creek and Deer Creek), and from Butte Creek and the Feather River, to Sacramento (i.e., to the Delta entry). This model can be used for forecasting by modeling survival rates as a function of individual (e.g., length, weight) and/or environmental covariates (e.g., water year type). Survival forecasts can be combined with predicted tributary juvenile outmigrant abundances and size distributions at RST sites to obtain a JPE forecast; srJPE, the integrated model, is described separately in Chapter 3 and on Figure 2.

2 Methods

2.1 Data

We used acoustic telemetry data to estimate 1) survival across multiple populations and years, and 2) travel time of tagged fish from release to Delta entry. We also evaluated the effects of a wide range of hydrological conditions on those survival estimates.

The tagging data used for this work was obtained through the Interagency Telemetry Advisory Group (ITAG). The Juvenile Salmon Acoustic Telemetry System (JSATS) acoustic transmitters (tags) were manufactured by Advanced Telemetry Systems (ATS), with a tag weight in air of 300 milligrams (mg) and a size of 10.7 x 5.0 x 2.8 millimeters (mm). These tags emit a uniquely coded signal at 416.7 kilohertz (kHz) at a pulse rate of 5 seconds and have an expected life of 32 days at these settings. Using a 5% tag-to-fish-weight burden, the 300-mg JSATS tags allowed juvenile salmon weighing at least 6.0 grams (g) and approximately 80 mm in fork length to be tagged. We used available data from both spring-run and fall-run smolt releases to increase the sample size because there was an insufficient number of smolt-size spring-run fish that were tagged. Fall-run juveniles are considered a good spring-run surrogate because they migrate through the Sacramento River at similar sizes and times of year. The model was fit to data from 14,520 tagged individuals across 11 years (2013–2024) from 43 release groups (23 in the upper Sacramento River and 20 in the Butte/Feather watershed) (Figure 1, Table 1). The size range of tagged hatchery fish was similar to the wild fish except for a few very large wild fish that were tagged in one of the release groups (Figures 3 and 4). Therefore, we assume hatchery fish adequately represented wild fish.

After release, tagged fish could be detected at acoustic receiver locations (RLs) deployed in the Sacramento mainstem and some bypass channels. We subset the detection data to include a few key RLs within the region of interest (defined as the Sacramento River from the confluence with Battle Creek to the city of Sacramento), based on receiver data consistency across years (Figure 2). The selected RLs include Woodson Bridge (river kilometer [rkm] 429), at the upstream end of the region of interest, Butte Bridge (rkm 341), near the city of Sacramento (rkm 171), and Delta exit. Since a secondary migration route through the Yolo Bypass exists during wet conditions, allowing fish to avoid migrating through the mainstem Sacramento River, we added data from receivers within and at the end of the Yolo Bypass (rkms 120 and 107) to the Sacramento receiver data, thus ensuring both potential routes were covered. The final detection location (Delta exit) combined data from two RLs in the Delta (at Chipps Island, rkm 71, and at Benicia, rkm 52). The JPE model only requires estimates of survival to Sacramento, which is very close to Delta entry. However, we included a Delta exit station to improve estimates of survival at Delta entry. Chipps Island receivers near the Delta exit station were added in 2017. Prior to this, the next downstream receivers along the migration route were at Benicia. Comparison of detections before and after 2017 suggest a higher detection rate could be observed in years after the additional receivers at Chipps were deployed.

To estimate travel time, we used the observed individual travel times of tagged fish from release to the four RLs (Woodson Bridge, Butte Bridge, Sacramento, Delta exit) to fit travel time models for upper Sacramento River fish, and from release to the two RLs (Sacramento and Delta exit) for Butte Creek and Feather River fish. Travel time can only be observed when fish are detected. Individuals not detected at any of the locations after release provide no information about travel time and were therefore not included in the travel time modeling.

2.2 Mark-recapture Analysis

We developed a Bayesian Cormak-Jolly-Seber (CJS) juvenile survival and travel time model in the Stan software package. The model was taken from the Stan example at https://mc-stan.org/docs/stan-users-guide/mark-recapture-models.html. The juvenile survival and travel time model estimates survival rates in each of four reaches based on detection data from stations located at the downstream boundary of each reach (Tables 2 and 3). The model is fit using individual capture histories, which are five-digit (for fish released in the upper Sacramento River) or three-digit (for fish released in Butte Creek and the Feather River) sequences of 0's or 1's for each detection location (CH[i,ir], where i represents the individual and ir represents the detection location). Since all individuals were marked prior to release, the first digit for all individual capture histories is 1. The remaining digits depend on whether the individual was detected (1) or not detected (0) at each station. Table 2 lists tag detection locations and associated reaches used in the modeling for fish released in the upper Sacramento River.

A core element of the juvenile survival and travel time model is that individuals known to be alive at downstream locations are assumed to have passed all upstream locations, and can therefore inform detection probability at those upstream locations. For example, an individual with the capture history CH[i,1:5] = 10010 must have been alive in the Release-Woodson, Woodson-Butte, and Butte-Sacramento reaches as it was detected at the Sacramento station (the '1' in the fourth digit, Table 2). Parameters defining survival rate are estimated using a Bernoulli distribution. The Bernoulli distribution calculates the likelihood of observing a 0 or 1 given an estimated probability (e.g., the probability of flipping a head for a single toss of balanced two-sided coin will have a probability of 0.5). Estimates of survival and detection probability also depend on on χ (chi in source code), the calculated probability of not being detected after the final observed detection. This probability is the sum of the probabilities of not surviving and the probabilities of surviving but not being detected.

Station-specific detection probabilities in each year (in logit space) were random normal variables drawn from a common normal hyper-distribution,

Equation 1.

$$pcap_{iyr,ir} \sim normal(\mu\_P_{ir}, \sigma\_P_{ir})$$

Where:

pcap are year (iyr) - and reach (ir) -specific detection probability in logit space so that transformed detection probabilities cannot be less than zero or greater than one.

μ_P and σ_P are the station-specific means and standard deviations of the normal hyper-distributions from which annual values for each reach are drawn.

In cases where detection probability is well-determined from the data, the estimated detection probabilities drawn from the hyper-distributions will be very close to the independent estimates (i.e., those estimated without a hyper-distribution), and these years contribute heavily to the estimates of the hyper parameters μ_P and σ_P. In cases when information about detection probability is low (e.g., Delta exit location due to the small number of fish surviving to this reach), the estimated detection probabilities will be more strongly influenced by the hyper-parameters and shrink towards the across-year mean μ_P values for each station.

We developed a series of survival models to understand factors driving survival rates, and this facilitated using the juvenile survival and travel time model to make forecasts of survival rates. The simplest model estimates reach-specific means and a random effect of release group by reach for both the upper Sacramento River (2a) and Butte/Feather (2b) fish,

Equation 2a.

$$surv\_100_{i,ir} = S\_bR_{ir} + S\_RE_{irg[i],ir}$$

Equations 2b.

$$survT\_100_{i,ir=1} = S\_bT_{itrib} + S\_RET_{irgT[i],ir=1}$$

$$survT\_100_{i,ir=2} = S\_bR_{ir=4} + S\_RET_{irgT[i],ir=2}$$

Where:

surv_100 and survT_100 are the logit-transformed survival rates for individual i in reach ir (with ir=1:4 for upper Sacramento releases (Table 1) and ir=1:2 for

Butte/Feather releases [Table 3]) and tributary itrib, over 100 km of stream length.

We scaled the survival over 100 km to allow to compare survival in reaches of different lengths (e.g, for upper Sacramento fish reach 1 = Release to Woodson Bridge = 43 km vs reach 2 = Woodson to Butte bridge = 88 km; refer to Tables 1 and 2). S_bR and S_bT represent the reach-specific and tributary-specific average survival rates (in logit space) per 100 km, and S_RE and S_RET are random effects for release group irg and irgT that individual 'i' belongs to (irg[i] = 1:23 and irgT[i] = 1:20) for each reach ir. Initially survival rates to Sacramento and to Delta exit were assumed to be the same because of the low fish count at Delta exit in some years, but for the model version presented here we estimated survival rates for those two reaches separately. This allowed for more flexibility in the survival estimates. The average survival rate from Sacramento to Delta exit was considered to be the same for both upper Sacramento River and Butte/Feather River fish (S_bR[ir=4]). The random release-group by reach effect are drawn from a zero-centered normal distribution,

Equation 3a.

$$S\_RE_{irg,ir} \sim normal(0, \sigma\_SRE_{ir})$$

Equation 3b.

$$S\_RET_{irgT,ir} \sim normal(0, \sigma\_SRET_{ir})$$

with estimated standard deviations σ_SRE and $\sigma\_S\mathrm{RET}$. The S_RE and S_RET random effects represent unexplained variation in reach-specific survival rates resulting from either annual effects for the upper Sacramento River or from variation in survival rates across release groups and reaches within years for the Butte/Feather submodels. We refer to this survival model, which does not include covariate effects, as the null model. Initially survival rates to Sacramento and to Delta exit were assumed to be the same because of the low fish count at Delta exit in some years, but for the model version presented here we estimated survival rates for those two reaches separately. This allowed for more flexibility in the survival estimates.

We then included fixed covariate effects to try and explain some of the unexplained variation modeled by the random effects. Ultimately the more variation that can be explained by fixed covariate effects, the higher the accuracy of survival rate forecasts. We added individual covariates to Equations 2a and 2b to account for the effect of fish size at release (i.e., fork length, weight or condition factor). Although fish tagged are all smolt-size fish, there was some significant variability in fish sizes both within and across release groups (Table 4). We also added an environmental covariate to account for the influence of hydrological conditions during fish migration. We looked at the peak flow during the month of fish release, a continuous variable that could vary across individuals (although individuals from a given release group all experienced the same monthly peak flow since they were released at the same time):

Equation 4a.

$$surv_{100_{i,ir}} = S_{bR_{ir}} + S_{bSz} \cdot Sz_i + S_{bCov} \cdot CovX_{i,ir} + S_{RE_{irg[i],ir}}$$

Equations 4b.

$$survT_{100_{i,ir=1}} = S\_bT_{itrib} + S\_bSz \cdot SzT_i + S\_bCovT \cdot CovXT_{i,ir=1} + S\_RET_{irgT[i],ir=1}$$

$$survT_{100_{i,ir=2}} = S\_bR_{ir=4} + S\_bSz \cdot SzT_i + S\_bCov \cdot CovXT_{i,ir=2} + S\_RET_{irgT[i],ir=2}$$

S_bSz is an estimated effect of the size (fork length, weight or condition factor (Fulton's K * 1000)) of each tagged fish at release, Sz_i and SzT_i represent individual size at release for the upper Sacramento River and Butte/Feather fish respectively. Note this effect allows individual variation in survival rates within release groups owing to variation in size or condition at release (Table 4).

S_bCov and S_bCovT are estimated fixed flow covariate effects, and $CovX_{i,ir}$ and $CovXT_{i,ir}$ are individual and reach specific continuous covariate values for the upper Sacramento River and Butte/Feather sub-models respectively. Note that the flow covariate was standardized using different means and standard deviations for upper Sacramento River versus Butte and Feather fish releases to account for differences in channel morphology and flow range observed in these different watersheds.

We also looked at categorical variables such as the water year type covariate based on California Department of Water Resources (DWR) water year indices (https://cdec.water.ca.gov/reportapp/javareports?name=WSIHIST). We also tested the influence of a flow exceedance year type covariate developed by California Department of Fish and Wildlife (CDFW) Instream Flow team to categorize years for each stream into three categories: wet, average, and dry. It is obtained by calculating the mean annual flow by water year for each stream and ranking the water years where the top 33% are wet, the middle 33% are average, and the bottom 33% are dry.

The DWR water year type and the CDFW flow exceedance water year indices were both similar across reach for a given year, and were added to the fish size effect as follows:

Equation 5a.

$$surv_{100_{i,ir}} = S_{bR_{ir}} + S_{bSz} \cdot Sz_i + S_{bCov_{1:j}} + S_{RE_{irg[i],ir}}$$

Equations 5b.

$$survT_{100_{i,ir=1}} = S\_bT_{itrib} + S\_bSz \cdot SzT_i + S\_bCov_{1:j} + S\_RET_{irgT[i],ir=1}$$

$$survT_{100_{i,ir=2}} = S\_bR_{ir=4} + S\_bSz \cdot SzT_i + S\_bCov_{1:j} + S\_RET_{irgT[i],ir=2}$$

Where:

$S\_bCov_{1:j}$ is an estimated categorical environmental covariate effect.

We considered the following:

- Two water year type levels (j=2)
  - Critical (C)/dry (D)
  - Below-normal (BN)/above-normal (AN)/wet (W)
- Three water year types (j=3)
  - C
  - D/BN
  - AN/W
- Three flow exceedance water year index values (j=3)
  - Dry
  - Average
  - Wet

Note that we only used two or three water year type categories, rather than the five defined by DWR, because we had in mind that this model will ultimately be used for forecasting purposes and we expect that five categories of hydrological conditions would be very difficult to identify early in the water year. Additionally, there were not enough years represented within each water year type category to include them all. For instance, there was only one above-normal year (2024) in our dataset. For j =2, S_bCov = 0 if the individual was released in a C/D/BN water year type, and 1 if released in a AN/W water year type (Table 1). Thus S_bR and S_bT represent the reach-specific survival rate in a C/D water year type. For j = 3, S_bCov = 0 if the individual was released in a C year, 1 if released in a D/BN year and 2 if released in a AN/W year. For the flow exceedance index, S_bCov = 0 if the individual was released in a dry year, 1 if released in an average year and 2 if released in a wet year.

Finally, the survival rate for each reach used in the model fitting is computed using,

Equation 6a.

$$surv_{i,ir} = inv\_logit(surv\_100_{i,ir})^{L_{ir}}$$

Equation 6b.

$$\mathrm{survT}_{\mathrm{i,ir}} = \mathrm{inv\_logit}(\mathrm{survT\_100}_{\mathrm{i,ir}})^{\mathrm{LT_{ir}}}$$

Where:

> L_{ir} and LT_{ir} are the ratio of each reach's length to 100 km for the upper Sacramento River and Butte/Feather submodels respectively (Tables 2 and 3, e.g., Butt_Sac reach length = 170/100).

This exponent adjusts the survival rate per 100 km to the survival rate for the reach. 'inv_logit' simply transforms the logit value of survival rate per 100 km so it ranges between 0 and 1.

To forecast smolt survival rate in a future year we sample from the joint posterior distributions of S_bR, S_bT and σ_SRE, σ_$\mathcal{S}$RET for the upper Sacramento River and Butte/Feather submodels respectively, and S_bCov and S_bCovT if a covariate forecast is available. We also sample from the posterior distribution of S_bSz when using the forecast in the integrated JPE model. A random draw of S_RE and S_RET is then taken and added to S_bR and S_bT to calculate survival (eqn. 2a and 2b). Reach specific S_RE would be drawn and the product of their survival rates used to calculate survival to the Delta. In cases where covariates can be forecasted (e.g., water year type, flow exceedance index), draws from the S_bCov and S_bCovT posteriors are also used to predict survival rates. We would expect forecasts from covariate models to be more accurate than from the null model because the former will explain some of the variation in release-group by reach random effects. However, note that the forecast model does not include uncertainty in the covariate forecast, though that could be incorporated into the model if available.

To compare model performance across models, we computed the leave-one-out cross-validation information criterion (LOOIC) for each model. LOOIC has the same goal as Aikake information criteria (AIC) to identify the model with the best predictive ability quantified by out-of-sample error. Like AIC, smaller LOOIC values indicate better out-of-sample performance. We also looked at the release group by reach random effect standard deviations (σ_$\mathcal{S}$RE[i] and σ_$\mathcal{S}$RET[i]) for each model to compare the magnitude of unexplained variation among models. Table 4 lists mean and coefficient of variation (CV) in the size of tagged Chinook salmon by release group. The condition factor is presented in units of 1,000 (i.e., 1,000 * 100 * weight/fork length ^3)

2.3 Travel Time Model

We used a latent-state Bayesian model to predict travel time from release to each downstream detection location. The travel time model predicts travel time in number of days for each individual to traverse each of the four reaches for upper Sacramento fish (Release-Woodson, Woodson-Butte, Butte-Sacramento, Sacramento-Delta) and two reaches for Butte Creek and Feather River fish (Release-Sacramento, Sacramento-Delta), based on mixed effects models with a fixed effect that depends on the peak flow during the month of release (that is, the same covariate used in the survival models) and the fish size at release. The sum of the reach-specific travel times to each detection location (e.g., release to Sacramento) is compared to the observed travel times to fit the model.

The core model prediction is the number of days to travel 100 km in each reach:

Equation 7a.

$$\log\left(D100_{i,ir}\right) = Tr\_bR_{ir} + Tr\_bSz \cdot Sz_i + Tr\_bCov \cdot CovX_{i,ir} + Tr\_RE_{irg[i],ir}$$

Equation 7b.

$$\log\left(DT100_{i,ir=1}\right) = Tr\_bT_{itrib} + Tr\_bSz \cdot SzT_i + Tr\_bCovT \cdot CovXT_{i,ir=1} + Tr\_RET_{irgT[i],ir=1}$$

$$\log\left(DT100_{i,ir=2}\right) = Tr\_bR_{ir=4} + Tr_{bSz} \cdot SzT_i + Tr_{bCov} \cdot CovXT_{i,ir=2} + Tr\_RET_{irgT[i],ir=2}$$

Where:

D100 and DT100 are the number of days for individual 'i' to travel 100 km in reach 'ir', for upper Sacramento River and Butte/Feather fish respectively.

Tr_bR and Tr_bTrib represent the reach-specific and tributary specific average number of days to travel 100 km in log space (across all years, release groups, and reaches). Tr_bSz, Tr_bCov and Tr_bCovT are estimated fixed effects for fish size (Sz) and environmental covariates CovX and CovXT, and Tr_RE and Tr_RET are random effects for each release group and each reach, for upper Sacramento River and Butte/Feather fish respectively.

The predicted travel time from release to each detection location ($Tr_{i,j}$) is then calculated from,

Equations 8a.

$$Tr_{i,ir=1} = D100_{i,ir} * \boldsymbol{Rkm_{ir}}$$

$$Tr_{i,ir} = Tr_{i,ir-1} + D100_{i,ir} * \boldsymbol{Rkm_{ir}} \text{ for ir=2:4}$$

Equations 8b.

$$TrT_{i,ir=1} = DT100_{i,ir=1} * \boldsymbol{RkmT_{ir=1}}$$

$$TrT_{i,ir=2} = TrT_{i,ir=1} + DT100_{i,ir=2} * \boldsymbol{Rkm_{ir=4}}$$

Where:

Rkm and RkmT are the length of each reach in units of 100 km (e.g., Rkm=1 indicates the reach is 100 km long).

Here we see that the reach-specific travel times (D100*Rkm) accumulate in a downstream direction to predict the total travel time from release to each location.

Random effects Tr_RE and Tr_RET are assumed to come from a normal distribution with a mean of 0 and an estimated standard deviation s_TrRE and s_TrRET,

Equation 9a.

$$Tr_{RE\,irg[i],ir} \sim normal\left(0, \sigma_{TrRE\,ir}\right)$$

Equation 9b.

$$Tr\_RET_{irg[i],ir} \sim normal(0, \sigma\_TrRET_{ir})$$

These effects account for factors not considered in the travel time model such as the effects of differences in fish size among and within release groups, and difference in river conditions among years and reaches.

The model is fit to the data assuming that the observed travel times from release to each detection location (ObsTr and ObsTrT) are lognormally distributed,

Equation 10a.

$$\boldsymbol{ObsTr_{i,ir}} \sim lognormal\left(\log\left(Tr_{i,ir}\right), \sigma\_Pro\right)$$

Equation 10b.

$$\boldsymbol{ObsTrT_{i,ir}} \sim lognormal\left(\log\left(TrT_{i,ir}\right), \sigma\_ProT\right)$$

Where:

the means are the log of travel times predicted in Equation 9, and the standard deviations s_Pro and s_ProT (unexplained process error) are estimated.

We used a lognormal likelihood because observed travel times cannot be negative. The likelihood is only applied to observed detections. For example, for an upper Sacramento individual with a capture history of 11010, the likelihood would only be applied to observations of travel time from release to Woodson and release to Sacramento. However, note that the travel time to the Sacramento station depends on the predictions of travel time to and from the Butte station, which was not observed. The travel time model predicts the latent (unobserved) states of travel time from Woodson to Butte and Butte to Sacramento to make a prediction at the Sacramento location, which can be compared to the observation. In the absence of this latent-state structure, a travel time model could only be fit to data for individuals detected at all locations, or only for cases where detections for an individual occur at adjacent locations. Both of these alternatives result in a considerable loss of information relative to the latent-state approach we have used.

The travel time model can be used to forecast travel time for the JPE model. When fitting the model, the random effects Tr_RE and Tr_RET are estimated from the data, as are the standard deviations of the distribution from which those random effects are drawn (s_TrRE and s_TrRET). When using the model in a forecast, we randomly draw from the posterior distributions of Tr_bR and Tr_bTrib, and s_TrRE and s_TrRET. Random effects are then drawn from normal distributions (0, s_TrRE) and (0, s_TrRET) to account for variation in travel time due to release-group by reach effects in the forecast. The uncertainty in the forecast therefore depends on both the uncertainty in model parameters (Tr_bR ,Tr_bTrib, s_TrRE and s_TrRET) and often more importantly, the magnitude of s_TrRE and s_TrRET. Random draws from Tr_bSz are also taken into account for the effect of fish size.

2.4 R Codes

The following R scripts were used to develop the models described above and produce the various survival estimates and series of figures:

- PrepData.R: Read in inp files with detections data and create data frame with key detection information and covariates. Save data frame in “Sac_data.csv” and “FeaBut_data.csv.”
- GetData.R: Read in Sac_data.csv and FeaBut_data.csv files and create key variables needed for Bayesian models.
- NoCov.stan and CovWY.stan, CovIndCont.stan: Stan scripts for null model, model water year type covariates, and individual level environmental covariates.
- Call_Model.R: Run Bayesian models and outputs.
- DiagnosticPlots.R: Create model outputs diagnostic tables and figures.
- SurvivalPlots.R: Collect, travel time, detection and survival probability estimates for each model and plot data.

3 Model Output

3.1 Survival Rate and Detection Probability Predictions

Mark-recapture models were fit to data from 14,520 tagged individuals across 11 years (2013–2024) from 43 release groups (23 in the upper Sacramento River and 20 in the Butte/Feather watershed; Table 1). We compared the null survival model, which does not contain covariate effects, with eight survival models that include combinations of fish size and water year type effects to identify the most predictive model that would form the basis of survival forecasts for the srJPE model. We first confirmed that all models were converging by checking that each model's variable Rhat was below 1.05. Only σ_SRE[4] had Rhat > 1.05. This was considered acceptable since this was for the through-Delta migration reach, and we were interested in survival from release downstream to only Sacramento (i.e., to the upstream end of the through-Delta reach).

We first tested models with one covariate at a time and estimated the LOOIC for each model and ranked them from lowest (best performance) to highest LOOIC. We found that the model with maximum peak flow during the month of fish release performed best. Models with DWR's three water year types and CDFW's flow exceedance index had LOOIC values that were close to each other, but higher than the best model. The second round of model testing included the peak monthly flow covariate, and we added a fish size metric to see if it would improve model fitting.

Because fish fork length and weight had similar LOOIC values, we opted to use fork length as the fish size metric in later model testing as this information is more commonly available and matches the variable measured at the RST locations (i.e., the data to which the survival forecast will be applied to calculate a JPE). The model with peak monthly flow at release and fish fork length covariates performed better than with peak flow alone (lower LOOIC; Table 5). We therefore used this model to estimate historical juvenile salmon survival rates and to forecast future survival for various flow and fork length values. We found that the more flexible model version with release group by reach random effects performed better (lower LOOIC) than the previous version with only release group random effects. The random effect's standard deviations for the max monthly flow + fork length model were also relatively low, although not the lowest among the various models tested (e.g., the flow exceedance model had lower σ_SRE[i] and σ_SRET[i] values). Overall, mean reach-specific random effects were higher and random effect's standard deviations were larger for the first reach from Release to Woodson Bridge and the last reach from Sacramento to Delta Exit (Table 5, and Figure 5). We suspect that σ_SRE[4] could be inflated due to a lack of convergence (Rhat > 1.05).

Detection probabilities were overall relatively high across reaches, except for the first two reaches in 2017, 2021, 2022 and 2024. Delta exit detections were variable with low detections before 2017 and higher ones from 2017 to 2019 and 2023 to 2024 (Figure 6). It is important to note that in a CJS model detection probability is unidentifiable from survival at the last location.

Because detection rates were not consistently higher after the addition of Chipps Island receivers in 2017 (e.g., low detections were observed from 2021 to 2023), we believe that those additional receivers did not significantly impact detection estimates at Delta exit. As highlighted in Tables 7 and 8, the detection probability estimates at Delta exit correlate with the numbers of fish detected at the Delta exit station. Years with smaller numbers of fish detected exiting the Delta had lower Delta detection probability, while years with larger numbers of fish detected had higher Delta detection probability. We assume the low numbers of fish detected at Delta exit is more likely due to a low detection probability and relatively high Delta survival rather than a high detection probability and relatively low Delta survival rate. However, large uncertainty was found in Delta exit detection probabilities, which could be caused by the low number of fish at Sacramento and Delta exit stations used to estimate detection probabilities, which in turn causes the model to shrink estimates toward the hyper parameter mean (Figure 6, Table 7).

Upper Sacramento River fish survival was higher from Release to Woodson Bridge and from Sacramento to Delta Exit, but large uncertainty was observed for the through-Delta survival. Survival rates generally decreased in the lower reaches of the Sacramento River (Figure 7). For Butte Creek and Feather River fish, survival was also higher and more variable from Sacramento to Delta Exit than from release to Sacramento. Overall, survival was higher during wetter conditions and lower during drier years, ranging from close to 0 in critical years to 0.72 in wet years (Figure 8). However, low survival was observed during some wet years, such as in Butte Creek fish tagged in the Sutter Bypass in 2019 (Figure 9). Some variability was also observed across release groups within a given year. This variability might be related to the differences in release timing, with fish released later in the spring likely to experience poorer migration conditions and lower survival even in an overall wetter year.

3.2 Survival Rate Model Forecasts

We then looked at survival forecasts for a range of flow values (Figure 7). Forecasted survival increased with wetter conditions with survival going from 0.05 to 0.53 for upper Sacramento River fish and from 0.15 to 0.97 for Butte Creek and Feather River fish. We also took a middle flow value and looked at survival forecast for a range of fish size (Figure 8). Survival rates for 39, 80 and 132 mm fish were 0.12, 0.19 and 0.30 for upper Sacramento River, 0.57, 0.65 and 0.75 for Butte Creek, and 0.12, 0.16 and 0.24 for Feather River (note that survival rates for fish smaller than approximately 70 mm were extrapolated beyond size range of tagged fish). Large variability around the survival forecasts is observed with the majority coming from random release group effects rather than uncertainty in the fixed flow or size effect (the posterior distribution of S_bCov, S_bCovT and S_bSz have relatively small standard deviations; Table 6 and Figures 7 and 8), suggesting that this variability is not linked to a large variability in the size or flow factors but rather other biological or environmental factors impacting juvenile survivals to Sacramento that were not included in this model.

3.3 Travel Time Predictions

Upper Sacramento fish migrated faster in the upper and middle Sacramento River reach and slower in the lower Sacramento and Delta, and Feather and Butte fish had similar travel times from release to Sacramento and in the Delta (Figures 9 and 10). Overall, upper Sacramento River fish were faster during wetter conditions, taking as little as 3.9 days to reach Sacramento in 2017 and as much as 8.5 days in 2016 (Figure 11). Feather River and Butte Creek fish travel times were less variable across years and release group, ranging from 2.4 days in 2019 to 5.8 days in 2014 to reach Sacramento (Figure 11).

4 Next Steps

We are continuing to investigate ways to further decrease uncertainty in survival forecasts by considering additional covariates (e.g., date of release, fish travel time, other flow variable metrics). We are also considering modeling survival for other spring-run watersheds such the Yuba River, where juvenile Chinook salmon tagging has been done in the past few years. The effects of fish size and flow on travel time were analyzed in greater detail for use in srJPE, and these results are reported in Chapter 3. The juvenile survival and travel time model will be updated with smaller fork lengths as the tagging technology improves.

Tables and Figures

Tables

Table 1. Wild and Hatchery Tagged Fish Groups, 2013 to 2024

Wild and hatchery tagged fish groups included in our analysis from 2013 to 2024. The water year type was developed by the State Water Resources Control Board for the Sacramento and San Joaquin River hydrologic basins, and is shown for each modeled year. “C” = critical, “D” = dry, “BN” = below-normal, “AN” = above-normal, and “W” = wet. More information can be found on the California Data Exchange Center website at https://cdec.water.ca.gov/reportapp/javareports?name=WSIHIST.

Year (Water Year Type)	Population	Origin	Release Dates	Sample Size
2013 (D)	Coleman fall-run	Hatchery	Mid-April to Late-April	300
2013 (D)	Mill Creek fall- and spring-run	Wild	Mid-April to Mid-May	59
2013 (D)	Feather River spring-run	Hatchery	Mid-April	302
2014 (C)	Feather River spring-run	Hatchery	Mid-April	300
2015 (C)	Mill Creek fall- and spring-run	Wild	Mid-April to Mid-May	185
2015 (C)	Feather River spring-run	Hatchery	Mid-March to Early-April	300
2015 (C)	Butte Creek fall- and spring-run	Wild	Early-April to Mid-April	141
2016 (BN)	Coleman fall-run	Hatchery	Early-April to Late-April	597
2016 (BN)	Butte Creek fall- and spring-run	Wild	Mid-April	200
2017 (W)	Coleman fall-run	Hatchery	Early-April to Late-April	580
2017 (W)	Mill Creek fall- and spring-run	Wild	Mid-May to Late-May	30
2017 (W)	Sacramento River fall- and spring-run	Wild*	Early-June	44
2017 (W)	Butte Creek fall- and spring-run	Wild	Early-May	190
2018 (BN)	Deer Creek fall- and spring-run	Wild	Early-May to Mid-May	26
2018 (BN)	Sacramento River fall- and spring-run	Wild[a]	Early-May to Early-June	307
2018 (BN)	Butte Creek fall- and spring-run	Wild	Early-April to Early-May	321
2019 (W)	Coleman fall-run	Hatchery	Mid-May to Late-May	500
2019 (W)	Feather River spring-run	Hatchery	Late-April	600

Year (Water Year Type)	Population	Origin	Release Dates	Sample Size
2019 (W)	Butte Creek fall- and spring-run	Wild	Early-May to Mid-May	236
2020 (D)	Coleman fall-run	Hatchery	Mid-May to Late-May	723
2020 (D)	Deer Creek fall- and spring-run	Wild	Late-March to Mid-May	12
2020 (D)	Feather River spring-run	Hatchery	Early-April	508
2020 (D)	Butte Creek fall- and spring-run	Wild	Mid-May	23
2021 (C)	Coleman fall-run	Hatchery	Late-April to Mid-May	961
2021 (C)	Feather River spring-run	Hatchery	Mid-March to Early-April	590
2021 (C)	Butte Creek fall- and spring-run	Wild	Early-April to Late-April	113
2022 (C)	Coleman fall-run	Hatchery	Mid-April to Late-April	596
2022 (C)	Sacramento River fall- and spring-run	Wild[a]	Mid-April to Mid-May	303
2023 (W)	Coleman fall-run	Hatchery	Late-April to Early-June	1,884
2023 (W)	Feather River spring-run	Hatchery	Early-April	490
2023 (W)	Butte Creek fall- and spring-run	Wild	Early-April to Early-May	287
2024 (AN)	Coleman fall-run	Hatchery	Early-April to End-May	1,899
2024 (AN)	Sacramento River fall- and spring-run	Wild[a]	Mid-June	62
2024 (AN)	Feather River spring-run	Hatchery	Mid-April to End-April	498
2024 (AN)	Butte Creek fall- and spring-run	Wild	Early-April to Mid-April	259

[a] Fish tagged at Red Bluff Diversion Dam in the Sacramento River could come from various tributaries including Battle Creek, where only 25% of Coleman Hatchery fall-run fish are marked. So unmarked tagged fish could either be from wild origin or hatchery unmarked origin.

Table 2. Upper Sacramento River Tag Detection Locations and Associated Reaches

Tag detection locations and associated reaches used in the modeling for fish released in the upper Sacramento River.

Reach	Reach Name	Reach Index	Reach Length (km)
Release Point to Woodson Bridge	Rel_Woo	1	43[a]
Woodson Bridge to Butte Bridge	Woo_Butt	2	88
Butte Bridge to Sacramento	Butt_Sac	3	170
Sacramento to Delta Exit	Sac_Delta	4	110

km = kilometer(s)

[a] There were several release locations (Battle Creek, RBDD, Mill Creek and Deer Creek) and for forecast purpose the reach length used for Release Point to Woodson Bridge was the mean distance from all combined release locations to Woodson Bridge.

Table 3. Butte Creek and the Feather River Tag Detection Locations and Associated Reaches

Tag detection locations and associated reaches used in the modeling for fish released in Butte Creek and the Feather River respectively.

Reach	Reach Name	Reach Index	Reach Length (km)
Release Point to Sacramento	Rel_Sac	1	Sacramento 117, Feather 92[a]
Sacramento to Delta Exit	Sac_Delta	2	110

km = kilometer(s)

[a] There were several release locations in both Butte Creek and Feather River studies, and for forecast purpose the reach length used for Release Point to Sacramento was the mean distance from all combined release locations, in Butte Creek and the Feather River respectively, to Sacramento.

Table 4. Mean and Coefficient of Variation in Size of Tagged Chinook Salmon by Release Group

Mean and coefficient of variation (CV) in the size of tagged Chinook salmon by release group. Condition factor is presented in units of 1,000 (i.e., 1,000 * 100 * weight/fork length ^3).

Release Group	Fork Length Mean (mm)	Fork Length CV (mm)	Weight Mean (gram)	Weight CV (gram)	Condition Factor Mean	Condition Factor CV
Coleman Hatchery fall-run 2013	84.6	0.03	6.8	0.11	1.12	0.11
Mill Creek fall- and spring-run 2013	84.2	0.13	7.3	0.45	1.12	0.07
Feather River spring-run 2013	91.7	0.06	8.4	0.17	1.08	0.05
Feather River spring-run 2014	84.9	0.03	7.0	0.10	1.14	0.05
Mill Creek fall- and spring-run 2015	86.8	0.07	7.4	0.27	1.11	0.08
Feather River spring-run 2015	86.4	0.04	7.3	0.12	1.13	0.05
Sutter Bypass fall- and spring-run 2015	104.7	0.12	13.5	0.40	1.12	0.09
Coleman Hatchery fall-run 2016	83.5	0.03	6.5	0.09	1.12	0.08
Sutter Bypass fall- and spring-run 2016	110.5	0.08	16.2	0.26	1.17	0.06
Coleman Hatchery fall-run 2017	82.0	0.03	6.6	0.07	1.20	0.05
Mill Creek fall- and spring-run 2017	86.1	0.05	7.4	0.17	1.15	0.04
Sacramento River fall- and spring-run 2017	93.8	0.12	9.8	0.40	1.13	0.05
Sutter Bypass fall- and spring-run 2017	93.4	0.09	8.90	0.35	1.06	0.05
Deer Creek fall- and spring-run 2018	82.7	0.03	6.6	0.09	1.16	0.05
Sacramento River fall- and spring-run 2018	93.2	0.07	9.4	0.24	1.14	0.06
Sutter Bypass fall- and spring-run 2018	91.9	0.10	8.7	0.34	1.10	0.06
Coleman Hatchery fall-run 2019	92.7	0.05	9.5	0.16	1.19	0.07

Release Group	Fork Length Mean (mm)	Fork Length CV (mm)	Weight Mean (gram)	Weight CV (gram)	Condition Factor Mean	Condition Factor CV
Feather River Hatchery spring-run 2019	89.7	0.04	8.2	0.14	1.14	0.05
Sutter Bypass fall- and spring-run 2019	91.8	0.06	8.3	0.20	1.06	0.05
Upper Butte Creek fall- and spring-run 2019	93.2	0.05	8.6	0	1.13	0
Coleman Hatchery fall-run 2020	89.6	0.04	8.3	0.14	1.16	0.08
Deer Creek fall- and spring-run 2020	127.6	0.06	21.1	0.20	1.01	0.09
Feather River Hatchery spring-run 2020	87.2	0.03	7.9	0.10	1.19	0.06
Upper Butte Creek fall- and spring-run 2020	89.2	0.05	7.6	0.19	1.06	0.07
Butte sink fall- and spring-run 2021	86.6	0.05	7.2	0.16	1.10	0.03
Feather River Hatchery spring-run 2021	89.2	0.04	8.2	0.14	1.16	0.05
Upper Butte Creek fall- and spring-run 2021	85.9	0.05	7.1	0.18	1.11	0.06
Coleman Hatchery fall-run 2021	84.6	0.04	7.1	0.17	1.17	0.08
Sacramento River fall- and spring-run 2021	89.0	0.06	8.3	0.20	1.17	0.06
Sacramento River fall- and spring-run 2022	91.8	0.07	8.5	0.28	1.08	0.05
Sacramento River spring JPE 2022	83.1	0.04	6.2	0.15	1.08	0.08
Sacramento River spring JPE 2023	90.2	0.10	8.8	0.32	1.16	0.10
Sacramento River spring pulse flow 2023	86.0	0.05	7.3	0.15	1.14	0.09
Feather River Hatchery spring-run 2023	86.3	0.05	7.2	0.16	1.11	0.09

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Release Group	Fork Length Mean (mm)	Fork Length CV (mm)	Weight Mean (gram)	Weight CV (gram)	Condition Factor Mean	Condition Factor CV
Butte sink fall- and spring-run 2023	95.3	0.08	9.5	0.25	1.07	0.06
Sutter Bypass fall- and spring-run 2023	100.3	0.06	12.2	0.18	1.19	0.05
Sacramento River fall- and spring-run 2024	91.7	0.07	8.6	0.22	1.11	0.06
Sacramento River spring JPE 2024	84.7	0.09	6.9	0.30	1.08	0.11
Sacramento River spring pulse flow 2024	101.3	0.07	13.0	0.24	1.23	0.06
Seasonal Survival 2024	87.4	0.04	8.6	0.11	1.28	0.06
Feather River Hatchery spring-run 2024	87.6	0.04	7.9	0.11	1.18	0.09
Butte sink fall- and spring-run 2024	103.8	0.06	12.7	0.22	1.11	0.06

CV = coefficient of variation

mm = millimeter(s)

Table 5. Leave-one-out cross-validation Information Criterion Scores and Reach-specific Random Effect's Standard Deviations

LOOIC scores and reach-specific random effect's standard deviations for each survival model, for both upper Sacramento (s_SRE) and tributary fish (s_SRET). The models are ranked from lowest to highest LOOIC value. Table 6 lists the parameter value statistics for best-performing model.

Model	LOOIC	σ_SRE[1]	σ_SRE[2]	σ_SRE[3]	σ_SRE[4]	σ_SRET[1]	σ_SRET[2]
MaxFlow_FL	35121.86	2.029237	1.211766	1.389289	2.344124	1.249758	2.208746
MaxFlow	35123.21	2.078765	1.218924	1.415127	2.649457	1.29565	2.432567
WY3	35193.35	2.001686	1.326505	1.060639	1.178838	0.659833	1.092073
Fexceed	35193.55	1.675984	1.176735	1.338244	1.440336	0.827424	1.809906
WY2	35197	2.012788	1.388553	1.113606	1.132425	0.708397	1.284184
Wgt	35199.7	2.158911	1.470892	1.528542	2.168941	0.947516	1.738998
FL	35199.76	2.205874	1.469408	1.527322	2.288283	0.973035	1.871165
NoCov	35200.02	2.194519	1.469232	1.574276	2.553795	0.982575	2.272754
CF	35201.37	2.217824	1.491967	1.542563	2.499604	0.97104	1.981793

FL = fork length

Table 6. Parameter Value Statistics for Best-performing Model (Peak Monthly Flow + Fork Length)

Parameter	Mean	se_mean	sd	2.50%	97.50%
S_bR[1]	0.68013	0.025999	0.465577	-0.19922	1.630364
S_bR[2]	0.299079	0.019724	0.290416	-0.27528	0.913173
S_bR[3]	0.449601	0.020437	0.351073	-0.23087	1.160776
S_bR[4]	1.662503	0.077882	0.760367	0.352582	3.238185
S_bT[1]	-0.34364	0.021004	0.446995	-1.1797	0.629921
S_bT[2]	-1.46934	0.023888	0.47121	-2.513	-0.59953
S_bCov	1.164535	0.008912	0.221032	0.744401	1.611157
S_bCovT	1.850118	0.016807	0.366675	1.201884	2.653316
S_bSz	0.056934	0.000694	0.025130	0.008646	0.105221

Table 7. Number of Upper Sacramento River Fish Detected at Each Receiver Location and at Receiver Locations 3 and 4 Combined

Number of upper Sacramento River fish detected at each receiver location (RL), and at RLs 3 and 4 (Sacramento and Delta exit) combined. Light blue rows show years with a large number of fish detected at the Delta exit (RL 4) while light pink rows show years with low number of fish detected at RL 4.

Year	StudyID	RL 1	RL 2	RL 3	RL 4	RL 3 + 4
2013	ColemanFall_2013	214	217	50	15	15
2013	MillCk_Wild_CHK_2013	47	26	6	1	1
2015	MillCk_Wild_CHK_2015	105	34	1	0	0
2016	ColemanFall_2016	526	349	54	16	16
2017	ColemanFall_2017	244	366	156	122	119
2017	MillCk_Wild_CHK_2017	20	17	12	10	9
2017	RBDD_2017	28	14	12	6	6
2018	DeerCk_Wild_CHK_2018	13	2	1	0	0
2018	RBDD_2018	160	29	10	0	0
2019	CNFH_FMR_2019	469	307	231	118	118
2020	CNFH_FMR_2020	626	258	66	1	1
2020	DeerCk_Wild_CHK_2020	9	8	3	1	1
2021	CNFH_FMR_2021	362	158	3	0	0
2021	Wild_stock_Chinook_Rbdd_2021	16	5	0	0	0
2022	MillCk_Wild_CHK_2022	4	0	0	0	0
2022	SacRiverSpringJPE_2022	375	55	31	6	6
2022	Wild_stock_Chinook_RBDD_2022	197	25	18	4	4
2023	SacRiverSpringJPE_2023	427	319	128	108	76

Year	StudyID	RL 1	RL 2	RL 3	RL 4	RL 3 + 4
2023	Spring_Pulse_2023	1143	873	517	396	384
2024	SacRiverSpringJPE_2024	380	95	259	103	78
2024	Seasonal_Survival_2024	14	23	20	18	16
2024	Spring_Pulse_2024	408	0	83	17	17
2024	Wild_stock_Chinook_Rbdd_2024	40	6	0	0	0

Table 8. Number of Butte Creek and Feather River Fish Detected at Each Receiver Location, and at Receiver Locations 1 and 2 Combined

Table 8 lists the number of Butte Creek and Feather River fish detected at each RL, and at RLs 1 and 2 (Sacramento and Delta exit) combined. Light blue rows show years with large number of fish detected at Delta exit (reach 2) while light pink rows show years with low number of fish detected at RL 2.

Year	StudyID	RL 1	RL 2	RLs 1+2
2013	FR_Spring_2013	51	12	12
2014	FR_Spring_2014	74	1	0
2015	FR_Spring_2015	25	0	0
2015	SB_Spring_2015	20	1	1
2016	SB_Spring_2016	54	10	10
2017	SB_Spring_2017	56	35	34
2018	SB_Spring_2018	118	57	57
2019	FR_Spring_2019	306	165	165
2019	SB_Spring_2019	34	5	5
2019	Upper_Butte_2019	8	2	2
2020	FR_Spring_2020	137	19	19
2020	Upper_Butte_2020	0	0	0
2021	Butte_Sink_2021	1	0	0
2021	FR_Spring_2021	169	17	17
2021	Upper_Butte_2021	0	0	0
2023	Butte_Sink_2023	50	45	43
2023	FR_Spring_2023	189	129	109
2023	SB_Spring_2023	45	37	35
2024	Butte_Sink_2024	44	24	22
2024	FR_Spring_2024	133	34	25

Figures

Figure 1. Release and Receiver Locations Used in the Juvenile Survival and Travel Time Model

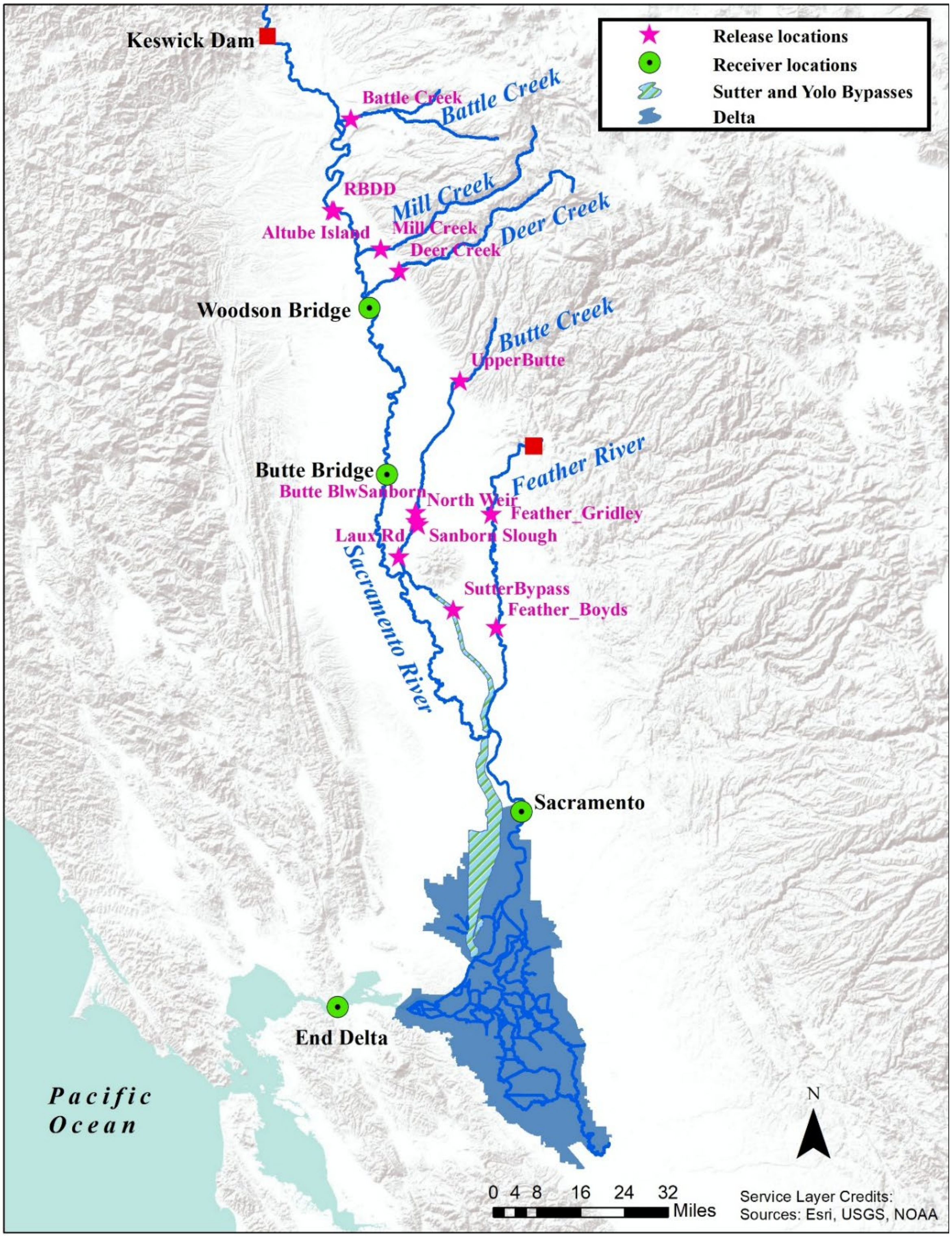

Figure 2. Conceptual Model Outlining Relationships Between Potential Submodels and Data

Conceptual model outlining the relationships between potential submodels and data in a spring-run JPE. The dashed red box indicates the juvenile survival and travel time model .

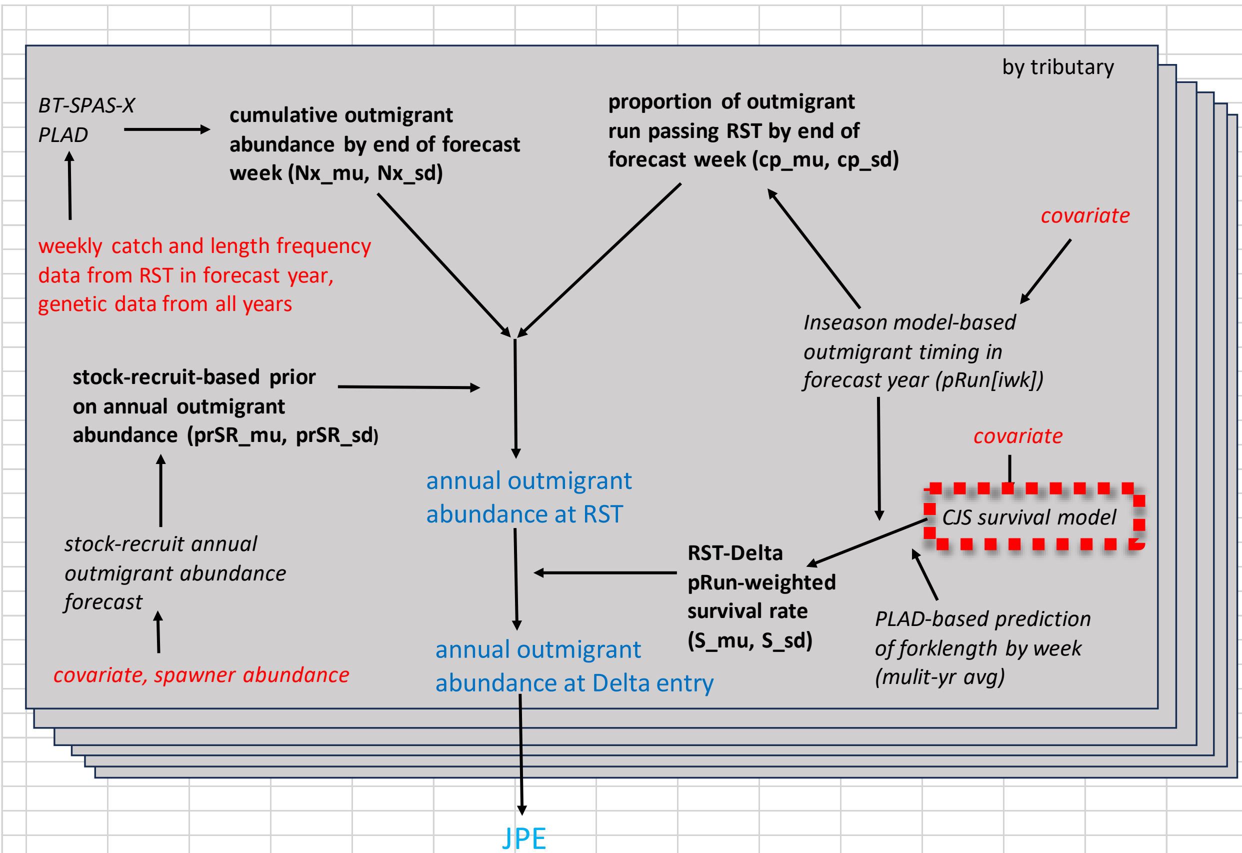

Figure 3. Mean Fork Length Distribution for Upper Sacramento and Butte Creek + Feather River Tagged Fish

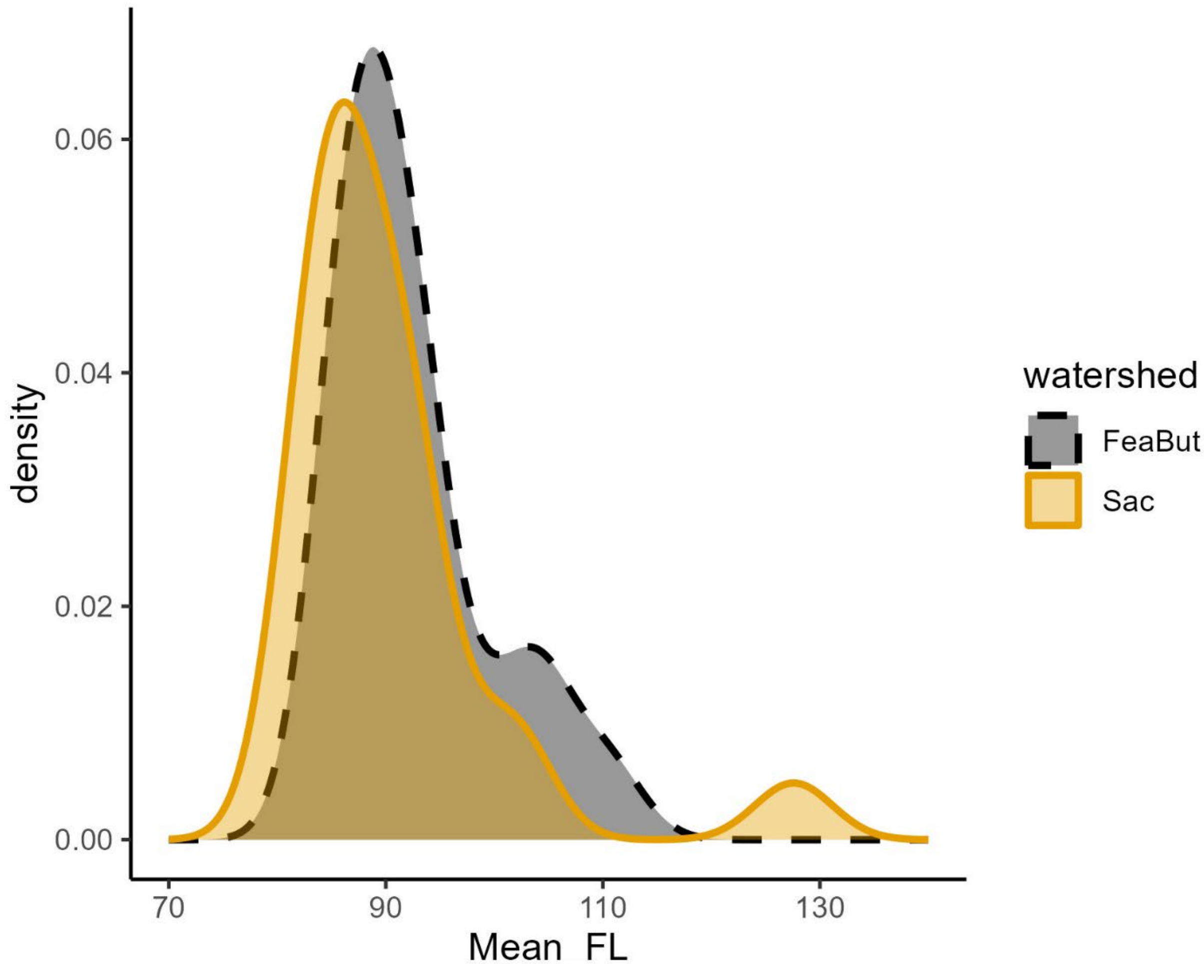

Figure 4. Mean, Minimum and Maximum Fork Length Distribution for Hatchery vs. Wild Origin Tagged Fish

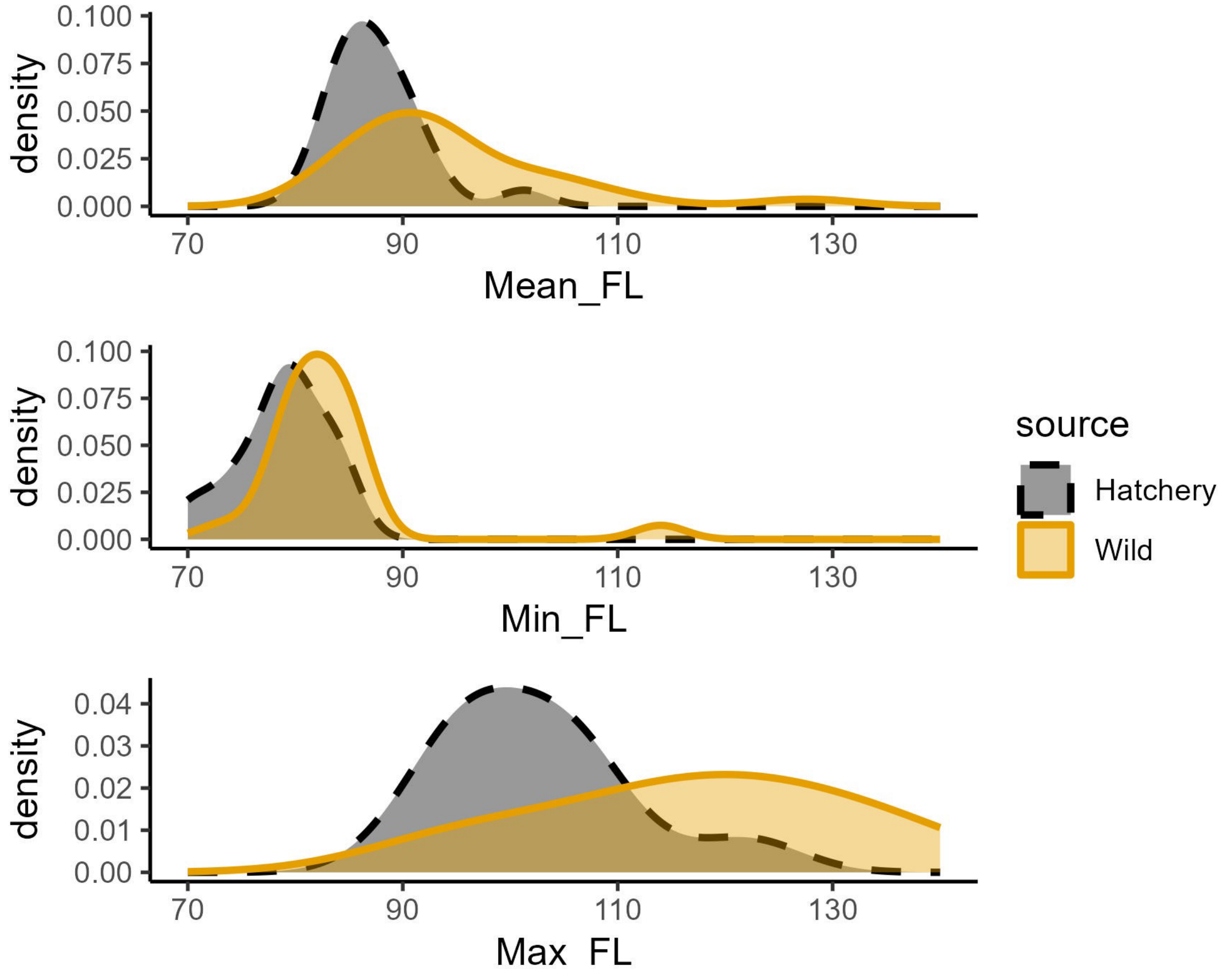

Figure 5. Reach-release Group Random Effects

Reach-release group random effects for the best-performing model (i.e., maximum peak flow + fork length) for upper Sacramento River fish (top) and Butte and Feather fish (bottom). Error bars represent the 25th and 75th percentiles.

Figure 5, Continued

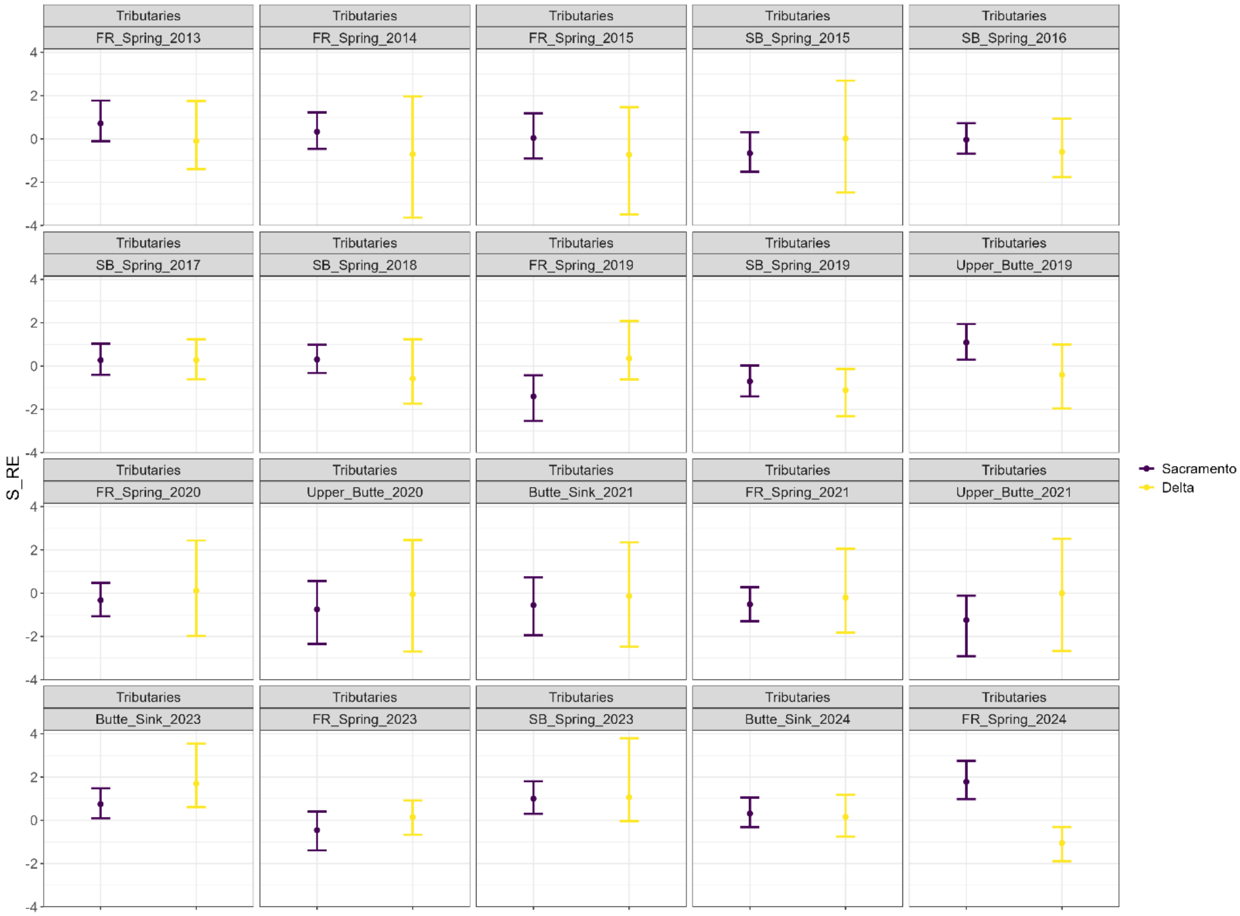

Figure 6. Detection Probability Colored by Receiver Location and Grouped by Year

Detection probability colored by receiver location (RL) and grouped by year. Error bars represent the 25th and 75th percentiles.

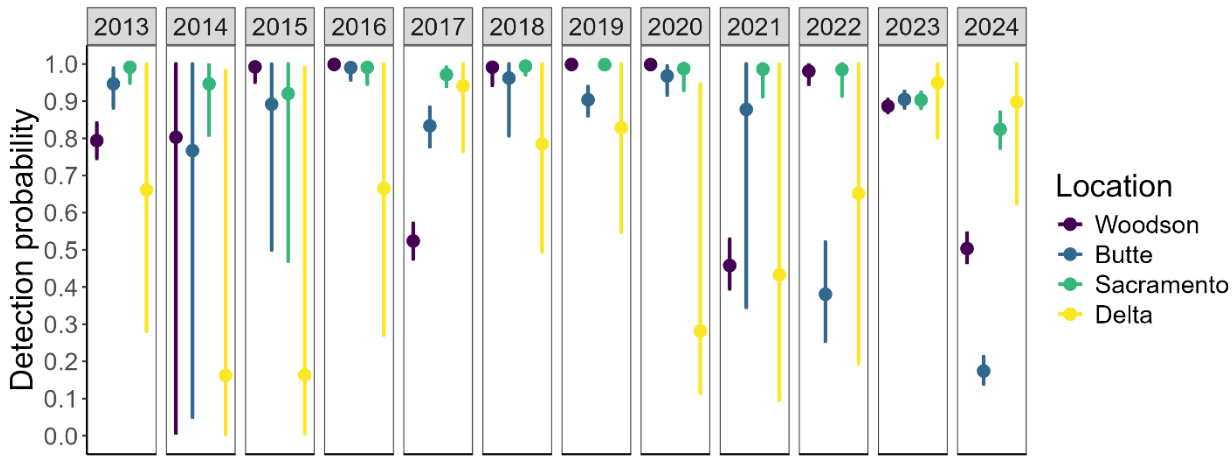

Figure 7. Reach-specific Survival Rates per 100 km for Upper Sacramento Fish per Release Group

Reach-specific survival rates per 100 km for upper Sacramento fish per release group. In the figure, error bars represent the 25th and 75th percentiles.

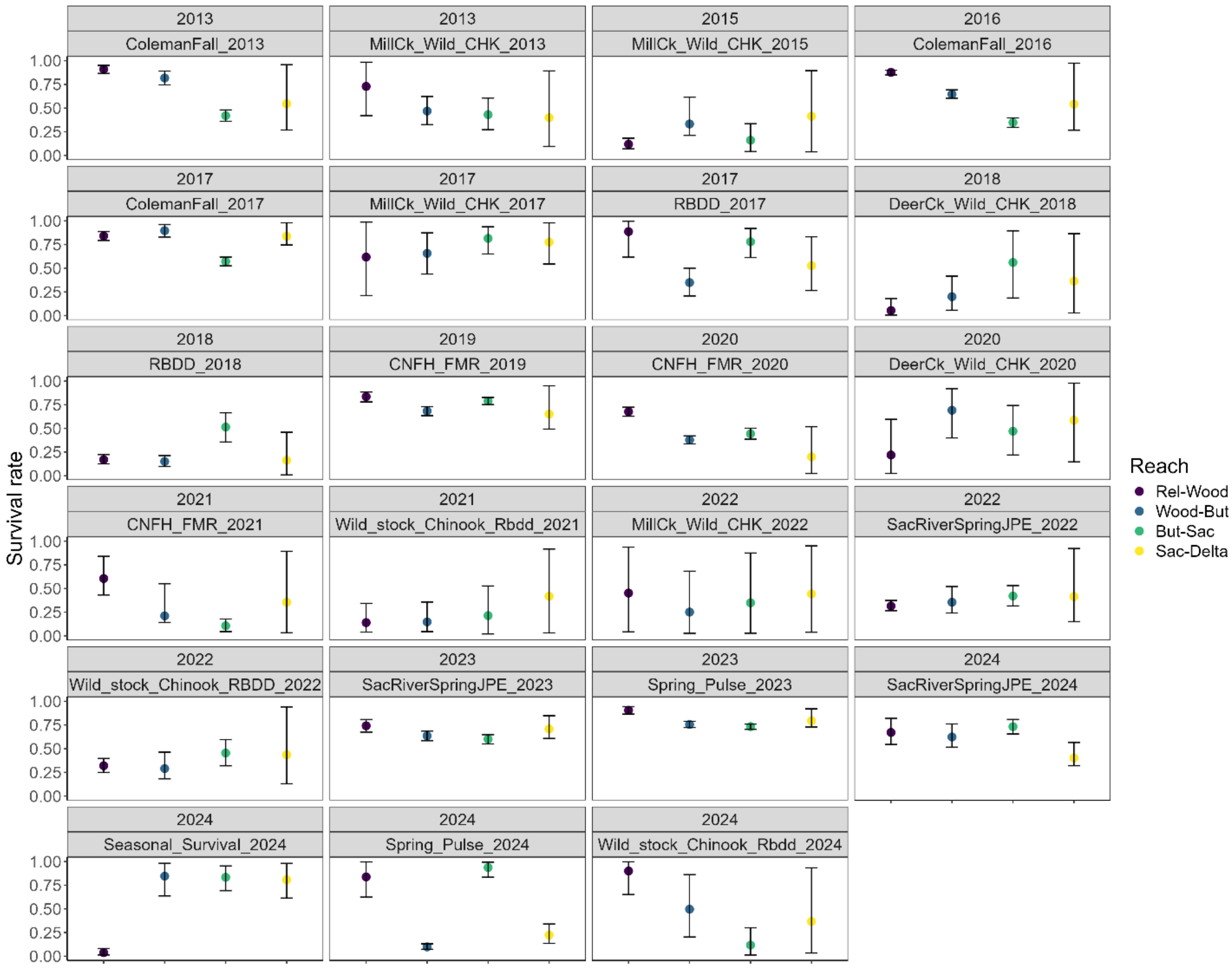

Figure 8. Reach-specific Survival Rates per 100 km for Butte Creek and Feather River Fish per Release Group

Reach-specific survival rates per 100 km for Butte Creek and Feather River fish per release group, and error bars represent the 25th and 75th percentiles.

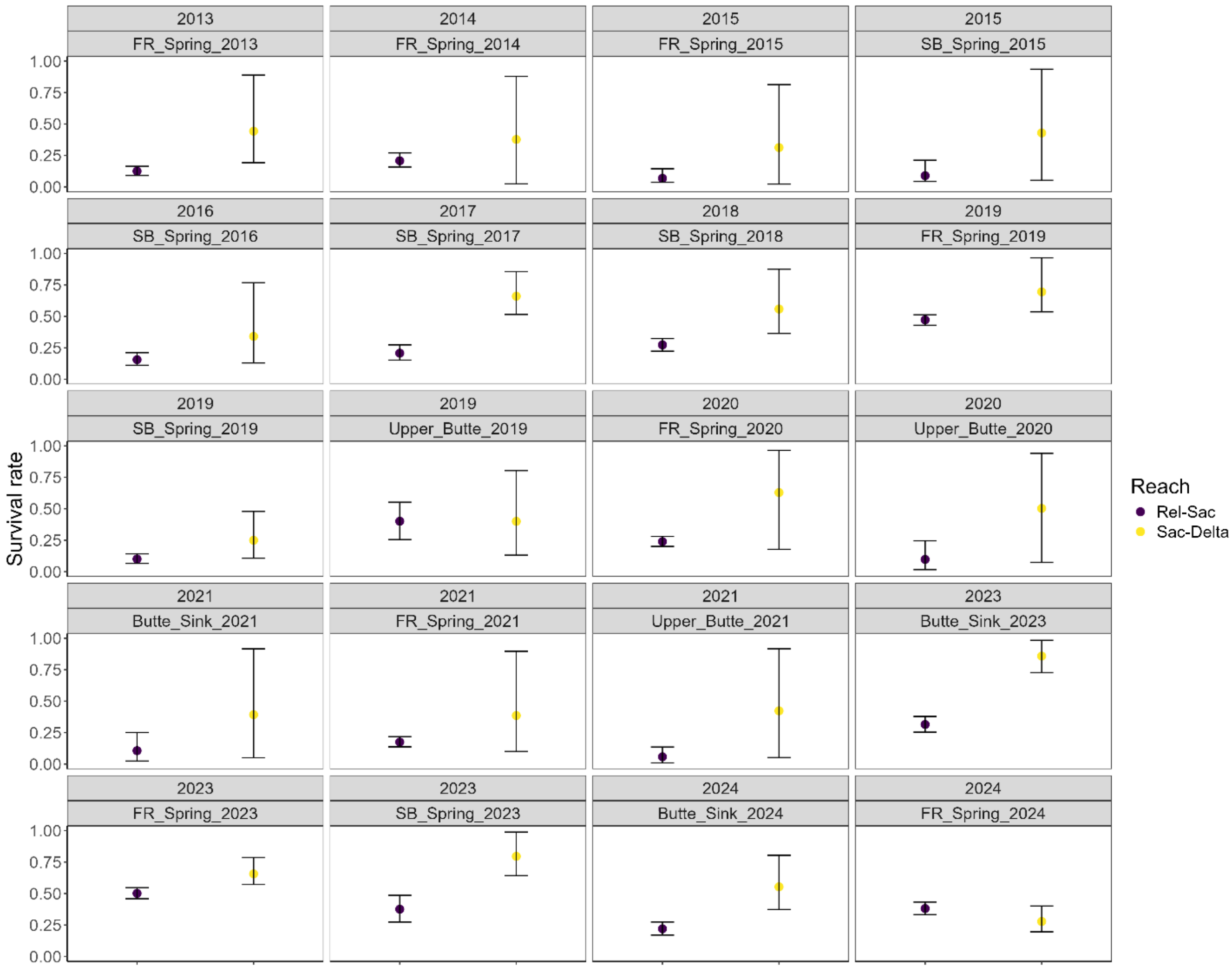

Figure 9. Release to Sacramento Survival Rates

Release to Sacramento survival rates for upper Sacramento and Butte Creek and Feather River fish, arranged by release group. As in the previous figures, error bars represent the 25th and 75th percentiles. Blue dots in Figure 9 show wetter years (i.e., above-normal and wet DWR water years), and red dots show drier years (i.e., critical, dry and below-normal water years).

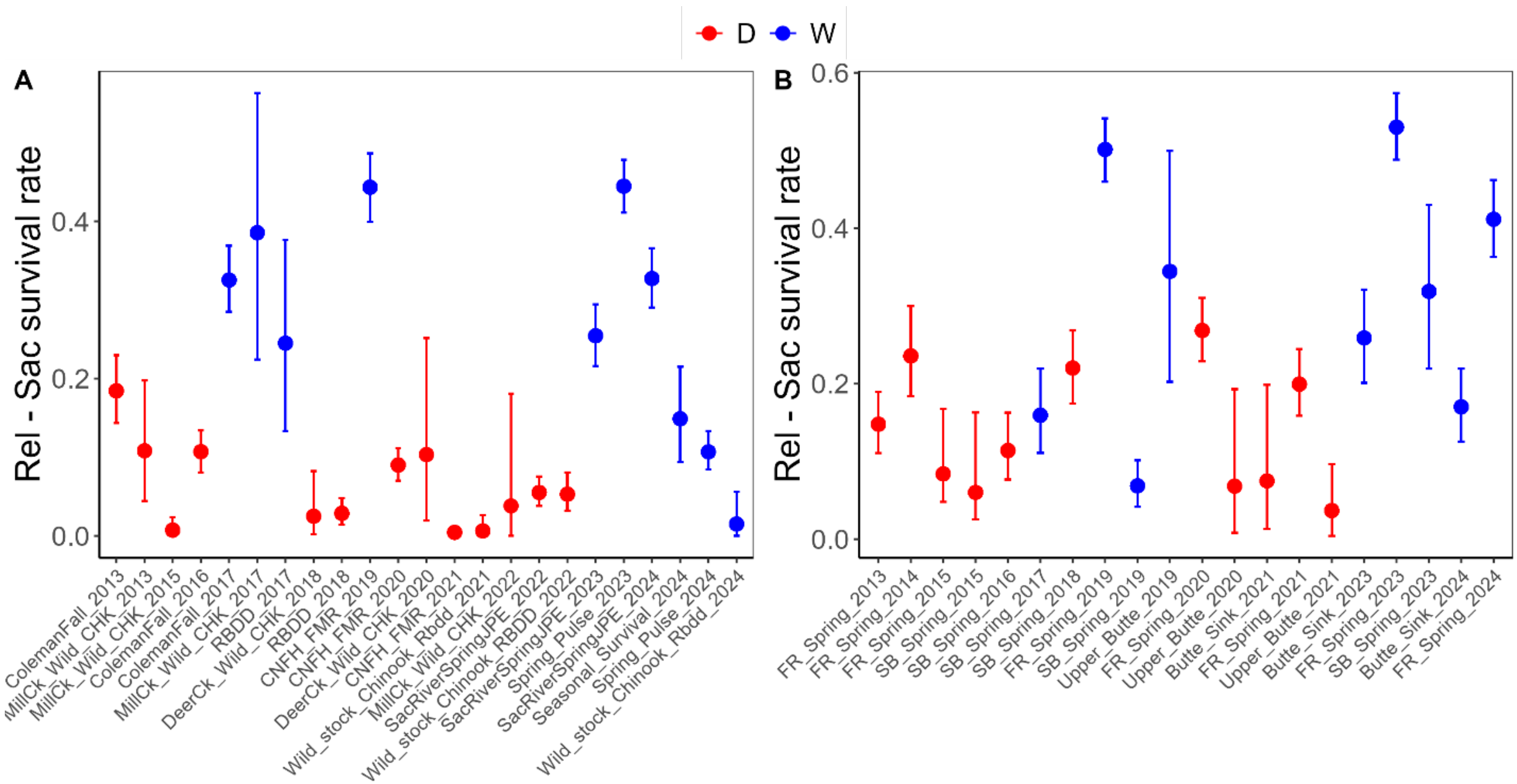

Figure 10. Release to Sacramento Survival Predictions, Higher Flow Values

Release to Sacramento survival predictions (with random effect in black and without random effect in blue) for:

- Upper Sacramento River fish and flows ranging from 4,000 to 40,000 cubic feet per second (cfs)
- Butte Creek
- Feather River fish for flows ranging from 150 to 30,500 cfs

The gray bands in Figure 10 show uncertainty in both the slope of the flow effect and the release group random effect. The blue bands show uncertainty without the release group random effect. Error bands are limited by the 25th and 75th percentiles. Black vertical bars at the bottom of the figures show peak monthly flows experienced by juvenile Chinook at release. Survival rate estimates, along with their error bars, are overlaid on top of the forecasted survival rates. Error bars represent the 25th and 75th percentiles. Results are shown for the average size fish (89 mm).

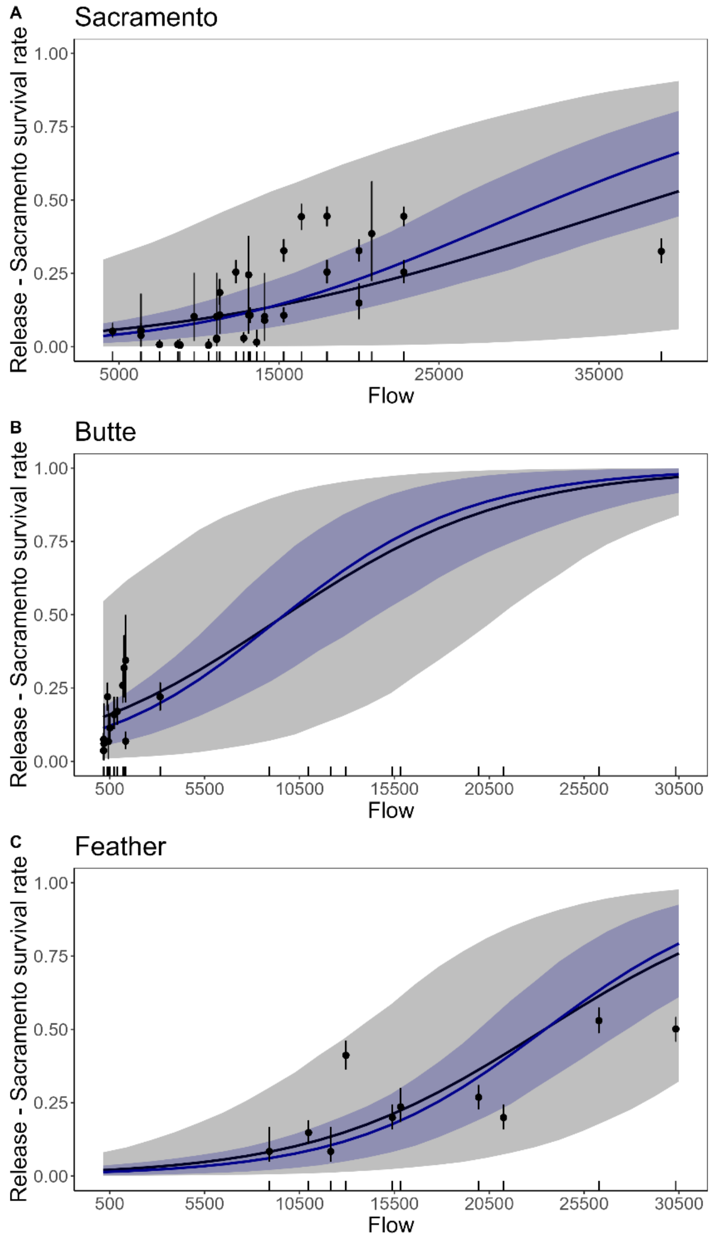

Figure 11. Release to Sacramento Survival Predictions, Middle Flow Values

Release to Sacramento survival predictions (with random effect in black and without random effect in blue) for:

- Upper Sacramento River fish and flows ranging from 4,000 to 40,000 cfs
- Butte Creek
- Feather River fish for flows ranging from 150 to 30,500 cfs

In Figure 11, the gray bands show uncertainty in both the slope of the flow effect and the release group random effect. The blue bands show uncertainty without the release group random effect. Error bands are limited by the 25th and 75th percentiles. Black vertical bars at the bottom of the figure show peak monthly flows experienced by juvenile Chinook at release. Survival rate estimates, along with their error bars, are overlaid on top of the forecasted survival rates. Error bars represent the 25 and 75 percentiles. Results are shown for the average size fish (89 mm).

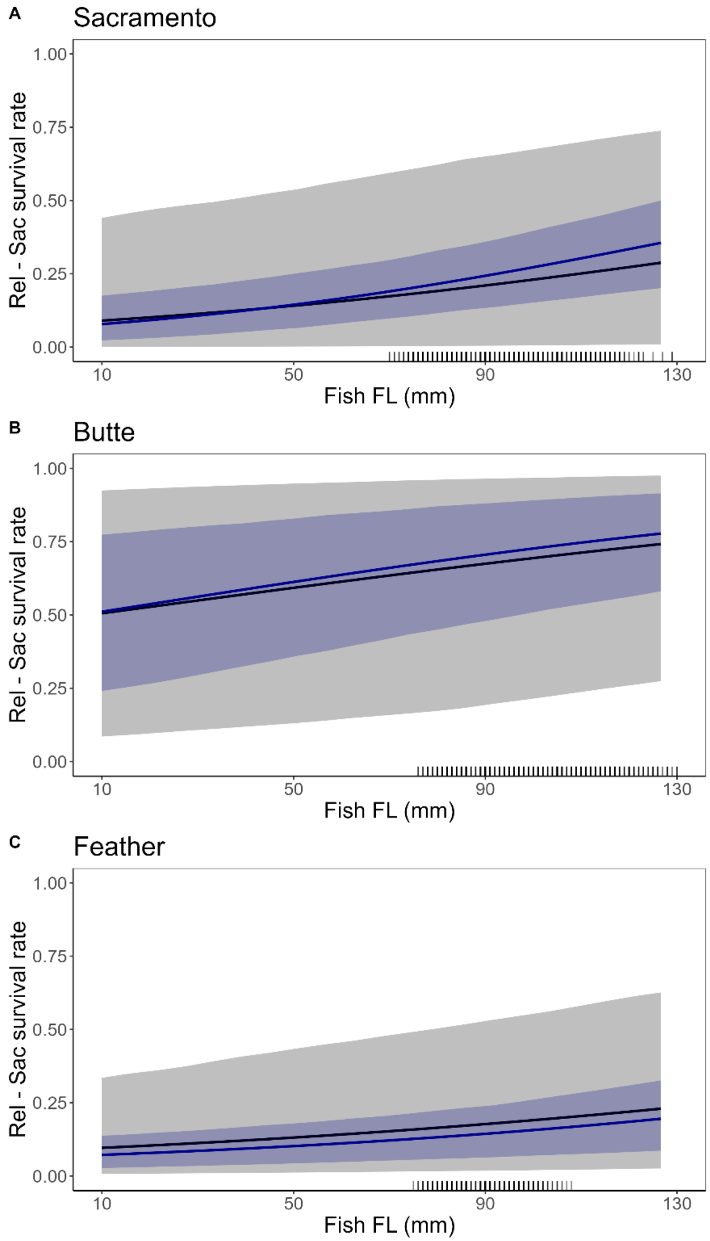

Figure 12. Reach-specific Travel Time Predictions in days per 100 km for Upper Sacramento Fish

Figure 12 shows upper Sacramento fish reach-specific travel time predictions in days per 100 km. Error bars represent the 25th and 75th percentiles. Figure 10 shows reach-specific travel time predictions in days per 100 km for Butte Creek and Feather River fish. Error bars represent the 25th and 75th percentiles.

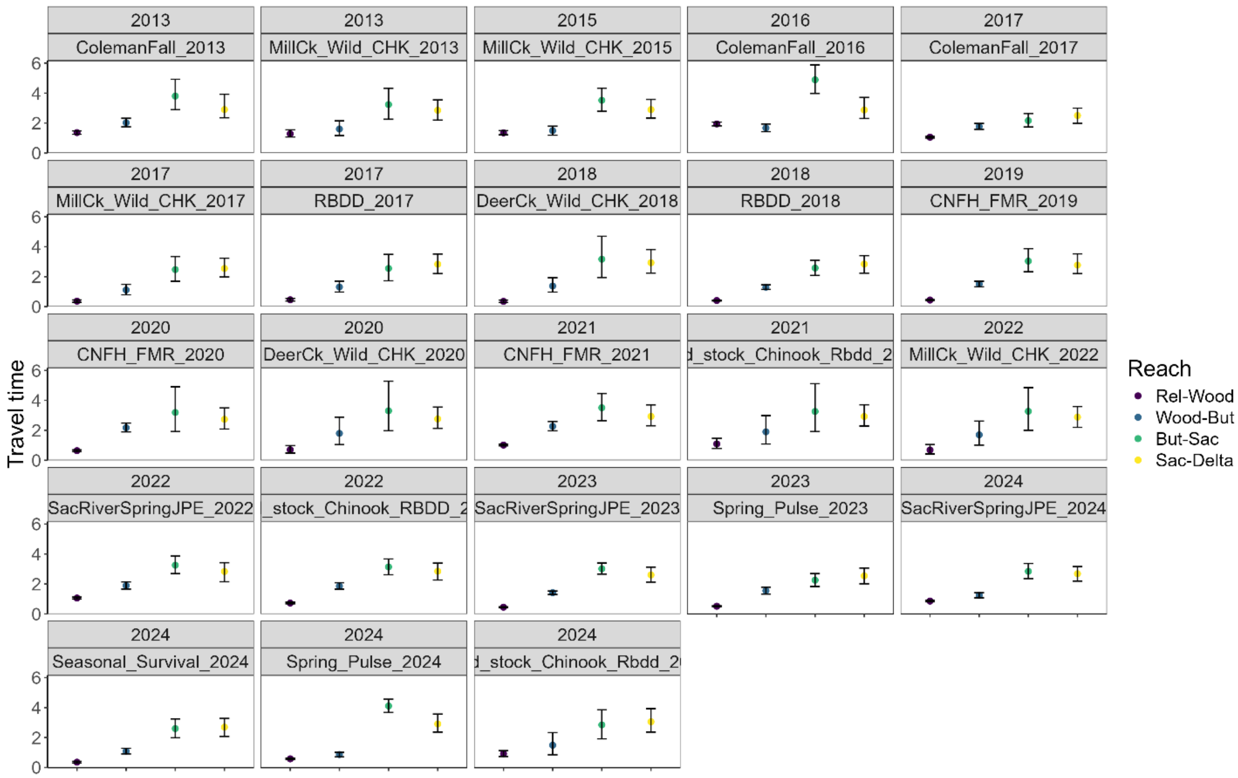

Figure 13. Reach-specific Travel Time Predictions in Days per 100 km for Butte Creek and Feather River Fish

Reach-specific travel time predictions (in days) per 100km for Butte Creek and Feather River fish. Error bars represent the 25 and 75 percentiles.

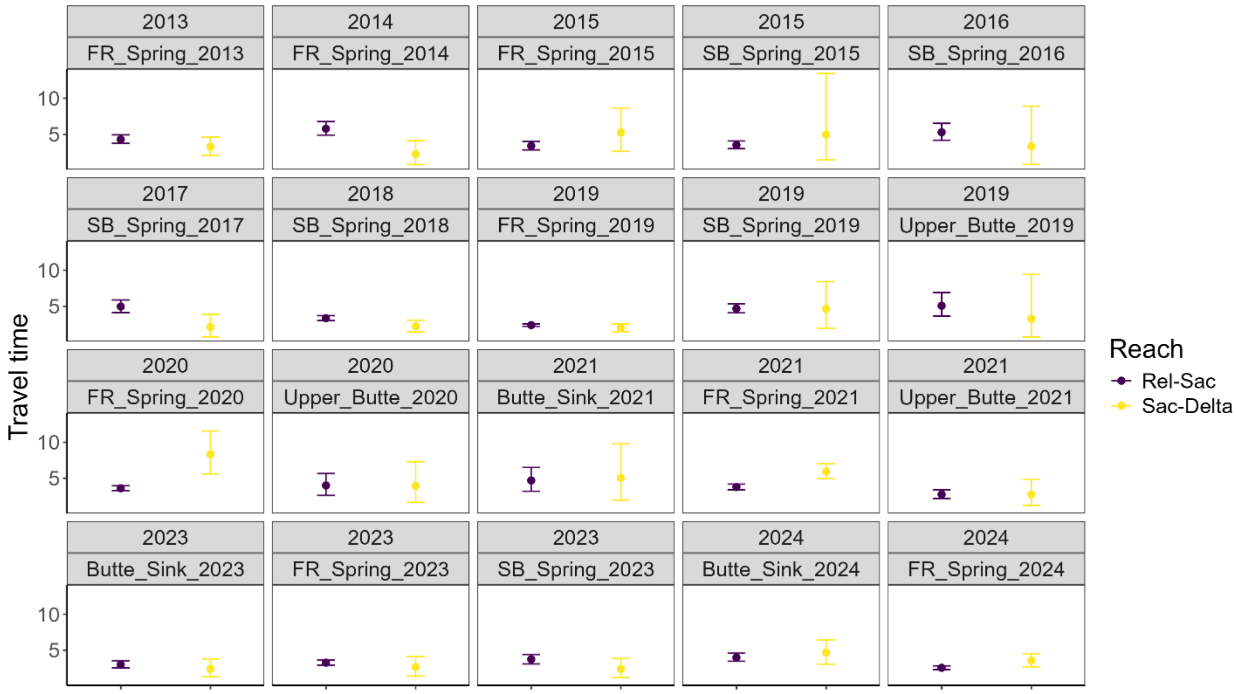

Figure 14. Release to Sacramento Travel Time Predictions in Days for Each Release Group

Release to Sacramento travel time predictions in days for each release group of:

- Upper Sacramento fish
- Butte and Feather fish

These are differentiated by color showing DWR water year type. Blue dots show wetter years (i.e., above-normal and wet water years), and red dots show drier years (i.e., critical, dry and below-normal water years). Error bars represent the 25th and 75th percentiles.