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Estimation of juvenile Steelhead survival and routing migrating through the Delta

2021 Six-Year Steelhead Survival Study: Statistical Methods and Results

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Executive summary

The 2021 San Joaquin River (SJR) steelhead acoustic telemetry study is a continuation of the Six-Year Steelhead Survival Study from 2011-2016. We used acoustic telemetry to assess survival, routing, and migration characteristics of juvenile steelhead from the SJR at Durham Ferry through the South Delta to ocean entry at Golden Gate (Figure 1). In 2021, a multiagency collaboration between UCSC, USFWS-Lodi, and ICF_ESA JV (under contract with DWR) surgically implanted 1,498 juvenile steelhead from the Mokelumne River Hatchery with JSATS acoustic transmitters in March, April, and May.

This report outlines the analytical methods used to address the six objectives outlined in our study plan:

i. Provide overall Delta outmigration survival estimates to Chipps Island, for all release weeks combined, as well as per release week.
ii. Provide overall outmigration survival per major migratory route, for all release weeks combined, as well as per release week.
iii. Provide reach-specific survival estimates through the SJR and OR migratory routes, for all release weeks combined, as well as per release week.
iv. Provide route entrainment estimates at important junctions, including Head of Old River (HOR) and Turner Cut (TC), for all release weeks combined, as well as per release week.
v. Perform a multivariate analysis to determine how environmental variables and water operations may have influenced routing probabilities and reach-specific survival.
vi. Provide these above estimates in such a way to be comparable to past study years, to the extent possible.

We developed a multistate mark recapture model to estimate survival and routing for juvenile steelhead migrating from the SJR through the California Delta to Ocean entry utilizing the space-for-time substitution. The space-for-time substitution links each capture occasion to a spatial location (e.g., river reach) to help account for the complex routing options and fixed receiver locations used in the system. We used a mixed effects structure with random effects applied to reach-specific survival, receiver detections, and routing. Coupled with multiple release locations to bolster survival estimates downstream of Durham Ferry (i.e., the HOR and Stockton releases), these methods present updated analytical methods compared to previous South Delta methods presented by Buchanan and coauthors. In addition, we developed a simulation to assess bias in parameter estimation across different sample sizes to infer the appropriate release sizes for each release group and release locations.

Survival was very low for outmigrating steelhead smolts in 2021, regardless of release group or location. Estimates from 2021 (<5%) were also lower than prior estimates from 2011-2016 (5-63%). Routing estimates at the HOR were comparable to dry and critically dry years without the rock HORB installed (<40% taking the SJR route at the HOR). Finally detection rates were also comparable between studies with most detection estimates >80% for all studies. The 2021 water year was classified as critically dry, with mean SJR inflows from 671-1,300 cfs and exports ranging from 1,276-1,600 cfs. Additionally water temperatures at Mossdale increased from 15.5-21.8°C during the study period. Future efforts will seek analytical methods to account for multiple covariates within the survival model.

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Introduction

The 2021 San Joaquin River (SJR) steelhead acoustic telemetry study is a continuation of the Six-Year Steelhead Survival Study from 2011-2016 (U.S. Bureau of Reclamation (USBR) et al. 2018c, 2018a, 2018b; Buchanan 2018a, 2018b, 2018c) and is included as action 3.4.11 of the 2019 NMFS Biological Opinion (U.S. National Marine Fisheries Service 2019). Like the original study, we used acoustic telemetry to assess survival, routing, and migration characteristics of juvenile steelhead from the SJR at Durham Ferry through the South Delta to ocean entry at Golden Gate (Figure 1). In 2021, a multiagency collaboration between UCSC, USFWS-Lodi, and ICF_ESA JV (under contract with DWR) surgically implanted 1,498 juvenile steelhead from the Mokelumne River Hatchery with JSATS acoustic transmitters in March, April, and May (Table 1).

The NMFS Biological Opinion (BiOp) includes actions that influence Central Valley Project (CVP)/State Water Project (SWP) export and discharges through the SJR and Old and Middle River (OMR) corridor during the study period (U.S. National Marine Fisheries Service 2019). Action 3.4.4 identified target OMR flows of no more negative than -5000 cfs from roughly January through June (the OMR season). In addition, Action 3.4.5 stipulates single-year and cumulative loss thresholds based on historic loss from 2010-2018. This threshold is no greater than 90% of the highest annual loss form 2010-2019. If 50% of the single-year threshold is exceeded, OMR flows will be reduced to a 14-day moving average of -3,500 cfs. If 75% of the threshold is exceeded, OMR flows will be reduced to a 14-day moving average of -2,500 cfs. Under both scenarios, these actions will remain in place may for the remainder of the OMR season unless a risk assessment based on real-time fish monitoring data finds the risk is no longer present (U.S. National Marine Fieries Service 2019).

The 2021 water year was critically low for the San Joaquin and Sacramento Rivers (water year indices of 1.3 and 3.8, respectively; https://cdec.water.ca.gov/reportapp/javareports?name=WSIHIST). These conditions were comparable to 2013-2015 from the previous studies, with additional dry water years in 2012 and 2016, along with a wet year in 2011. In addition to the export reduction actions to meet OMR flow standards and SJR discharnge (outlined in (U.S. National Marine Fisheries Service 2019), the releases for 2021 were planned to utilize and estimate the effects of a spring pulse flow in April. Thus, this study was intended to refine measures for pretecting CA Central Valley steelhead, including those outlined above and explicitly stated in the 2019 BiOp.

Experienced taggers surgically implanted acoustic transmitters and PIT tags into the body cavity of steelhead. Fish were released over three 1-week periods upstream of the Delta at Durham Ferry, in Old River (OR) just below splitting from the SJR, and in the SJR near Stockton. Acoustic tags were detectable on a telemetry array deployed in the SJR downstream of Durham Ferry and throughout the California Delta, Delta exit (Chipps Island), Benicia, Ocean entry (Golden Gate Bridge), and upstream on the Sacramento River (Figure 1). This array was similar to the historical 6-year survival studies (Buchanan 2018c) and allows for comparable inferences with the prior studies. We developed a multistate mark recapture model to estimate survival and routing for juvenile steelhead migrating from the SJR through the California Delta to Ocean entry.

This report outlines the analytical methods used to address the six objectives outlined in our study plan:

vii. Provide overall Delta outmigration survival estimates to Chipps Island, for all release weeks combined, as well as per release week.
viii. Provide overall outmigration survival per major migratory route, for all release weeks combined, as well as per release week.
ix. Provide reach-specific survival estimates through the SJR and OR migratory routes, for all release weeks combined, as well as per release week.
x. Provide route entrainment estimates at important junctions, including Head of Old River (HOR) and Turner Cut (TC), for all release weeks combined, as well as per release week.
xi. Perform a multivariate analysis to determine how environmental variables and water operations may have influenced routing probabilities and reach-specific survival.
xii. Provide these above estimates in such a way to be comparable to past study years, to the extent possible.

Field Methods

Tagging Protocol

An experienced staff of five from UCSC performed the tagging operations during the three weeks of tagging. This included two taggers, two data recorders (one per tagger), and one fish manager (who ensured a steady, controlled flow of fish getting processed by the taggers). In addition, two fish release teams of two persons each released fish daily, for a total of nine staff per day of the project (with the exception of Mondays when release teams were not needed or Fridays when tagging team was not needed; see weekly schedule below). One release team performed two of the daily releases (likely Durham Ferry as well as a supplemental site), while the other release team performed the third release (at the other supplemental site).

Experienced taggers performed surgery in as sterile an environment as possible. Fish were placed ventral-side up on a surgery cradle and had water diffused with a maintenance anesthesia solution passed over gill membranes continuously throughout the procedure. A sterilized, individually-coded, JSATs tag was inserted through an incision into the peritoneal cavity of the fish. The incision was closed with two simple sutures and fish were transferred to an aerated recovery tank as soon as possible post-surgery. PIT tags were also inserted into the peritoneal cavity, which allowed the detection of acoustic-tagged steelhead captured in the CVP or SWP salvage tanks.

Receiver Array

Between existing realtime JSATs receivers managed by USGS and UCSC, along with realtime and autonomous receivers maintained by UC Davis, and receivers deployed and maintained by USGS/Environmental Science Associates (under contract by DWR), the receiver array depicted in colors red, blue and orange in (Figure 1) represent the receivers operational during the 2021 steelhead telemetry project. No receivers were deployed at Medford Island, in contrast to some previous years' studies (Buchanan 2018c). Through conversations with R. Buchanan (University of Washington), we believed that Medford Island was not a critical site for a South Delta routing and survival analysis. UCSC ensured that receivers for the 2021 study were deployed before the first releases of tagged steelhead.

Schedule

The fish were tagged and released over a 1-week period in each of March, April, and May. Tagging occurred Monday-Thursday and releases occurred approximately 24 hours after tagging Tuesday-Friday. These fish were released upstream of the Delta at Durham Ferry (DF release), in Old River just below splitting from the SJR (HOR release), and in the SJR near Stockton (ST release; Figure 1; Table 1).

Sample Size

In total, USBR supplied 1,000 JSATs tags for this study, along with 50 tags for battery life tests. In addition, CaDWR supplied an additional 300 tags to be released, with the condition that 100 of those 300 be released at the HOR site the week of April 12. So as to balance the design, we proposed to distribute those remaining 200 extra tags equally across the remaining the three weeks. Daily fish released were distributed 50% to Durham Ferry, 25% to HOR, and 25% to Stockton. Therefore, in total, 1,200 fish were used over three weeks, so 400 fish per week, and 100 fish per day (see Table 1).

Release Protocol

Fish were held at the hatchery overnight after tagging. Fish were transported via coolers to release sites. Fish were tempered with river water (at a rate not to exceed 2°C change per hour), until cooler temperature was within 2°C of river water temperature. Fish were then released directly into the river from the shore.

For sites with tidal influence (HOR and Stockton), fish were released during a slack tide that occurred during daylight (at least 1.5 hours after sunrise and no later than 2 hours before sunset). Slack tides were offset by 2-4 hours between these sites, so releases were not simultaneous. For sites with no tidal influence (Durham Ferry), fish were released in the morning, no earlier than 1.5 hours after sunrise (so as to avoid periods of high predation risk), and no later than noon (to avoid warmer waters).

Statistical Methods

We developed a multistate mark recapture model to estimate survival and routing for juvenile steelhead migrating from the SJR through the California Delta to Ocean entry (Figures 2-4). Similar to other models developed for estimating survival and routing through the California Central Valley (U.S. Bureau of Reclamation (USBR) et al. 2018c; Perry et al. 2018; Buchanan et al. 2021), we utilized the space-for-time substitution. The space-for-time substitution links each capture occasion to a spatial location (e.g., river reach) to help account for the complex routing options and fixed receiver locations used in the system. This means that detections for fish i at receiver j indicate passage from upstream reach k into reach j (see model assumptions described in the next paragraph). There is no time component inherent for how long a fish can remain in reach j, therefore they can move through quickly or can remain for an unlimited time (i.e., have non-detections listed for the remaining capture occasions).

We developed new analytical methods using a mixed effects structure with random effects applied to reach-specific survival, receiver detections, and routing. Coupled with using multiple release locations to bolster survival estimates downstream of Durham Ferry (i.e., the HOR and Stockton releases), these methods present updated analytical methods compared to previous South Delta methods presented by Buchanan and coauthors (see Buchanan 2018c; Buchanan et al. 2021 and citations within). In addition, we developed a simulation to assess bias in parameter estimation across different sample sizes to infer the appropriate release sizes for each release group and release locations.

The model estimates reach-specific survival rates and detection probabilities, along with routing probabilities for the different routes outmigrating steelhead may take to get from Delta entry at Mossdale to Delta exit at Chipps Island. The model was developed in Template Model Builder (TMB; Kristensen et al. 2016), which is a frequentist methodology that is very effective estimating large numbers of random effects. The TMB models and all data processing were run through program R version 4.2.3 (R Core Team 2023).

Data Processing

JSATS California Fish Tracking databases for this study were obtained from ERDDAP on March 6, 2023. These databases, which are under development, include information related to receiver deployments, tagging of salmonids, and salmonid detections.

The tagging database was obtained from https://oceanview.pfeg.noaa.gov/erddap/tabledap/FED_JSATS_taggedfish.html, with optional constraint study_id specified as "SJ_Steelhead_2021". Relevant data collected on tagged Mokelumne River Hatchery steelhead smolts included fish ID, fish release date-time, fish length (mm), release location, and release latitude and longitude. The tagged fish database contains a fish ID (i.e., tag) key that links to the detections database.

The detection database was downloaded from https://oceanview.pfeg.noaa.gov/erddap/tabledap/FED_JSATS_detects.html, with optional constraint study_id specified as "SJ_Steelhead_2021". An acoustic transmitter can register repeated detections of an individual tagged fish over a short time interval, some of which are false detections. Moreover, these repeated detects are not necessary for survival and movement analyses. Therefore, prior to public release of data on ERDDAP, acoustic detection data were filtered to remove false detections and reduce repeated detections. The initial filtering process applied to the raw detection data is described by NMFS (U.S. National Marine Fisheries Service 2021), and also included the collating of individual detections into detection events. Unique detection events were defined by the detection of an individual fish ID at a specific receiver, until the fish was detected at a new receiver, or there was a 60-minute time delay before being detected again at the same receiver. The time stamp of the detection event corresponds to the first time of tag transmission for the event. Hereafter, detection events are referred to as "detections" for succinctness.

After data were obtained from ERDDAP, another round of data cleaning made additional corrections to the data prior to use in the predator filter and survival model analyses. First, times recorded on Stockton receivers (SJG) were one hour behind and were adjusted. Release times as recorded in the data were averages across individual batches of fish released on a specific date for a release site. Therefore, actual release times for release groups could be up to 30 minutes earlier than the listed time stamp in the detection data. This presented a problem when there were detections for a fish prior to the listed release time. For example, one of the Stockton release groups had release times that were 29 minutes later than the actual release. Adjustments were made to reflect true release times.

The Mossdale telemetry receiver had inaccurate GPS coordinates, and were corrected (corrected latitude = 37.79228, corrected longitude = -121.307). Old River Quimby, Holland Cut Quimby, RT_Old River, and RT_Middle River receivers were removed from the analyses due to very limited detections and/or deployment dates during the study (see Figure 1). Detections corresponding to two receivers (GC_D1 and GC_D2) were completely removed due to high prevalence of false positive detections. Similarly, detection histories were scrutinized for individual implausible tag transmissions, and those detections were removed. Implausible detections were recorded at many receivers, although Grant Line, Old River Tracy, and CVP Trash Rack were particularly noisy.

The detections database contains a deployment ID key that links deployments of individual receivers to corresponding detections of tagged fish at those sites. The deployment ID was used as key because individual receiver serial numbers could be removed from a site and redeployed at a new site within a single migration season.

The receiver database was accessed at https://oceanview.pfeg.noaa.gov/erddap/tabledap/FED_JSATS_receivers.html with no defined optional constraints. Once downloaded, the receiver database was filtered to receivers only within the SJR, South Delta, West Delta, Carquinez Strait, and SF Bay receiver regions, along the outmigration path for SJR steelhead. In addition to region, receivers in ERDDAP are labeled at two other spatial scales: receiver location (location for a single receiver) with corresponding latitude and longitude coordinates, and receiver general location (location of one or more receivers) with corresponding receiver general latitudes and longitudes (see Table 2). Receiver general locations often distinguish between upstream (US) and downstream (DS) lines of receivers or gates, which otherwise have the same site name (e.g., OR_HOR_US and OR_HOR_DS). Detections per tag, collated at receiver general locations, were analyzed by the multistate model to estimate survival and migration probabilities.

Distinguishing between Steelhead and Predator Detections

During migration to the estuary, *O. mykiss* smolts may be consumed by a number of predatory fish species, including Striped Bass *Morone saxatilis*, Largemouth Bass *Micropterus salmoides*, Channel Catfish *Ictalurus punctatus*, and White Catfish *Ameiurus catus* (Michel et al. 2018). Once consumed, the tag originally belonging to the smolt may continue to be acoustically detected while in the predator. These predated tag detections, if not omitted from the analyzed capture histories, could in certain circumstances bias the estimated state-specific survival rates for steelhead smolts. In particular, tags that are consumed by predators that migrate will introduce bias into a mark-recapture model. The longer/farther a tag remains in a predator, the greater the bias introduced into survival estimates. If a smolt is eaten in reach k and the tag remains in reach k, the mark-recapture model will correctly "assign" that mortality to reach k. If the predator moves to reach j, then the model will assign mortality to reach j, introducing a slight bias. The farther that predator travels, the more bias introduced. Thus, if the predator remains in the Delta, bias will not necessarily be introduced into the estimate of through-Delta survival. However, if the predator makes it past Chipps Island with the tag, this could bias the estimate of through-Delta survival high (i.e., true survival is lower than what we estimated). To address this potential source of bias, we developed a predator filter that identified and removed "predator-type" detections from the dataset of migrating tags, leaving only "smolt-type" detections to be analyzed by the mark-recapture model. The full, unfiltered dataset of all tag detections (including both predator-type and smolt-type detections) comprised a second dataset for analysis.

Previous studies have identified a number of behavioral metrics that could be indicative of salmonid predator movements in the SJR and Delta (U.S. Bureau of Reclamation (USBR) et al. 2018c; Buchanan and Whitlock 2022). It should be noted that we did not attempt to incorporate all metrics into the predator filter developed for this study, but instead relied on expert advice (e.g., R. Buchanan and conversations within the Central Valley Tag Predation SOP working group) to highlight key metrics toward a simplified filter that may change as predator filtering approaches evolve.

The predator filter applied in this study focused on four metrics as potential indicators of predator behavior, including upstream movement past Mossdale, repeated detections near the HOR or at water export facilities, and migration rate. First, as with Chinook Salmon smolts, steelhead smolts were not expected to move either upstream or against flow for very long distances. In particular, a movement back upstream after previously moving downstream of Mossdale may be associated with steelhead predators. This is because once steelhead smolts pass the Delta entrance at the HOR, it can be assumed that subsequent upstream migrations will be minimal (R. Buchanan, pers. comm.; U.S. Bureau of Relation (USBR) et al. 2018c). The HOR itself may also be a site of increased predation risk for salmonids, particularly when temperatures increase to coincide with the thermal preferences of piscine predators such as striped bass (Michel et al. 2020). A third potential indicator of predator behavior related to detections at the CVP and/or SWP export facilities (hereafter, "facilities"; corresponds to receiver general locations CVP Trash Rack, SWP CCF Inlet, CC intake, Clifton Court DS Radial Gates 2). Once smolts reached the facilities, it was expected that they would only leave through salvage and transport (Buchanan et al. 2018c). Steelhead predators cannot fit through the louvers at SWP to enter salvage, and most are also too large to enter the CVP holding tanks (R. Buchanan, pers. comm.). Repeated detections of a tag at the facilities therefore are more likely the result of tag consumption by a predator than resident smolts. The fourth metric, migration rate (km/hr), is often used to identify salmonid predators. The swimming speeds of these predators can greatly exceed those of weaker, migrating steelhead smolts (see U.S. Bureau of Reclation (USBR) et al. 2018c). Although previous studies (e.g., U.S. Bureau of Reclation (USBR) et al. 2018c) have used both minimum (representing resident predators) and maximum migration rate thresholds to define predator-type transitions, we focused on maximum migration rates. Consumption of tags by faster moving, highly migratory predators, such as striped bass (see Michel et al. 2020) would be more likely to bias survival estimates of outmigrating steelhead.

Metrics were calculated using data summarized per tag at the array level. Detections at receiver general locations were further collated to the broader, site level array to help identify potential predator movements and behaviors. Averaged latitudes and longitudes estimated for each array, along with receiver general location coordinates are provided in Table 3. An appropriate parametric distribution was fit to each metric, as needed. Thresholds for predator-type detections were quantified based on bootstrap estimates of parameters and corresponding uncertainty for the fitted parametric distribution. Those detections that were equal to or exceeded the 0.95 quantile were labeled as predator-type detections for the purposes of this study. An advantage to using the data to establish thresholds for predator-type detections is that environmental conditions (e.g., flow, temperature, and other water quality metrics; see Lehman et al. 2017) fluctuate temporally, which could lead to differences in predator (and smolt) movements across years. Instead, in the absence of data on known smolt and predator movements during the 2021 water year, we used the complete distribution of each metric to identify atypical behaviors that were more likely to be predator movements while assuming that the majority of values in the distribution resulted from migratory smolts.

For the HOR sites (which included the SJR and OR sites nearest to HOR, plus Mossdale) and facility detection metrics, we fit a statistical distribution to each using a truncated dataset for fish with at least one detection at the location of interest. We then transformed each dataset by subtracting one to better fit known count distributions with low values and a larger quantity of zeros (e.g., negative binomial, Poisson, zero-inflated distributions). Distributions were fit to data using the R package **fitdistrplus** (Delignette-Muller and Dutang 2015). Chi-square tables of observed versus theoretical counts of detections and corresponding goodness-of-fit tests revealed no significant differences between actual facilities detections and the negative binomial fit to the data (χ^2= 0.83; p = 0.36). Of the four distributions tested (negative binomial, Poisson, zero-inflated Poisson, and zero-inflated negative binomial), all showed differences when tested against the observed detections at HOR sites ($p < 0.05$), although the negative binomial distribution had the lowest AIC value (AIC = 2434.462). The zero-inflated negative binomial distribution had an AIC value that was essentially the same (AIC = 2434.463) as the negative binomial distribution, and lower than that of the Poisson (AIC = 2680.470) or zero-inflated Poisson (AIC = 2612.184). Estimation of the 0.95 quantile from the fitted negative binomial distributions corresponded to a median value of four detections at the facilities (μ= 0.69; Figure 5), and five detections at HOR sites (μ = 1.05; Figure 6) for the back transformed datasets. Thus, ≥ 4 facility detections and ≥ 5 HOR site detections were used as the lower threshold values for predator-type detections in the predator filter.

Migration rates were calculated by estimating the transition distances between sequential pairs of detections at arrays and dividing those distances by time. The process involved snapping detections at receivers to nodes along a flow network of the Delta created with the R package **riverdist** (functions and flow network provided by the Delta predator filter R package **DPF,** forthcoming). Several steps were taken to ensure that calculated migrations rates were realistic and reflected study questions. For example, very short transitions between release and adjacent receivers (e.g., HOR release to HOR sites on the SJR or OR, Stockton release to SJG or Durham Ferry release to the downstream Durham Ferry site) were excluded from migration rate calculations. Recorded release times had been approximated per group of releases and therefore could contribute to inaccurate movement rates. Following Buchanan (2018c), intermediate visits (i.e., multiple trips back and forth to same array) were also removed and only final routes retained to better reflect the rates at which steelhead were outmigrating. The same final routes were used as inputs to the multistate mark-recapture model, and only those transitions analyzed by the model were used to establish predator filter thresholds. Finally, several transitions were comprised of detections at non-adjacent receivers but were still considered useful data for establishing the distribution of migration rates for each transition. For those cases, we used the broader migration rate calculated on non-adjacent receiver transitions in place of the missing migration rates for adjacent receiver transitions.

Once relevant transitions and data were identified, we visualized continuous distributions of log migration rates per transition within a region and estimated the 0.95 quantile per transition as the threshold for predator-type distributions using the R package **ggridges** (see Figures 7-10; Table 4). The distributions were computed from kernel density estimates, where the bandwidth used in the smoothed estimate varied jointly per region based on the data. Bandwidth directly affects smoothing, with higher bandwidth corresponding to more smoothing. Because each tagged fish had a different number of transitions between detection events, we calculated per fish the proportion of transitions at very high migration rates (i.e., at or above the 0.95 quantile for each transition). We found that relatively few fish had more than one-quarter of their transitions correspond to these very high migration rates; 0.25 was a fairly consistent break in the migration rate histograms across the nine release groups (Figure 11). We explored this threshold as a potential indicator of predator behavior for the predator filter.

Two variants of predator filter were applied to remove predator-type detections prior to the construction of capture histories and subsequent analysis by the mark-recapture model.

(1) A 1-hit filter that identified a predator-type detection based on any one of the following metric thresholds:

    (a) At least five HOR site visits
    (b) At least four visits to the CVP and/or SWP facilities
    (c) At least 1 upstream migration from downstream of Mossdale back up to Mossdale or upstream

(d) More than one-quarter of transitions between arrays exceed the 95th percentile of log migration rate.

(2) A multi-hit filter based on the following previously defined criteria:

(a) Either (c), or two of the following: (a), (b), or (d).

These two filters, along with the unfiltered data, were intended to represent book-ends for potential predators and subsequent survival estimates. The unfiltered data assumes all detections are smolts and provides the upper bounds for survival estimates. The data using the 1-hit filter represents the lower bounds for survival as it takes the least amount of questionable actions to be classified as a predator. Finally, the multi-hit filter represents a middle-range between the unfiltered data and the 1-hit-filtered data. For either predator filter variant, any detection corresponding to the threshold value for each metric was flagged in the predator-filtered datasets. The flagged detection and any subsequent detections were labeled as predator-type detections and removed from the tag's detection history.

Constructing Capture Histories

Capture (detection) histories (CH) were created for all tags to enable analysis by the multistate mark-recapture model with space-for-time substitution. A capture history provided the release location and the sequence of detections at receiver general locations as a tag migrated downstream along a route through the reaches of the study area. Although the capture histories were generally compiled using receiver general locations, there were a few cases where detections at receiver general locations were aggregated to simplify routing and/or increase sample sizes of analyzed reaches. GC_U and Grant_Line_US were combined, as were Old_River_Tracy_U1 and Old_River_Tracy_U2. Detections for sites around the CVP Trash Rack (CVP_Trash_Rack_DS, CVP_Trash_Rack_US, and Central Valley Project Trash Rack 1) were also combined.

Once the detection locations and adjacent reaches for analysis were determined, numbered states were assigned to the reaches. A full model of all releases included 27 total states/reaches across 14 capture occasions, although see description in *Survival Model* for release-specific routing and states. Because a number of Stockton released tags were observed to move upstream from the release site through Howard and around the HOR, Stockton released tags were allowed to follow this route or move downstream toward MAC or Turner_Cut. Capture histories were tailored to exclude illegal transitions between states in the model structure (see lines between states for allowed transitions in Figures 2-4, and description in *Survival Model*). Tags were also expected to advance to one of the possible downstream states at each subsequent capture occasion (see Figures 2-4) to fit the space-for-time multistate model assumptions.

Three different versions of capture histories were generated for model analysis corresponding to the full (unfiltered) dataset, the multi-hit predator-filtered dataset, and the 1-hit predator-filtered dataset. We present model results from these three applications to provide a range of reach-specific survival and route entrainment estimates for consideration.

Survival Model

Reach-specific survival $\phi_{i,k}$ represents the probability of individual i surviving from reach k to j. Survival was estimated using a mixed effects linear model

$$logit(\phi_{i,k}) = \beta_{0,g_i} + \beta_1 L_i + \mathrm{B}_{k,g_i} \qquad 1$$

where β_{0,g_i} is the intercept for release group g_i, β_1 is the regression coefficient for length-at-tagging L_i, and B_{k,g_i} is a normally distributed random effect following

$$\mathrm{B}_{k,g_i} \sim \begin{matrix} if\ k \leq 3 & N(0,\sigma_{\beta,1}) \\ else & N(0,\sigma_{\beta,2}) \end{matrix} \qquad 2$$

with a mean of zero and a standard deviation of $\sigma_{\beta,x}$ shared across release groups. We assumed immediate post-release survival (reaches $k = (1,2,3)$) may be different than survival in subsequent reaches $k > 3$, which is represented by different standard deviations $\sigma_{\beta,x}$ for the random effect. By setting $\beta_{0,1} = \beta_{0,2} = \beta_{0,3}$ and $\mathrm{B}_{k,1} = \mathrm{B}_{k,2} = \mathrm{B}_{k,3}$, we are assuming survival for an individual of length L_i remains constant between the March, April, and May releases. By setting $\beta_{0,1} \neq \beta_{0,2} \neq \beta_{0,3}$ and $\mathrm{B}_{k,1} \neq \mathrm{B}_{k,2} \neq \mathrm{B}_{k,3}$, we are allowing reach-specific survival for an individual of length L_i to be different across each release group.

Multistate mark recapture models rely on transition matrices to describe how individuals move, and ultimately survive, from capture occasion x to occasion $x + 1$. For this model, we developed three transition matrices that represent each release site (Durham Ferry, HOR, and Stockton in Figures 2-4, respectively). Each matrix is based off of the Durham Ferry transition matrix, but has slight differences based on the release location. We start by describing routing for fish released at Durham Ferry, then touch on the differences in the transition matrix for HOR and ST releases. Before jumping into details, it is important to discuss two major assumptions for fish movement. The first is that fish cannot swim upstream, so a fish with $CH = (1,4,5,6, \dots)$ cannot move to back upstream to state 5 after state 6 (i.e., $CH = (1,4,5,6,5 \dots)$ is not allowed). All capture histories are based on the most downstream state reached. Second, capture histories for fish that pass a junction multiple times are based on final route selection. For example, a fish detected moving from Durham Ferry to Middle River, back up to the Head of OR and down the SJ route (e.g., detections at (1,4,5,6,12,13,12,6,7,8…) will utilize the SJ route for $CH = (1,4,5,6,7,8 \dots)$. These assumptions and decisions for creating capture histories are common for multistate mark-recapture models utilizing the space-for-time substitution (e.g., Perry et al. 2010).

Within the transition matricies, there are several dummy states used. Effectively there are two types of dummy states

1) Pre-release dummy states with a detection rates of 100% and survival of 100% and
2) Unseen dummy states with detection rates of 0% and survival of 100%.

These states are used for keeping the different routing options consistent such that a fish taking any route will reach Chipps Island on capture occasion 11. These dummy states do not influence the likelihood because detection rates and survival are known values. Pre-release dummy states are used in the HOR releases (states 31, 32, and 33; Figure 3) and Stockton releases (states 39; Figure 4). The unseen dummy states are scattered throughout each movement matrix (states 28, 29, and 30; Figures 2-4), with additional states (34-38) immediately post-release for the Stockton releases for individuals heading toward MacDonald Island or TC.

Fish released at Durham Ferry have five major routing options once they enter the Delta at Mossdale (reach 6). The two SJR routes consist of the SJR Mainstem and TC Routes. The three OR Routes include Middle River (MR), OR mainstem, and Grant Line Canal (GLC) Routes.

1) Both SJR routes have fish remaining in the SJR past the HOR where $CH = (1,4,5,6,7,8,9, \dots)$.
    a. SJR Mainstem Route: fish remain in the SJR at the HOR and make it to MacDonald Island $CH = (\dots,9,10, \dots)$. Once they make it to state 10, they have four options to reach Chipps Island, take Three-Mile Slough or Jersey Point (states 22 and 23) or head towards the CVP or SWP (states 19 and 20).
    b. TC Route: fish remain in the SJR at the HOR and take TC into the interior Delta $CH = (\dots,9,11, \dots)$. Similar to the SJR Mainstem Route, once they make it to state 11, they

have four options to reach Chipps Island, take Three-Mile Slough or Jersey Point (states 22 and 23) or head towards the CVP or SWP (states 19 and 20).

2) The three OR routes have fish moving into OR after reach 6 where $CH = (1,4,5,6,12, \ldots)$.
    a. Fish may take MR route $CH = (1,4,5,6,12,13,0, \ldots)$, which includes an unseen dummy state (0), and may volitionally make it to Chipps Island via the Middle or Old River Hwy-4 bridge (reaches 14 or 17) and pass Three-mile Slough or Jersey Point (reaches 22 or 23). Alternatively, fish may get salvaged at the CVP or SWP pumping facilities (reaches 19 or 20).
    b. Fish remain in OR at both the junctions with MR and GLC $CH = (1,4,5,6,12,15,16, \ldots)$. After reach 16, fish may go to Chipps Island via the Middle or Old River Hwy-4 bridge (reaches 14 or 17) and pass Three-mile Slough or Jersey Point (reaches 22 or 23). Alternatively, fish may get salvaged at the CVP or SWP pumping facilities (reaches 19 or 20).
    c. Fish remain in OR at the junction with MR and become entrained into GLC $CH = (1,4,5,6,12,15,18, \ldots)$. After reach 18, fish may go to Chipps Island via the Middle or Old River Hwy-4 bridge (reaches 14 or 17) and pass Three-mile Slough or Jersey Point (reaches 22 or 23). Alternatively, fish may get salvaged at the CVP or SWP pumping facilities (reaches 19 or 20).

For the DF transition matrix, we have three non-detection dummy states (Detection = 0% and survival = 100%; reaches 28, 29, and 30). In addition, we explicitly modeled dual-line receiver gates (i.e., two receiver lines located in close proximity) with 100% survival in reach 26 (i.e., Golden Gate East). This allowed us to obtain an estimate of survival for reach 25 (from Benicia Bridge to Golden Gate East), as opposed to the joint probability of surviving and being detected.

For fish released at HOR, individuals can utilize any of the SJ or OR routes (Figure 3). The only difference for these fish is the capture histories contain known dummy states (Detection = 100% and Survival = 100%). These dummy states are represented by states 31-33 and HOR releases into reach 2, $CH = (31,32,33,2, \ldots)$. These represent pre-release states in order to match capture occasions represented by the Durham Ferry releases. After selection of the ST or OR routes (i.e., after reach 2), the HOR release transition matrix is identical to the DF transition matrix (Figures 3, 2).

The structure for ST releases is slightly different and incorporate both pre-release dummy states (39) and unseen dummy reaches (Detection = 0% and Survival = 100%, reaches 34-38). Fish are allowed to swim downstream towards MacDonald Island and TC (reaches 10 and 11) to take either SJ route. Fish taking the SJ routes have additional unseen dummy reaches after release in reach 3 $CH = (39,3,0,0,0,0,0,10, \ldots)$ or $CH = (39,3,0,0,0,0,0,11, \ldots)$. Additionally, fish may swim upstream toward the HOR and select the OR routes $CH = (39,3,7,6,12, \ldots)$. Routing after reaches 10, 11, and 12 are identical to the DF routing along both SJ and OR routes (Figures 4, 2). For the ST release groups, structuring the model this way allowed us to utilize data for individuals that swam upstream toward the HOR to improve estimates of survival and routing in the OR routes.

Route entrainment probabilities $\psi_{g_i,r_i,k,j}$ for release group g_i and release location r_i describe the probability a fish will transition from reach k to reach j. Similar to Buchanan (2018c), we modeled the main outmigration paths that fish migrating from the SJR can take. For routing options at 2-way junctions, such as fish released at Durham Ferry that reach the HOR (reach 6), they can remain in the SJR route

$$\psi_{g_i,1,6,7} = \rho_{g_i,x=3} \tag{3}$$

or take the OR route

$$\psi_{g_i,1,6,12} = \left(1 - \rho_{g_i,x=3}\right) \tag{4}$$

where $\rho_{g_i,x=3}$ is the probability of remaining in the SJR at the HOR (parameters defined in Tables 16-18). As you will note when looking at the routing map, there are instances where fish have >2 route selection options (e.g., states 10, 11, 16, 18, and 28 have 3-4 routing options; Figures 2-4). We modeled these parameters as 2-part functions, or joint probabilities, where we broke up individual transition probabilities into easier-to-handle components that can be easily integrated in TMB. For example, fish i in state 10 (they remained in the SJR route past MacDonald Island, MAC) could

1. stay in the central Delta and take Three-mile Slough to get to Chipps Island

$$\psi_{g_i,r_i,10,22} = \left(1 - \rho_{g_i,6}\right) * \rho_{g_i,2} \tag{5}$$

2. stay in the central Delta and swim past Jersey Point to get to Chipps Island

$$\psi_{g_i,r_i,10,23} = \left(1 - \rho_{g_i,6}\right) * \left(1 - \rho_{g_i,2}\right) \tag{6}$$

3. head towards the pumping facilities and get entrained into the CVP

$$\psi_{g_i,r_i,10,19} = \rho_{g_i,6} * \rho_{g_i,1} \tag{7}$$

4. or head towards the pumping facilities and get entrained into the SWP

$$\psi_{g_i,r_i,10,20} = \rho_{g_i,6} * \left(1 - \rho_{g_i,1}\right) \tag{8}$$

where $\rho_{g_i,x}$ is the probability of taking routing option x (see Tables 16-18). We modeled $\rho_{g_i,x}$ as a logit-transformed normally distributed random effect. Because the probability of taking route x or route y is arbitrary from a fish's perspective relative to a statistical model and to avoid any unintentional bias, we estimated the mean hyperprior μ_ρ and used an informative standard deviation of log(1.75) to approximate a uniform prior at mean hyperprior values of zero. The hypermean μ_ρ was shared across all release groups. Similar to survival, by setting routing probabilies $\rho_{1,x} = \rho_{2,x} = \rho_{3,x}$, we are holding routing at each junction constant across release group g_i or allowing routing to vary between each release group by having $\rho_{1,x} \neq \rho_{2,x} \neq \rho_{3,x}$.

Detection probabilities (P_j) represent the probability a tagged fish will be detected transitioning from reach k to reach j given the fish is alive and acoustic transmitter is functional. Detection probability for each receiver gate p_j was treated as a logit-transformed normally distributed random effect with a mean of zero and standard deviation of σ_p. In order to reduce the complexity of the model, we condensed most dual-line receivers into a single detection event (except at the Golden Gate dual-line receivers; Figures 2-4). For fish passing these condensed dual-line receivers, we classified a "detection" within the model as the transmitter being detected by at least one of the gates. Therefore, the detection probability for condensed dual-line gates was estimated as

$$P_j = 1 - \left(1 - p_j\right)^2 \tag{9}$$

and for standard single-line gates $P_j = p_j$. This allowed us to minimize bias in the random effect structure for detection by explicitly accounting for the increased detection probabilities at the condensed dual-line receivers. Detection probabilities for each reach were held constant over each release group as it seems likely that detection at a given site would remain relatively stable over time. This also reduces the number of parameters to be estimated and reduces model complexity.

A multinomial distribution was used to calculate the likelihood. With the multinomial likelihood, the probability of being observed in reach j is the product of survival in reach k, the detection probability entering reach j and the probability of transitioning from reach k to reach j. This is a multiplicative process for each capture occasion. For example, a fish released at Durham Ferry (1), detected at DF_DS (4), SJ_BCA (5), SJ_HOR (7), MAC (10), CCF_inlet (20), Chipps (24), and Golden Gate East (26) would have a capture history of $CH = (1,4,5,0,7,0,0,10,20,0,24,0,26,0)$. This likelihood would be

$$l = \phi_1 P_4 * \phi_4 P_5 * \phi_5(1-P_6) * \phi_6 \psi_{g_i,1,6,7} P_7 * \phi_7(1-P_8) * \phi_8(1-P_9) * \phi_9 \psi_{g_i,1,9,10} P_{10} * \phi_{10} \psi_{g_i,1,10,20} P_{20} * \phi_{20}(1-P_{21}) * \phi_{21} P_{24} * \phi_{24}(1-P_{25}) * \phi_{25} P_{26} * (1-P_{27}) \quad 10$$

and needs to be calculated for every fish.

Model Testing and Simulation

We developed a simulation to assess the multistate mark-recapture model for bias and the ability to estimate parameters. In addition, we conducted a sample-size estimation procedure. The simulation was set up to mimic a single release group (e.g., the March releases) and followed the study design (e.g., three release locations with 50% of releases at Durham Ferry, 25% at the HOR, and 25% at Stockton). Reach-specific survival rates were randomly generated and set such that through-Delta survival was approximately 5%, with the intercept for the survival mixed-effects regression equal to 0.5, the slope for the survival-length relationship generated from a uniform distribution between 0.0-0.2, and reach-specific random effects generated from a uniform distribution between 0 and 1. Single-line detection rates were generated from a uniform random distribution between 0.5 and 2 on the logit-scale (between 62% and 88%). These probabilities represent worst-case sencarios with low survival and lower than expected detection rates. Transition probabilities were modeled between 48-52% to ensure some fish utilized each route. These transition probabilities likely do not reflect true *O. mykiss* transition probabilities, but were designed to test the model structure.

For the simulation, we assessed sample sizes ranging from 200 to 500 tags in increments of 50. For each sample size, we ran 200 simulations. To assess bias, we compared the median estimates for each simulation to the true value. Additionally, we calculated the number of simulations in which the true value for a given parameter was not within the 95% confidence intervals. Finally, we looked at the impact of sample size on the standard error estimates.

Analysis of Tag Battery Life and Retention

Approximately 5% of the tags available were randomly selected for use in a battery life and tag retention study. This study was lead by UCSC staff and details of the methods can be found in Notch et al. (2022). Briefly, a total of 78 tags were tested for battery life and tag retention. Seventy-seven tags made it to the estimated run-time of 79 days (98.7%), with one tag dying early at 76 days. Mean run time was 124 days with a range from 76-155. A total of four tags were shed (5.1%), but only one was found 39 days after tagging. In addition, there was one mortality of tagged fish (1.3% mortality). Given the high battery life, low tagging mortality, and difficulty in finding shed tags, we did not incorporate this information into the model.

Analysis of Travel Time to Chipps Island

Travel times (in days) for all tags that made it to Chipps Island, including the 17 fish that were trucked from the facilities to the Western Delta, were calculated. Following Buchanan (2018a), the harmonic mean was used as a summary of travel times. Estimates of travel time encompassed all release months but were segregated by both release location and route (SJR vs. Interior Delta). Travel times to Chipps Island across both routes were also calculated. Importantly, because release times were not considered reliable for individual tags, release times were excluded from the calculated rate. In addition to calculating travel times based on all tags (i.e., the unfiltered dataset), travel times to Chipps were also calculated based on the multi-hit and 1-hit predator-filtered datasets.

Multivariate Analysis on Survival & Routing

To assess the effects of environmental conditions on through-Delta survival and routing at the HOR, we used estimates from 2011-2016 for each release group reported in Buchanan et al. (2021), reports (Buchanan 2018a, 2018b, 2018c, USBR 2018a, 2018b, 2018c), and estimates from this 2021 study. All data utilized a predator filter, with the 2021 data using the multi-hit filter (Tables C2, C3, C4). Covariates assessed were related to environmental conditions (Delta inflow, Delta outflow, SJR inflow, Sacramento River Inflow, and Temperature) along with management-based covariates (exports, Inflow:Exports [IE] ratio for total Delta Inflow, SJR Inflow:Export ratio, and Sacramento River Inflow:Export ratio, and the presence of a rock barrier at the Head of Old River [HORB]). Flow and export related covariates were obtained from the Dayflow database (reported on a daily time-step; https://data.cnra.ca.gov/dataset/dayflow) and temperature was recorded at Mossdale (recorded on a 15-minute interval; https://wdl.water.ca.gov/waterdatalibrary/). Covariates were averaged over the release period and represent general conditions fish experienced during outmigration. This time period may not represent the exact conditions fish experienced when migrating through the Delta, but represent a simple approximation of their experienced conditions.

We performed a multivariate analysis on survival using a generalized logistic model

$$logit(\hat{S}_i) = \mathrm{A} + \frac{\mathrm{K} + \mathrm{A}}{1 + e^{-(\beta_0 + \beta_1 * B_i + \beta_2 * x_i + \beta_3 * T_i)}} \quad 11$$

where $\hat{S}_i$ is the predicted survival from release group i, A is the left horizontal asymptote, K is the right horizontal asymptote, $\beta_0, \ldots, \beta_3$ are the regression coefficients, B_i represents barrier status with $B_i = 1$ represents conditions in which the HORB was completed prior to release for group i and $B_i = 0$ when the HORB was not installed or under construction, x_i is the inflow/outflow/export covarites (discussed above), and T_i is the temperature at Mossdale. We used a generalized logistic function for the analysis because survival appeared to reach an asymptote of less than 100% through-Delta survival (survival range from 3-69%; Figures 17-18). We used a maximum likelihood framework with a normal likelihood

$$NLL = -\sum_{i=1}^{n} \log\left(\frac{1}{\sqrt{2\pi\sigma^2}} e^{-\frac{(S_i - \hat{S}_i)^2}{2\sigma^2}}\right) \quad 12$$

where NLL is the negative log likelihood, σ is the standard error, and S_i are the observed survival estimates for each release group. Finally, we used optim in R to minimize the NLL.

Multivariate analysis for routing used similar methods for survival with $\mathrm{A} = 1$ and $\mathrm{K} = 1$ (i.e., a standard logistic regression). Attempts at fitting the model with covarates did not produce reasonable results. The exception was the covariates for presence/absence of the HORB. Therefore, no formal multivariate analysis for routing was pursued.

Results

Simulation Results

The multistate mark recapture model was assessed via simulation to assess for bias in survival, transition, and detection probabilities. We also conducted a sample-size simulation to assess the impact of fewer tags being released with each release group.

Survival was estimated using a mixed effects framework with 1) fixed parameters representing a fish length effect and regression intercept and 2) a random reach effect. The effect representing fish length (assumed to be a positive relationship between survival and length-at-tagging) didn't show bias across sample sizes, but the standard error associated with the estimates decreased with increasing sample sizes (Figure A1). The survival intercept showed a high degree of bias across all sample sizes in which the model consistently overestimated the survival (Figure A1). Reach-specific survival random effects (Figure A2), were likewise biased, suggesting an identifiability issue between the random effect and intercept (e.g., Ogle and Barber 2020). Correcting the identifiability issue (i.e., assessing the sum of the intercept and random reach effect; Ogle and Barber 2020) showed no bias in the estimates of reach-specific survival across all sample sizes (Figure A3). Standard error estimates declined with increasing sample sizes (Figure A4). Derived survival estimates representing regional and route-specific survival were likewise unbiased and showed similar trends with standard error estimates (Figure A5, A6). Additionally, standard error estimates were generally higher as you move farther away from the release sites, highlighting the mortality process decreasing the sample sizes at these sites as you get closer to the ocean and once fish enter the Delta and are dispersed among multiple routes (Figure A6).

Transition probabilities were highly variable, but unbiased (Figure A7). The variability in transition probabilities was smaller when closer to release sites (e.g.the probability of remaining in the SJR at TC, probability of moving downstream for the Stockton releasese, the probabitity of taking the SJR Route for HOR released fish, and the probabitity of taking the SJR route at the HOR for fish released at Durham Ferry; Figure A7), Standard error estimates for these parameters decreased with higher sample sizes and were higher for the OR routes when fish were dispersed among multiple routes (Figure A8).

Detection probabilities showed bias when looking at the single-line estimates (Figure A9), but this bias was less pronounced when accounting for dual-line detection probabilities (Figure A10). For instance, most dual-line estimates were unbiased when accounting for detection at one or both receivers in a dual line (equation 9) except for Jersey Point, Three-Mile Slough, Chipps Island and Benicia (Figure A10). Similar to other estimates, the detection standard errors declined with higher sample sizes (Figure A11).

Detections

A total of 600 fish were released at Durham Ferry. Of the fish that were detected downstream of HOR (254), most fish selected the OR routes (211) compared to the SJR routes (43). A total of 19 fish were detected at Chipps Island. For the March releases, eight were detected at Chipps Island and all took OR routes, with six detected moving past Jersey Point, one via the SWP, and one took an unknown route. For the April releases, eleven were detected at Chipps Island with three taking the SJR routes (two via the SJR route and one via TC route) and eight taking the OR routes (two took the OR mainstem route and six took the GLC route). There were no fish released at Durham Ferry detected at Chipps Island in the May release. A total of six fish were salvaged from the Durham Ferry Releases.

A total of 600 fish were released at HOR and most remained in the OR route (433) compared to taking the SJR routes (97). A total of 18 fish were detected at Chipps Island, two from the March release, six form the April release, and ten from the May release. Of the fish that made it to Chipps Island, three fish took the SJR mainstem route and 15 took OR routes. Six of the fish released at HOR that made it to Chipps Island were detected at the pumping facilities, seven detected at Jersey Point, and five made it to Chipps via an unknown route.

A total of 298 fish were released at Stockton, with 26 detected at Chipps (seven in March, ten in April, and nine in May). A total of 59 fish were detected downstream of release and 53 went upstream towards the HOR routes (two of these fish were detected at Chipps Island and took the GLC routes). Most fish that made it to Chipps Island were detected moving past Jersey Point (17) or Three-Mile Slough (six), few were detected at the pumps (two), and one via an unknown route.

Environmental Conditions During Releases

We calculated weekly mean flow, temperature, and exports for the three release weeks; daily averages are visually represented in Figures 12-15. Flow and temperature data near Vernalis were downloaded from the California Data Exchange Center. Weekly mean flow (cfs) was March=864, April=1504, May=708, and weekly mean temperature (°C) was March=16.5, April=18.1, May=21.9. The daily range for the study period (March 23 – May 7) was flow (min=557, max=1771) and temperature (min=14.4, max=25.6).

Exports data were downloaded from the California Department of Water Resources dayflow website. Weekly mean exports (cfs) at the Central Valley Project were March=831, April=806, May=801; State Water Project were March=293, April=391, May=377; and total exports were March=1258, April=1431, May=1452. The daily export range (cfs) for the study period (March 23 – May 7) was Central Valley Project (min=395, max=877), State Water Project (min=0, max=699), and total exports (min=598, max=1715). Weekly mean export to inflow ratio was March=0.09, April=0.13, May=0.15. The daily export to inflow ratio for the study period was min=0.04 and max=0.17.

Model Results – All data

Release/reach-specific Survival

All release groups combined

Mean survival for all releases was generally low throughout the system. Survival from Durham Ferry to Delta-entry at Mossdale was 0.40, through-Delta (Delta entry at Mossdale to Chipps Island) survival was 0.04, and through-Bay (Chipps Island to Golden Gate West) was 0.59 (Table 7). Survival for fish taking the SJR Routes had 0.03 survival with equally low survival for fish staying in the SJR (0.03), which was higher than those taking the TC route (0.02; Table 7). Fish taking the OR routes had survival rates of 0.04, with equally low survival of fish taking the MR routes (0.03), OR route (0.04), or taking the GLC route (0.04; Table 7). Post-release survival ranged from 0.90 for the HOR releases to 0.39 for the ST releases (Table 11). Reach-specific survival rates for an average-sized fish ranged from 0.89 for fish entering the Delta at Mossdale (reach 6) to 0.18 for fish entrained into the CVP (reach 19) or detected entering the CVP (reach 19; Table 11).

March

Survival was low across for all three March releases locations. Survival from Durham Ferry to Delta-entry was 0.66, through-Delta survival was 0.05, and through-Bay was 0.44 (Table 8). Survival for fish taking the SJR Routes had 0.02 survival with slightly higher survival for fish staying in the SJR (0.03) compared to those taking the TC route (0.02; Table 8). Fish taking the OR routes had survival rates of 0.06, with lowest survival of fish taking the MR routes (0.02) compared to those staying in the OR route (0.06) or taking the GLC route (0.06; Table 8). Post-release survival ranged from 0.94 for the DF releases to 0.37 for the ST releases (Table 12). Reach-specific survival rates for an average-sized fish ranged from 0.94 for fish entering the Delta at Mossdale (reach 6) to 0.15 for fish entering the MR Route (reach 13) or detected entering the CVP (reach 19; Table 12).

April

In general, survival was lower for the April releases than for the March releases, except for through-bay survival. Survival from Durham Ferry to Delta-entry was 0.54, through-Delta survival was 0.04, and through-Bay was 0.66 (Table 9). Survival for fish taking the SJR Routes had 0.05 survival with slightly higher survival for fish staying in the SJR (0.07) compared to those taking the TC route (0.03; Table 9). Fish taking the OR routes had survival rates of 0.04, with lowest survival of fish taking the MR routes (0.03) compared to those staying in the OR route (0.04) or taking the GLC route (0.04; Table 9). Post-release survival ranged from 0.90 for the HOR releases to 0.44 for the ST releases (Table 13). Reach-specific survival rates for an average-sized fish ranged from 0.88 for fish entering SJ_BCA to Delta

Entry at Mossdale (reach 5) to 0.14 for fish moving past the OR Hwy 4 bridge to either Three-Mile Slough or Jersey Point (reach 17; Table 13).

May

Survival was lowest for the May releases, although through-bay survival was higher than March. Survival from Durham Ferry to Delta-entry was 0.12, through-Delta survival was 0.02, and through-Bay was 0.66 (Table 10). Survival for fish taking the SJR Routes had 0.02 survival with slightly higher survival for fish staying in the SJR (0.02) compared to those taking the TC route (0.01; Table 10). Fish taking the OR routes had survival rates of 0.03, with lowest survival of fish taking the GLC routes (0.02) compared to those staying in the OR route (0.04) or taking the MR route (0.04; Table 10). Post-release survival ranged from 0.87 for the HOR releases to 0.35 for the ST releases (Table 14). Reach-specific survival rates for an average-sized fish ranged from 0.80 for fish entering the Delta at Mossdale (reach 6) to 0.14 for fish moving past the OR Hwy 4 bridge to either Three-Mile Slough or Jersey Point (reach 17; Table 14).

Covariates

We incorporated a mixed-effects regression to estimate survival, including fixed effects representing a release-specific intercept and length-based survival covariate in the model. Overall mean tagging length was 218.2 mm (range 124-299 mm). Monthly size distributions were similar, with mean tagging length of 211.0 mm (range 152-286 mm) in March, in April the mean was 226.4 mm (range 152-298 mm), and a mean in May of 216.2 mm (range 124-299 mm). The release-specific intercept showed the similar values for March and April releases (mean values of 0.44 and 0.41, respectively) and low estimates for May (mean values of 0.08), indicative of lower reach-specific survival, on average (Tables 12-14). The length-survival relationship was assumed to be constant over all release groups. We found a significant (i.e., 95% confidence intervals did not overlap zero) positive relationship between length and survival (Tables 12-14).

Release/reach-specific Routing

All release groups combined

Routing probabilities across all release groups (reported in Table 15) showed few DF released fish remained in the SJR at the Head of OR (22%) compared to taking OR routes (78%). For fish that remained in the SJR, slightly more than half remained in the SJR past TC (64%) and few of these fish headed towards the pumps after passing MacDonald Island (7%). Some SJR route fish that took TC (36%) went towards the pumps (37%). Very few fish that took the MR route (2%) and 76% of those fish that took the MR route headed towards the pumps. Relatively few remained in OR at the split with GLC (24%) and often ended up at the pumping facilities (71%). For fish taking GLC at the split with OR (76%), 41% were entrained by the pumping facilities. Most fish released at the HOR remained in OR (84%) and just over half of fish went downstream in the ST releases (52%).

Given the model structure, we modeled entrainment by the SWP or CVP as a constant across all routing options. We estimated roughly half of fish were entrained by the CVP (56%) compared to the SWP (44%; Table 15). Route selection from the interior Delta to Chipps Island via Three-Mile Slough or Jersey Point was also constant across routing options. Most fish took Jersey Point (82%) to get to Chipps Island via the interior Delta (Table 15).

March

Routing probabilities for March (reported in Table 16) showed few DF released fish remained in the SJR at the Head of OR (16%) compared to taking OR routes (84%). For fish that remained in the SJR, slightly more than half remained in the SJR past TC (59%) and few of these fish headed towards the pumps after passing MacDonald Island (7%). Some SJR fish that took TC (41%) went towards the pumps (26%). Very few fish that took the MR route (7%) and 76% of those fish that took the MR route headed towards the pumps. Relatively few remained in OR at the split with GLC (22%) and often ended up at the pumping facilities (81%). For fish taking GLC at the split with OR (78%), only 26% were entrained by the pumping facilities. Most fish released at the HOR remained in OR (89%) and just over half of fish went downstream in the ST releases (61%).

Given the model structure, we modeled entrainment by the SWP or CVP as a constant across all routing options. We estimated roughly half of fish were entrained by the CVP (56%) compared to the SWP (44%; Table 16). Route selection from the interior Delta to Chipps Island via Three-Mile Slough or Jersey Point was also constant across routing options. Most fish took Jersey Point (92%) to get to Chipps Island via the interior Delta (Table 16).

April

Routing probabilities for April (reported in Table 17) showed few DF released fish remained in the SJR at the Head of OR (13%) compared to taking OR routes (87%; Table 17). For fish that remained in the SJR, slightly more than half remained in the SJR past TC (60%) and few of these fish headed towards the pumps after passing MacDonald Island (12%). Some SJR fish that took TC (40%) went towards the pumps (26%). Very few fish that took the MR route (1%) and 76% of those fish that took the MR route headed towards the pumps. Relatively few remained in OR at the split with GLC (25%) and often ended up at the pumping facilities (64%). For fish taking GLC at the split with OR (75%), 53% were entrained by the pumping facilities. Most fish released at the HOR remained in OR (86%) and less than half of fish went downstream in the ST releases (38%; Table 17).

Given the model structure, we modeled entrainment by the SWP or CVP as a constant across all routing options. We estimated roughly half of fish were entrained by the CVP (44%) compared to the SWP (56%; Table 17). Route selection from the interior Delta to Chipps Island via Three-Mile Slough or Jersey Point was also constant across routing options. Most fish took Jersey Point (77%) to get to Chipps Island via the interior Delta (Table 17).

May

Routing probabilities for April (reported in Table 18) showed few DF released fish remained in the SJR at the Head of OR (24%) compared to taking OR routes (76%; Table 18). For fish that remained in the SJR, slightly more than half remained in the SJR past TC (72%) and few of these fish headed towards the pumps after passing MacDonald Island (5%). The SJR route fish that took TC (28%) often went towards the pumps (40%). Very few fish that took the MR route (1%) and 76% of those fish that took the MR route headed towards the pumps. Relatively few remained in OR at the split with GLC (24%) and often ended up at the pumping facilities (67%). For fish taking GLC at the split with OR (76%), 46% were entrained by the pumping facilities. Most fish released at the HOR remained in OR (76%) and about half of fish went downstream in the ST releases (57%; Table 18).

Given the model structure, we modeled entrainment by the SWP or CVP as a constant across all routing options. We estimated over half of fish were entrained by the CVP (67%) compared to the SWP (33%; Table 18). Route selection from the interior Delta to Chipps Island via Three-Mile Slough or Jersey Point was also constant across routing options. Most fish took Jersey Point (70%) to get to Chipps Island via the interior Delta (Table 18).

Detection Probabilities

Detection probabilities for single-line receiver gates were often >90% (16 of 24 gates; Table 19). Some locations had <80% single-line detection rates, but were often associated with combined-dual lines, resulting in the detection probability for the combined gates being >84% (i.e., the probability of being detected at the upstream gate, downstream gate, or both gates; TC = 96%, MR_HWY4 = 92%, Three-Mile Slough = 84%, Benicia = 86%; Table 19). The exception is MR_OR, which was not a dual-line receiver gate and had a 79% detection rate (Table 19). Detection probabilities we held constant over each release group.

Model Results – Predator Filters

We developed two predator filters for these data, a 1-hit filter and a multi-hit filter. A total of 125 fish had detections that were removed due to exceeding predator thresholds for the 1-hit filter and 49 had detections removed for the multi-hit filter. Very few fish that made it to Chipps Island were flagged as predators. All fish released at DF were classified as smolt-type behaviors for both filters, one fish from the HOR release was flagged as a predator using the 1-hit filter, and one fish from the ST release was flagged as a predator using the 1-hit filter.

Derived survival estimates (e.g., survival to Delta Entry, through-Delta survival, through-Bay survival, etc.) were very similar between the models using predator filtered data compared to unfiltered data (Tables 7-10, B1-B4, C1-C4). For the 1-hit filter, most derived survival rates showed little differences (estimates from the 1-hit filter within $\pm$0.01 of the unfiltered data). The exception was for through-Bay survival, in which we estimated survival rates 0.02 higher in March and survival rates 0.01-0.03 lower in April and May using the 1-hit filter compared to the unfiltered data (Tables 7-10, B1-B4, C1-C4). Derived survival estimates using the multi-hit filter were very similar to those using the unfiltered data (Tables 7-10, B1-B4, C1-C4).

Reach-specific differences in reach-specific survival rates were generally within $\pm$0.05 units between the model with unfiltered data compared to model results using either predator filter (Tables 11-14, B5-B8, C5-C8). A few reaches in the March and May release groups had larger differences in survival between the unfiltered data and the 1-hit predator filter, for example with the data using no predator filter (Tables 12-14)

- Reach 14 in the March release with survival rates of 0.53 (unfiltered) and 0.68 (1-hit filter)
- Reach 9 in the May release with survival rates of 0.46 (unfiltered) and 0.70 (1-hit filter), and
- Reach 20 in the May release with survival rates of 0.51 (unfiltered) and 0.37 (1-hit filter).

Based on the implementation of the predator filter, differences in the survival rates between the unfiltered vs. predator filtered data occurred at the reach-level, but didn't propagate over larger spatial scales (e.g., through-Delta estimates).

Estimates of routing and detection were also similar between models using all datasets (Tables 15-18, B9-B12, C9-C12). The only notable differences in routing were

- probability of heading towards the CVP/SWP after taking TC (reach 11), with the unfiltered probability of 0.46 and 1-hit filter probability of 0.32,
- probability of heading towards the CVP/SWP after taking TC (reach 11), with the unfiltered probability of 0.26 and 1-hit filter probability of 0.11, and
- probability of remaining in the SJR at the junction with OR (reach 6) with the unfiltered probability of 0.42 and 1-hit filter probability of 0.31,

although the 95% confidence intervals were large for these estimates (Tables 16-18). Detection estimates were within $\pm$0.02 units between models using unfiltered vs. predator filtered data (Tables 19, B13, C13).

Travel Time

Travel times for the 63 tagged fish that made it to Chipps Island, based on the unfiltered dataset, are provided in Table 5. Across release months, fish released at Durham Ferry that traveled along the SJR route to Chipps Island had the longest average travel time at 14.33 days (SE = 2.08 days), although only two Durham Ferry released fish used this route. The next longest average travel time to Chipps Island corresponded to Stockton releases that used the Interior Delta route (mean = 13.94 days; SE = 2.91 days). It was much faster for Stockton released fish to use the SJR to get to Chipps Island (mean = 7.32 days, SE = 1.11 days). Releases from the HOR spent the least amount of time traveling to Chipps Island, regardless of whether they moved along the SJR (mean = 6.60 days, SE = 0.73 days; based on only three fish) or Interior Delta (mean = 6.67 days, SE = 1.77 days). One HOR released fish spent only two days enroute to Chipps, by moving through the Interior Delta. Among Durham Ferry releases, the shortest time spent in transit to Chipps Island was just under four days. The distribution of travel times for each combination of release location and route is provided as cumulative frequency plots (Figure 16). The maximum time spent traveling to Chipps Island overall was ~ 27 days.

Based on the 1-hit predator filter, two tags that made it to Chipps Island were identified as having predator-type detections (SJSH2021-252 and SJSH2021-790). Once the capture histories of these two tags were removed, travel times to Chipps Island only reduced slightly for the Durham Ferry and HOR release groups moving through the Interior Delta and increased slightly for the Stockton release group moving through the SJR (see Table 6). None of the tags identified by the multi-hit predator filter were among the arrivals at Chipps Island.

Multivariate Analysis on Survival & Routing

Through-Delta survival estimates estimated by Buchanan et al. (2021) from acoustic telemetry studies between 2011 and 2016 showed higher survival (6-69%) than those estimated in 2021 (2-5%; Figure 17). Environmetnal (SJR inflow and temperature) and managed (exports and IE ratio) conditions during 2021 were comparable to the prior studies for critically dry water years (Figures 17, 18). The multivariate analysis indicated that Delta inflow, Delta outflow, exports, and the IE ratio were the best models describing variation in survival (i.e., ΔAIC < 5; Table 21) with the Delta inflow and exports models being nearly identical (ΔAIC values of 0.0 and 0.3, respectively). Across all models, the presence of the HORB was associated with higher survival and there was a negative relationship between survival and temperature (Figure 18; Table 21). Models using IE ratio and SAC inflow had some parameter estimates with very large standard errors and questionable estimates (extremely large positive and negative values; Table 21).

Routing at the HOR was highly dependent on the presence/absence of the HORB (rock barrier at the head of Old River; Figure 19). When the HORB was in place, most fish (>90%) took the SJR route. During dry and critically dry water years without the HORB, most fish took the OR route (Figure 19), except for the April release in 2012. It should be noted the HORB was under construction from March 15 to April 11 and fish were released from April 4-7. There was no correlation between routing at the HOR and covariates assessed (see Figure 20 for examples).

Discussion

Survival was very low for outmigrating steelhead smolts in 2021. These low survival rates were evident across each release group and release location. Estimates from 2021 (<5%) were also lower than prior estimates from 2011-2016 (5-63%; from Buchanan et al. 2022). The 2021 study occurred during a critically low water year in both the Sacramento and SJR basins. Comparing estimates from 2021 to other critically dry years in 2013-2015 (6-45%; from Buchanan et al. 2022), we see that survival in 2021 was still remarkably low. Routing estimates at the HOR were comparable to dry and critically dry years without the rock HORB installed (<40% taking the SJR route at the HOR). Finally detection rates were also comparable between studies with most detection estimates >80% for all studies (see Buchanan 2018a, 2018b, 2018c, USBR 2018a, 2018b, 2018c). While parameter estimates from 2021 appear comparable to the prior 6-year steelhead study results, survival was consistently low across all conditions in 2021. Note, the discussion focuses on results obtained from the 1-hit predator fitler.

The 2021 water year was classified as critically dry, with mean SJR inflows from 671-1,300 cfs and exports ranging from 1,276-1,600 cfs, resulting in higher export rates than SJR inflow for each release group (SJR inflow/exports were 0.66, 0.81, and 0.47 for the release groups). While more water was being pumped than entering via the SJR, OMR flows did not exceed the BiOp requrirement during the release weeks (tidally averaged flows across the release groups were -1,314, -970, and -564 cfs). Additionally water temperatures at Mossdale increased from 15.5-21.8°C during the study period. Given the environmental conditions and extremely slow survival during this study, it will be very challenging to detect any survival benefits of the spring pulse flow with the existing model structure. This is a consistent issue with these analysis methods when we are unable to incorporate multiple covariates into the survival components of the mark-recaputre model. Future efforts will seek analytical methods to account for multiple covariates within the survival model.

Incorporating covariates within the multistate modeling framework is challenging across the temporal and spatial extent of this study. Therefore we only incorporated a fixed length-effect and random reach effects within the model. Similar to work by Buchanan et al. (2022), we found a positive relationship between smolt length and survival. Although we did not directly incorporate temperature into the multistate models, an inverse trend in survival with Mossdale temperature is evident during release weeks, with highest survival and lowest temperatures in March, lowest survival and highest temperatures in May, and multi-hit value in April. Given the high temperatures, especially in May, it seems likely that high temperatures and low flows in the SJR contributed to the very low survival from Durham Ferry to Delta Entry (0.12 compared to survival >0.44 March and April). These trends in survival and temperature were present when comparing to previous studies as well (Table 21; Figure 18; Buchanan et al. 2022). Correlating the other covariates with survival showed higher survival with higher inflows, exports and IE ratios, similar to results from Buchanan et al. (2022). In the future, we will investigate methods to estimate the effects of temperature, inflow and exports on survival within the multistate mark recapture model framework.

Within the random effects framework of this model, we were able to compare survival patterns across region, route, and down to individual reach across each release group (i.e., month). At a the regional scale, we see highest survival from Durham Ferry to Delta entry (mean 39% and range 10-67%) and from Delta exit to the Golden Gate Bridge (through-bay survival; mean 58% and range 46-64%). Survival rates from release to Delta entry were highest in March and April, through-Delta survival was low across all months, and through-Bay survival was highest in May (Tables XXX). Prior south Delta steelhead survival studies did not have (or use) detections at Golden Gate Bridge and the results here show relatively high survival of smolts that make it past Chipps Island.

Similar to Buchanan et al. (2022), survival rates were similar for fish taking either the SJR and OR routes. These consistent findings showing similar survival between the SJR and OR routes run counter to longstanding expectations that it is better to keep fish in the SJR which adds additional evidence that the SJR route provides better survival benefits. Buchanan et al. (2022) consistently showed higher survival for fish taking the SJR route. For the SJR routes, prior studies for both steelhead and fall-run Chinook consistently show lower survival of fish taking the TC route (Buchanan et al. 2022). Looking at through-Delta survival for these routes, we found equally low survival for fish taking either route. However, looking closely at the reach-specific estimates after fish pass MacDonald Island (reach 10) or TC (reach 11), you can see consistently lower survival for fish entrained into TC (mean reach 11 survival of 41% compared to Mean reach 10 survival of 59%; Table XXX), similar to trends identified by previous studies (Buchanan et al. 2022). Similar to the SJR routes, survival along the OR routes were low across the board (2-6%; Tables). Overall, we detected similar route-specific patterns survival compared to previous studies when no barrier at HOR was installed (i.e., no detectable differences in survival between the SJR or OR routes), even though survival was much lower in 2021 compared to prior years.

Reach-specific trends in survival across each release group highlight areas which show both consistent patterns across time (either high or low) and other areas with inconstant survival trends. Looking at the release-specific survival estimates, we can see that survival for both the Durham Ferry and HOR releases was generally high (86-94%), except for the May release at Durham Ferry when water temperatures at the release site was very high (mean temperatures over the release period recorded downstream at Mossdale were >21°C and survival estimates of 52%). Survival for fish released at Stockton was low across all release groups (34-41%). Along the SJR route, we see the area downstream of the split with OR to Howard (reach 7) having very low survival across all months. All routes near the interior Delta (reaches 10, 11, 13, 14, 16, 17) had low to moderate survival. Finally, areas near and/or associated with the pumping facilies (reaches 19-21), particularly fish salvaged and trucked to releases near Chipps Island had low survival (reacges 19 and 21; 18-26%). Given that each route modeled in this analysis had at least one reach with very low survival, it is hardly surprising that through-Detla survival rates were similar for all routes.

Similar to studies by R. Buchanan (Buchanan 2018a, 2018b, 2018c, USBR 2018a, 2018b, 2018c), the biggeset driving factor in routing at the HOR was the presence/absence of the rock barrier (HORB). There was no HORB installed for the 2021 study and the majority of fish released at Durham Ferry took the OR routes (>80%). Interestingly, there was a higher proportion of fish (42%) that remained in the SJR during the May release. This estimate was similar to 2011 (the only wet year) and several releases where the HORB was partially installed (April 2012 and late-March 2015). However, it should be noted that the Durham Ferry release in May experienced very low survival from release to Delta-entry (12%, compared to >54% for the other releases; Tables 8-10). In fact, only 23 fish made it to Delta-entry in May and 10 took the SJR route (>109 fish made it in other months with 14-19 taking the SJR routes). This low sample size likely contributed to the high proportion of fish taking the SJR route for the May release, which also resulted in larger confidence intervals (Table 18).

We developed two different predator filters for this effort. As a reminder the multi-hit needs multiple hits on the predator filter to be considered a predator and the 1-hit filter needs a single hit to be classified as a predator. The unfiltered data and the 1-hit filtered data can be considered bookends on the survival estimtes. These predator filters differ from prior filters developed by R. Buchanan on steelhead (USBR 2018c). The Buchanan predator filter was developed based on expert opinion across multiple lines of evidence (List). Our predator filter is slightly different in that we utilize statistical distributions to classify individual metrics as being a predator-type or smolt-type metric. For simplicity, we only utilized the upper extreme values for classifying predators (i.e., the upper 95% of observations were classified as predator types). Thus it is important to note that the predator classifications from 2011-2016 data are different than those reported in this document.

We feel it is important to discuss the implications of the predator filters as opposed to differences between the Buchanan filter method and ours. As very few tags were classified as predators made it to Chipps Island, there is very little difference in the to-Delta, through-Delta, and through-Bay survival estimates from the filtered and unfiltered data. The biggest differences in the survival estimates come from the reach-specific survival estimates. This is due to differences in where capture histories are truncated (i.e., what reach is associated with a mortality event). For mobile predators (e.g., striped bass), moving past multiple receivers will introduce bias into our reach-specific survival estimates and if the tag is moving towards Chipps Island (the farther they move, the more bias is introuduced). As we didn't know exactly when/where a tag was predated, our predator filter attempted to account for this type of predation event based on weight-of-evidence using our criteria. If the predated tag moves upstream (which we do not account for in the model, but may be flagged as a predator in the filter) or remains in the same reach (not accounted for in the predator filter), the capture history will be identical for the unfiltered data and the data run through the two predator filters. Given the predator filtering process, careful consideration of the data should be used when using these results to identify reaches of exceptionally good or poor survival to target management actions (e.g., habitat restoration).

A major component for future iterations of the modeling effort is to incorporate additional covariates into the survival model. Because this model uses the space-for-time substittion, it is challenging to incorporate time-based covariates into the model (e.g., mean temperature while individual i was in reach j). For fish with known transitions, this will be easy to calculate because we know when that individual enters and exits reach j. For fish that only make it part of they way through the Delta, these calculations get tricky within TMB because the likelihood needs to account for all possible routing options for the unseen states. Therefore, incorporating covariates for unknown transitions will require background calculations using random effects. One way to do this is to incorporate travel time into the model, such that survival is linked with the amount of time spent in a given reach. This will allow us to incorporate covariates based on travel time for those unseen states. Regardless of how additional covariates are incorporated into the model, developing methods to directly estimate the effects of temperature, SJR inflow, exports, OMR flows, etc. will be beneficial for understanding the impacts of water management on juvenile steelhead outmigration survival and routing.

Our study provides an updated study design utilizing multiple release groups and associated analytical methods to estimate survival, routing, and detection probabilities of juvenile steelhead migrating through the Sacramento – San Joaquin River Delta. While the model structure differed from prior models by R. Buchanan, our results are directly comparable to the prior studies. Results show that through-Delta outmigrating survival of juvenile steelhead was extremely low for fish taking either the SJR or OR routes in 2021. Survival estimates were lower than those from the previous study from 2011-2016, even though environemental conditions were similar to other release groups. Further advancements to the methods outlined here, in particular those designed to incorporate additional covariates into the estimates of survival and routing, should provide better insight into the effects of water operations on juvenile steelhead outmigration characteristics.

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Tables

Table 1. Release numbers for each day and release location. A total of 1,498 fish were released during the study. The April and May releases had additional tags provided by the CA Department of Water Resources to increase releases at the Head of Old River (HOR).

	March				April*				May*			
Release Site	23	24	25	26	13	14	15	16	4	5	6	7
Durham Ferry	50	50	50	50	50	50	50	50	50	50	50	50
Head of OR	25	25	25	25	50	50	50	50	75	75	75	75
Stockton	25	25	25	25	25	25	25	25	24	25	24	25
Total	100	100	100	100	125	125	125	125	149	150	149	150

Table 2. Receiver general locations, and latitude and longitude coordinates used in 2021 study.

Receiver general location	Latitude	Longitude
DurhamFerryUS_1	37.68641	-121.256
DurhamFerry_Rel	37.6878	-121.262
Durhamferry	37.691385	-121.271
SJ_BCA	37.73285	-121.296
Mossdale	37.792563	-121.307
Old_River_Tracy_U	37.807435	-121.539
Head_of_Old_River	37.807888	-121.329
Old_River_Tracy_D	37.810345	-121.543
SJ_HOR_US	37.81156	-121.319
OR_HOR_US	37.813585	-121.335
SJ_HOR_DS	37.813773	-121.318
OR_HOR_DS	37.81545	-121.334
CVP_Trash_Rack	37.816793	-121.559
Grant_Line_DS	37.819642	-121.449
Grant_Line_US	37.819941	-121.436
OR_MidR	37.82005	-121.378
GoldenGateW	37.82212	-122.469
GoldenGateE	37.824229	-122.461
MR_OR	37.82429	-121.379
Clifton_Court_DS_Radial_Gates_2	37.8298	-121.557
CC_intake_J	37.83051	-121.594
Howard	37.874266	-121.333
OR_hwy4_US	37.893689	-121.567
MidR_hwy4_US	37.89547	-121.493
OR_hwy4_DS	37.896585	-121.566
MidR_hwy4_DS	37.89781	-121.495
SJG_US	37.935395	-121.331
SJG_DS	37.93627	-121.334
Stockton_Rel	37.937782	-121.334
MiddleRiver_RR_Bridge	37.939346	-121.533
OldRiver_RR_Bridge	37.939472	-121.56
TurnerCut_3	37.988425	-121.465
TurnerCut_2	37.99008	-121.461
MAC_US	38.01635	-121.462
MAC_DS	38.02303	-121.465
BeniciaW	38.040668	-122.123
BeniciaE	38.043238	-122.123
ChippsE	38.045121	-121.91
ChippsW	38.046281	-121.916
Jersey_Point_W	38.05024	-121.693
Jersey_Point_E	38.05586	-121.689
Three_Mile_South	38.107345	-121.684
Three_Mile_North	38.11085	-121.683

Table 3. Receiver locations, arrays used for the 2021 predator analysis, and the corresponding averaged latitude and longitude coordinates.

Receiver general location	Array	Averaged Latitude	Averaged Longitude
DurhamFerryUS_1	DurhamFerryUS_1	37.68641	-121.25649
DurhamFerry_Rel	DurhamFerry_Rel	37.6878	-121.26219
Durhamferry	Durhamferry	37.691385	-121.271155
SJ_BCA	SJ_BCA	37.73285	-121.29557
Mossdale	Mossdale	37.7925625	-121.3068775
Old_River_Tracy_U	Old_River_Tracy	37.8088898	-121.5411487
Head_of_Old_River	Head_of_Old_River	37.807888	-121.329475
Old_River_Tracy_D	Old_River_Tracy	37.8088898	-121.5411487
SJ_HOR_US	SJ_HOR	37.8126667	-121.318574
OR_HOR_US	OR_HOR	37.8145175	-121.3347775
SJ_HOR_DS	SJ_HOR	37.8126667	-121.318574
OR_HOR_DS	OR_HOR	37.8145175	-121.3347775
CVP_Trash_Rack	CVP_Trash_Rack	37.816793	-121.5586372
Grant_Line_DS	Grant_Line	37.819791	-121.4425875
Grant_Line_US	Grant_Line	37.819791	-121.4425875
OR_MidR	OR_MidR	37.82005	-121.378395
GoldenGateW	GoldenGate	37.8231746	-122.465142
GoldenGateE	GoldenGate	37.8231746	-122.465142
MR_OR	MR_OR	37.82429	-121.378845
Clifton_Court_DS_Radial_Gates_2	Clifton_Court_DS_Radial_Gates	37.8298	-121.5569967
CC_intake_J	CC_intake	37.83051	-121.59437
Howard	Howard	37.874266	-121.332904
OR_hwy4_US	OR_hwy4	37.8951368	-121.5666025
MidR_hwy4_US	MidR_hwy4	37.89664	-121.49379
OR_hwy4_DS	OR_hwy4	37.8951369	-121.5666025
MidR_hwy4_DS	MidR_hwy4	37.89664	-121.49379
SJG_US	SJG	37.9358325	-121.33243
SJG_DS	SJG	37.9358325	-121.33243
Stockton_Rel	Stockton	37.937782	-121.33374
MiddleRiver_RR_Bridge	MiddleRiver_RR_Bridge	37.939346	-121.532974
OldRiver_RR_Bridge	OldRiver_RR_Bridge	37.939472	-121.560455
TurnerCut_3	TurnerCut	37.9892525	-121.46291
TurnerCut_2	TurnerCut	37.9892525	-121.46291
MAC_US	MAC	38.01969	-121.4636833
MAC_DS	MAC	38.01969	-121.4636833
BeniciaW	Benicia	38.0419526	-122.1229907
BeniciaE	Benicia	38.0419526	-122.1229907
ChippsE	Chipps	38.0457011	-121.9127193
ChippsW	Chipps	38.0457011	-121.9127193
Jersey_Point_W	Jersey_Point	38.05305	-121.6912588
Jersey_Point_E	Jersey_Point	38.05305	-121.6912588
Three_Mile_South	Three_Mile	38.1090975	-121.6836425
Three_Mile_North	Three_Mile	38.1090975	-121.6836425

Table 4. The estimated 0.95 quantile for log migration rate for each transition between arrays. These quantiles are the minimum migration rates identified as predator-type detections by the predator filter.

Transition between arrays	Log migration rate threshold (km/hr)
Benicia to GoldenGate	0.453
CC intake to Chipps	0.607
CC intake to Jersey Point	-2.155
CVP Trash Rack to Chipps	0.137
CVP Trash Rack to Jersey Point	-0.302
Chipps to Benicia	0.399
Clifton Court DS Radial Gates to CC intake	0.149
Durhamferry to SJ BCA	0.672
Grant Line to CVP Trash Rack	0.538
Grant Line to Clifton Court DS Radial Gates	0.438
Grant Line to MidR hwy4	0.219
Grant Line to OR hwy4	0.994
Howard to SJG	0.700
Howard to SJ HOR	0.137
Jersey Point to Chipps	0.731
MAC to Jersey Point	0.234
MAC to OR hwy4	-0.148
MAC to Three Mile	0.756
MidR hwy4 to Jersey Point	0.0825
MidR hwy4 to Three Mile	0.162
Mossdale to OR HOR	0.970
Mossdale to SJ HOR	0.744
OR HOR to MR OR	-0.612
OR HOR to OR MidR	0.461
OR MidR to Grant Line	0.641
OR MidR to Old River Tracy	-1.435
OR hwy4 to Jersey Point	0.719
OR hwy4 to Three Mile	0.141
Old River Tracy to CVP Trash Rack	-4.260
Old River Tracy to Clifton Court DS Radial Gates	-1.843
SJG to Howard	-0.184
SJG to MAC	1.113
SJG to TurnerCut	-0.526
SJ BCA to Mossdale	0.354
SJ HOR to Howard	1.049
SJ HOR to OR HOR	0.649
Three Mile to Chipps	0.293
TurnerCut to Jersey Point	-0.329
TurnerCut to MidR hwy4	0.0682
TurnerCut to OR hwy4	-1.020
TurnerCut to Three Mile	-1.253

Table 5. Summary statistics for travel times (days) to Chipps Island, by route and release location for the unfiltered dataset.

Release location	Route	Mean travel time (days)	Travel time standard error (days)
Durham Ferry	Interior Delta	12.43	1.91
Durham Ferry	San Joaquin River	14.33	2.08
Head of Old River	Interior Delta	6.67	1.77
Head of Old River	San Joaquin River	6.60	0.73
Stockton	Interior Delta	13.94	2.91
Stockton	San Joaquin River	7.32	1.11

Table 6. Summary statistics for travel times (days) to Chipps Island, by route and release location for the 1-hit predator filtered dataset.

Release location	Route	Mean travel time (days)	Travel time standard error (days)
Durham Ferry	Interior Delta	10.71	2.09
Durham Ferry	San Joaquin River	14.33	2.08
Head of Old River	Interior Delta	5.88	2.58
Head of Old River	San Joaquin River	6.60	0.73
Stockton	Interior Delta	13.93	2.91
Stockton	San Joaquin River	7.63	1.14

Table 7. Mean derived survival estimates for all releases combined. Parameter estimates were obtained from the model using data without a predator filter. Parameter estimates (Est.) and standard errors (SE) were estimated on the logit-scale and transformed into mean probabilities with lower and upper 95% confidence intervals (L_{95} and U_{95} respectively).

		Logit-Scale		Probabilities		
Parameter Description	Parameter	Est.	SE	Mean	L_{95}	U_{95}
Survival from Durham Ferry to Delta Entry (Mossdale)	lphi_DE	-0.39	0.10	0.40	0.36	0.45
Survival from Delta Entry to Chipps via San Joaquin Route	lphi_SJSJ	-3.35	0.33	0.03	0.02	0.06
Survival from Delta Entry to Chipps via Turner Cut Route	lphi_SJTC	-4.04	0.40	0.02	0.01	0.04
Survival from Delta Entry to Chipps via Middle River Route	lphi_ORMR	-3.57	0.49	0.03	0.01	0.07
Survival from Delta Entry to Chipps via Old River Route	lphi_OROR	-3.08	0.21	0.04	0.03	0.07
Survival from Delta Entry to Chipps via Grant Line Canal Route	lphi_ORGL	-3.21	0.17	0.04	0.03	0.05
Survival from Delta Entry to Chipps via San Joaquin River Routes (SJR and TC)	lphi_SJ	-3.54	0.32	0.03	0.02	0.05
Survival from Delta Entry to Chipps via Old River Routes (MR, OR, GLC)	lphi_OR	-3.19	0.17	0.04	0.03	0.05
Through-Delta Survival	lphi_TD	-3.25	0.16	0.04	0.03	0.05
Through-Bay Survival	lphi_TB	0.35	0.29	0.59	0.45	0.71
Survival from SJ downstream of HOR to Turner Cut	lphi_SJtTC	-2.37	0.30	0.09	0.05	0.14
Survival from Durham Ferry to Benicia	lphi_DFtB	-4.59	0.19	0.01	0.01	0.01
Survival from Head of Old River Release to Benicia	lphi_HORtB	-3.49	0.17	0.03	0.02	0.04
Survival from Stockton Release to Benicia	lphi_STtB	-2.26	0.19	0.09	0.07	0.13
Difference HOR release survival and HOR-reach survival *not logit space	dphi_HOR	0.01	0.03			
Difference in ST release survival and ST-reach survival *not logit space	dphi_ST	-0.15	0.07			

Table 8. Derived survival estimates for the March releases. Parameter estimates were obtained from the model using data without a predator filter. Parameter estimates (Est.) and standard errors (SE) were estimated on the logit-scale and transformed into mean probabilities with lower and upper 95% confidence intervals (L_{95} and U_{95} respectively).

		Logit-Scale		Probabilities		
Parameter Description	Parameter	Est.	SE	Mean	L_{95}	U_{95}
Survival from Durham Ferry to Delta Entry (Mossdale)	lphi_DE	0.68	0.15	0.66	0.60	0.72
Survival from Delta Entry to Chipps via San Joaquin Route	lphi_SJSJ	-3.66	0.71	0.03	0.01	0.09
Survival from Delta Entry to Chipps via Turner Cut Route	lphi_SJTC	-4.06	0.78	0.02	0.00	0.07
Survival from Delta Entry to Chipps via Middle River Route	lphi_ORMR	-3.84	0.86	0.02	0.00	0.10
Survival from Delta Entry to Chipps via Old River Route	lphi_OROR	-2.79	0.43	0.06	0.03	0.12
Survival from Delta Entry to Chipps via Grant Line Canal Route	lphi_ORGL	-2.70	0.30	0.06	0.04	0.11
Survival from Delta Entry to Chipps via San Joaquin River Routes (SJR and TC)	lphi_SJ	-3.81	0.70	0.02	0.01	0.08
Survival from Delta Entry to Chipps via Old River Routes (MR, OR, GLC)	lphi_OR	-2.76	0.29	0.06	0.03	0.10
Through-Delta Survival	lphi_TD	-2.87	0.28	0.05	0.03	0.09
Through-Bay Survival	lphi_TB	-0.26	0.49	0.44	0.23	0.67
Survival from SJ downstream of HOR to Turner Cut	lphi_SJtTC	-2.65	0.67	0.07	0.02	0.21
Survival from Durham Ferry to Benicia	lphi_DFtB	-3.72	0.32	0.02	0.01	0.04
Survival from Head of Old River Release to Benicia	lphi_HORtB	-3.30	0.33	0.04	0.02	0.07
Survival from Stockton Release to Benicia	lphi_STtB	-2.15	0.32	0.10	0.06	0.18
Difference HOR release survival and HOR-reach survival *not logit space	dphi_HOR	-0.03	0.03			
Difference in ST release survival and ST-reach survival *not logit space	dphi_ST	-0.16	0.16			

Table 9. Derived survival estimates for the April releases. Parameter estimates were obtained from the model using data without a predator filter. Parameter estimates (Est.) and standard errors (SE) were estimated on the logit-scale and transformed into mean probabilities with lower and upper 95% confidence intervals (L_{95} and U_{95} respectively).

		Logit-Scale		Probabilities		
Parameter Description	Parameter	Est.	SE	Mean	L_{95}	U_{95}
Survival from Durham Ferry to Delta Entry (Mossdale)	lphi_DE	0.18	0.15	0.54	0.47	0.61
Survival from Delta Entry to Chipps via San Joaquin Route	lphi_SJSJ	-2.67	0.47	0.06	0.03	0.15
Survival from Delta Entry to Chipps via Turner Cut Route	lphi_SJTC	-3.39	0.59	0.03	0.01	0.10
Survival from Delta Entry to Chipps via Middle River Route	lphi_ORMR	-3.62	0.83	0.03	0.01	0.12
Survival from Delta Entry to Chipps via Old River Route	lphi_OROR	-3.20	0.29	0.04	0.02	0.07
Survival from Delta Entry to Chipps via Grant Line Canal Route	lphi_ORGL	-3.23	0.25	0.04	0.02	0.06
Survival from Delta Entry to Chipps via San Joaquin River Routes (SJR and TC)	lphi_SJ	-2.90	0.46	0.05	0.02	0.12
Survival from Delta Entry to Chipps via Old River Routes (MR, OR, GLC)	lphi_OR	-3.23	0.25	0.04	0.02	0.06
Through-Delta Survival	lphi_TD	-3.18	0.23	0.04	0.03	0.06
Through-Bay Survival	lphi_TB	0.66	0.46	0.66	0.44	0.83
Survival from SJ downstream of HOR to Turner Cut	lphi_SJtTC	-1.93	0.43	0.13	0.06	0.25
Survival from Durham Ferry to Benicia	lphi_DFtB	-3.96	0.25	0.02	0.01	0.03
Survival from Head of Old River Release to Benicia	lphi_HORtB	-3.31	0.24	0.04	0.02	0.06
Survival from Stockton Release to Benicia	lphi_STtB	-2.23	0.30	0.10	0.06	0.16
Difference HOR release survival and HOR-reach survival *not logit space	dphi_HOR	0.04	0.04			
Difference in ST release survival and ST-reach survival *not logit space	dphi_ST	-0.16	0.11			

Table 10. Derived survival estimates for the May releases. Parameter estimates were obtained from the model using data without a predator filter. Parameter estimates (Est.) and standard errors (SE) were estimated on the logit-scale and transformed into mean probabilities with lower and upper 95% confidence intervals (L_{95} and U_{95} ,respectively).

		Logit-Scale		Probabilities		
Parameter Description	Parameter	Est.	SE	Mean	L_{95}	U_{95}
Survival from Durham Ferry to Delta Entry (Mossdale)	lphi_DE	-2.03	0.23	0.12	0.08	0.17
Survival from Delta Entry to Chipps via San Joaquin Route	lphi_SJSJ	-3.71	0.48	0.02	0.01	0.06
Survival from Delta Entry to Chipps via Turner Cut Route	lphi_SJTC	-4.68	0.71	0.01	0.00	0.04
Survival from Delta Entry to Chipps via Middle River Route	lphi_ORMR	-3.26	0.80	0.04	0.01	0.16
Survival from Delta Entry to Chipps via Old River Route	lphi_OROR	-3.23	0.34	0.04	0.02	0.07
Survival from Delta Entry to Chipps via Grant Line Canal Route	lphi_ORGL	-3.70	0.32	0.02	0.01	0.04
Survival from Delta Entry to Chipps via San Joaquin River Routes (SJR and TC)	lphi_SJ	-3.91	0.47	0.02	0.01	0.05
Survival from Delta Entry to Chipps via Old River Routes (MR, OR, GLC)	lphi_OR	-3.56	0.31	0.03	0.02	0.05
Through-Delta Survival	lphi_TD	-3.69	0.28	0.02	0.01	0.04
Through-Bay Survival	lphi_TB	0.66	0.51	0.66	0.41	0.84
Survival from SJ downstream of HOR to Turner Cut	lphi_SJtTC	-2.54	0.40	0.07	0.03	0.15
Survival from Durham Ferry to Benicia	lphi_DFtB	-6.09	0.37	0.00	0.00	0.00
Survival from Head of Old River Release to Benicia	lphi_HORtB	-3.87	0.30	0.02	0.01	0.04
Survival from Stockton Release to Benicia	lphi_STtB	-2.40	0.34	0.08	0.04	0.15
Difference HOR release survival and HOR-reach survival *not logit space	dphi_HOR	0.01	0.07			
Difference in ST release survival and ST-reach survival *not logit space	dphi_ST	-0.14	0.10			

Table 11. Mean reach-specific survival random effects estimates (Est.) and standard errors (SE) on the logit-scale and derived reach-specific survival estimates for an average-sized fish with lower and upper 95% confidence intervals (L_{95} and U_{95}, respectively) across all release groups. Bottom four parameters represent the fixed effects intercept, effect of length on survival, and standard deviation (SD) hyperparameters for the reach-specific random effects. The * indicates parameter held constant over release groups within the model. Parameter estimates were obtained from the model using data without a predator filter.

	Logit-Scale		Derived Reach-Specific Est.		
Parameter Description	Est.	SE	Mean	L_{95}	U_{95}
RE for Reach 1: DF release	0.79	0.02	0.69	0.68	0.70
RE for Reach 2: HOR release	0.90	0.01	0.71	0.70	0.72
RE for Reach 3: ST release	0.39	0.03	0.60	0.58	0.61
RE for Reach 4: DF_DS to SJ_BCA	0.61	0.02	0.65	0.64	0.66
RE for Reach 5: SJ_BCA to Mossdale	0.80	0.03	0.69	0.68	0.70
RE for Reach 6: Mossdale to SJ_HOR or OR_HOR	0.89	0.02	0.71	0.70	0.72
RE for Reach 7: SJ-HOR to Howard	0.33	0.03	0.58	0.57	0.60
RE for Reach 8: Howard to SJG	0.58	0.08	0.64	0.60	0.68
RE for Reach 9: SJG to MAC or TC	0.51	0.10	0.63	0.58	0.67
RE for Reach 10: MAC to 3-mile, Jersey Point, CVP or SWP	0.61	0.07	0.65	0.61	0.68
RE for Reach 11: Turner Cut to 3-mile, Jersey Point, CVP or SWP	0.41	0.09	0.60	0.56	0.64
RE for Reach 12: OR_HOR to OR_MR junction	0.72	0.02	0.67	0.66	0.68
RE for Reach 13: MR_OR to MR_HWY4, OR_HWY4, CVP, or SWP	0.33	0.15	0.58	0.51	0.65
RE for Reach 14: MR_HWY4 to 3-mile or Jersey Point	0.31	0.11	0.58	0.52	0.63
RE for Reach 15: OR_MidR to OR_Tracy or GLC	0.77	0.02	0.68	0.67	0.69
RE for Reach 16: OR_Tracy to MR_HWY4, OR_HWY4, CVP, or SWP	0.64	0.06	0.65	0.62	0.68
RE for Reach 17: OR_HWY4 to 3-mile or Jersey Point	0.20	0.04	0.55	0.53	0.57
RE for Reach 18: GLC to MR_HWY4, OR_HWY4, CVP, or SWP	0.54	0.04	0.63	0.61	0.65
RE for Reach 19: CVP trash rack to Chipps Island	0.18	0.05	0.54	0.52	0.57
RE for Reach 20: CCF_inlet to CCF_intake	0.58	0.07	0.64	0.61	0.67
RE for Reach 21: CCF_intake to Chipps Island	0.20	0.06	0.55	0.52	0.58
RE for Reach 22: 3-mile to Chipps Island	0.53	0.13	0.63	0.57	0.68
RE for Reach 23: Jersey Point to Chipps Island	0.76	0.07	0.68	0.65	0.71
RE for Reach 24: Chipps Island to Benicia	0.78	0.05	0.68	0.66	0.71
RE for Reach 25: Benicia to Golden Gate E	0.75	0.07	0.68	0.65	0.71

Table 12. Reach-specific survival random effects estimates (Est.) and standard errors (SE) on the logit-scale and derived reach-specific survival estimates for an average-sized fish with lower and upper 95% confidence intervals (L_{95} and U_{95}, respectively) from the March release. Bottom four parameters represent the fixed effects intercept, effect of length on survival, and standard deviation (SD) hyperparameters for the reach-specific random effects. The * indicates parameter held constant over release groups. Parameter estimates were obtained from the model using data without a predator filter.

	Logit-Scale		Derived Reach-Specific Est.		
Parameter Description	Est.	SE	Mean	L95	U95
RE for Reach 1: DF release	2.25	0.42	0.94	0.78	0.98
RE for Reach 2: HOR release	1.93	0.46	0.91	0.70	0.98
RE for Reach 3: ST release	-0.96	0.37	0.37	0.14	0.70
RE for Reach 4: DF_DS to SJ_BCA	0.88	0.35	0.79	0.50	0.93
RE for Reach 5: SJ_BCA to Mossdale	1.73	0.40	0.90	0.68	0.97
RE for Reach 6: Mossdale to SJ_HOR or OR_HOR	2.36	0.46	0.94	0.78	0.99
RE for Reach 7: SJ-HOR to Howard	-1.62	0.47	0.23	0.06	0.59
RE for Reach 8: Howard to SJG	0.02	0.79	0.61	0.15	0.93
RE for Reach 9: SJG to MAC or TC	-0.50	0.91	0.49	0.08	0.91
RE for Reach 10: MAC to 3-mile, Jersey Point, CVP, SWP	-0.50	0.58	0.48	0.14	0.84
RE for Reach 11: Turner Cut to 3-mile, Jersey Point, CVP, SWP	-0.49	0.67	0.49	0.12	0.87
RE for Reach 12: OR_HOR to OR_MR junction	0.71	0.35	0.76	0.46	0.92
RE for Reach 13: MR_OR to MR_HWY4, OR_HWY4, CVP, SWP	-2.20	0.86	0.15	0.02	0.63
RE for Reach 14: MR_HWY4 to 3-mile or Jersey Point	-0.32	1.01	0.53	0.08	0.94
RE for Reach 15: OR_MidR to OR_Tracy or GLC	0.53	0.36	0.73	0.41	0.91
RE for Reach 16: OR_Tracy to MR_HWY4, OR_HWY4, CVP, SWP	-0.09	0.56	0.59	0.20	0.89
RE for Reach 17: OR_HWY4 to 3-mile or Jersey Point	-1.22	0.52	0.32	0.08	0.70
RE for Reach 18: GLC to MR_HWY4, OR_HWY4, CVP, SWP	-0.49	0.41	0.49	0.19	0.80
RE for Reach 19: CVP trash rack to Chipps Island	-2.16	0.83	0.15	0.02	0.63
RE for Reach 20: CCF_inlet to CCF_intake	1.42	0.93	0.87	0.36	0.99
RE for Reach 21: CCF_intake to Chipps Island	-1.75	0.76	0.21	0.03	0.69
RE for Reach 22: 3-mile to Chipps Island	-0.71	1.14	0.43	0.04	0.93
RE for Reach 23: Jersey Point to Chipps Island	1.43	0.75	0.87	0.45	0.98
RE for Reach 24: Chipps Island to Benicia	0.26	0.57	0.67	0.26	0.92
RE for Reach 25: Benicia to Golden Gate E	0.19	0.67	0.65	0.21	0.93
Intercept for the survival mixed-effects regression	0.44	0.31			
Slope for the survival-length relationship*	0.52	0.04			
Log(SD) for Release-specific random effect hyperparameter*	0.43	0.25			
Log(SD) for Reach-specific random effect hyperparameter*	0.30	0.12			

Table 13. Reach-specific survival random effects estimates (Est.) and standard errors (SE) on the logit-scale and derived reach-specific survival estimates for an average-sized fish with lower and upper 95% confidence intervals (L_{95} and U_{95}, respectively) from the April release. Bottom four parameters represent the fixed effects intercept, effect of length on survival, and standard deviation (SD) hyperparameters for the reach-specific random effects. The * indicates parameter held constant over release groups. Parameter estimates were obtained from the model using data without a predator filter.

	Logit-Scale		Derived Reach-Specific Est.		
Parameter Description	Est.	SE	Mean	L95	U95
RE for Reach 1: DF release	1.50	0.37	0.87	0.64	0.96
RE for Reach 2: HOR release	1.77	0.38	0.90	0.70	0.97
RE for Reach 3: ST release	-0.67	0.36	0.44	0.18	0.74
RE for Reach 4: DF_DS to SJ_BCA	0.50	0.34	0.71	0.41	0.90
RE for Reach 5: SJ_BCA to Mossdale	1.53	0.40	0.88	0.64	0.97
RE for Reach 6: Mossdale to SJ_HOR or OR_HOR	1.39	0.39	0.86	0.61	0.96
RE for Reach 7: SJ-HOR to Howard	-0.73	0.38	0.42	0.16	0.73
RE for Reach 8: Howard to SJG	-0.01	0.61	0.60	0.20	0.90
RE for Reach 9: SJG to MAC or TC	-0.06	0.67	0.59	0.17	0.91
RE for Reach 10: MAC to 3-mile, Jersey Point, CVP, SWP	0.64	0.66	0.74	0.30	0.95
RE for Reach 11: Turner Cut to 3-mile, Jersey Point, CVP, SWP	-0.68	0.67	0.43	0.10	0.84
RE for Reach 12: OR_HOR to OR_MR junction	1.16	0.34	0.83	0.58	0.94
RE for Reach 13: MR_OR to MR_HWY4, OR_HWY4, CVP, SWP	-1.17	1.10	0.32	0.03	0.88
RE for Reach 14: MR_HWY4 to 3-mile or Jersey Point	-2.10	0.88	0.16	0.02	0.65
RE for Reach 15: OR_MidR to OR_Tracy or GLC	1.41	0.36	0.86	0.63	0.96
RE for Reach 16: OR_Tracy to MR_HWY4, OR_HWY4, CVP, SWP	-0.17	0.45	0.56	0.23	0.85
RE for Reach 17: OR_HWY4 to 3-mile or Jersey Point	-2.24	0.48	0.14	0.03	0.43
RE for Reach 18: GLC to MR_HWY4, OR_HWY4, CVP, or SWP	-0.20	0.37	0.55	0.25	0.82
RE for Reach 19: CVP trash rack to Chipps Island	-1.94	0.52	0.18	0.04	0.52
RE for Reach 20: CCF_inlet to CCF_intake	-0.96	0.48	0.37	0.11	0.73
RE for Reach 21: CCF_intake to Chipps Island	-1.87	0.60	0.19	0.04	0.58
RE for Reach 22: 3-mile to Chipps Island	0.45	0.85	0.70	0.20	0.96
RE for Reach 23: Jersey Point to Chipps Island	0.85	0.67	0.78	0.34	0.96
RE for Reach 24: Chipps Island to Benicia	1.40	0.63	0.86	0.50	0.97
RE for Reach 25: Benicia to Golden Gate E	0.78	0.62	0.77	0.35	0.95
Intercept for the survival mixed-effects regression	0.41	0.30			
Slope for the survival-length relationship*	0.52	0.04			
Log(SD) for Release-specific random effect hyperparameter*	0.43	0.25			
Log(SD) for Reach-specific random effect hyperparameter*	0.30	0.12			

Table 14. Reach-specific survival random effects estimates (Est.) and standard errors (SE) on the logit-scale and derived reach-specific survival estimates for an average-sized fish with lower and upper 95% confidence intervals (L_{95} and U_{95}, respectively) from the May release. Bottom four parameters represent the fixed effects intercept, effect of length on survival, and standard deviation (SD) hyperparameters for the reach-specific random effects. The * indicates parameter held constant over release groups. Parameter estimates were obtained from the model using data without a predator filter.

	Logit-Scale		Derived Reach-Specific Est.		
Parameter Description	Est.	SE	Mean	L95	U95
RE for Reach 1: DF release	0.20	0.34	0.57	0.27	0.82
RE for Reach 2: HOR release	1.86	0.35	0.87	0.66	0.96
RE for Reach 3: ST release	-0.70	0.37	0.35	0.12	0.67
RE for Reach 4: DF_DS to SJ_BCA	-0.79	0.36	0.33	0.12	0.65
RE for Reach 5: SJ_BCA to Mossdale	0.39	0.45	0.61	0.27	0.87
RE for Reach 6: Mossdale to SJ_HOR or OR_HOR	1.74	0.58	0.86	0.52	0.97
RE for Reach 7: SJ-HOR to Howard	-0.73	0.38	0.34	0.12	0.66
RE for Reach 8: Howard to SJG	0.06	0.49	0.54	0.20	0.85
RE for Reach 9: SJG to MAC or TC	-0.23	0.56	0.46	0.14	0.82
RE for Reach 10: MAC to 3-mile, Jersey Point, CVP, SWP	0.30	0.55	0.59	0.21	0.89
RE for Reach 11: Turner Cut to 3-mile, Jersey Point, CVP, SWP	-0.89	0.75	0.31	0.05	0.78
RE for Reach 12: OR_HOR to OR_MR junction	0.20	0.33	0.57	0.27	0.82
RE for Reach 13: MR_OR to MR_HWY4, OR_HWY4, CVP, SWP	-0.03	1.36	0.51	0.04	0.96
RE for Reach 14: MR_HWY4 to 3-mile or Jersey Point	-1.22	1.04	0.24	0.02	0.82
RE for Reach 15: OR_MidR to OR_Tracy or GLC	0.82	0.36	0.71	0.40	0.90
RE for Reach 16: OR_Tracy to MR_HWY4, OR_HWY4, CVP, SWP	1.09	0.68	0.76	0.32	0.96
RE for Reach 17: OR_HWY4 to 3-mile or Jersey Point	-1.88	0.53	0.14	0.03	0.46
RE for Reach 18: GLC to MR_HWY4, OR_HWY4, CVP, or SWP	0.23	0.42	0.58	0.25	0.85
RE for Reach 19: CVP trash rack to Chipps Island	-1.49	0.53	0.20	0.05	0.56
RE for Reach 20: CCF_inlet to CCF_intake	-0.02	0.70	0.51	0.13	0.88
RE for Reach 21: CCF_intake to Chipps Island	-1.51	0.78	0.19	0.03	0.67
RE for Reach 22: 3-mile to Chipps Island	-0.29	0.75	0.45	0.09	0.87
RE for Reach 23: Jersey Point to Chipps Island	0.43	0.64	0.63	0.21	0.91
RE for Reach 24: Chipps Island to Benicia	1.32	0.64	0.80	0.39	0.96
RE for Reach 25: Benicia to Golden Gate E	1.44	0.74	0.82	0.37	0.97
Intercept for the survival mixed-effects regression	0.08	0.30			
Slope for the survival-length relationship*	0.52	0.04			
Log(SD) for Release-specific random effect hyperparameter*	0.43	0.25			
Log(SD) for Reach-specific random effect hyperparameter*	0.30	0.12			

Table 15. Mean routing random effects estimates (Est.) and standard errors (SE) on the logit-scale and mean transformed routing estimates with lower and upper 95% confidence intervals (L_{95} and U_{95}, respectively) from all release groups. Parameter estimates were obtained from the model using data without a predator filter.

		Logit-Scale		Transformed Est.		
Par.	Parameter Description	Est.	SE	Mean	L_{95}	U_{95}
ρ_1	Prob. Of entering CVP vs. SWP	0.24	0.24	0.56	0.44	0.67
ρ_2	Prob. Of taking 3-mile vs. Jersey Point to Chipps Island	-1.49	0.35	0.18	0.10	0.31
ρ_3	Prob. Of remaining in SJ @ HOR for DF release	-1.29	0.19	0.22	0.16	0.28
ρ_4	Prob. Of taking SJ route for HOR release vs. OR route	-1.67	0.14	0.16	0.13	0.20
ρ_5	Prob. Of going downstream @ ST release	0.09	0.19	0.52	0.43	0.61
ρ_6	Prob. Of remaining in SJ @ Turner Cut	0.56	0.24	0.64	0.52	0.74
ρ_7	Prob. Of heading to pumps after passing MAC	-2.53	0.60	0.07	0.02	0.20
ρ_8	Prob. Of heading to pumps after entering Turner Cut	-0.54	0.59	0.37	0.16	0.65
ρ_9	Prob. Of taking MR @ MR-OR split	-3.86	0.36	0.02	0.01	0.04
ρ_{10}	Prob. Of heading to interior delta vs. pumps from MR	-1.16	1.05	0.24	0.04	0.71
ρ_{11}	Prob. Of heading to interior via MR_HWY4 vs OR_HWY4 from MR	-1.18	1.05	0.24	0.04	0.70
ρ_{12}	Prob. Of taking OR @ OR-GLC split	-1.18	0.13	0.24	0.19	0.28
ρ_{13}	Prob. Of heading to interior delta vs. pumps from OR	-0.90	0.32	0.29	0.18	0.43
ρ_{14}	Prob. Of heading to interior delta via MR_HWY4 vs. OR_Hwy4 from OR	-1.45	0.58	0.19	0.07	0.42
ρ_{15}	Prob. Of heading to interior delta vs. pumps from GLC	0.37	0.21	0.59	0.49	0.69
ρ_{16}	Prob. Of heading to interior delta via MR_HWY4 vs. OR_Hwy4 from GLC	-2.65	0.43	0.07	0.03	0.14

Table 16. Routing random effects estimates (Est.) and standard errors (SE) on the logit-scale and mean transformed routing estimates with lower and upper 95% confidence intervals (L_{95} and U_{95}, respectively) from the March release. The * indicates parameter held constant over release groups. Parameter estimates were obtained from the model using data without a predator filter.

		Logit-Scale		Transformed Est.		
Par.	Parameter Description	Est.	SE	Mean	L95	U95
ρ_1	Prob. Of entering CVP vs. SWP	-0.23	0.28	0.44	0.31	0.58
ρ_2	Prob. Of taking 3-mile vs. Jersey Point to Chipps Island	-1.19	0.49	0.23	0.10	0.44
ρ_3	Prob. Of remaining in SJ @ HOR for DF release	-1.89	0.28	0.13	0.08	0.21
ρ_4	Prob. Of taking SJ route for HOR release vs. OR route	-1.82	0.21	0.14	0.10	0.20
ρ_5	Prob. Of going downstream @ ST release	-0.48	0.30	0.38	0.26	0.53
ρ_6	Prob. Of remaining in SJ @ Turner Cut	0.42	0.41	0.60	0.41	0.77
ρ_7	Prob. Of heading to pumps after passing MAC	-2.04	0.83	0.12	0.03	0.40
ρ_8	Prob. Of heading to pumps after entering Turner Cut	-1.04	0.98	0.26	0.05	0.71
ρ_9	Prob. Of taking MR @ MR-OR split	-4.25	0.55	0.01	0.00	0.04
ρ_{10}	Prob. Of heading to interior delta vs. pumps from MR	-1.17	1.77	0.24	0.01	0.91
ρ_{11}	Prob. Of heading to interior via MR_HWY4 vs OR_HWY4 from MR	-1.19	1.76	0.23	0.01	0.91
ρ_{12}	Prob. Of taking OR @ OR-GLC split	-1.09	0.16	0.25	0.20	0.32
ρ_{13}	Prob. Of heading to interior delta vs. pumps from OR	-0.56	0.40	0.36	0.21	0.55
ρ_{14}	Prob. Of heading to interior delta via MR_HWY4 vs. OR_Hwy4 from OR	-1.47	0.71	0.19	0.05	0.48
ρ_{15}	Prob. Of heading to interior delta vs. pumps from GLC	-0.12	0.24	0.47	0.35	0.59
ρ_{16}	Prob. Of heading to interior delta via MR_HWY4 vs. OR_Hwy4 from GLC	-2.16	0.50	0.10	0.04	0.23
μ_ρ	Hyperparameter mean of transition probability in logit space*	-1.17	0.29			

Table 17. Routing random effects estimates (Est.) and standard errors (SE) on the logit-scale and mean transformed routing estimates with lower and upper 95% confidence intervals (L_{95} and U_{95}, respectively) from the April release. The * indicates parameter held constant over release groups. Parameter estimates were obtained from the model using data without a predator filter.

		Logit-Scale		Transformed Est.		
Par.	Parameter Description	Est.	SE	Mean	L95	U95
ρ_1	Prob. Of entering CVP vs. SWP	-0.23	0.28	0.44	0.31	0.58
ρ_2	Prob. Of taking 3-mile vs. Jersey Point to Chipps Island	-1.19	0.49	0.23	0.10	0.44
ρ_3	Prob. Of remaining in SJ @ HOR for DF release	-1.89	0.28	0.13	0.08	0.21
ρ_4	Prob. Of taking SJ route for HOR release vs. OR route	-1.82	0.21	0.14	0.10	0.20
ρ_5	Prob. Of going downstream @ ST release	-0.48	0.30	0.38	0.26	0.53
ρ_6	Prob. Of remaining in SJ @ Turner Cut	0.42	0.41	0.60	0.41	0.77
ρ_7	Prob. Of heading to pumps after passing MAC	-2.04	0.83	0.12	0.03	0.40
ρ_8	Prob. Of heading to pumps after entering Turner Cut	-1.04	0.98	0.26	0.05	0.71
ρ_9	Prob. Of taking MR @ MR-OR split	-4.25	0.55	0.01	0.00	0.04
ρ_{10}	Prob. Of heading to interior delta vs. pumps from MR	-1.17	1.77	0.24	0.01	0.91
ρ_{11}	Prob. Of heading to interior via MR_HWY4 vs OR_HWY4 from MR	-1.19	1.76	0.23	0.01	0.91
ρ_{12}	Prob. Of taking OR @ OR-GLC split	-1.09	0.16	0.25	0.20	0.32
ρ_{13}	Prob. Of heading to interior delta vs. pumps from OR	-0.56	0.40	0.36	0.21	0.55
ρ_{14}	Prob. Of heading to interior delta via MR_HWY4 vs. OR_Hwy4 from OR	-1.47	0.71	0.19	0.05	0.48
ρ_{15}	Prob. Of heading to interior delta vs. pumps from GLC	-0.12	0.24	0.47	0.35	0.59
ρ_{16}	Prob. Of heading to interior delta via MR_HWY4 vs. OR_Hwy4 from GLC	-2.16	0.50	0.10	0.04	0.23
μ_ρ	Hyperparameter mean of transition probability in logit space*	-1.17	0.29			

Table 18. Routing random effects estimates (Est.) and standard errors (SE) on the logit-scale and mean transformed routing estimates with lower and upper 95% confidence intervals (L_{95} and U_{95}, respectively) from the May release. The * indicates parameter held constant over release groups. Parameter estimates were obtained from the model using data without a predator filter.

		Logit-Scale		Transformed Est.		
Par.	Parameter Description	Est.	SE	Mean	L95	U95
ρ_1	Prob. Of entering CVP vs. SWP	0.70	0.38	0.67	0.49	0.81
ρ_2	Prob. Of taking 3-mile vs. Jersey Point to Chipps Island	-0.84	0.48	0.30	0.14	0.52
ρ_3	Prob. Of remaining in SJ @ HOR for DF release	-0.31	0.41	0.42	0.25	0.62
ρ_4	Prob. Of taking SJ route for HOR release vs. OR route	-1.15	0.15	0.24	0.19	0.30
ρ_5	Prob. Of going downstream @ ST release	0.30	0.35	0.57	0.40	0.73
ρ_6	Prob. Of remaining in SJ @ Turner Cut	0.92	0.41	0.72	0.53	0.85
ρ_7	Prob. Of heading to pumps after passing MAC	-2.97	1.07	0.05	0.01	0.29
ρ_8	Prob. Of heading to pumps after entering Turner Cut	-0.41	1.13	0.40	0.07	0.86
ρ_9	Prob. Of taking MR @ MR-OR split	-4.67	0.83	0.01	0.00	0.05
ρ_{10}	Prob. Of heading to interior delta vs. pumps from MR	-1.17	1.77	0.24	0.01	0.91
ρ_{11}	Prob. Of heading to interior via MR_HWY4 vs OR_HWY4 from MR	-1.17	1.77	0.24	0.01	0.91
ρ_{12}	Prob. Of taking OR @ OR-GLC split	-1.16	0.24	0.24	0.16	0.33
ρ_{13}	Prob. Of heading to interior delta vs. pumps from OR	-0.71	0.49	0.33	0.16	0.56
ρ_{14}	Prob. Of heading to interior delta via MR_HWY4 vs. OR_Hwy4 from OR	-0.89	0.79	0.29	0.08	0.66
ρ_{15}	Prob. Of heading to interior delta vs. pumps from GLC	0.18	0.32	0.54	0.39	0.69
ρ_{16}	Prob. Of heading to interior delta via MR_HWY4 vs. OR_Hwy4 from GLC	-3.50	0.98	0.03	0.00	0.17
μ_ρ	Prob. Of heading to interior delta via MR_HWY4 vs. OR_Hwy4 from GLC	-1.17	0.29			

Table 19. Detection probability estimates (Est.) and standard errors (SE) on the logit-scale and and transformed estimates with lower and upper 95% confidence intervals (L_{95} and U_{95}, respectively). The bottom two parameters represent the hyperparameter mean and standard deviation (SD) for the distribution of random effects. Detection estimates represent detection at a single-line and detection of combined dual-line receivers so detection across both lines is $P = 1 - \left(1 - 1/e^{-lgt_p}\right)^2$. Parameter estimates were obtained from the model using data without a predator filter.

		Logit-Scale		Transformed Est.			Dual-
Par.	Parameter Description	Est.	SE	Mean	L95	U95	Line Est.
p_1	Logit Detection: DF_DS	3.46	0.32	0.97	0.94	0.98	
p_2	Logit Detection: SJ_BCA	3.84	0.41	0.98	0.95	0.99	
p_3	Logit Detection: Mossdale	3.94	0.45	0.98	0.96	0.99	
p_4	Logit Detection: SJ_HOR (Combined dual-line)	3.37	0.74	0.97	0.87	0.99	1.00
p_5	Logit Detection: Howard	2.55	1.42	0.93	0.44	1.00	
p_6	Logit Detection: SJG (Combined dual-line)	5.13	0.64	0.99	0.98	1.00	1.00
p_7	Logit Detection: MAC (Combined dual-line)	1.94	0.83	0.87	0.57	0.97	0.98
p_8	Logit Detection: Turner Cut (Combined dual-line)	1.33	0.46	0.79	0.61	0.90	0.96
p_9	Logit Detection: OR_HOR (Combined dual-line)	2.30	0.87	0.91	0.64	0.98	0.99
p_{10}	Logit Detection: MR_OR	1.33	0.39	0.79	0.64	0.89	
p_{11}	Logit Detection: MR_HWY4 (Combined dual-line)	0.89	0.34	0.71	0.56	0.83	0.92
p_{12}	Logit Detection: OR_MidR	2.21	0.53	0.90	0.76	0.96	
p_{13}	Logit Detection: OR_Tracy (Combined dual-line)	2.69	1.23	0.94	0.57	0.99	1.00
p_{14}	Logit Detection: OR_HWY4 (Combined dual-line)	2.83	1.14	0.94	0.65	0.99	1.00
p_{15}	Logit Detection: GLC (Combined dual-line)	2.63	1.29	0.93	0.52	0.99	1.00
p_{16}	Logit Detection: CVP_trash_rack	3.00	0.47	0.95	0.89	0.98	
p_{17}	Logit Detection: CCF_Inlet	2.41	1.55	0.92	0.35	1.00	
p_{18}	Logit Detection: CCF_Intake	1.60	0.49	0.83	0.65	0.93	
p_{19}	Logit Detection: 3-mile Slough (Combined dual-line)	0.39	0.39	0.60	0.41	0.76	0.84
p_{20}	Logit Detection: Jersey Point (Combined dual-line)	3.02	1.03	0.95	0.73	0.99	1.00
p_{21}	Logit Detection: Chipps Island (Combined dual-line)	2.48	1.45	0.92	0.41	1.00	0.99
p_{22}	Logit Detection: Benicia (Combined dual-line)	0.54	0.35	0.63	0.46	0.77	0.86
p_{23}	Logit Detection: Golden Gate E	1.94	0.56	0.87	0.70	0.95	
p_{24}	Logit Detection: Golden Gate W	2.92	1.08	0.95	0.69	0.99	
μ_p	Hyperparameter mean detection probability in logit space	2.45	0.36				
$log(\sigma_p)$	Hyperparameter log(SD) for detection random effect	0.37	0.21				

Table 20. Through-Delta (Mossdale to Chipps Island) survival with 95% confidence intervals from 2011-2016 and 2021 with environmental and management covariates. Covarates were averaged between the first release (day start) to last release (day end) for each release group. Inflow, outflow, exports and Inflow:Export ratios (IE) were obtained from Dayflow for San Joaquin River (SJR), Sacramento River (SAC) and system-wide (overall). A physical rock barrier was in place for some release groups at the head of Old River (HORB fully installed = 1, no HORB = 0).

Year	Month	Day Start	Day End	Surv.	Lower 95%	Upper 95%	Delta Inflow	SJR Inflow	SAC Inflow	Delta Outflow	Exports	Overall IE	SJR IE	SAC IE	Temp C	HORB 1=Yes
2011	3	22	26	0.69	0.63	0.75	195,971	16,740	84,560	197,773	3,122	206.8	17.8	86.4	11	0
2011	4	3	7	0.52	0.46	0.58	128,724	29,840	70,400	121,139	5,804	22.2	5.1	12.1	15	0
2011	4	17	21	0.44	0.38	0.50	73,121	26,380	40,100	64,954	6,330	11.6	4.2	6.3	16	0
2011	5	11	26	0.6	0.54	0.66	51,945	11,669	36,381	47,605	3,261	16.5	3.7	11.6	16	0
2011	6	15	18	0.38	0.28	0.48	57,248	10,525	43,475	43,723	9,766	5.9	1.1	4.5	18	0
2012	4	4	7	0.26	0.22	0.30	28,923	1,950	25,750	25,717	1,938	15.0	1.0	13.4	16	0
2012	5	1	6	0.35	0.29	0.41	28,221	2,963	23,800	23,405	2,809	10.3	1.1	8.7	18	1
2012	5	18	23	0.33	0.25	0.41	13,685	2,515	9,987	6,481	4,716	2.9	0.5	2.1	20	1
2013	3	6	9	0.15	0.11	0.19	14,746	1,733	12,300	8,116	5,823	2.5	0.3	2.1	14	0
2013	4	3	6	0.09	0.05	0.13	19,452	1,483	16,950	19,829	1,523	12.8	1.0	11.1	20	0
2013	5	8	11	0.2	0.16	0.24	15,723	3,573	11,150	11,355	2,223	7.1	1.6	5.0	17	0
2014	4	24	27	0.43	0.37	0.49	10,292	2,935	6,488	8,067	3,155	3.3	0.9	2.1	16	1
2014	5	21	24	0.06	0.02	0.10	8,017	757	6,365	4,052	1,392	5.8	0.5	4.6	21	1
2015	3	4	7	0.15	0.09	0.21	11,221	586	9,403	5,359	4,845	2.3	0.1	1.9	16	0
2015	3	25	28	0.35	0.29	0.41	10,966	820	6,940	7,558	1,863	5.9	0.4	3.7	19	0
2015	4	22	25	0.2	0.12	0.28	7,985	610	5,768	5,254	1,609	5.0	0.4	3.6	20	1
2016	2	24	27	0.39	0.33	0.45	20,344	858	18,775	13,552	5,904	3.4	0.1	3.2	16	0
2016	3	16	19	0.42	0.38	0.46	112,114	3,868	76,300	104,086	7,711	14.4	0.5	9.9	17	0
2016	4	27	30	0.59	0.55	0.63	17,038	2,830	12,925	12,526	2,916	5.8	1.0	4.4	16	1
2021	3	23	26	0.05	0.03	0.09	11,842	842	10,480	9,115	1,276	9.3	0.7	8.2	16	0
2021	4	13	16	0.04	0.02	0.06	10,538	1,300	8,688	7,119	1,600	6.6	0.8	5.4	19	0
2021	5	4	7	0.02	0.01	0.04	6,834	672	5,608	3,357	1,448	4.7	0.5	3.9	22	0

Table 21: Generalized logistic multivariate model comparison on correlating through Delta survival with the presence of the head of Old River Barrier (HORB), covariates, and Mossdale water temperature. Covariates, HORB, and temperature values were averaged over the release period and maximum likelihood covariate estimates with standard errors in parentheses.

Model Covariate	NLL	AIC	ΔAIC	Right Asymptote A	Left Asymptote κ	Intercept β_0	HORB β_1	Covariate β_2	Temperature β_3	$\log(\sigma)$
Delta Inflow	21.8	57.6	0.0	0.83 (1.42)	-6.00 (7.88)	5.37 (8.99)	-0.90 (1.06)	-0.81 (1.00)	0.11 (0.14)	-0.43 (0.15)
Delta Outflow	22.3	58.7	1.0	1.38 (2.38)	-6.96 (12.14)	2.05 (5.45)	-0.73 (1.08)	-0.46 (0.68)	0.10 (0.15)	-0.40 (0.15)
Exports	22.0	57.9	0.3	-0.39 (0.19)	-452 (8006)	20.68 (17.21)	-0.53 (0.30)	-3.86 (1.29)	0.12 (0.05)	-0.42 (0.15)
IE ratio	28.0	70.1	12.5	1.51 (2.4)	-122 (1567)	-5.47 (11.86)	-0.39 (0.41)	-0.18 (0.23)	0.12 (0.13)	-0.14 (0.15)
SJR Inflow	24.3	62.5	4.9	3.06 (11.45)	-12.52 (71.94)	-0.61 (5.47)	-0.30 (1.12)	-0.19 (0.72)	0.07 (0.25)	-0.32 (0.15)
SJR IE	32.3	78.6	21.0	0.26 (*NA*)	-1.42 (*NA*)	-92.63 (*NA*)	333 (*NA*)	-213 (*NA*)	17.02 (*NA*)	0.05 (*NA*)
SR Inflow	27.5	69.1	11.4	-0.24 (0.26)	-2.09 (0.27)	571 (103839)	-795 (9341)	-968 (13917)	546 (2379)	-0.17 (0.15)
SR IE	28.8	71.5	13.9	1.49 (0.89)	-103 (3021)	-5.63 (24.3)	-0.37 (0.57)	-0.11 (0.12)	0.13 (0.20)	-0.11 (0.15)

Figures

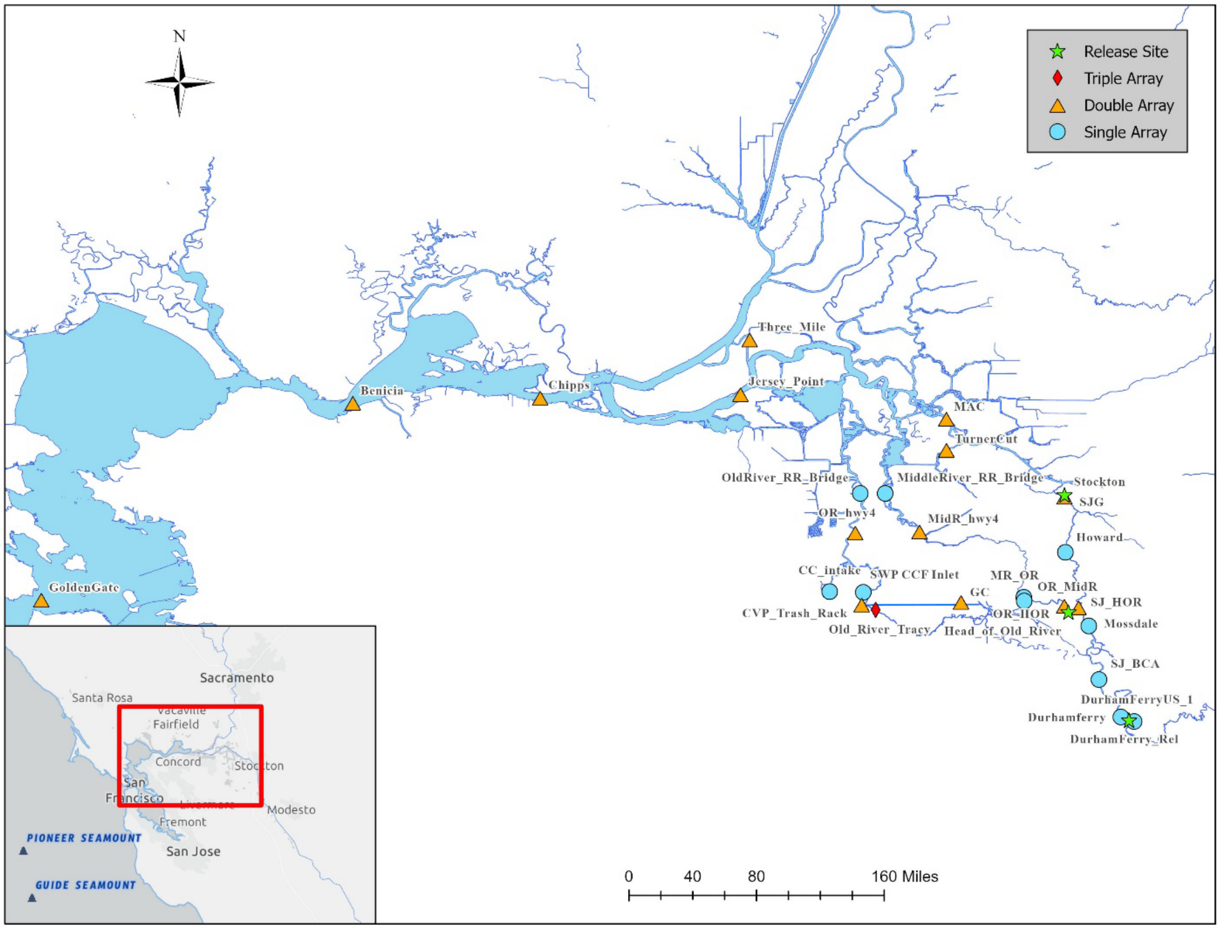

Figure 1. Receiver distribution and release locations in 2021. Note that the Old River Tracy receiver is a dual line, not a triple line.

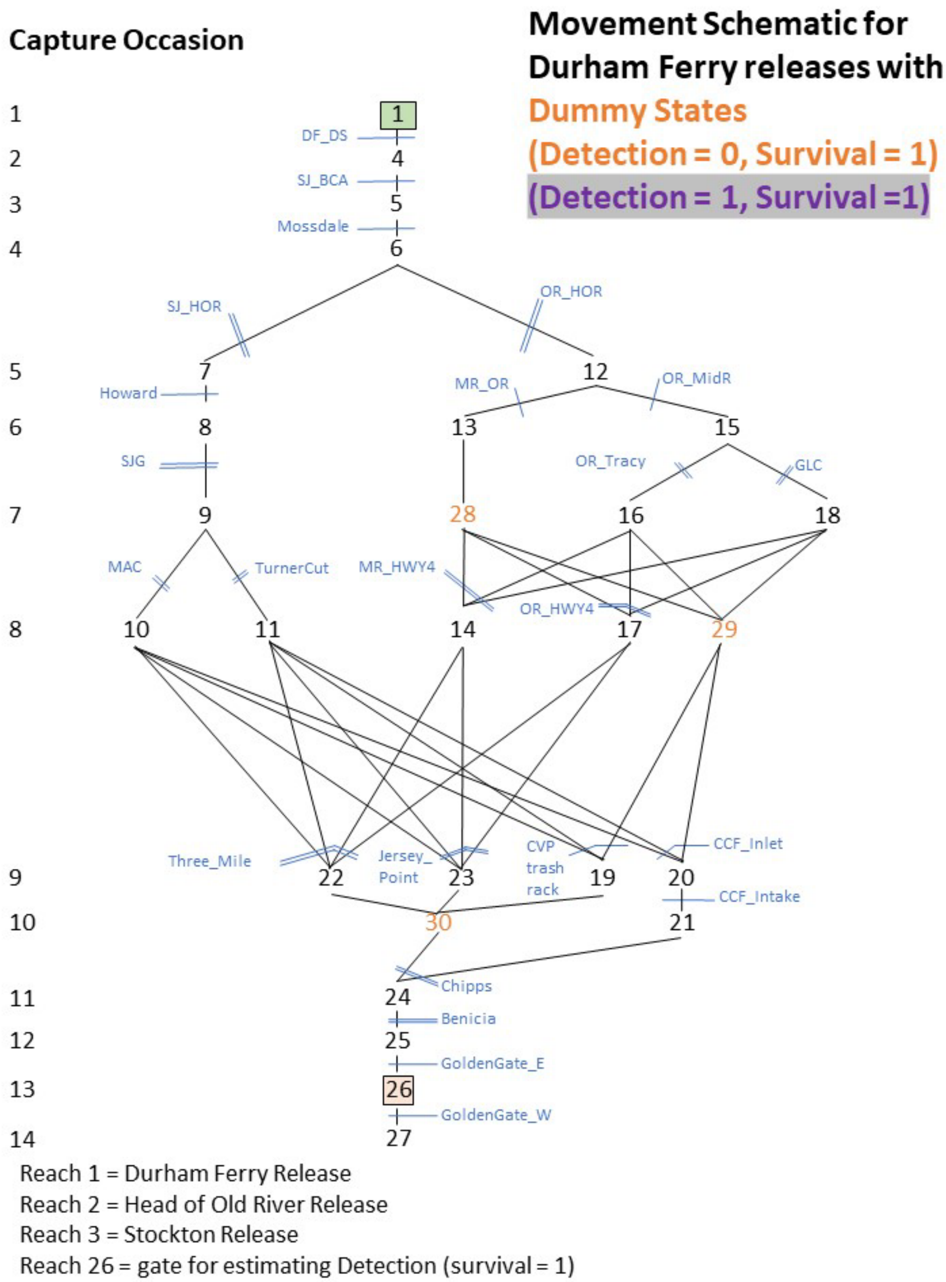

Figure 2. Movement schematic for 2021 releases at Durham Ferry. Numbers within the routing schematic are reaches (states) between receiver general locations indicated by blue single lines (single-arrays) or double lines (dual-arrays). Connecting (black) lines show downstream route options between states. Potential states for the capture histories were limited to those horizontally aligned with the capture occasions listed on the left. Dummy states were added to ensure consistency in capture histories at any given capture occasion (e.g., regardless of route taken, fish would make it to Chipps Island (reach 24) at occasion 11). Dummy states in orange had detection rates of 0 and survival of 1. Dummy states in purple were assigned detection and survival of 1 representing pre-release states.

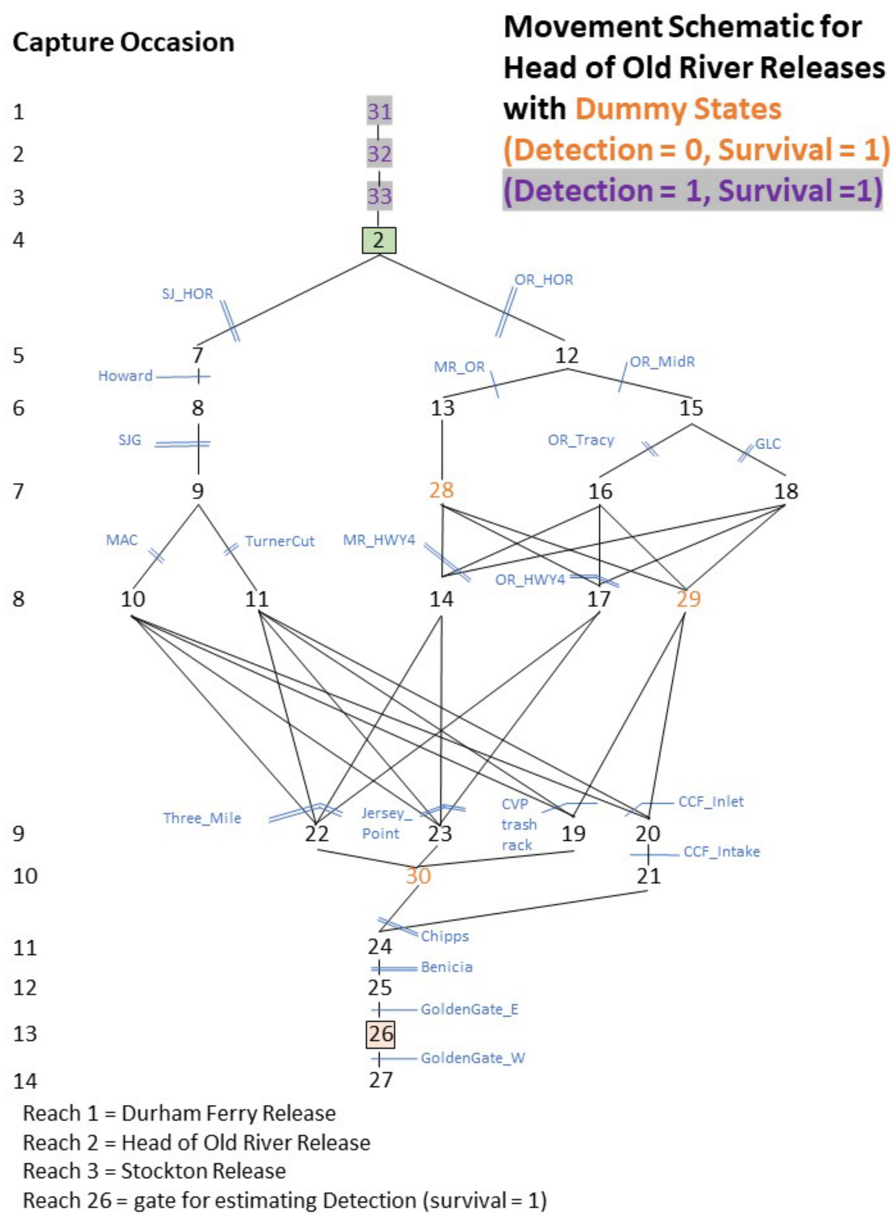

Figure 3. Movement schematic for 2021 releases at Head of Old River. Numbers within the routing schematic are reaches (states) between receiver general locations indicated by blue single lines (single-arrays) or double lines (dual-arrays). Connecting (black) lines show downstream route options between states. Potential states for the capture histories were limited to those horizontally aligned with the capture occasions listed on the left. Dummy states were added to ensure consistency in capture histories at any given capture occasion (e.g., regardless of route taken, fish would make it to Chipps Island (reach 24) at occasion 11). Dummy states in orange had detection rates of 0 and survival of 1. Dummy states in purple were assigned detection and survival of 1 representing pre-release states.

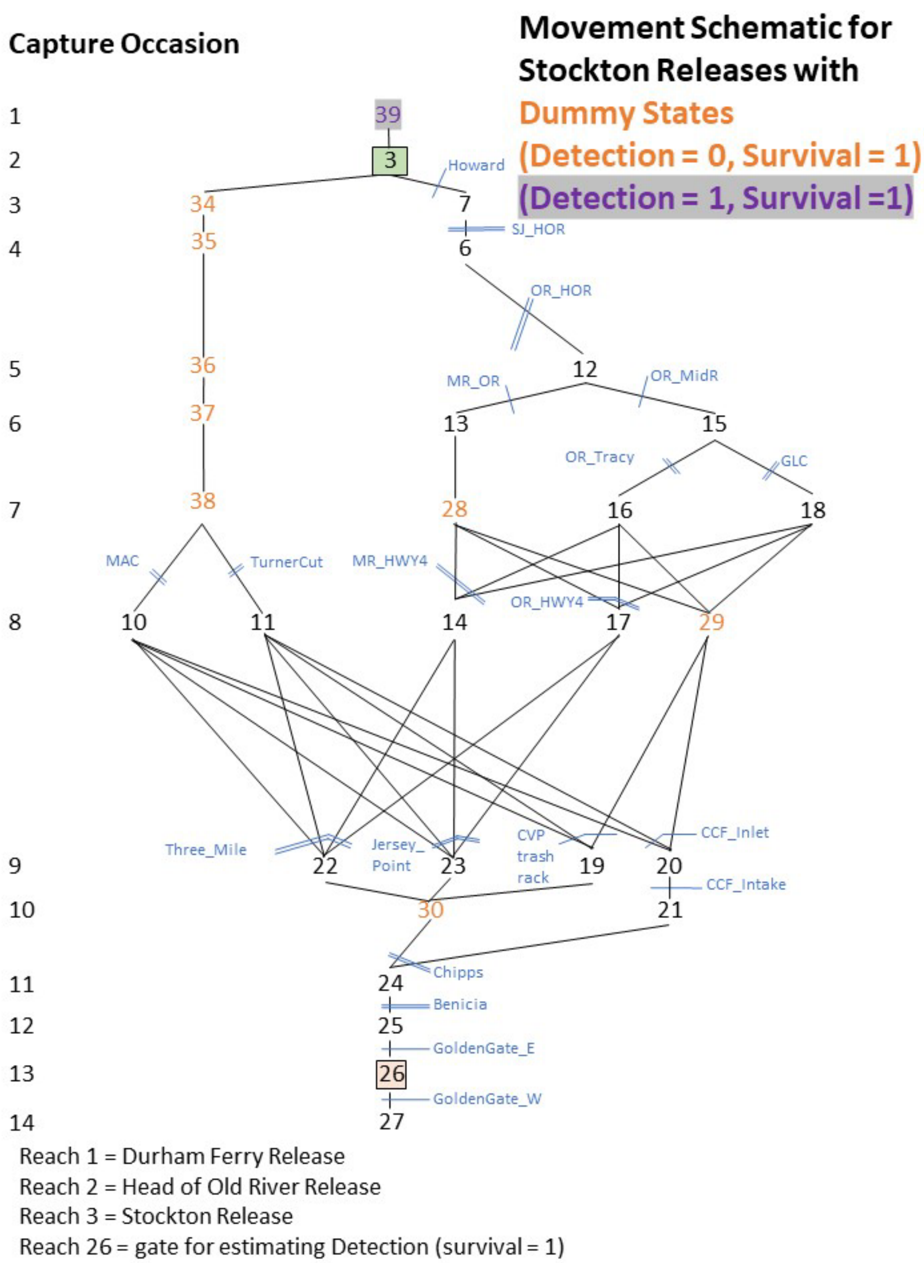

Figure 4. Movement schematic for 2021 releases at Stockton. Numbers within the routing schematic are reaches (states) between receiver general locations indicated by blue single lines (single-arrays) or double lines (dual-arrays). Connecting (black) lines show route options between states. Potential states for the capture histories were limited to those horizontally aligned with the capture occasions listed on the left. Dummy states were added to ensure consistency in capture histories at any given capture occasion (e.g., regardless of route taken, fish would make it to Chipps Island (reach 24) at occasion 11). Dummy states in orange had detection rates of 0 and survival of 1. Dummy states in purple were assigned detection and survival of 1 representing pre-release states.

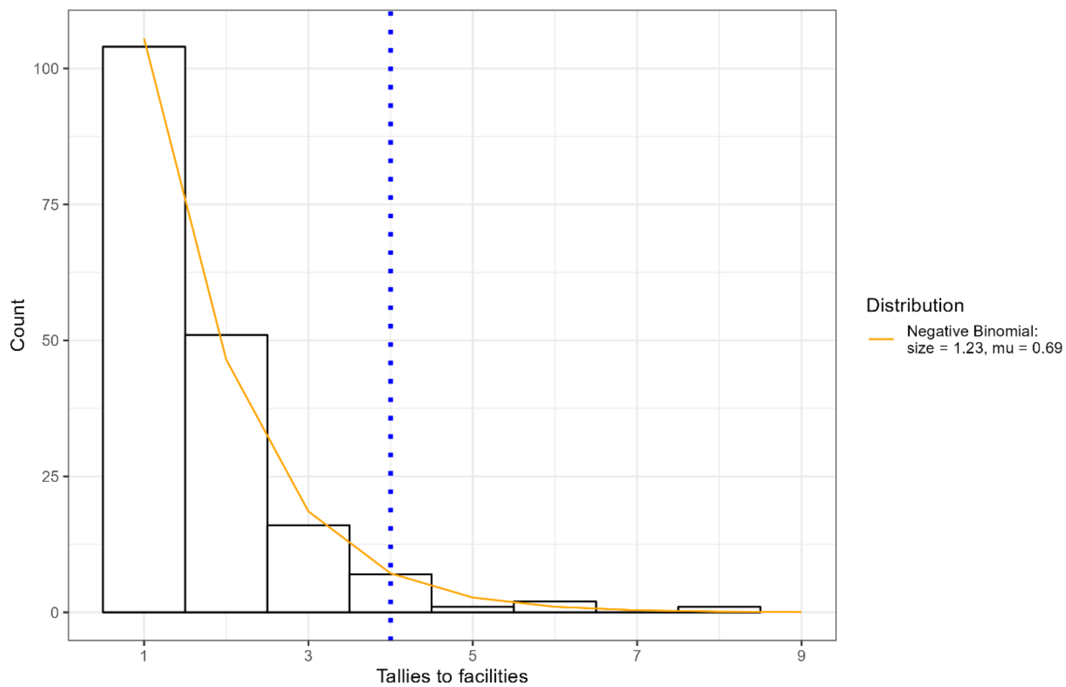

Figure 5. Negative binomial distribution (orange line) fit to the histogram of the number of detections of a tag at the SWP or CVP water export facilities. Estimated parameters for the fitted distribution are provided in the legend. The blue dotted line corresponds to 0.95 quantile for the number of detections.

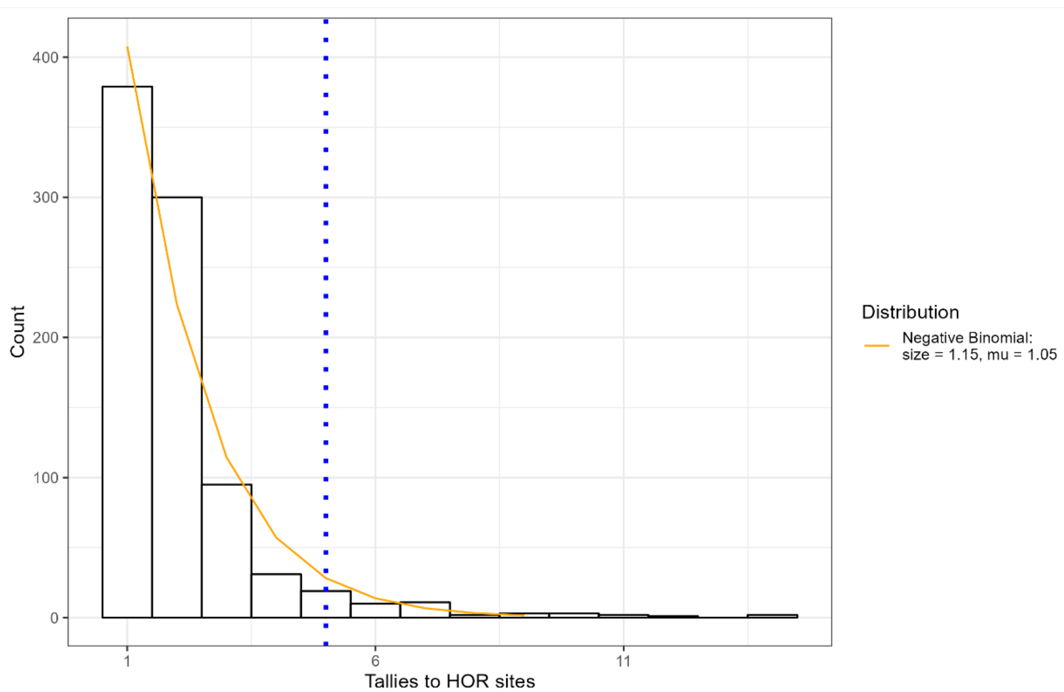

Figure 6. Negative binomial distribution (orange line) fit to the histogram of the number of detections of a tag at sites around the Head of Old River (HOR). Estimated parameters for the fitted distribution are provided in the legend. The blue dotted line corresponds to 0.95 quantile for the number of detections.

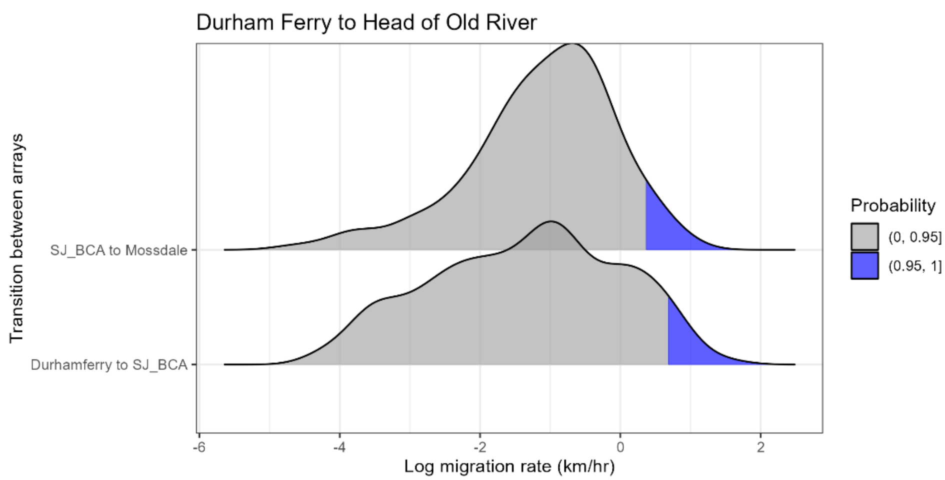

Figure 7. Smoothed histograms of counts of log migration rates (km/hr) at each transition between receiver arrays for the region between Durham Ferry and the Head of Old River. Shaded blue areas are the upper 0.05 quantile of migration rates observed per transition.

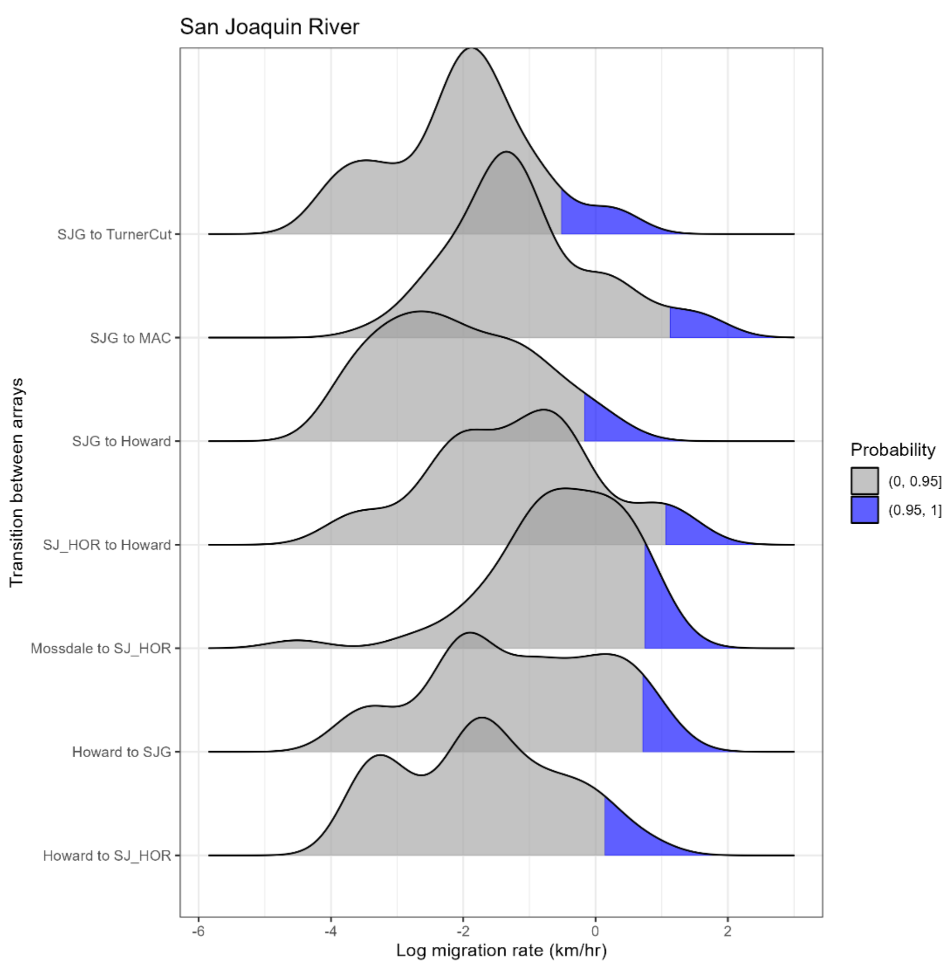

Figure 8. Smoothed histograms of counts of log migration rates (km/hr) at each transition between receiver arrays for the San Joaquin River region. Shaded blue areas are the upper 0.05 quantile of migration rates observed per transition.

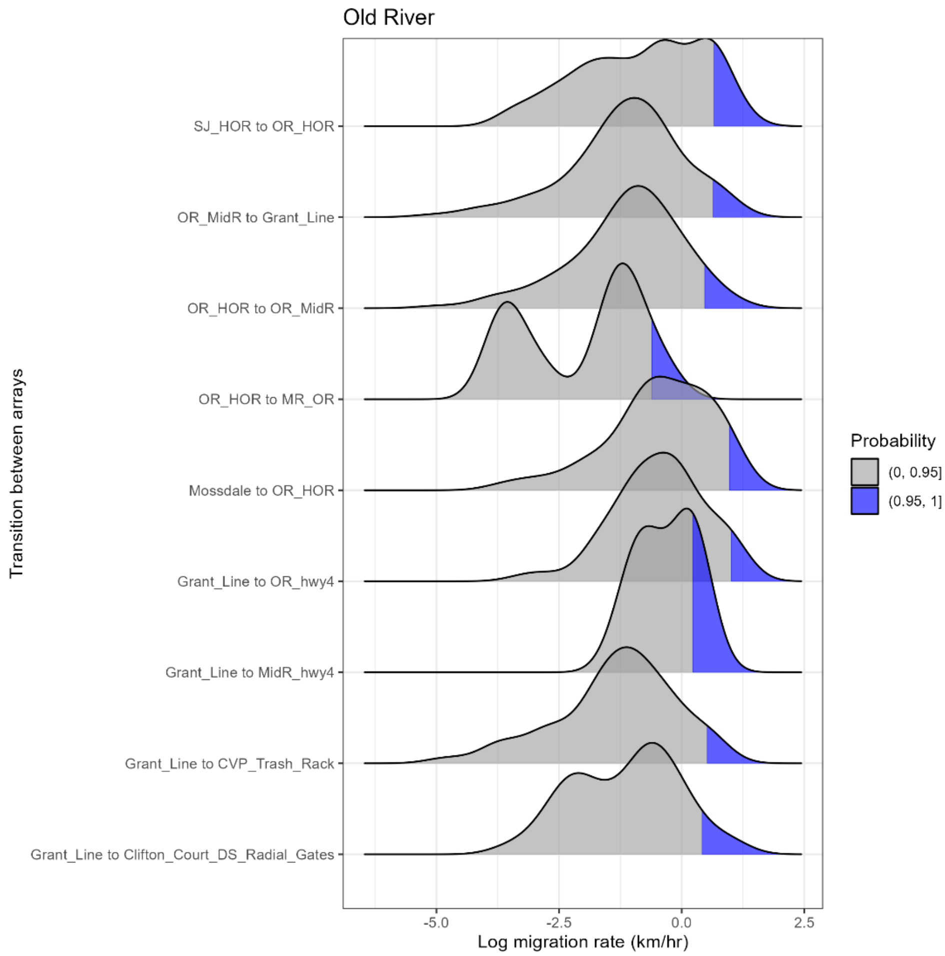

Figure 9. Smoothed histograms of counts of log migration rates (km/hr) at each transition between receiver arrays for the Old River region. Shaded blue areas are the upper 0.05 quantile of migration rates observed per transition.

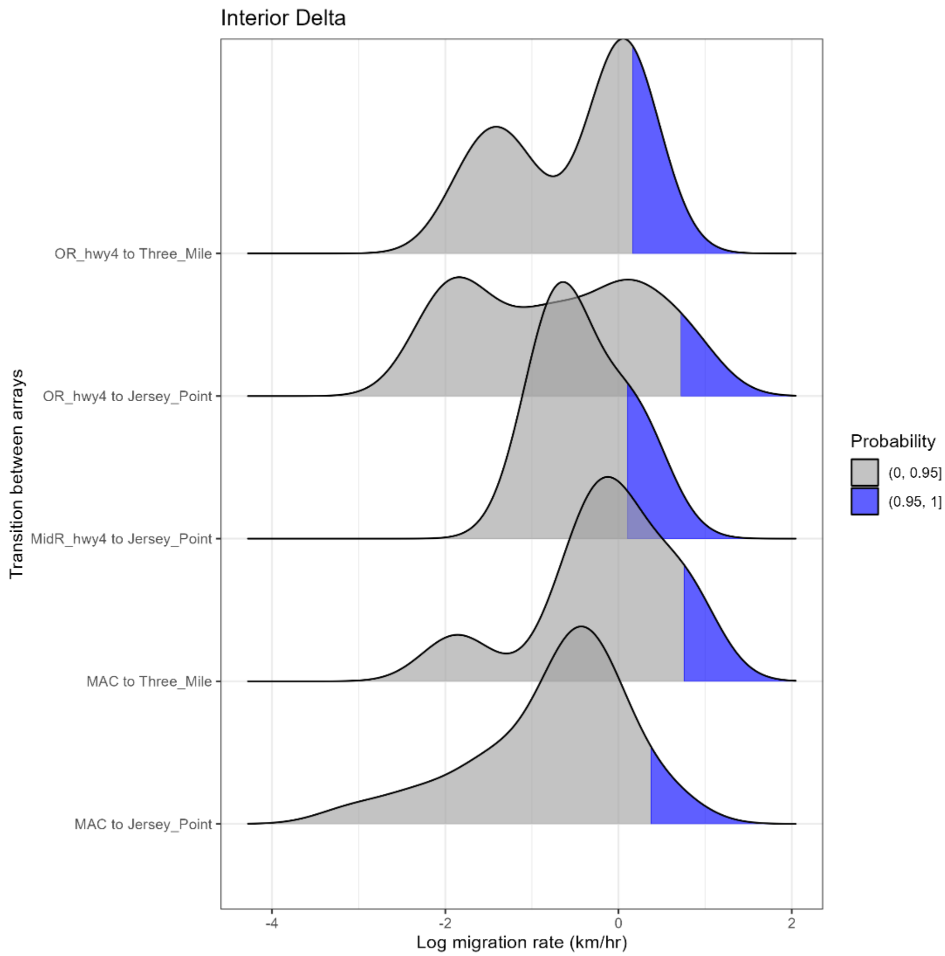

Figure 10. Smoothed histograms of counts of log migration rates (km/hr) at each transition between receiver arrays for the Interior Delta region. Shaded blue areas are the upper 0.05 quantile of migration rates observed per transition.

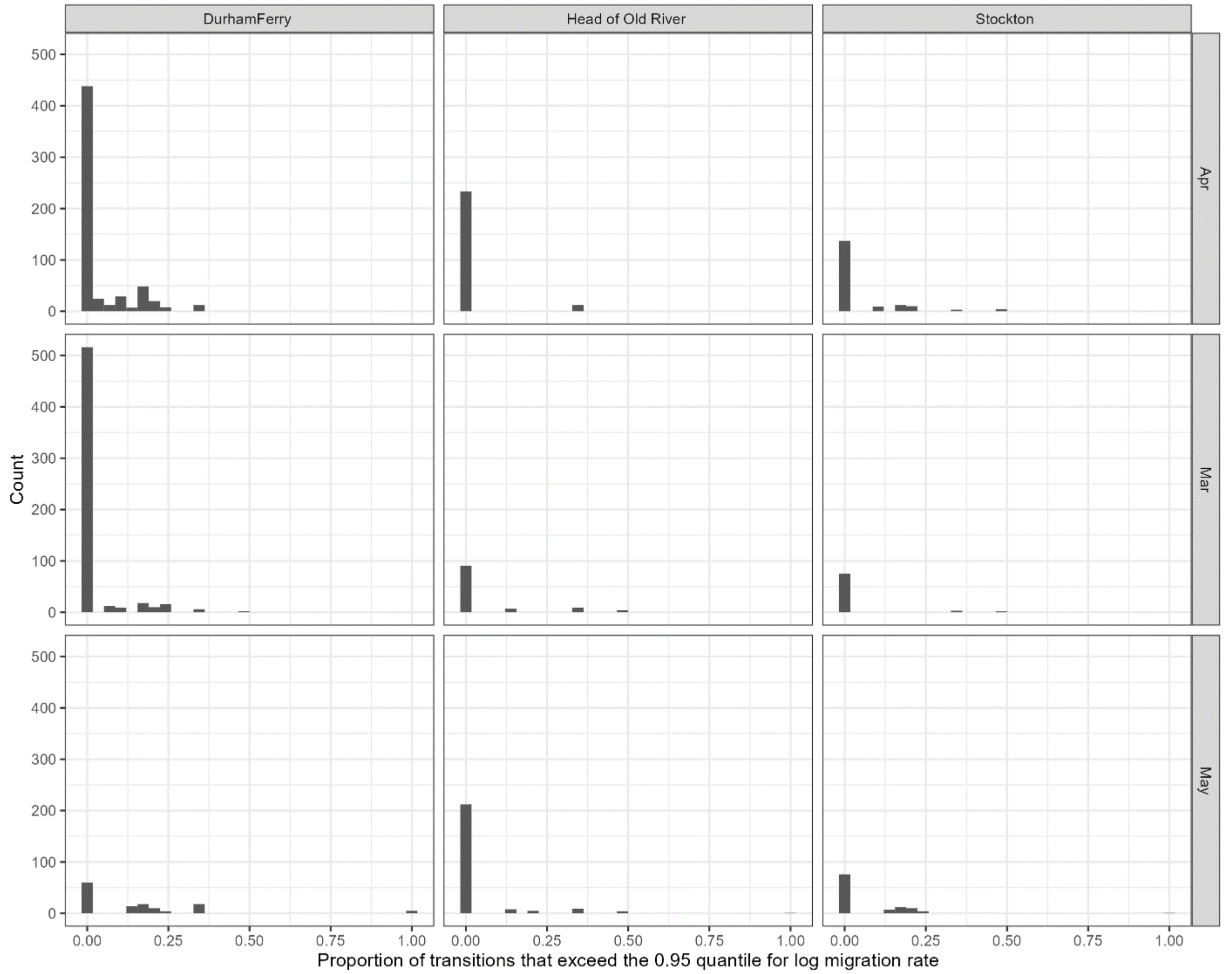

Figure 11. Histograms of the proportion of a tag's transitions between arrays that exceed the 0.95 quantile for log migration rate (km/hr), for each release group.

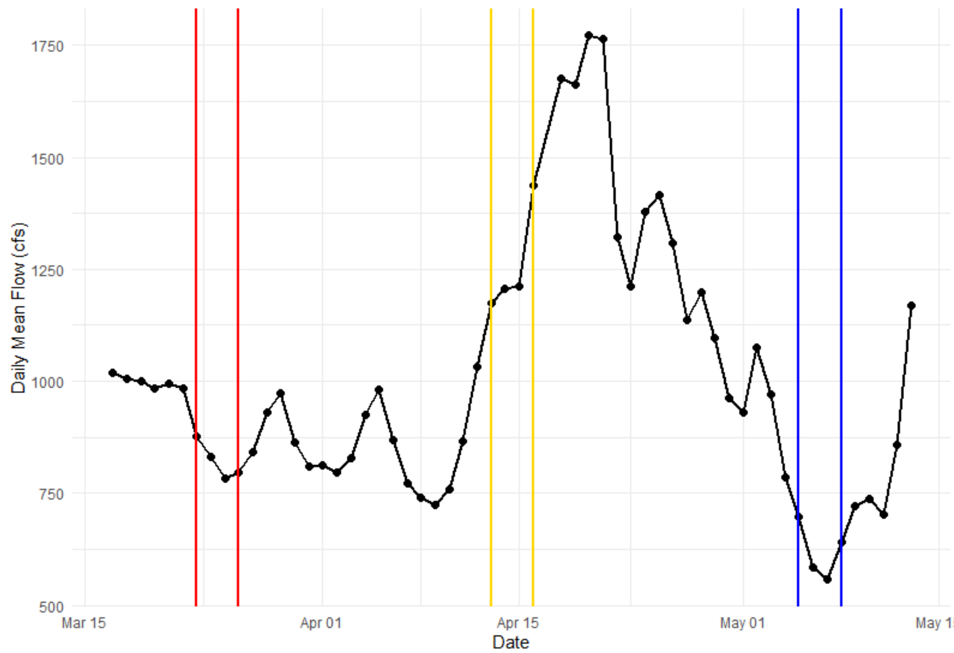

Figure 12. Daily mean flow (cubic feet per second, cfs) at Vernalis. Release weeks denoted by colors: March (red), April (yellow), May (blue).

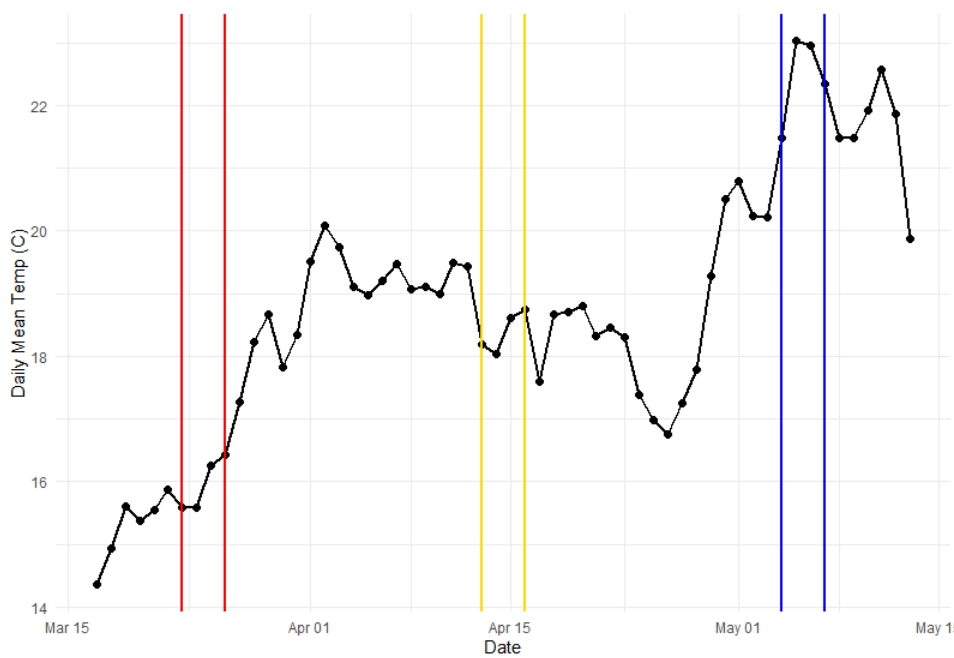

Figure 13. Daily mean water temperature (°C) at Vernalis. Release weeks denoted by colors: March (red), April (yellow), May (blue).

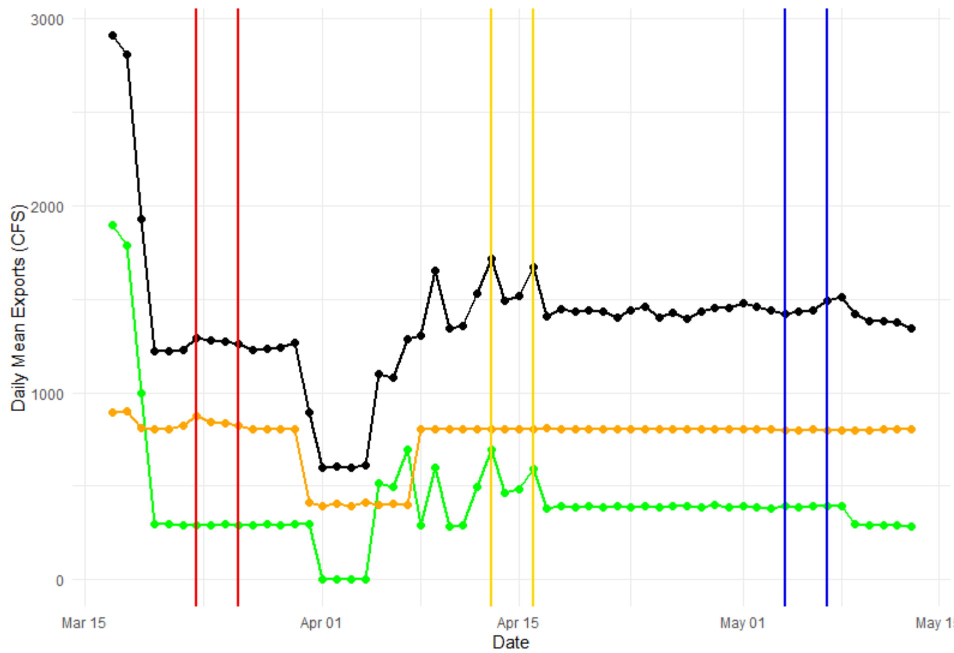

Figure 14. Daily mean Central Valley Project (orange), State Water Project (green), and total exports (black). Release weeks denoted by colors: March (red), April (yellow), May (blue).

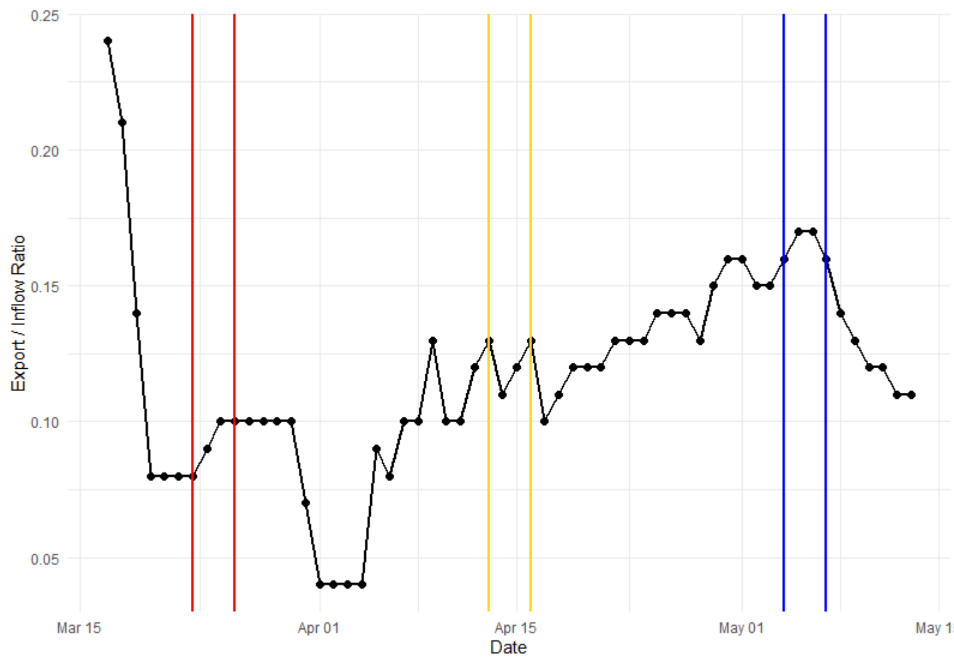

Figure 15. Daily mean export/inflow ratio. Release weeks denoted by colors: March (red), April (yellow), May (blue).

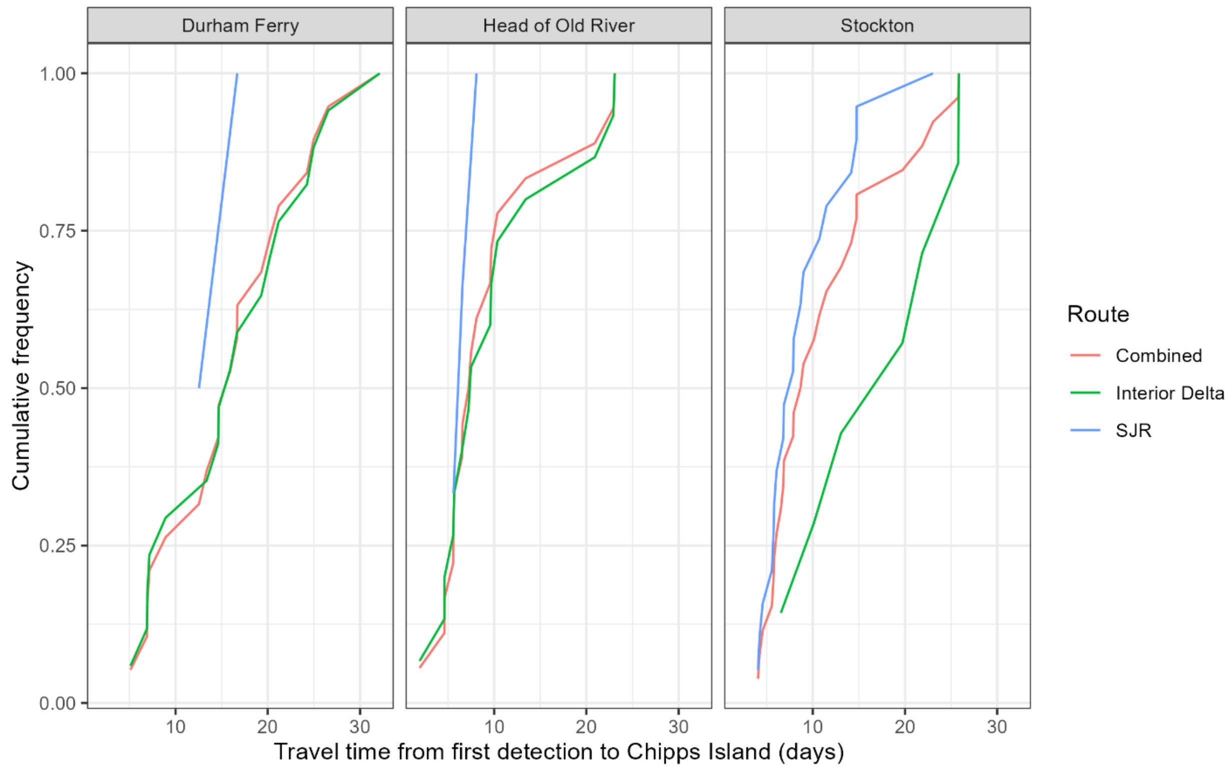

Figure 16. For those fish that made it to Chipps Island, the cumulative frequency of travel times (in days) from release to Chipps Island, based on the unfiltered dataset. Cumulative frequencies of travel times are displayed by route (San Joaquin River (SJR), Interior Delta, or Combined SJR and Interior Delta) and release location (Durham Ferry, Head of Old River, or Stockton).

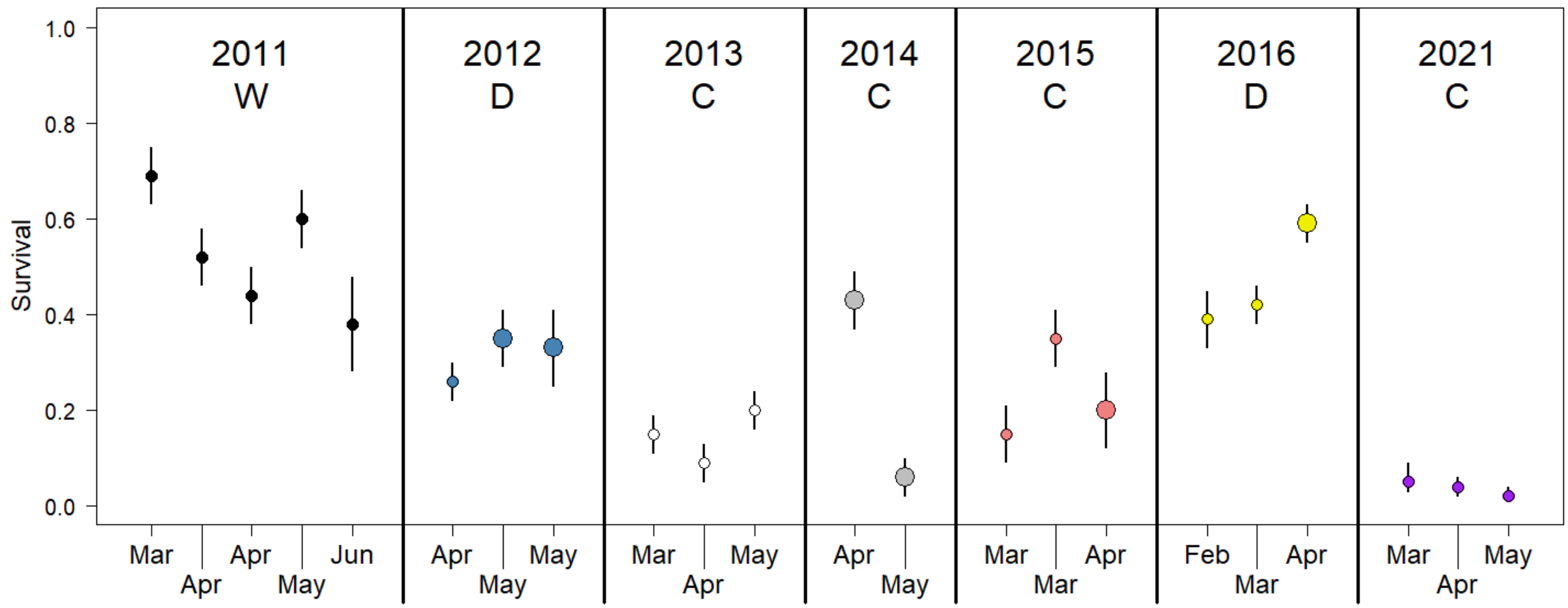

Figure 17. Juvenile steelhead through-Delta survival with 95% confidence intervals (from Mossdale to Chipps Island) from 2011-2016 (reported in Buchanan et al. 2021) and 2021. Water year types for the San Joaquin River Basin were wet (W), dry (D), and critically dry (C) during the studies. Point colors represent year and size represents the presence (large points) or absence (small points) of the head of Old River barrier (HORB).

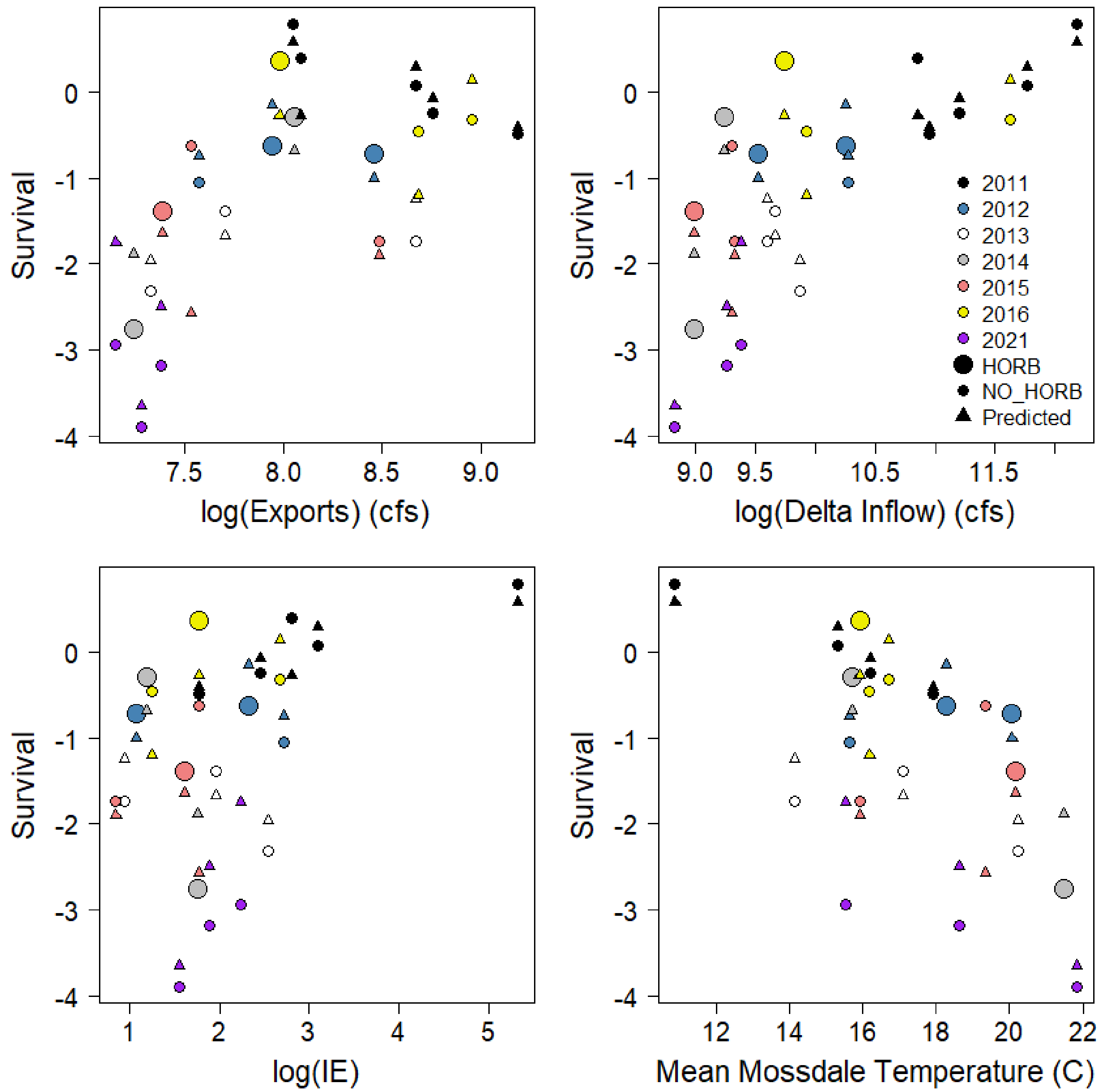

Figure 18. Juvenile steelhead through-Delta survival (from Mossdale to Chipps Island) from 2011-2016 (reported in Buchanan et al. 2021) and 2021. Environmental (total Delta inflow and mean temperature at Mossdale) and management (exports and Inflow:Export (IE) ratio) conditions were calcaulated as the mean values over the release period. The head of Old River barrier (HORB) was not installed in some years (2011, 2013, and 2021).

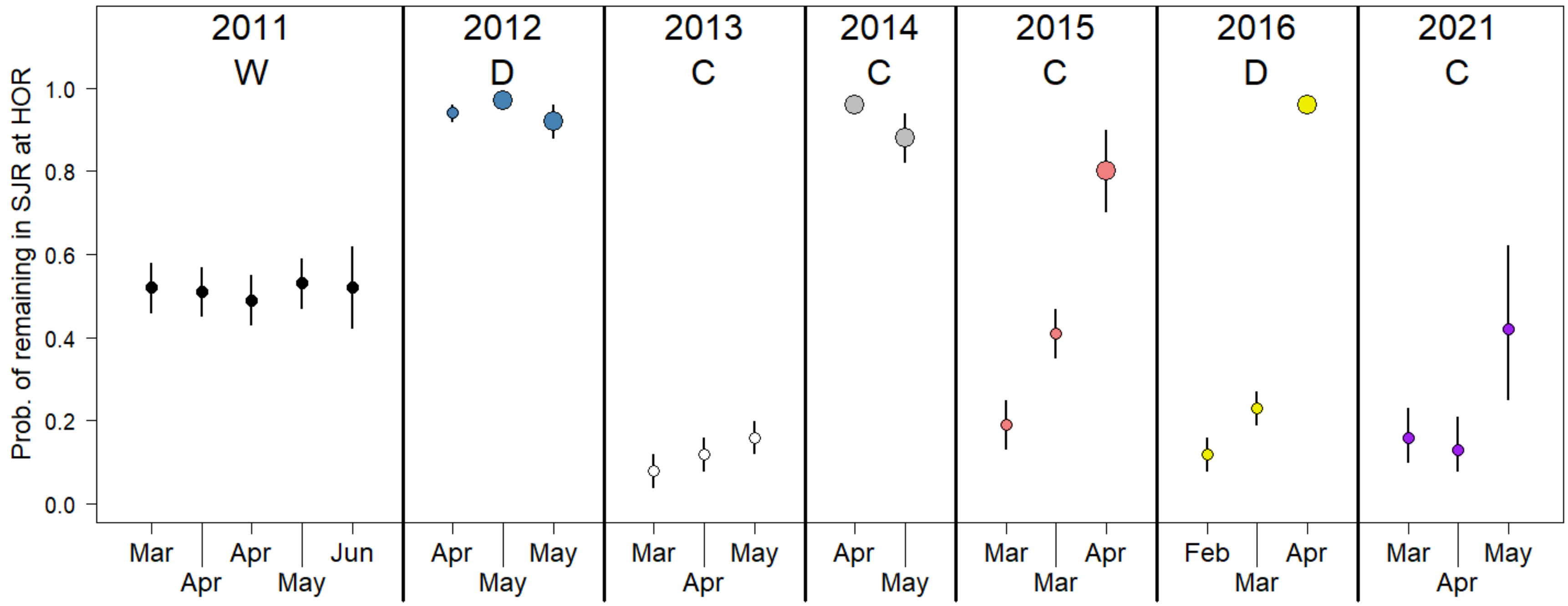

Figure 19. Juvenile steelhead routing at the Head of Old River (probability of remaining in the San Joaquin River) with 95% confidence intervals from 2011-2016 (reported in Buchanan 2018a, 2018b, 2018c, USBR 2018a, 2018b, 2018c) and 2021. Water year types for the San Joaquin River Basin were wet (W), dry (D), and critically dry (C) during the studies. Point colors represent year and size represents the presence (large points) or absence (small points) of the head of Old River barrier (HORB).

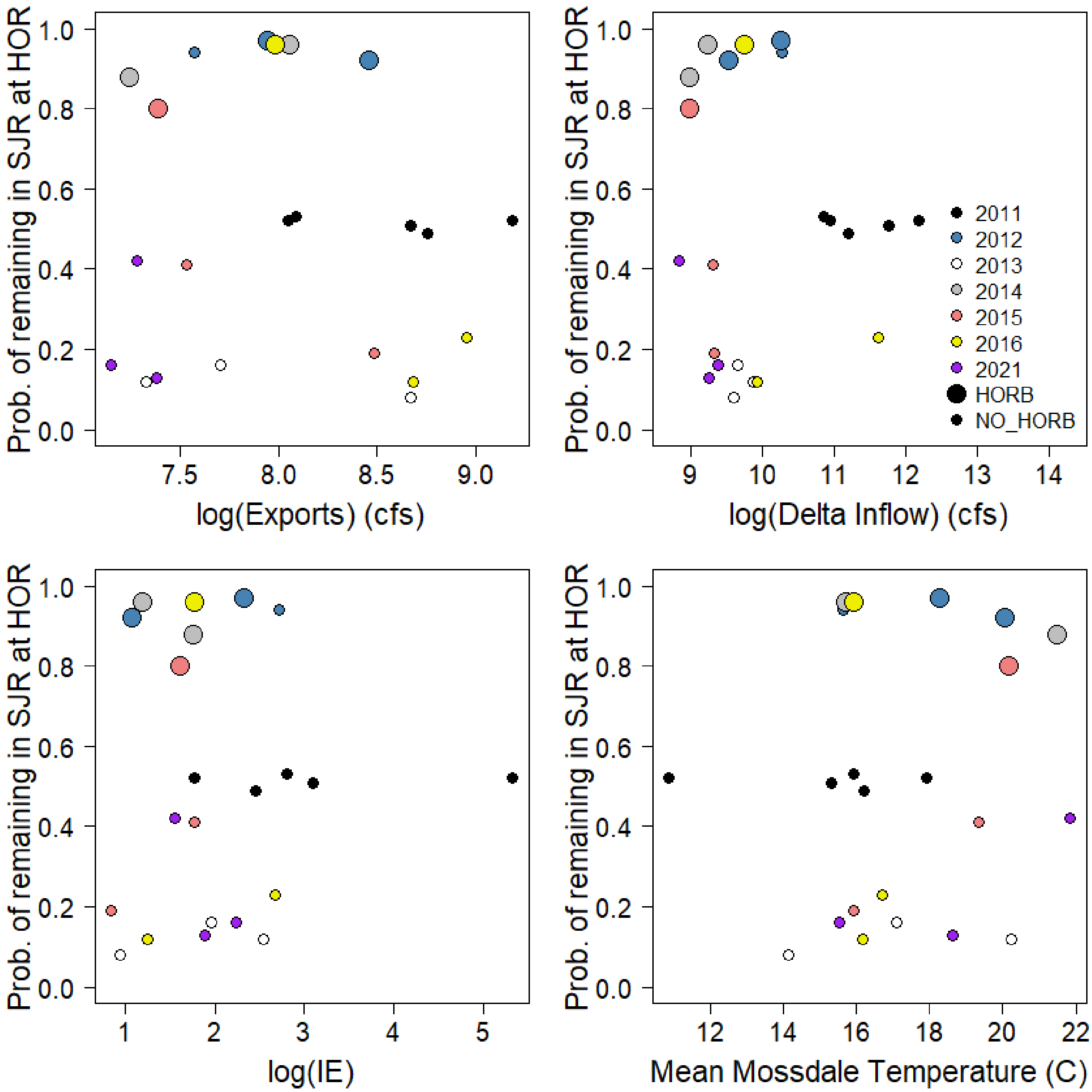

Figure 20. Juvenile steelhead routing at the Head of Old River from 2011-2016 and 2021. Environmental (total Delta inflow and mean temperature at Mossdale) and management (exports and Inflow:Export (IE) ratio) conditions were calcaulated as the mean values over the release period. The head of Old River barrier (HORB) was not installed in some years (2011, 2013, and 2021).

Appendix

Appendix A: Simulation Results

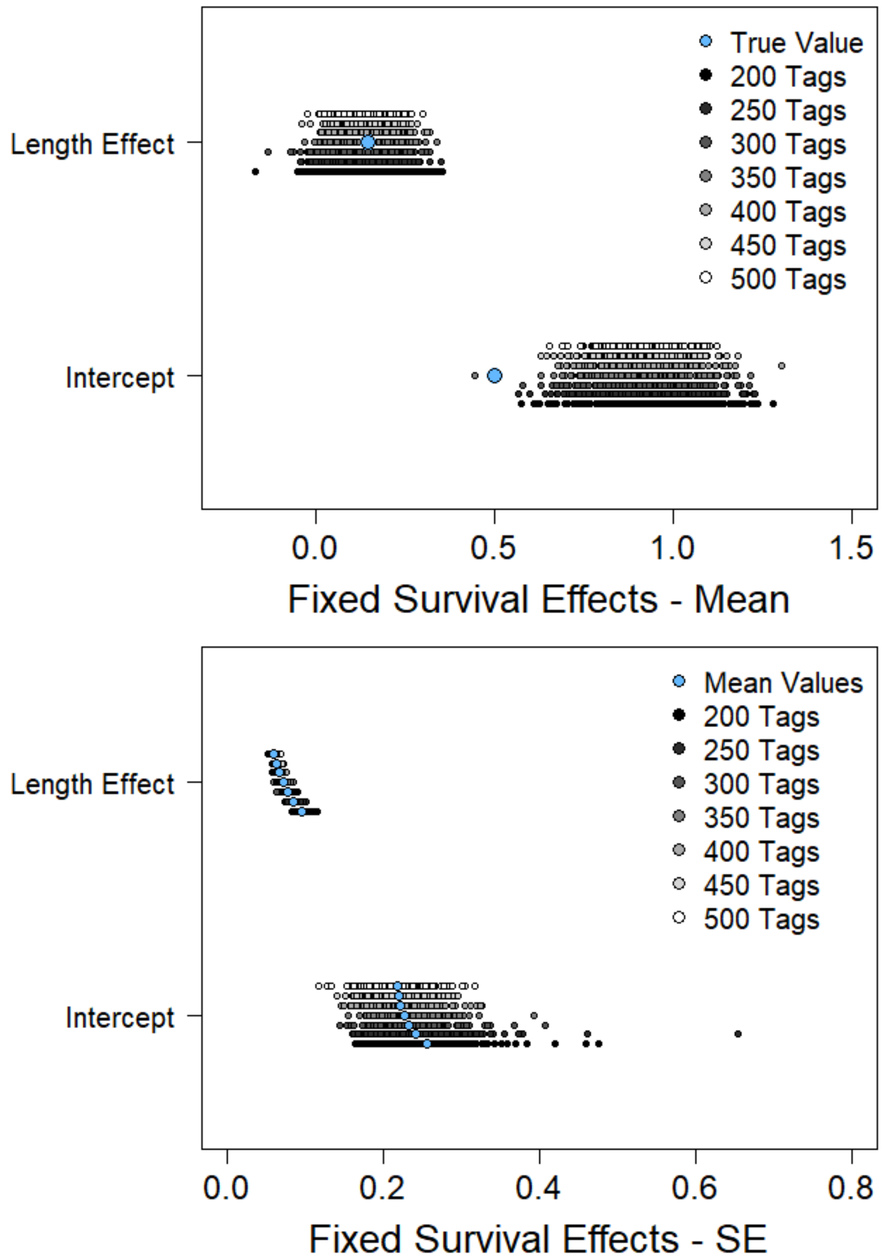

Figure A1. Simulation results for the fixed length effect and intercept on survival. The top pannel represents the mean estimate and bottom represents standard error.

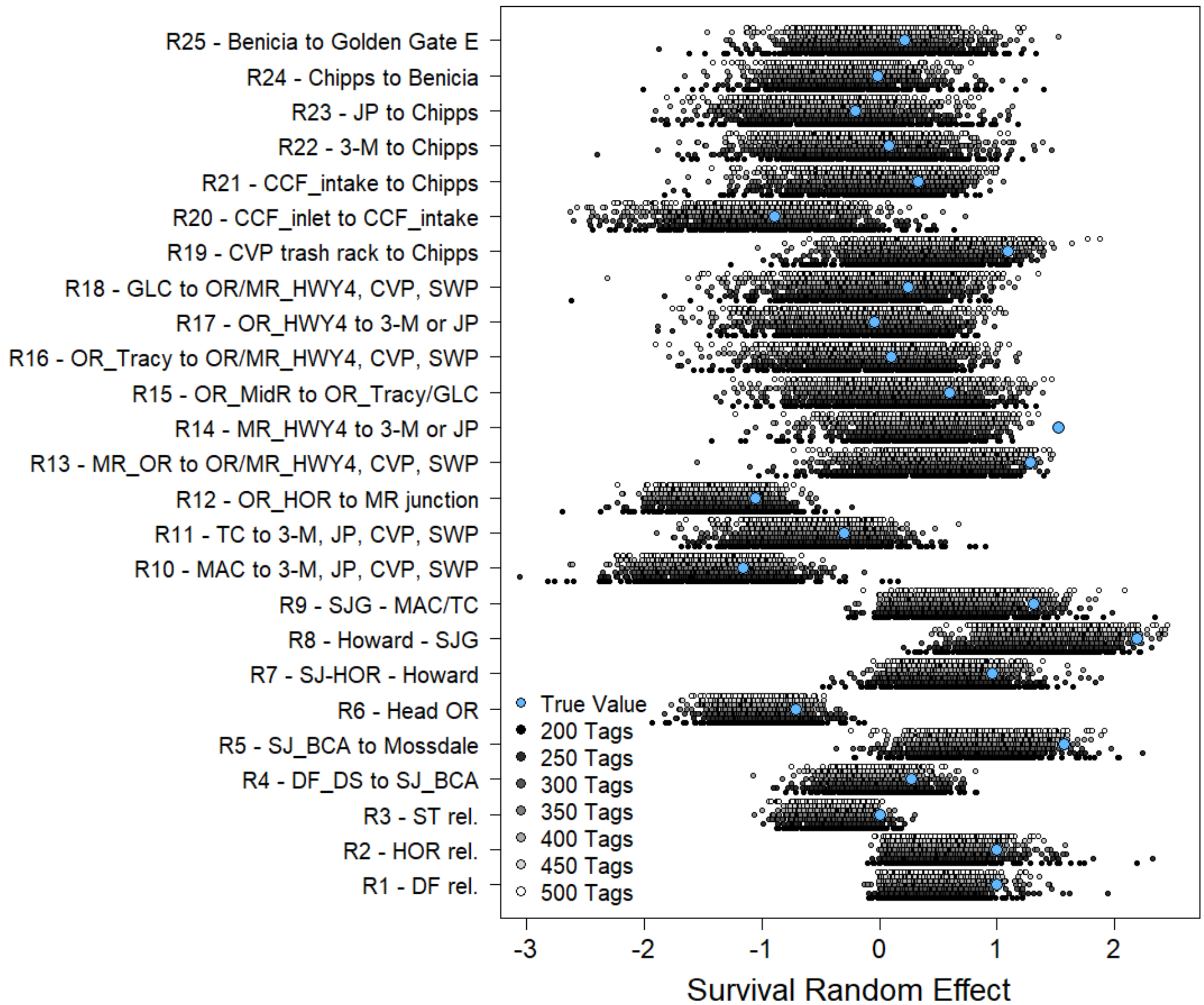

Figure A2. Mean estimates for reach-specific random effect on survival. Survival random effects are on the logit scale.

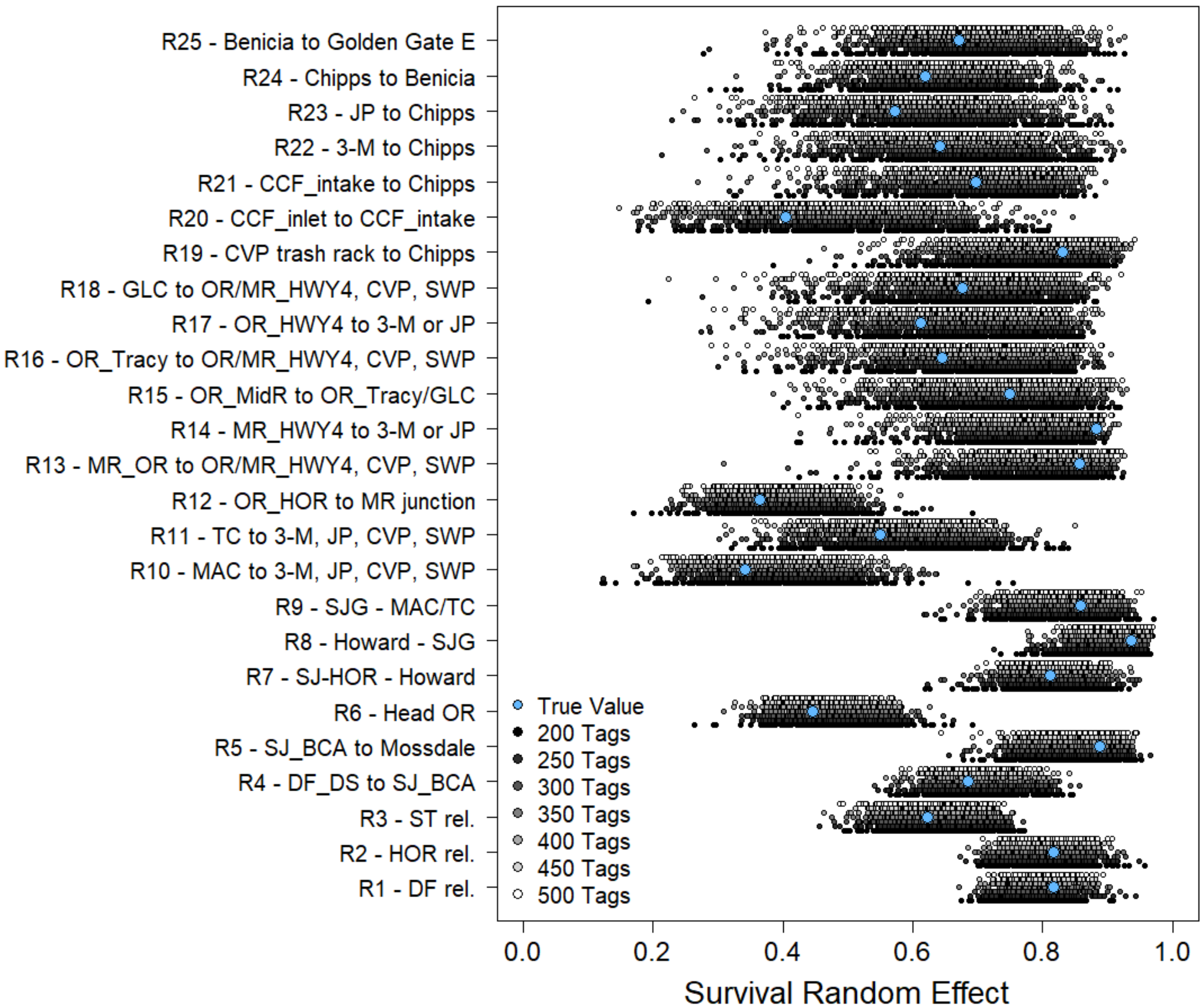

Figure A3. Mean simulated reach-specific survival estimates incorporating the intercept (Figure A1) and random effect on survival (Figure A2). Reach specific survival was calculated using the mean length of tagged fish (e.g., reach-specific survival = survival intercept + random reach effect).

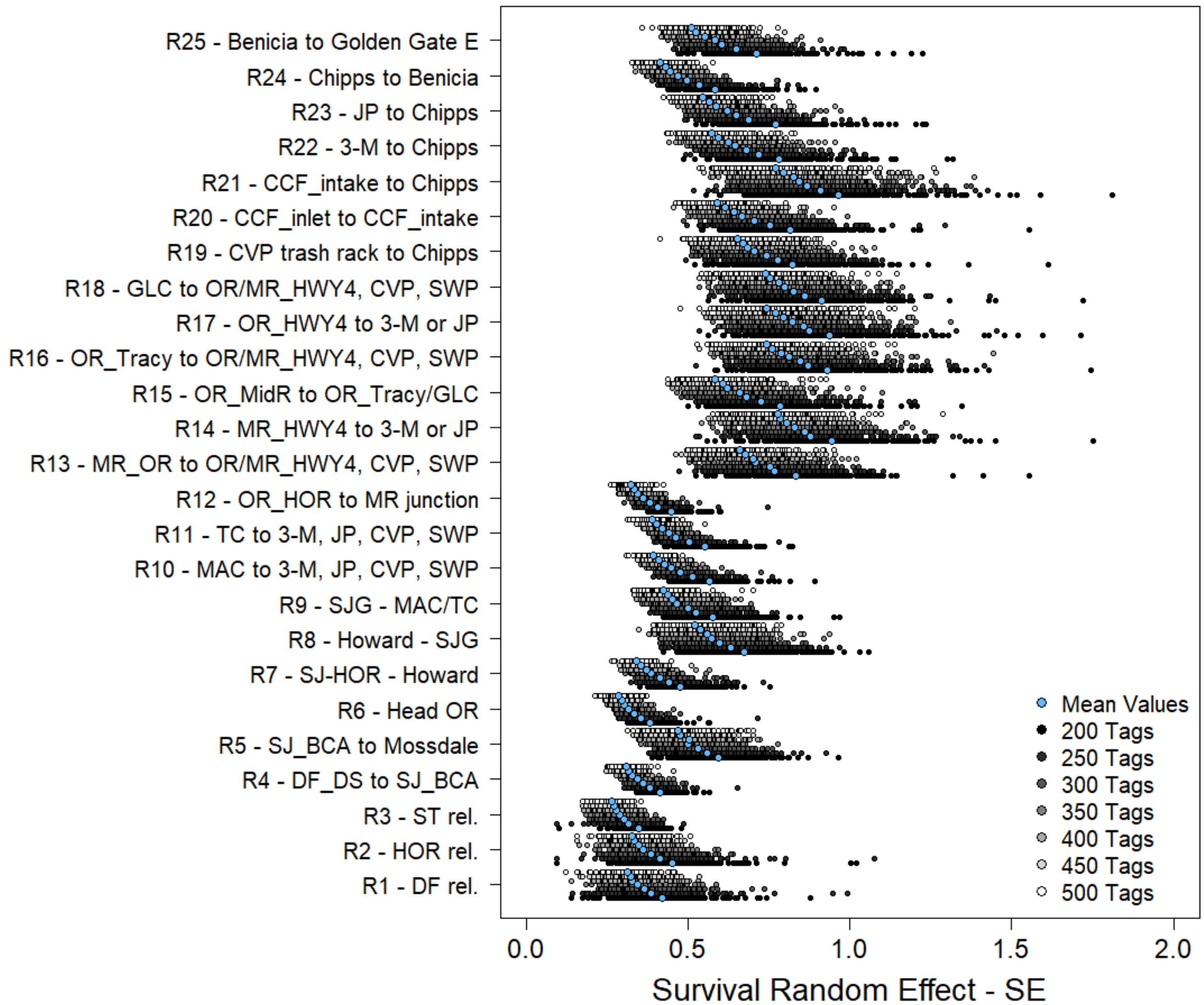

Figure A4. Standard error estimates for reach-specific random effects on survival (e.g., corresponds with Figure A2).

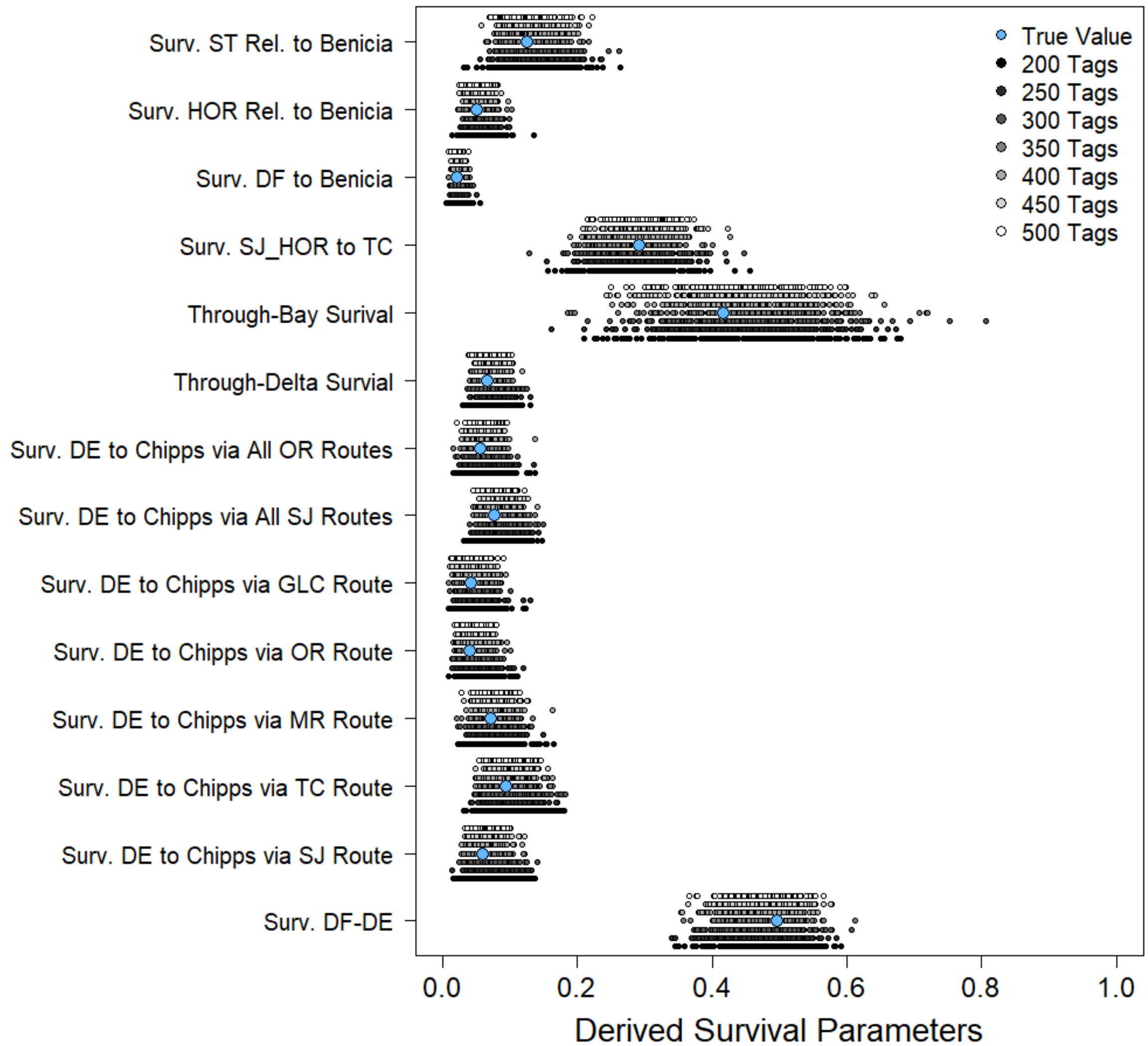

Figure A5. Mean derived regional and route-specific survival estimates for areas of interest.

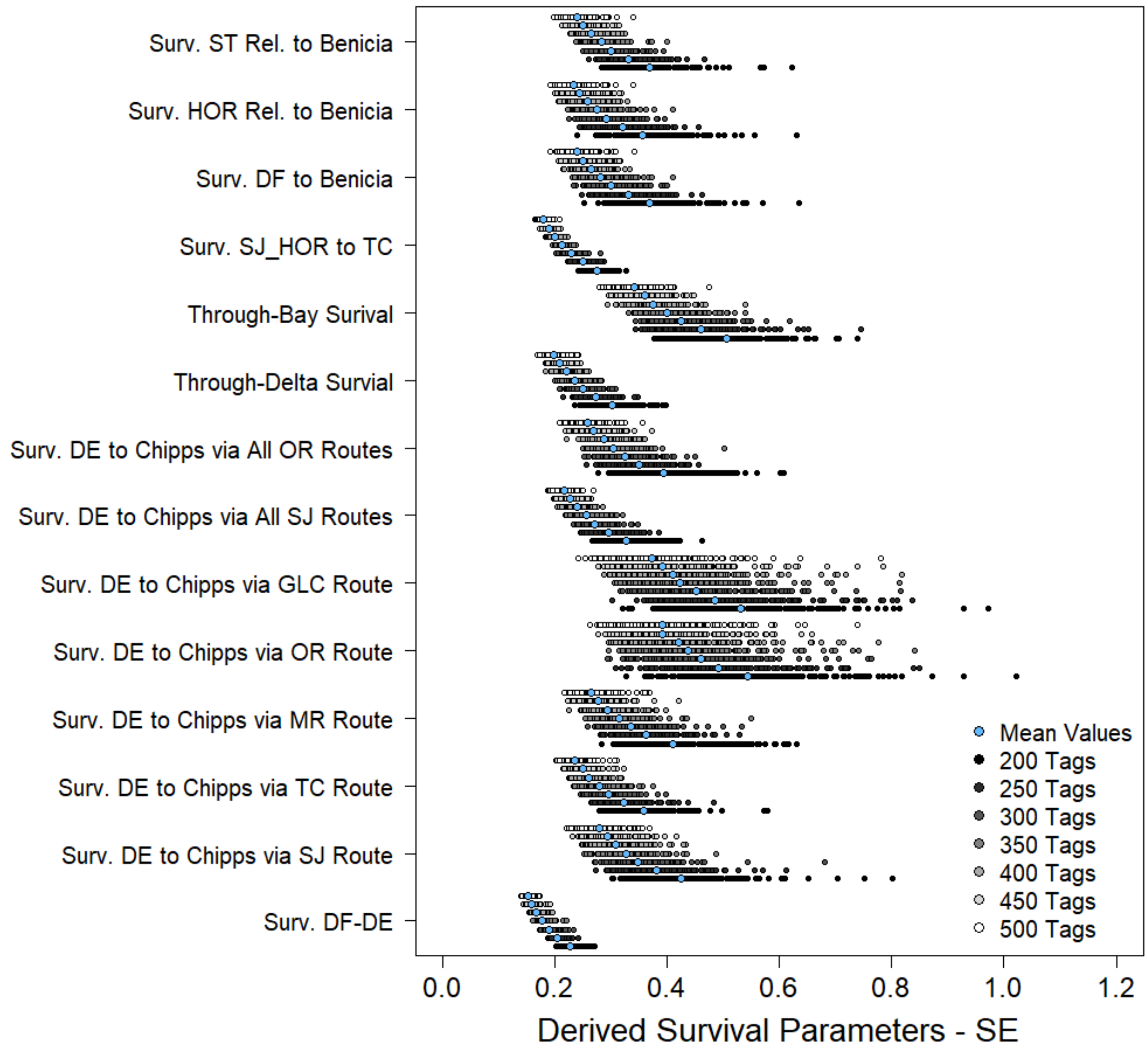

Figure A6. Standard errors for derived regional and route-specific survival estimates for areas of interest.

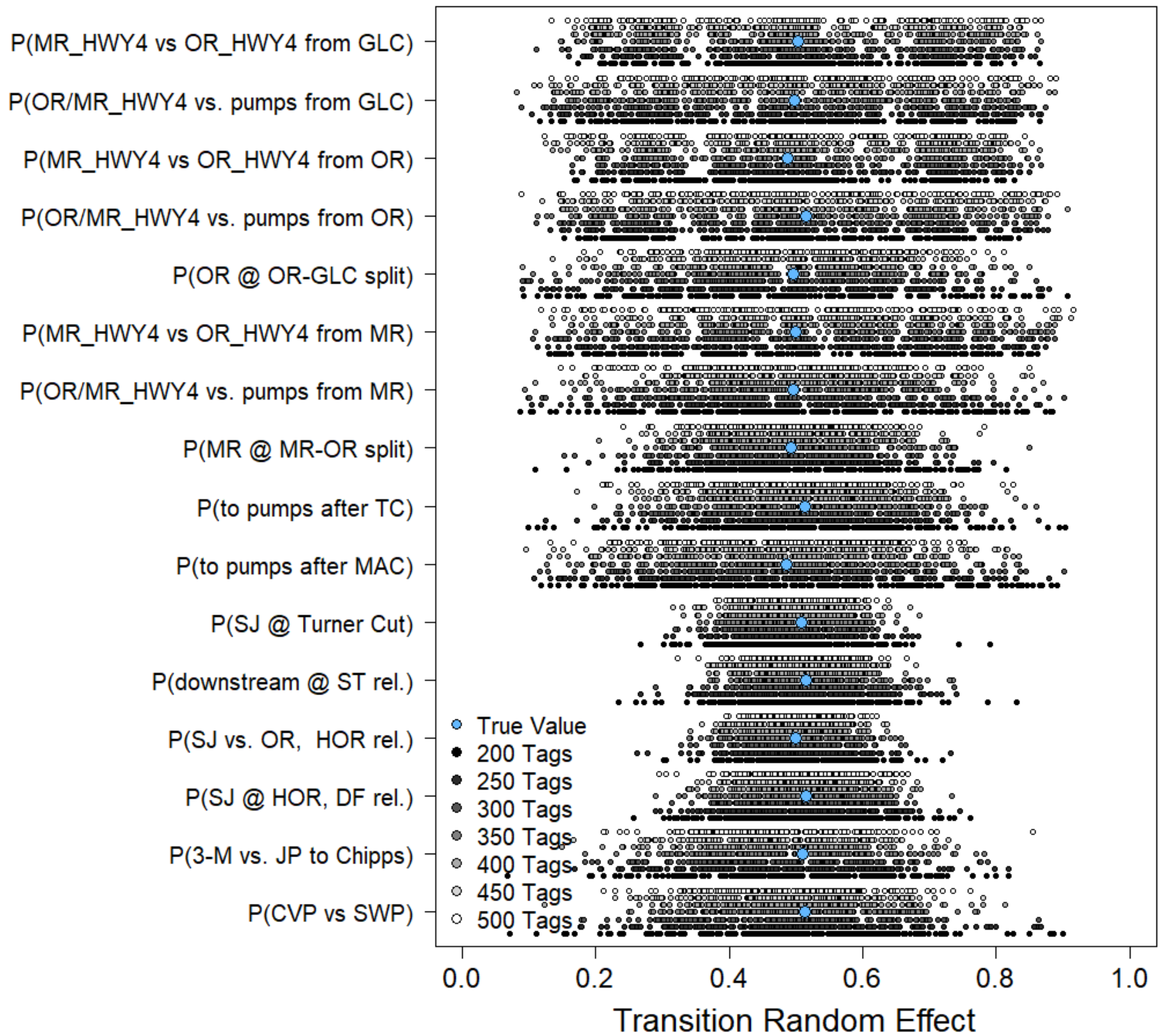

Figure A7. Mean transition estimates for at each simulated juncture in the South Delta. Parameters were estimated using a random effects framework.

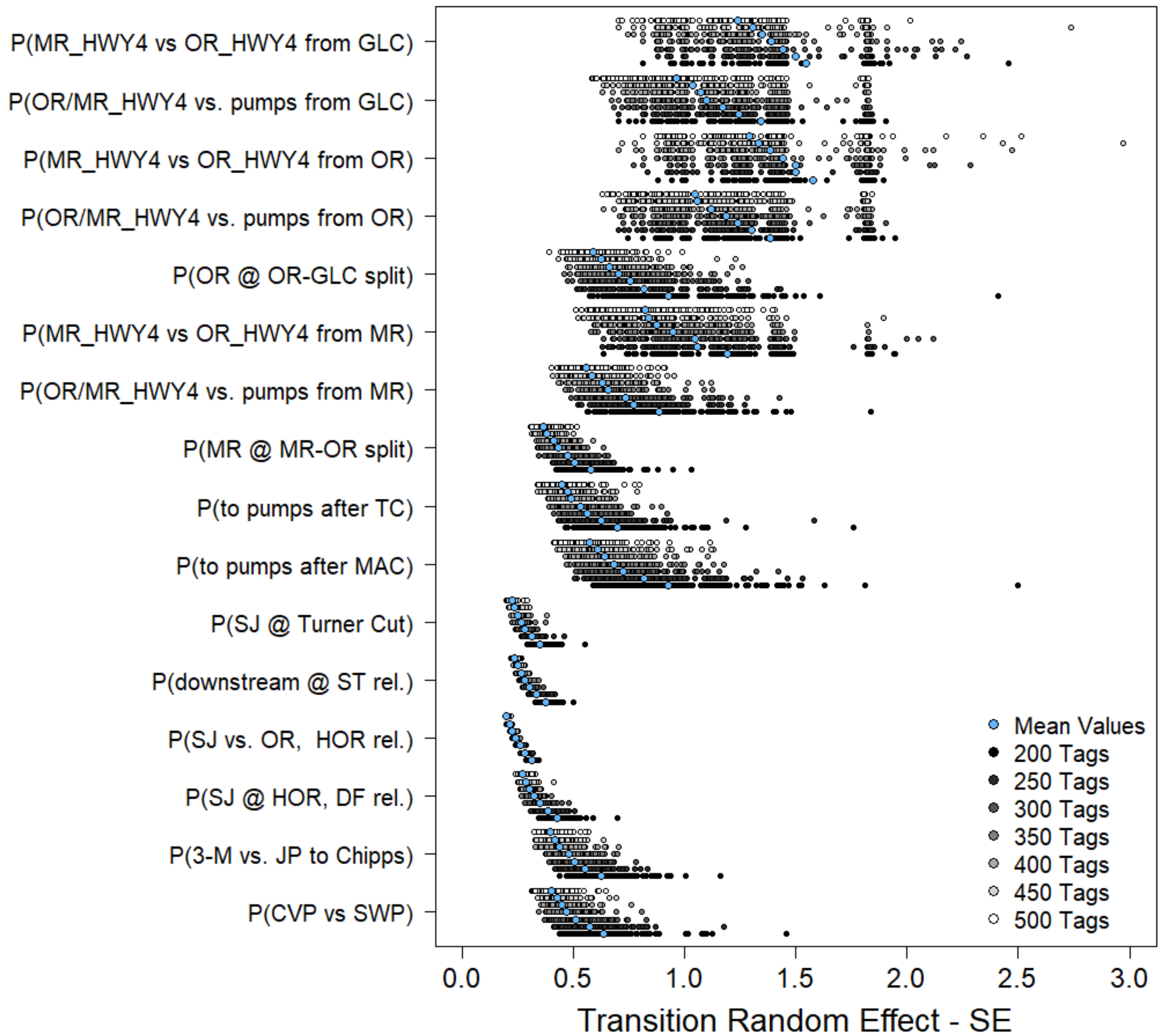

Figure A8. Standard errors for transition estimates for at each simulated juncture in the South Delta. Parameters were estimated using a random effects framework.

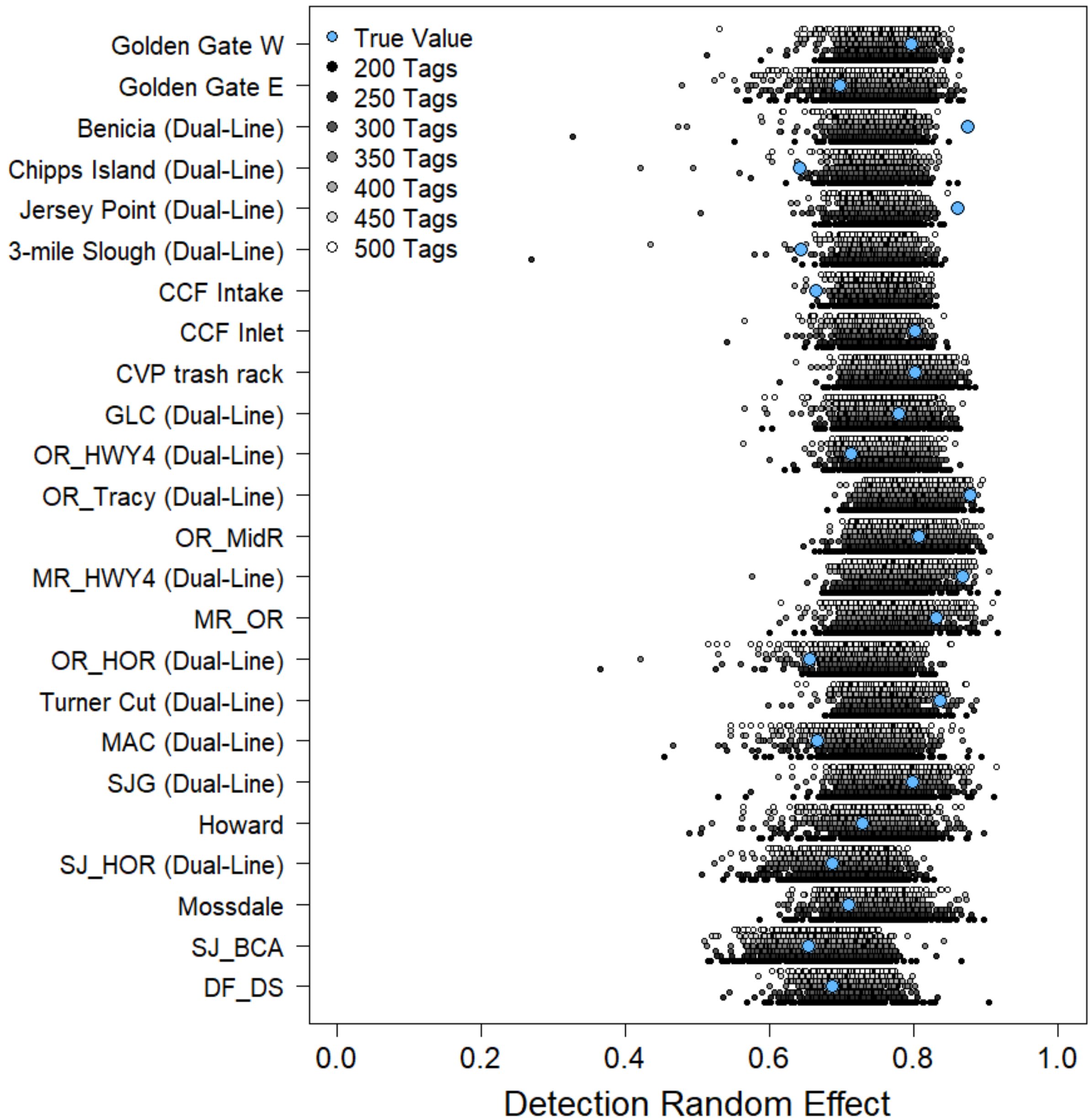

Figure A9. Means estimates for simulated single-line receiver detection probabilities using the random effects framework. Detection probabilities were simulated as a random effect representing a single receiver line at all sites and detection at sites with dual-line receivers were calculated from equation 9. Dual line detection probabilities are shown in Figure A10.

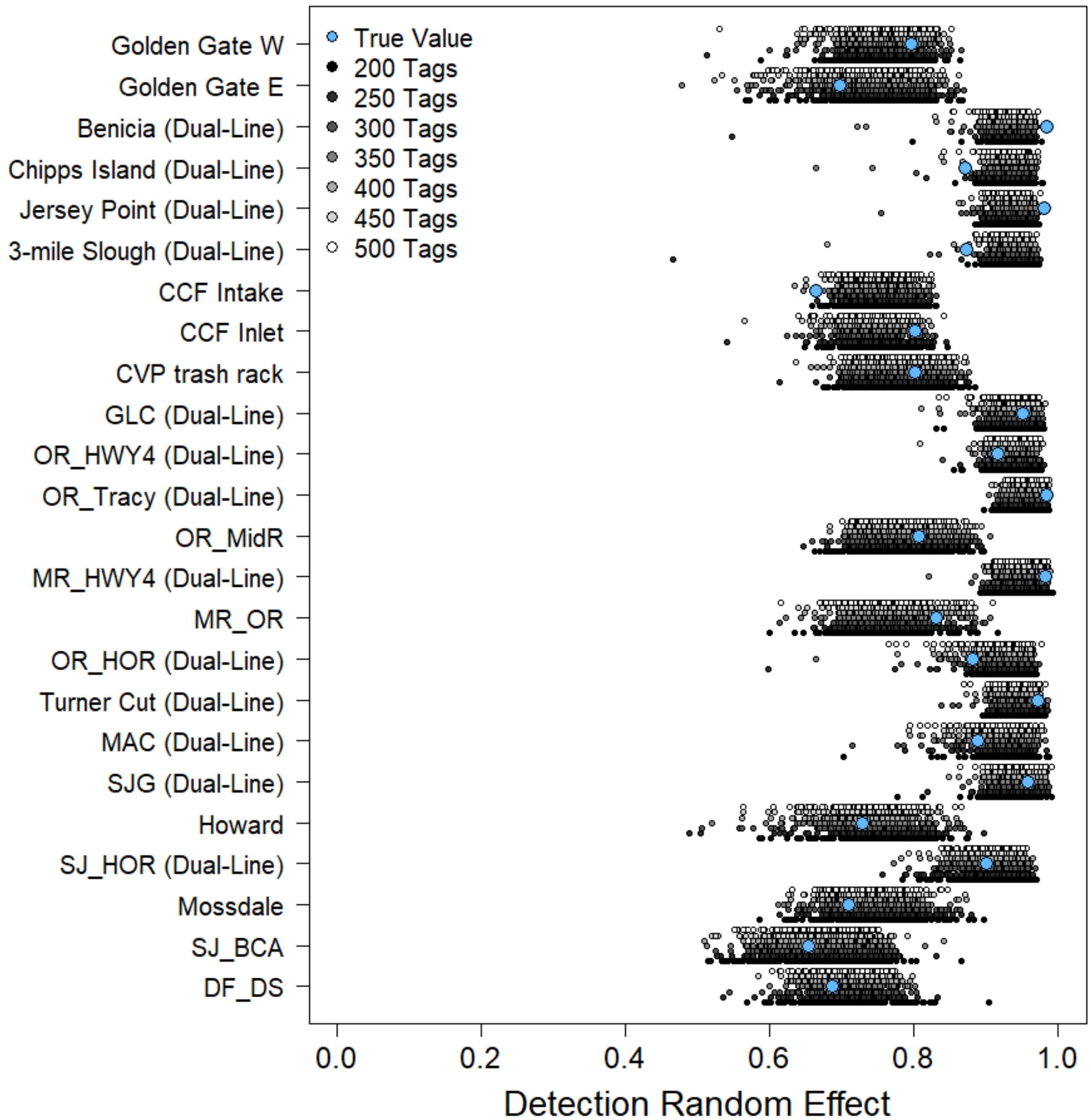

Figure A10. Means estimates for simulated single-line receiver detection probabilities using the random effects framework. Note, the estimates for dual-line receivers represented as the brobability of being detected by at least one line of the dual-line receiver array. Detection probabilities for a single line at the dual-line sites are shown in Figure A9.

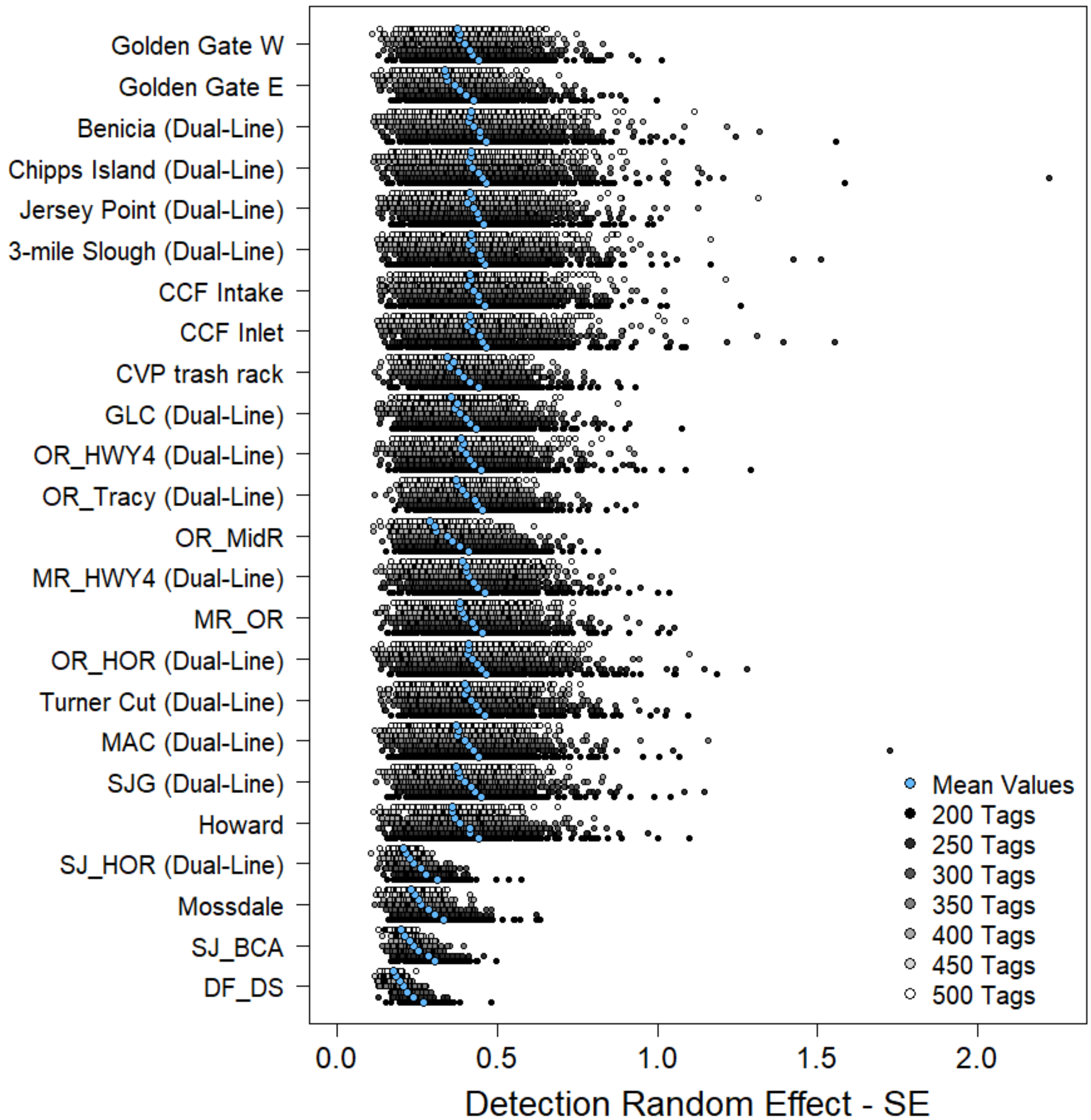

Figure A9. Standard error estimates for simulated single-line receiver detection probabilities using the random effects framework. Detection probabilities were simulated as a random effect representing a single receiver line at all sites and detection at sites with dual-line receivers were calculated from equation 9.

Appendix B: Model Results from the 1-hit Predator Filter

Table B1. Mean derived survival estimates for all releases combined. Parameter estimates were obtained from the model using data processed with the 1-hit predator filter. Parameter estimates (Est.) and standard errors (SE) were estimated on the logit-scale and transformed into mean probabilities with lower and upper 95% confidence intervals (L_{95} and U_{95} respectively).

		Logit-Scale		Probabilities		
Parameter Description	Parameter	Est.	SE	Mean	L_{95}	U_{95}
Survival from Durham Ferry to Delta Entry (Mossdale)	lphi_DE	-0.46	0.11	0.39	0.34	0.44
Survival from Delta Entry to Chipps via San Joaquin Route	lphi_SJSJ	-3.46	0.33	0.03	0.02	0.06
Survival from Delta Entry to Chipps via Turner Cut Route	lphi_SJTC	-4.01	0.41	0.02	0.01	0.04
Survival from Delta Entry to Chipps via Middle River Route	lphi_ORMR	-3.51	0.48	0.03	0.01	0.07
Survival from Delta Entry to Chipps via Old River Route	lphi_OROR	-3.18	0.22	0.04	0.03	0.06
Survival from Delta Entry to Chipps via Grant Line Canal Route	lphi_ORGL	-3.29	0.18	0.04	0.03	0.05
Survival from Delta Entry to Chipps via San Joaquin River Routes (SJR and TC)	lphi_SJ	-3.60	0.33	0.03	0.01	0.05
Survival from Delta Entry to Chipps via Old River Routes (MR, OR, GLC)	lphi_OR	-3.27	0.17	0.04	0.03	0.05
Through-Delta Survial	lphi_TD	-3.31	0.16	0.04	0.03	0.05
Through-Bay Surival	lphi_TB	0.32	0.29	0.58	0.44	0.71
Survival from SJ downstream of HOR to Turner Cut	lphi_SJtTC	-2.44	0.30	0.08	0.05	0.13
Survial from Durham Ferry to Benicia	lphi_DFtB	-4.71	0.19	0.01	0.01	0.01
Survial from Head of Old River Release to Benicia	lphi_HORtB	-3.51	0.17	0.03	0.02	0.04
Survial from Stockton Release to Benicia	lphi_STtB	-2.31	0.19	0.09	0.06	0.13
Difference HOR release survival and HOR-reach survival *not logit space	dphi_HOR	0.05	0.03			
Difference in ST release survival and ST-reach survival *not logit space	dphi_ST	-0.21	0.08			

Table B2. Derived survival estimates for the March releases. Parameter estimates were obtained from the model using data processed with the 1-hit predator filter. Parameter estimates (Est.) and standard errors (SE) were estimated on the logit-scale and transformed into mean probabilities with lower and upper 95% confidence intervals (L_{95} and U_{95} respectively).

		Logit-Scale		Probabilities		
Parameter Description	Parameter	Est.	SE	Mean	L_{95}	U_{95}
Survival from Durham Ferry to Delta Entry (Mossdale)	lphi_DE	0.70	0.15	0.67	0.60	0.73
Survival from Delta Entry to Chipps via San Joaquin Route	lphi_SJSJ	-3.75	0.71	0.02	0.01	0.09
Survival from Delta Entry to Chipps via Turner Cut Route	lphi_SJTC	-4.01	0.78	0.02	0.00	0.08
Survival from Delta Entry to Chipps via Middle River Route	lphi_ORMR	-3.57	0.83	0.03	0.01	0.12
Survival from Delta Entry to Chipps via Old River Route	lphi_OROR	-2.85	0.43	0.05	0.02	0.12
Survival from Delta Entry to Chipps via Grant Line Canal Route	lphi_ORGL	-2.71	0.30	0.06	0.04	0.11
Survival from Delta Entry to Chipps via San Joaquin River Routes (SJR and TC)	lphi_SJ	-3.85	0.69	0.02	0.01	0.08
Survival from Delta Entry to Chipps via Old River Routes (MR, OR, GLC)	lphi_OR	-2.77	0.29	0.06	0.03	0.10
Through-Delta Survival	lphi_TD	-2.90	0.28	0.05	0.03	0.09
Through-Bay Survival	lphi_TB	-0.17	0.50	0.46	0.24	0.69
Survival from SJ downstream of HOR to Turner Cut	lphi_SJtTC	-2.66	0.65	0.07	0.02	0.20
Survival from Durham Ferry to Benicia	lphi_DFtB	-3.68	0.32	0.02	0.01	0.05
Survival from Head of Old River Release to Benicia	lphi_HORtB	-3.22	0.32	0.04	0.02	0.07
Survival from Stockton Release to Benicia	lphi_STtB	-2.14	0.32	0.11	0.06	0.18
Difference HOR release survival and HOR-reach survival *not logit space	dphi_HOR	0.00	0.04			
Difference in ST release survival and ST-reach survival *not logit space	dphi_ST	-0.19	0.16			

Table B3. Derived survival estimates for the April releases. Parameter estimates were obtained from the model using data processed with the 1-hit predator filter. Parameter estimates (Est.) and standard errors (SE) were estimated on the logit-scale and transformed into mean probabilities with lower and upper 95% confidence intervals (L_{95} and U_{95} respectively).

		Logit-Scale		Probabilities		
Parameter Description	Parameter	Est.	SE	Mean	L_{95}	U_{95}
Survival from Durham Ferry to Delta Entry (Mossdale)	lphi_DE	0.17	0.15	0.54	0.47	0.61
Survival from Delta Entry to Chipps via San Joaquin Route	lphi_SJSJ	-2.87	0.49	0.05	0.02	0.13
Survival from Delta Entry to Chipps via Turner Cut Route	lphi_SJTC	-3.31	0.61	0.04	0.01	0.11
Survival from Delta Entry to Chipps via Middle River Route	lphi_ORMR	-3.63	0.80	0.03	0.01	0.11
Survival from Delta Entry to Chipps via Old River Route	lphi_OROR	-3.31	0.30	0.04	0.02	0.06
Survival from Delta Entry to Chipps via Grant Line Canal Route	lphi_ORGL	-3.29	0.26	0.04	0.02	0.06
Survival from Delta Entry to Chipps via San Joaquin River Routes (SJR and TC)	lphi_SJ	-2.99	0.49	0.05	0.02	0.12
Survival from Delta Entry to Chipps via Old River Routes (MR, OR, GLC)	lphi_OR	-3.30	0.26	0.04	0.02	0.06
Through-Delta Survival	lphi_TD	-3.26	0.24	0.04	0.02	0.06
Through-Bay Survival	lphi_TB	0.54	0.45	0.63	0.41	0.81
Survival from SJ downstream of HOR to Turner Cut	lphi_SJtTC	-2.10	0.46	0.11	0.05	0.23
Survival from Durham Ferry to Benicia	lphi_DFtB	-4.05	0.26	0.02	0.01	0.03
Survival from Head of Old River Release to Benicia	lphi_HORtB	-3.37	0.25	0.03	0.02	0.05
Survival from Stockton Release to Benicia	lphi_STtB	-2.35	0.31	0.09	0.05	0.15
Difference HOR release survival and HOR-reach survival *not logit space	dphi_HOR	0.07	0.04			
Difference in ST release survival and ST-reach survival *not logit space	dphi_ST	-0.19	0.12			

Table B4. Derived survival estimates for the May releases. Parameter estimates were obtained from the model using data processed with the 1-hit predator filter. Parameter estimates (Est.) and standard errors (SE) were estimated on the logit-scale and transformed into mean probabilities with lower and upper 95% confidence intervals (L_{95} and U_{95} ,respectively).

		Logit-Scale		Probabilities		
Parameter Description	Parameter	Est.	SE	Mean	L_{95}	U_{95}
Survival from Durham Ferry to Delta Entry (Mossdale)	lphi_DE	-2.25	0.25	0.10	0.06	0.15
Survival from Delta Entry to Chipps via San Joaquin Route	lphi_SJSJ	-3.76	0.48	0.02	0.01	0.06
Survival from Delta Entry to Chipps via Turner Cut Route	lphi_SJTC	-4.71	0.70	0.01	0.00	0.03
Survival from Delta Entry to Chipps via Middle River Route	lphi_ORMR	-3.34	0.79	0.03	0.01	0.14
Survival from Delta Entry to Chipps via Old River Route	lphi_OROR	-3.39	0.36	0.03	0.02	0.06
Survival from Delta Entry to Chipps via Grant Line Canal Route	lphi_ORGL	-3.86	0.33	0.02	0.01	0.04
Survival from Delta Entry to Chipps via San Joaquin River Routes (SJR and TC)	lphi_SJ	-3.95	0.48	0.02	0.01	0.05
Survival from Delta Entry to Chipps via Old River Routes (MR, OR, GLC)	lphi_OR	-3.72	0.32	0.02	0.01	0.04
Through-Delta Survival	lphi_TD	-3.79	0.30	0.02	0.01	0.04
Through-Bay Survival	lphi_TB	0.59	0.50	0.64	0.40	0.83
Survival from SJ downstream of HOR to Turner Cut	lphi_SJtTC	-2.57	0.41	0.07	0.03	0.14
Survival from Durham Ferry to Benicia	lphi_DFtB	-6.39	0.40	0.00	0.00	0.00
Survival from Head of Old River Release to Benicia	lphi_HORtB	-3.94	0.30	0.02	0.01	0.03
Survival from Stockton Release to Benicia	lphi_STtB	-2.43	0.34	0.08	0.04	0.15
Difference HOR release survival and HOR-reach survival *not logit space	dphi_HOR	0.09	0.09			
Difference in ST release survival and ST-reach survival *not logit space	dphi_ST	-0.26	0.11			

Table B5. Mean reach-specific survival random effects estimates (Est.) and standard errors (SE) on the logit-scale and derived reach-specific survival estimates for an average-sized fish with lower and upper 95% confidence intervals (L_{95} and U_{95}, respectively) across all release groups. Parameter estimates were obtained from the model using data processed with the 1-hit predator filter.

	Logit-Scale		Derived Reach-Specific Est.		
Parameter Description	Est.	SE	Mean	L_{95}	U_{95}
RE for Reach 1: DF release	0.77	0.02	0.68	0.68	0.69
RE for Reach 2: HOR release	0.89	0.01	0.71	0.70	0.71
RE for Reach 3: ST release	0.37	0.03	0.59	0.58	0.60
RE for Reach 4: DF_DS to SJ_BCA	0.60	0.02	0.65	0.64	0.66
RE for Reach 5: SJ_BCA to Mossdale	0.81	0.03	0.69	0.68	0.71
RE for Reach 6: Mossdale to SJ_HOR or OR_HOR	0.84	0.03	0.70	0.68	0.71
RE for Reach 7: SJ-HOR to Howard	0.31	0.03	0.58	0.56	0.59
RE for Reach 8: Howard to SJG	0.55	0.08	0.64	0.60	0.67
RE for Reach 9: SJG to MAC or TC	0.58	0.10	0.64	0.59	0.69
RE for Reach 10: MAC to 3-mile, Jersey Point, CVP or SWP	0.59	0.07	0.64	0.61	0.68
RE for Reach 11: Turner Cut to 3-mile, Jersey Point, CVP or SWP	0.41	0.10	0.60	0.56	0.64
RE for Reach 12: OR_HOR to OR_MR junction	0.70	0.02	0.67	0.66	0.68
RE for Reach 13: MR_OR to MR_HWY4, OR_HWY4, CVP, or SWP	0.34	0.14	0.58	0.51	0.65
RE for Reach 14: MR_HWY4 to 3-mile or Jersey Point	0.37	0.11	0.59	0.54	0.64
RE for Reach 15: OR_MidR to OR_Tracy or GLC	0.74	0.02	0.68	0.67	0.69
RE for Reach 16: OR_Tracy to MR_HWY4, OR_HWY4, CVP, or SWP	0.60	0.07	0.65	0.62	0.67
RE for Reach 17: OR_HWY4 to 3-mile or Jersey Point	0.21	0.04	0.55	0.53	0.57
RE for Reach 18: GLC to MR_HWY4, OR_HWY4, CVP, or SWP	0.53	0.04	0.63	0.61	0.65
RE for Reach 19: CVP trash rack to Chipps Island	0.19	0.05	0.55	0.52	0.57
RE for Reach 20: CCF_inlet to CCF_intake	0.52	0.07	0.63	0.59	0.66
RE for Reach 21: CCF_intake to Chipps Island	0.24	0.08	0.56	0.52	0.60
RE for Reach 22: 3-mile to Chipps Island	0.53	0.12	0.63	0.57	0.68
RE for Reach 23: Jersey Point to Chipps Island	0.74	0.07	0.68	0.65	0.71
RE for Reach 24: Chipps Island to Benicia	0.78	0.05	0.69	0.66	0.71
RE for Reach 25: Benicia to Golden Gate E	0.73	0.07	0.68	0.65	0.70

Table B6. Reach-specific survival random effects estimates (Est.) and standard errors (SE) on the logit-scale and derived reach-specific survival estimates for an average-sized fish with lower and upper 95% confidence intervals (L_{95} and U_{95}, respectively) from the March release. Bottom four parameters represent the fixed effects intercept, effect of length on survival, and standard deviation (SD) hyperparameters for the reach-specific random effects. The * indicates parameter held constant over release groups. Parameter estimates were obtained from the model using data processed with the 1-hit predator filter.

	Logit-Scale		Derived Reach-Specific Est.		
Parameter Description	Est.	SE	Mean	L_{95}	U_{95}
RE for Reach 1: DF release	2.27	0.41	0.94	0.79	0.98
RE for Reach 2: HOR release	1.84	0.44	0.91	0.69	0.98
RE for Reach 3: ST release	-1.03	0.36	0.35	0.13	0.67
RE for Reach 4: DF_DS to SJ_BCA	0.95	0.35	0.80	0.53	0.93
RE for Reach 5: SJ_BCA to Mossdale	1.69	0.39	0.89	0.68	0.97
RE for Reach 6: Mossdale to SJ_HOR or OR_HOR	1.87	0.41	0.91	0.71	0.98
RE for Reach 7: SJ-HOR to Howard	-1.59	0.46	0.24	0.07	0.58
RE for Reach 8: Howard to SJG	0.02	0.78	0.61	0.16	0.93
RE for Reach 9: SJG to MAC or TC	-0.47	0.88	0.49	0.09	0.91
RE for Reach 10: MAC to 3-mile, Jersey Point, CVP or SWP	-0.62	0.59	0.45	0.13	0.82
RE for Reach 11: Turner Cut to 3-mile, Jersey Point, CVP or SWP	-0.69	0.69	0.44	0.10	0.84
RE for Reach 12: OR_HOR to OR_MR junction	0.57	0.34	0.73	0.44	0.91
RE for Reach 13: MR_OR to MR_HWY4, OR_HWY4, CVP, or SWP	-1.97	0.85	0.18	0.02	0.67
RE for Reach 14: MR_HWY4 to 3-mile or Jersey Point	0.34	1.14	0.68	0.11	0.97
RE for Reach 15: OR_MidR to OR_Tracy or GLC	0.46	0.36	0.71	0.40	0.90
RE for Reach 16: OR_Tracy to MR_HWY4, OR_HWY4, CVP, or SWP	-0.37	0.55	0.51	0.17	0.85
RE for Reach 17: OR_HWY4 to 3-mile or Jersey Point	-1.07	0.52	0.35	0.10	0.73
RE for Reach 18: GLC to MR_HWY4, OR_HWY4, CVP, or SWP	-0.48	0.40	0.49	0.19	0.79
RE for Reach 19: CVP trash rack to Chipps Island	-1.84	0.82	0.20	0.03	0.69
RE for Reach 20: CCF_inlet to CCF_intake	1.27	0.92	0.85	0.33	0.98
RE for Reach 21: CCF_intake to Chipps Island	-1.57	0.76	0.24	0.04	0.72
RE for Reach 22: 3-mile to Chipps Island	-0.65	1.10	0.44	0.05	0.93
RE for Reach 23: Jersey Point to Chipps Island	1.34	0.73	0.85	0.44	0.98
RE for Reach 24: Chipps Island to Benicia	0.44	0.58	0.71	0.30	0.93
RE for Reach 25: Benicia to Golden Gate E	0.18	0.66	0.65	0.22	0.92
Intercept for the survival mixed-effects regression	0.43	0.30			
Slope for the survival-length relationship*	0.54	0.04			
Log(SD) for Release-specific random effect hyperparameter*	0.42	0.25			
Log(SD) for Reach-specific random effect hyperparameter*	0.25	0.12			

Table B7. Reach-specific survival random effects estimates (Est.) and standard errors (SE) on the logit-scale and derived reach-specific survival estimates for an average-sized fish with lower and upper 95% confidence intervals (L_{95} and U_{95}, respectively) from the April release. Bottom four parameters represent the fixed effects intercept, effect of length on survival, and standard deviation (SD) hyperparameters for the reach-specific random effects. The * indicates parameter held constant over release groups. Parameter estimates were obtained from the model using data processed with the 1-hit predator filter.

	Logit-Scale		Derived Reach-Specific Est.		
Parameter Description	Est.	SE	Mean	L_{95}	U_{95}
RE for Reach 1: DF release	1.41	0.36	0.86	0.62	0.95
RE for Reach 2: HOR release	1.82	0.37	0.90	0.71	0.97
RE for Reach 3: ST release	-0.75	0.35	0.41	0.16	0.71
RE for Reach 4: DF_DS to SJ_BCA	0.61	0.34	0.73	0.44	0.90
RE for Reach 5: SJ_BCA to Mossdale	1.57	0.40	0.87	0.64	0.96
RE for Reach 6: Mossdale to SJ_HOR or OR_HOR	1.21	0.37	0.83	0.57	0.95
RE for Reach 7: SJ-HOR to Howard	-0.82	0.37	0.39	0.15	0.70
RE for Reach 8: Howard to SJG	0.11	0.64	0.62	0.21	0.91
RE for Reach 9: SJG to MAC or TC	-0.17	0.68	0.55	0.15	0.89
RE for Reach 10: MAC to 3-mile, Jersey Point, CVP or SWP	0.66	0.65	0.74	0.31	0.95
RE for Reach 11: Turner Cut to 3-mile, Jersey Point, CVP or SWP	-0.45	0.74	0.48	0.11	0.87
RE for Reach 12: OR_HOR to OR_MR junction	1.06	0.33	0.81	0.55	0.93
RE for Reach 13: MR_OR to MR_HWY4, OR_HWY4, CVP, or SWP	-1.08	1.07	0.33	0.03	0.88
RE for Reach 14: MR_HWY4 to 3-mile or Jersey Point	-1.99	0.85	0.16	0.02	0.65
RE for Reach 15: OR_MidR to OR_Tracy or GLC	1.36	0.35	0.85	0.62	0.95
RE for Reach 16: OR_Tracy to MR_HWY4, OR_HWY4, CVP, or SWP	-0.21	0.44	0.54	0.22	0.83
RE for Reach 17: OR_HWY4 to 3-mile or Jersey Point	-2.22	0.49	0.14	0.03	0.42
RE for Reach 18: GLC to MR_HWY4, OR_HWY4, CVP, or SWP	-0.13	0.36	0.56	0.26	0.82
RE for Reach 19: CVP trash rack to Chipps Island	-1.87	0.51	0.18	0.04	0.51
RE for Reach 20: CCF_inlet to CCF_intake	-1.07	0.47	0.33	0.10	0.69
RE for Reach 21: CCF_intake to Chipps Island	-1.64	0.60	0.22	0.05	0.62
RE for Reach 22: 3-mile to Chipps Island	0.46	0.83	0.69	0.20	0.95
RE for Reach 23: Jersey Point to Chipps Island	0.76	0.66	0.76	0.32	0.95
RE for Reach 24: Chipps Island to Benicia	1.35	0.62	0.85	0.49	0.97
RE for Reach 25: Benicia to Golden Gate E	0.70	0.60	0.74	0.34	0.94
Intercept for the survival mixed-effects regression	0.36	0.29			
Slope for the survival-length relationship*	0.54	0.04			
Log(SD) for Release-specific random effect hyperparameter*	0.42	0.25			
Log(SD) for Reach-specific random effect hyperparameter*	0.25	0.12			

Table B8. Reach-specific survival random effects estimates (Est.) and standard errors (SE) on the logit-scale and derived reach-specific survival estimates for an average-sized fish with lower and upper 95% confidence intervals (L_{95} and U_{95}, respectively) from the May release. Bottom four parameters represent the fixed effects intercept, effect of length on survival, and standard deviation (SD) hyperparameters for the reach-specific random effects. The * indicates parameter held constant over release groups. Parameter estimates were obtained from the model using data processed with the 1-hit predator filter.

	Logit-Scale		Derived Reach-Specific Est.		
Parameter Description	Est.	SE	Mean	L_{95}	U_{95}
RE for Reach 1: DF release	0.03	0.33	0.52	0.24	0.78
RE for Reach 2: HOR release	1.83	0.34	0.87	0.65	0.96
RE for Reach 3: ST release	-0.70	0.37	0.34	0.12	0.65
RE for Reach 4: DF_DS to SJ_BCA	-0.98	0.36	0.28	0.10	0.58
RE for Reach 5: SJ_BCA to Mossdale	0.65	0.48	0.66	0.30	0.90
RE for Reach 6: Mossdale to SJ_HOR or OR_HOR	1.20	0.55	0.77	0.40	0.95
RE for Reach 7: SJ-HOR to Howard	-0.89	0.37	0.30	0.10	0.61
RE for Reach 8: Howard to SJG	-0.29	0.51	0.44	0.14	0.79
RE for Reach 9: SJG to MAC or TC	0.84	0.69	0.70	0.26	0.94
RE for Reach 10: MAC to 3-mile, Jersey Point, CVP or SWP	0.33	0.55	0.59	0.22	0.88
RE for Reach 11: Turner Cut to 3-mile, Jersey Point, CVP or SWP	-0.84	0.74	0.31	0.06	0.77
RE for Reach 12: OR_HOR to OR_MR junction	0.27	0.32	0.58	0.29	0.82
RE for Reach 13: MR_OR to MR_HWY4, OR_HWY4, CVP, or SWP	-0.03	1.29	0.50	0.04	0.96
RE for Reach 14: MR_HWY4 to 3-mile or Jersey Point	-1.13	1.01	0.25	0.03	0.81
RE for Reach 15: OR_MidR to OR_Tracy or GLC	0.69	0.35	0.67	0.37	0.88
RE for Reach 16: OR_Tracy to MR_HWY4, OR_HWY4, CVP, or SWP	1.03	0.66	0.74	0.31	0.95
RE for Reach 17: OR_HWY4 to 3-mile or Jersey Point	-1.80	0.52	0.15	0.03	0.46
RE for Reach 18: GLC to MR_HWY4, OR_HWY4, CVP, or SWP	0.20	0.41	0.56	0.24	0.83
RE for Reach 19: CVP trash rack to Chipps Island	-1.38	0.53	0.21	0.05	0.56
RE for Reach 20: CCF_inlet to CCF_intake	-0.55	0.69	0.37	0.08	0.80
RE for Reach 21: CCF_intake to Chipps Island	-1.07	0.83	0.26	0.04	0.76
RE for Reach 22: 3-mile to Chipps Island	-0.26	0.74	0.44	0.10	0.86
RE for Reach 23: Jersey Point to Chipps Island	0.44	0.63	0.62	0.21	0.91
RE for Reach 24: Chipps Island to Benicia	1.32	0.63	0.79	0.39	0.96
RE for Reach 25: Benicia to Golden Gate E	1.42	0.71	0.81	0.37	0.97
Intercept for the survival mixed-effects regression	0.03	0.29			
Slope for the survival-length relationship*	0.54	0.04			
Log(SD) for Release-specific random effect hyperparameter*	0.42	0.25			
Log(SD) for Reach-specific random effect hyperparameter*	0.25	0.12			

Table B9. Mean routing random effects estimates (Est.) and standard errors (SE) on the logit-scale and mean transformed routing estimates with lower and upper 95% confidence intervals (L_{95} and U_{95}, respectively) from all release groups. Parameter estimates were obtained from the model using data processed with the 1-hit predator filter.

		Logit-Scale		Transformed Est.		
Par.	Parameter Description	Est.	SE	Mean	L_{95}	U_{95}
ρ_1	Prob. of entering CVP vs. SWP	0.21	0.25	0.55	0.43	0.67
ρ_2	Prob. of taking 3-mile vs. Jersey Point to Chipps Island	-1.46	0.35	0.19	0.10	0.32
ρ_3	Prob. of remaining in SJ @ HOR for DF release	-1.44	0.20	0.19	0.14	0.26
ρ_4	Prob. of taking SJ route for HOR release vs. OR route	-1.70	0.14	0.15	0.12	0.19
ρ_5	Prob. of going downstream @ ST release	0.05	0.20	0.51	0.42	0.61
ρ_6	Prob. of remaining in SJ @ Turner Cut	0.69	0.25	0.67	0.55	0.76
ρ_7	Prob. of heading to pumps after passing MAC	-2.52	0.61	0.07	0.02	0.21
ρ_8	Prob. of heading to pumps after entering Turner Cut	-1.10	0.69	0.25	0.08	0.56
ρ_9	Prob. of taking MR @ MR-OR split	-3.88	0.36	0.02	0.01	0.04
ρ_{10}	Prob. of heading to interior delta vs. pumps from MR	-1.22	1.05	0.23	0.04	0.70
ρ_{11}	Prob. of heading to interior via MR_HWY4 vs OR_HWY4 from MR	-1.23	1.05	0.23	0.04	0.69
ρ_{12}	Prob. of taking OR @ OR-GLC split	-1.16	0.13	0.24	0.19	0.29
ρ_{13}	Prob. of heading to interior delta vs. pumps from OR	-0.83	0.33	0.30	0.19	0.46
ρ_{14}	Prob. of heading to interior delta via MR_HWY4 vs. OR_Hwy4 from OR	-1.43	0.58	0.19	0.07	0.43
ρ_{15}	Prob. of heading to interior delta vs. pumps from GLC	0.27	0.21	0.57	0.46	0.67
ρ_{16}	Prob. of heading to interior delta via MR_HWY4 vs. OR_Hwy4 from GLC	-2.73	0.46	0.06	0.03	0.14

Table B10. Routing random effects estimates (Est.) and standard errors (SE) on the logit-scale and mean transformed routing estimates with lower and upper 95% confidence intervals (L_{95} and U_{95}, respectively) from the April release. The * indicates parameter held constant over release groups. Parameter estimates were obtained from the model using data processed with the 1-hit predator filter.

		Logit-Scale		Transformed Est.		
Par.	Parameter Description	Est.	SE	Mean	L_{95}	U_{95}
ρ_1	Prob. of entering CVP vs. SWP	0.14	0.51	0.53	0.30	0.76
ρ_2	Prob. of taking 3-mile vs. Jersey Point to Chipps Island	-2.40	0.80	0.08	0.02	0.30
ρ_3	Prob. of remaining in SJ @ HOR for DF release	-1.57	0.24	0.17	0.11	0.25
ρ_4	Prob. of taking SJ route for HOR release vs. OR route	-2.15	0.34	0.10	0.06	0.18
ρ_5	Prob. of going downstream @ ST release	0.34	0.35	0.58	0.42	0.74
ρ_6	Prob. of remaining in SJ @ Turner Cut	0.38	0.43	0.59	0.39	0.77
ρ_7	Prob. of heading to pumps after passing MAC	-2.51	1.19	0.07	0.01	0.45
ρ_8	Prob. of heading to pumps after entering Turner Cut	-0.75	1.07	0.32	0.06	0.79
ρ_9	Prob. of taking MR @ MR-OR split	-2.73	0.38	0.06	0.03	0.12
ρ_{10}	Prob. of heading to interior delta vs. pumps from MR	-1.21	1.78	0.23	0.01	0.91
ρ_{11}	Prob. of heading to interior via MR_HWY4 vs OR_HWY4 from MR	-1.24	1.76	0.22	0.01	0.90
ρ_{12}	Prob. of taking OR @ OR-GLC split	-1.24	0.26	0.23	0.15	0.33
ρ_{13}	Prob. of heading to interior delta vs. pumps from OR	-1.22	0.74	0.23	0.07	0.56
ρ_{14}	Prob. of heading to interior delta via MR_HWY4 vs. OR_Hwy4 from OR	-2.01	1.36	0.12	0.01	0.66
ρ_{15}	Prob. of heading to interior delta vs. pumps from GLC	0.90	0.43	0.71	0.51	0.85
ρ_{16}	Prob. of heading to interior delta via MR_HWY4 vs. OR_Hwy4 from GLC	-2.66	0.77	0.07	0.02	0.24
μ_ρ	Hyperparameter mean of transition probability in logit space*	-1.22	0.29			

Table B11. Routing random effects estimates (Est.) and standard errors (SE) on the logit-scale and mean transformed routing estimates with lower and upper 95% confidence intervals (L_{95} and U_{95}, respectively) from the April release. The * indicates parameter held constant over release groups. Parameter estimates were obtained from the model using data processed with the 1-hit predator filter.

		Logit-Scale		Transformed Est.		
Par.	Parameter Description	Est.	SE	Mean	L_{95}	U_{95}
ρ_1	Prob. of entering CVP vs. SWP	-0.22	0.29	0.45	0.31	0.59
ρ_2	Prob. of taking 3-mile vs. Jersey Point to Chipps Island	-1.14	0.50	0.24	0.11	0.46
ρ_3	Prob. of remaining in SJ @ HOR for DF release	-1.94	0.29	0.13	0.08	0.20
ρ_4	Prob. of taking SJ route for HOR release vs. OR route	-1.77	0.21	0.15	0.10	0.20
ρ_5	Prob. of going downstream @ ST release	-0.56	0.31	0.36	0.24	0.51
ρ_6	Prob. of remaining in SJ @ Turner Cut	0.77	0.45	0.68	0.47	0.84
ρ_7	Prob. of heading to pumps after passing MAC	-2.05	0.83	0.11	0.02	0.40
ρ_8	Prob. of heading to pumps after entering Turner Cut	-2.11	1.31	0.11	0.01	0.61
ρ_9	Prob. of taking MR @ MR-OR split	-4.22	0.56	0.01	0.00	0.04
ρ_{10}	Prob. of heading to interior delta vs. pumps from MR	-1.22	1.77	0.23	0.01	0.90
ρ_{11}	Prob. of heading to interior via MR_HWY4 vs OR_HWY4 from MR	-1.24	1.76	0.23	0.01	0.90
ρ_{12}	Prob. of taking OR @ OR-GLC split	-1.08	0.17	0.25	0.20	0.32
ρ_{13}	Prob. of heading to interior delta vs. pumps from OR	-0.62	0.42	0.35	0.19	0.55
ρ_{14}	Prob. of heading to interior delta via MR_HWY4 vs. OR_Hwy4 from OR	-1.37	0.73	0.20	0.06	0.51
ρ_{15}	Prob. of heading to interior delta vs. pumps from GLC	-0.27	0.25	0.43	0.32	0.56
ρ_{16}	Prob. of heading to interior delta via MR_HWY4 vs. OR_Hwy4 from GLC	-2.05	0.50	0.11	0.05	0.26
μ_ρ	Hyperparameter mean of transition probability in logit space*	-1.22	0.29			

Table B12. Routing random effects estimates (Est.) and standard errors (SE) on the logit-scale and mean transformed routing estimates with lower and upper 95% confidence intervals (L_{95} and U_{95}, respectively) from the May release. The * indicates parameter held constant over release groups. Parameter estimates were obtained from the model using data processed with the 1-hit predator filter

		Logit-Scale		Transformed Est.		
Par.	Parameter Description	Est.	SE	Mean	L_{95}	U_{95}
ρ_1	Prob. of entering CVP vs. SWP	0.72	0.39	0.67	0.49	0.82
ρ_2	Prob. of taking 3-mile vs. Jersey Point to Chipps Island	-0.85	0.48	0.30	0.14	0.52
ρ_3	Prob. of remaining in SJ @ HOR for DF release	-0.80	0.48	0.31	0.15	0.53
ρ_4	Prob. of taking SJ route for HOR release vs. OR route	-1.18	0.15	0.24	0.19	0.29
ρ_5	Prob. of going downstream @ ST release	0.37	0.36	0.59	0.42	0.74
ρ_6	Prob. of remaining in SJ @ Turner Cut	0.92	0.41	0.71	0.53	0.85
ρ_7	Prob. of heading to pumps after passing MAC	-2.99	1.07	0.05	0.01	0.29
ρ_8	Prob. of heading to pumps after entering Turner Cut	-0.43	1.13	0.39	0.07	0.86
ρ_9	Prob. of taking MR @ MR-OR split	-4.69	0.83	0.01	0.00	0.05
ρ_{10}	Prob. of heading to interior delta vs. pumps from MR	-1.22	1.77	0.23	0.01	0.91
ρ_{11}	Prob. of heading to interior via MR_HWY4 vs OR_HWY4 from MR	-1.22	1.77	0.23	0.01	0.91
ρ_{12}	Prob. of taking OR @ OR-GLC split	-1.17	0.24	0.24	0.16	0.33
ρ_{13}	Prob. of heading to interior delta vs. pumps from OR	-0.64	0.50	0.34	0.16	0.58
ρ_{14}	Prob. of heading to interior delta via MR_HWY4 vs. OR_Hwy4 from OR	-0.90	0.79	0.29	0.08	0.66
ρ_{15}	Prob. of heading to interior delta vs. pumps from GLC	0.18	0.32	0.54	0.39	0.69
ρ_{16}	Prob. of heading to interior delta via MR_HWY4 vs. OR_Hwy4 from GLC	-3.48	0.99	0.03	0.00	0.18
μ_ρ	Prob. of heading to interior delta via MR_HWY4 vs. OR_Hwy4 from GLC	-1.22	0.29			

Table B13. Detection probability estimates (Est.) and standard errors (SE) on the logit-scale and and transformed estimates with lower and upper 95% confidence intervals (L_{95} and U_{95}, respectively). The bottom two parameters represent the hyperparameter mean and standard deviation (SD) for the distribution of random effects. Detection estimates represent detection at a single-line and detection of combined dual-line receivers so detection across both lines is $P = 1 - \left(1 - 1/e^{-lgt_p}\right)^2$. Parameter estimates were obtained from the model using data processed with the 1-hit predator filter.

		Logit-Scale		Transformed Est.			Dual-
Par.	Parameter Description	Est.	SE	Mean	L_{95}	U_{95}	Line Est.
p_1	Logit Detection: DF_DS	3.44	0.32	0.97	0.94	0.98	
p_2	Logit Detection: SJ_BCA	4.22	0.49	0.99	0.96	0.99	
p_3	Logit Detection: Mossdale	3.91	0.45	0.98	0.95	0.99	
p_4	Logit Detection: SJ_HOR (Combined dual-line)	3.20	0.76	0.96	0.85	0.99	1.00
p_5	Logit Detection: Howard	2.53	1.43	0.93	0.43	1.00	
p_6	Logit Detection: SJG (Combined dual-line)	5.09	0.64	0.99	0.98	1.00	1.00
p_7	Logit Detection: MAC (Combined dual-line)	1.94	0.82	0.87	0.58	0.97	0.98
p_8	Logit Detection: Turner Cut (Combined dual-line)	1.33	0.50	0.79	0.59	0.91	0.96
p_9	Logit Detection: OR_HOR (Combined dual-line)	2.15	0.90	0.90	0.59	0.98	0.99
p_{10}	Logit Detection: MR_OR	1.32	0.39	0.79	0.64	0.89	
p_{11}	Logit Detection: MR_HWY4 (Combined dual-line)	0.98	0.35	0.73	0.57	0.84	0.93
p_{12}	Logit Detection: OR_MidR	2.12	0.54	0.89	0.74	0.96	
p_{13}	Logit Detection: OR_Tracy (Combined dual-line)	2.67	1.26	0.94	0.55	0.99	1.00
p_{14}	Logit Detection: OR_HWY4 (Combined dual-line)	2.82	1.14	0.94	0.64	0.99	1.00
p_{15}	Logit Detection: GLC (Combined dual-line)	2.59	1.32	0.93	0.50	0.99	1.00
p_{16}	Logit Detection: CVP_trash_rack	2.98	0.47	0.95	0.89	0.98	
p_{17}	Logit Detection: CCF_Inlet	2.40	1.56	0.92	0.34	1.00	
p_{18}	Logit Detection: CCF_Intake	1.55	0.51	0.82	0.64	0.93	
p_{19}	Logit Detection: 3-mile Slough (Combined dual-line)	0.39	0.39	0.60	0.41	0.76	0.84
p_{20}	Logit Detection: Jersey Point (Combined dual-line)	2.97	1.06	0.95	0.71	0.99	1.00
p_{21}	Logit Detection: Chipps Island (Combined dual-line)	2.46	1.47	0.92	0.40	1.00	0.99
p_{22}	Logit Detection: Benicia (Combined dual-line)	0.50	0.35	0.62	0.46	0.77	0.86
p_{23}	Logit Detection: Golden Gate E	1.92	0.57	0.87	0.69	0.95	
p_{24}	Logit Detection: Golden Gate W	2.91	1.09	0.95	0.69	0.99	
μ_p	Hyperparameter mean detection probability in logit space	2.43	0.37				
$log(\sigma_p)$	Hyperparameter log(SD) for detection random effect	0.38	0.21				

Appendix C: Model Results from the Multi-hit Predator Filter

Table C1. Mean derived survival estimates for all releases combined. Parameter estimates were obtained from the model using data processed with the 1-hit predator filter. Parameter estimates (Est.) and standard errors (SE) were estimated on the logit-scale and transformed into mean probabilities with lower and upper 95% confidence intervals (L_{95} and U_{95} respectively).

		Logit-Scale		Probabilities		
Parameter Description	Parameter	Est.	SE	Mean	L_{95}	U_{95}
Survival from Durham Ferry to Delta Entry (Mossdale)	lphi_DE	-0.31	0.10	0.42	0.38	0.47
Survival from Delta Entry to Chipps via San Joaquin Route	lphi_SJSJ	-3.40	0.32	0.03	0.02	0.06
Survival from Delta Entry to Chipps via Turner Cut Route	lphi_SJTC	-4.09	0.40	0.02	0.01	0.04
Survival from Delta Entry to Chipps via Middle River Route	lphi_ORMR	-3.57	0.48	0.03	0.01	0.07
Survival from Delta Entry to Chipps via Old River Route	lphi_OROR	-3.13	0.21	0.04	0.03	0.06
Survival from Delta Entry to Chipps via Grant Line Canal Route	lphi_ORGL	-3.24	0.17	0.04	0.03	0.05
Survival from Delta Entry to Chipps via San Joaquin River Routes (SJR and TC)	lphi_SJ	-3.59	0.32	0.03	0.01	0.05
Survival from Delta Entry to Chipps via Old River Routes (MR, OR, GLC)	lphi_OR	-3.22	0.17	0.04	0.03	0.05
Through-Delta Survial	lphi_TD	-3.29	0.16	0.04	0.03	0.05
Through-Bay Surival	lphi_TB	0.34	0.29	0.58	0.44	0.71
Survival from SJ downstream of HOR to Turner Cut	lphi_SJtTC	-2.43	0.29	0.08	0.05	0.14
Survial from Durham Ferry to Benicia	lphi_DFtB	-4.59	0.19	0.01	0.01	0.01
Survial from Head of Old River Release to Benicia	lphi_HORtB	-3.50	0.17	0.03	0.02	0.04
Survial from Stockton Release to Benicia	lphi_STtB	-2.27	0.19	0.09	0.07	0.13
Difference HOR release survival and HOR-reach survival *not logit space	dphi_HOR	0.04	0.03			
Difference in ST release survival and ST-reach survival *not logit space	dphi_ST	-0.15	0.07			

Table C2. Derived survival estimates for the March releases. Parameter estimates were obtained from the model using data processed with the 1-hit predator filter. Parameter estimates (Est.) and standard errors (SE) were estimated on the logit-scale and transformed into mean probabilities with lower and upper 95% confidence intervals (L_{95} and U_{95} respectively).

		Logit-Scale		Probabilities		
Parameter Description	Parameter	Est.	SE	Mean	L_{95}	U_{95}
Survival from Durham Ferry to Delta Entry (Mossdale)	lphi_DE	0.74	0.15	0.68	0.61	0.74
Survival from Delta Entry to Chipps via San Joaquin Route	lphi_SJSJ	-3.68	0.71	0.02	0.01	0.09
Survival from Delta Entry to Chipps via Turner Cut Route	lphi_SJTC	-4.07	0.78	0.02	0.00	0.07
Survival from Delta Entry to Chipps via Middle River Route	lphi_ORMR	-3.78	0.83	0.02	0.00	0.11
Survival from Delta Entry to Chipps via Old River Route	lphi_OROR	-2.84	0.43	0.06	0.02	0.12
Survival from Delta Entry to Chipps via Grant Line Canal Route	lphi_ORGL	-2.71	0.30	0.06	0.04	0.11
Survival from Delta Entry to Chipps via San Joaquin River Routes (SJR and TC)	lphi_SJ	-3.83	0.69	0.02	0.01	0.08
Survival from Delta Entry to Chipps via Old River Routes (MR, OR, GLC)	lphi_OR	-2.78	0.28	0.06	0.03	0.10
Through-Delta Survival	lphi_TD	-2.89	0.27	0.05	0.03	0.09
Through-Bay Survival	lphi_TB	-0.27	0.49	0.43	0.23	0.67
Survival from SJ downstream of HOR to Turner Cut	lphi_SJtTC	-2.67	0.66	0.06	0.02	0.20
Survival from Durham Ferry to Benicia	lphi_DFtB	-3.72	0.32	0.02	0.01	0.04
Survival from Head of Old River Release to Benicia	lphi_HORtB	-3.30	0.32	0.04	0.02	0.07
Survival from Stockton Release to Benicia	lphi_STtB	-2.15	0.32	0.10	0.06	0.18
Difference HOR release survival and HOR-reach survival *not logit space	dphi_HOR	-0.01	0.03			
Difference in ST release survival and ST-reach survival *not logit space	dphi_ST	-0.16	0.16			

Table C3. Derived survival estimates for the April releases. Parameter estimates were obtained from the model using data processed with the 1-hit predator filter. Parameter estimates (Est.) and standard errors (SE) were estimated on the logit-scale and transformed into mean probabilities with lower and upper 95% confidence intervals (L_{95} and U_{95} respectively).

		Logit-Scale		Probabilities		
Parameter Description	Parameter	Est.	SE	Mean	L_{95}	U_{95}
Survival from Durham Ferry to Delta Entry (Mossdale)	lphi_DE	0.26	0.15	0.56	0.49	0.63
Survival from Delta Entry to Chipps via San Joaquin Route	lphi_SJSJ	-2.72	0.46	0.06	0.03	0.14
Survival from Delta Entry to Chipps via Turner Cut Route	lphi_SJTC	-3.43	0.58	0.03	0.01	0.09
Survival from Delta Entry to Chipps via Middle River Route	lphi_ORMR	-3.62	0.81	0.03	0.01	0.12
Survival from Delta Entry to Chipps via Old River Route	lphi_OROR	-3.25	0.29	0.04	0.02	0.06
Survival from Delta Entry to Chipps via Grant Line Canal Route	lphi_ORGL	-3.27	0.25	0.04	0.02	0.06
Survival from Delta Entry to Chipps via San Joaquin River Routes (SJR and TC)	lphi_SJ	-2.95	0.46	0.05	0.02	0.11
Survival from Delta Entry to Chipps via Old River Routes (MR, OR, GLC)	lphi_OR	-3.27	0.25	0.04	0.02	0.06
Through-Delta Survival	lphi_TD	-3.22	0.23	0.04	0.02	0.06
Through-Bay Survival	lphi_TB	0.65	0.46	0.66	0.44	0.82
Survival from SJ downstream of HOR to Turner Cut	lphi_SJtTC	-1.97	0.43	0.12	0.06	0.24
Survival from Durham Ferry to Benicia	lphi_DFtB	-3.96	0.25	0.02	0.01	0.03
Survival from Head of Old River Release to Benicia	lphi_HORtB	-3.32	0.24	0.03	0.02	0.05
Survival from Stockton Release to Benicia	lphi_STtB	-2.24	0.30	0.10	0.06	0.16
Difference HOR release survival and HOR-reach survival *not logit space	dphi_HOR	0.07	0.04			
Difference in ST release survival and ST-reach survival *not logit space	dphi_ST	-0.16	0.11			

Table C4. Derived survival estimates for the May releases. Parameter estimates were obtained from the model using data processed with the 1-hit predator filter. Parameter estimates (Est.) and standard errors (SE) were estimated on the logit-scale and transformed into mean probabilities with lower and upper 95% confidence intervals (L_{95} and U_{95} ,respectively).

		Logit-Scale		Probabilities		
Parameter Description	Parameter	Est.	SE	Mean	L_{95}	U_{95}
Survival from Durham Ferry to Delta Entry (Mossdale)	lphi_DE	-1.93	0.22	0.13	0.09	0.18
Survival from Delta Entry to Chipps via San Joaquin Route	lphi_SJSJ	-3.81	0.48	0.02	0.01	0.05
Survival from Delta Entry to Chipps via Turner Cut Route	lphi_SJTC	-4.77	0.70	0.01	0.00	0.03
Survival from Delta Entry to Chipps via Middle River Route	lphi_ORMR	-3.31	0.79	0.04	0.01	0.15
Survival from Delta Entry to Chipps via Old River Route	lphi_OROR	-3.30	0.35	0.04	0.02	0.07
Survival from Delta Entry to Chipps via Grant Line Canal Route	lphi_ORGL	-3.76	0.32	0.02	0.01	0.04
Survival from Delta Entry to Chipps via San Joaquin River Routes (SJR and TC)	lphi_SJ	-4.00	0.48	0.02	0.01	0.04
Survival from Delta Entry to Chipps via Old River Routes (MR, OR, GLC)	lphi_OR	-3.63	0.31	0.03	0.01	0.05
Through-Delta Survival	lphi_TD	-3.77	0.29	0.02	0.01	0.04
Through-Bay Survival	lphi_TB	0.63	0.51	0.65	0.41	0.84
Survival from SJ downstream of HOR to Turner Cut	lphi_SJtTC	-2.64	0.40	0.07	0.03	0.14
Survival from Durham Ferry to Benicia	lphi_DFtB	-6.08	0.37	0.00	0.00	0.00
Survival from Head of Old River Release to Benicia	lphi_HORtB	-3.89	0.30	0.02	0.01	0.04
Survival from Stockton Release to Benicia	lphi_STtB	-2.41	0.34	0.08	0.04	0.15
Difference HOR release survival and HOR-reach survival *not logit space	dphi_HOR	0.07	0.07			
Difference in ST release survival and ST-reach survival *not logit space	dphi_ST	-0.14	0.10			

Table C5. Mean reach-specific survival random effects estimates (Est.) and standard errors (SE) on the logit-scale and derived reach-specific survival estimates for an average-sized fish with lower and upper 95% confidence intervals (L_{95} and U_{95}, respectively) across all release groups. Parameter estimates were obtained from the model using data processed with the multi-hit predator filter.

	Logit-Scale		Derived Reach-Specific Est.		
Parameter Description	Est.	SE	Mean	L_{95}	U_{95}
RE for Reach 1: DF release	0.79	0.02	0.69	0.68	0.70
RE for Reach 2: HOR release	0.90	0.01	0.71	0.70	0.72
RE for Reach 3: ST release	0.39	0.03	0.60	0.58	0.61
RE for Reach 4: DF_DS to SJ_BCA	0.63	0.02	0.65	0.64	0.66
RE for Reach 5: SJ_BCA to Mossdale	0.81	0.03	0.69	0.68	0.70
RE for Reach 6: Mossdale to SJ_HOR or OR_HOR	0.85	0.03	0.70	0.69	0.71
RE for Reach 7: SJ-HOR to Howard	0.33	0.03	0.58	0.57	0.60
RE for Reach 8: Howard to SJG	0.58	0.08	0.64	0.60	0.68
RE for Reach 9: SJG to MAC or TC	0.51	0.10	0.63	0.58	0.67
RE for Reach 10: MAC to 3-mile, Jersey Point, CVP or SWP	0.61	0.07	0.65	0.61	0.68
RE for Reach 11: Turner Cut to 3-mile, Jersey Point, CVP or SWP	0.41	0.09	0.60	0.56	0.64
RE for Reach 12: OR_HOR to OR_MR junction	0.72	0.02	0.67	0.66	0.68
RE for Reach 13: MR_OR to MR_HWY4, OR_HWY4, CVP, or SWP	0.33	0.14	0.58	0.51	0.65
RE for Reach 14: MR_HWY4 to 3-mile or Jersey Point	0.31	0.11	0.58	0.52	0.63
RE for Reach 15: OR_MidR to OR_Tracy or GLC	0.76	0.02	0.68	0.67	0.69
RE for Reach 16: OR_Tracy to MR_HWY4, OR_HWY4, CVP, or SWP	0.62	0.06	0.65	0.62	0.68
RE for Reach 17: OR_HWY4 to 3-mile or Jersey Point	0.20	0.04	0.55	0.53	0.57
RE for Reach 18: GLC to MR_HWY4, OR_HWY4, CVP, or SWP	0.54	0.04	0.63	0.61	0.65
RE for Reach 19: CVP trash rack to Chipps Island	0.18	0.05	0.55	0.52	0.57
RE for Reach 20: CCF_inlet to CCF_intake	0.58	0.07	0.64	0.61	0.67
RE for Reach 21: CCF_intake to Chipps Island	0.20	0.06	0.55	0.52	0.58
RE for Reach 22: 3-mile to Chipps Island	0.53	0.12	0.63	0.57	0.68
RE for Reach 23: Jersey Point to Chipps Island	0.75	0.07	0.68	0.65	0.71
RE for Reach 24: Chipps Island to Benicia	0.77	0.05	0.68	0.66	0.71
RE for Reach 25: Benicia to Golden Gate E	0.74	0.07	0.68	0.65	0.71

Table C6. Reach-specific survival random effects estimates (Est.) and standard errors (SE) on the logit-scale and derived reach-specific survival estimates for an average-sized fish with lower and upper 95% confidence intervals (L_{95} and U_{95}, respectively) from the March release. Bottom four parameters represent the fixed effects intercept, effect of length on survival, and standard deviation (SD) hyperparameters for the reach-specific random effects. The * indicates parameter held constant over release groups. Parameter estimates were obtained from the model using data processed with the multi-hit predator filter.

	Logit-Scale		Derived Reach-Specific Est.		
Parameter Description	Est.	SE	Mean	L_{95}	U_{95}
RE for Reach 1: DF release	2.26	0.41	0.94	0.78	0.98
RE for Reach 2: HOR release	1.95	0.45	0.91	0.71	0.98
RE for Reach 3: ST release	-0.94	0.37	0.37	0.14	0.69
RE for Reach 4: DF_DS to SJ_BCA	1.02	0.35	0.81	0.54	0.94
RE for Reach 5: SJ_BCA to Mossdale	1.70	0.39	0.89	0.68	0.97
RE for Reach 6: Mossdale to SJ_HOR or OR_HOR	2.07	0.42	0.92	0.74	0.98
RE for Reach 7: SJ-HOR to Howard	-1.60	0.46	0.24	0.06	0.58
RE for Reach 8: Howard to SJG	0.03	0.78	0.61	0.16	0.93
RE for Reach 9: SJG to MAC or TC	-0.47	0.89	0.49	0.08	0.91
RE for Reach 10: MAC to 3-mile, Jersey Point, CVP or SWP	-0.48	0.58	0.48	0.14	0.84
RE for Reach 11: Turner Cut to 3-mile, Jersey Point, CVP or SWP	-0.47	0.67	0.49	0.12	0.87
RE for Reach 12: OR_HOR to OR_MR junction	0.73	0.35	0.76	0.47	0.92
RE for Reach 13: MR_OR to MR_HWY4, OR_HWY4, CVP, or SWP	-2.14	0.85	0.15	0.02	0.63
RE for Reach 14: MR_HWY4 to 3-mile or Jersey Point	-0.30	1.00	0.53	0.08	0.94
RE for Reach 15: OR_MidR to OR_Tracy or GLC	0.55	0.36	0.73	0.42	0.91
RE for Reach 16: OR_Tracy to MR_HWY4, OR_HWY4, CVP, or SWP	-0.28	0.55	0.54	0.18	0.86
RE for Reach 17: OR_HWY4 to 3-mile or Jersey Point	-1.20	0.51	0.32	0.08	0.70
RE for Reach 18: GLC to MR_HWY4, OR_HWY4, CVP, or SWP	-0.47	0.40	0.49	0.19	0.79
RE for Reach 19: CVP trash rack to Chipps Island	-1.98	0.82	0.17	0.02	0.66
RE for Reach 20: CCF_inlet to CCF_intake	1.39	0.91	0.86	0.36	0.99
RE for Reach 21: CCF_intake to Chipps Island	-1.71	0.75	0.22	0.03	0.69
RE for Reach 22: 3-mile to Chipps Island	-0.67	1.12	0.44	0.05	0.93
RE for Reach 23: Jersey Point to Chipps Island	1.41	0.73	0.86	0.45	0.98
RE for Reach 24: Chipps Island to Benicia	0.27	0.56	0.67	0.27	0.92
RE for Reach 25: Benicia to Golden Gate E	0.20	0.67	0.65	0.22	0.93
Intercept for the survival mixed-effects regression	0.42	0.31			
Slope for the survival-length relationship*	0.52	0.04			
Log(SD) for Release-specific random effect hyperparameter*	0.43	0.25			
Log(SD) for Reach-specific random effect hyperparameter*	0.27	0.12			

Table C7. Reach-specific survival random effects estimates (Est.) and standard errors (SE) on the logit-scale and derived reach-specific survival estimates for an average-sized fish with lower and upper 95% confidence intervals (L_{95} and U_{95}, respectively) from the April release. Bottom four parameters represent the fixed effects intercept, effect of length on survival, and standard deviation (SD) hyperparameters for the reach-specific random effects. The * indicates parameter held constant over release groups. Parameter estimates were obtained from the model using data processed with the multi-hit predator filter.

	Logit-Scale		Derived Reach-Specific Est.		
Parameter Description	Est.	SE	Mean	L_{95}	U_{95}
RE for Reach 1: DF release	1.50	0.37	0.87	0.65	0.96
RE for Reach 2: HOR release	1.78	0.38	0.90	0.70	0.97
RE for Reach 3: ST release	-0.66	0.35	0.44	0.18	0.73
RE for Reach 4: DF_DS to SJ_BCA	0.60	0.34	0.73	0.44	0.90
RE for Reach 5: SJ_BCA to Mossdale	1.65	0.41	0.89	0.66	0.97
RE for Reach 6: Mossdale to SJ_HOR or OR_HOR	1.17	0.37	0.83	0.57	0.95
RE for Reach 7: SJ-HOR to Howard	-0.72	0.37	0.42	0.16	0.73
RE for Reach 8: Howard to SJG	-0.01	0.60	0.60	0.20	0.90
RE for Reach 9: SJG to MAC or TC	-0.05	0.67	0.59	0.18	0.90
RE for Reach 10: MAC to 3-mile, Jersey Point, CVP or SWP	0.63	0.65	0.74	0.31	0.95
RE for Reach 11: Turner Cut to 3-mile, Jersey Point, CVP or SWP	-0.66	0.66	0.44	0.11	0.83
RE for Reach 12: OR_HOR to OR_MR junction	1.10	0.33	0.82	0.57	0.94
RE for Reach 13: MR_OR to MR_HWY4, OR_HWY4, CVP, or SWP	-1.12	1.08	0.33	0.03	0.88
RE for Reach 14: MR_HWY4 to 3-mile or Jersey Point	-2.05	0.86	0.16	0.02	0.65
RE for Reach 15: OR_MidR to OR_Tracy or GLC	1.40	0.36	0.86	0.63	0.96
RE for Reach 16: OR_Tracy to MR_HWY4, OR_HWY4, CVP, or SWP	-0.21	0.44	0.55	0.22	0.84
RE for Reach 17: OR_HWY4 to 3-mile or Jersey Point	-2.17	0.47	0.15	0.04	0.43
RE for Reach 18: GLC to MR_HWY4, OR_HWY4, CVP, or SWP	-0.21	0.36	0.55	0.25	0.81
RE for Reach 19: CVP trash rack to Chipps Island	-1.93	0.51	0.18	0.04	0.52
RE for Reach 20: CCF_inlet to CCF_intake	-0.95	0.47	0.37	0.12	0.72
RE for Reach 21: CCF_intake to Chipps Island	-1.85	0.59	0.19	0.04	0.57
RE for Reach 22: 3-mile to Chipps Island	0.45	0.84	0.70	0.20	0.96
RE for Reach 23: Jersey Point to Chipps Island	0.84	0.66	0.78	0.35	0.96
RE for Reach 24: Chipps Island to Benicia	1.39	0.62	0.86	0.50	0.97
RE for Reach 25: Benicia to Golden Gate E	0.78	0.61	0.76	0.36	0.95
Intercept for the survival mixed-effects regression	0.40	0.29			
Slope for the survival-length relationship*	0.52	0.04			
Log(SD) for Release-specific random effect hyperparameter*	0.43	0.25			
Log(SD) for Reach-specific random effect hyperparameter*	0.27	0.12			

Table C8. Reach-specific survival random effects estimates (Est.) and standard errors (SE) on the logit-scale and derived reach-specific survival estimates for an average-sized fish with lower and upper 95% confidence intervals (L_{95} and U_{95}, respectively) from the May release. Bottom four parameters represent the fixed effects intercept, effect of length on survival, and standard deviation (SD) hyperparameters for the reach-specific random effects. The * indicates parameter held constant over release groups. Parameter estimates were obtained from the model using data processed with the multi-hit predator filter.

	Logit-Scale		Derived Reach-Specific Est.		
Parameter Description	Est.	SE	Mean	L_{95}	U_{95}
RE for Reach 1: DF release	0.21	0.33	0.57	0.28	0.82
RE for Reach 2: HOR release	1.87	0.34	0.87	0.66	0.96
RE for Reach 3: ST release	-0.69	0.37	0.35	0.13	0.66
RE for Reach 4: DF_DS to SJ_BCA	-0.73	0.36	0.34	0.12	0.65
RE for Reach 5: SJ_BCA to Mossdale	0.57	0.45	0.65	0.31	0.89
RE for Reach 6: Mossdale to SJ_HOR or OR_HOR	1.34	0.52	0.80	0.45	0.95
RE for Reach 7: SJ-HOR to Howard	-0.75	0.37	0.34	0.12	0.65
RE for Reach 8: Howard to SJG	0.07	0.49	0.53	0.20	0.84
RE for Reach 9: SJG to MAC or TC	-0.22	0.56	0.46	0.14	0.82
RE for Reach 10: MAC to 3-mile, Jersey Point, CVP or SWP	0.31	0.55	0.59	0.22	0.88
RE for Reach 11: Turner Cut to 3-mile, Jersey Point, CVP or SWP	-0.87	0.74	0.31	0.06	0.77
RE for Reach 12: OR_HOR to OR_MR junction	0.25	0.33	0.58	0.29	0.82
RE for Reach 13: MR_OR to MR_HWY4, OR_HWY4, CVP, or SWP	-0.03	1.32	0.51	0.04	0.96
RE for Reach 14: MR_HWY4 to 3-mile or Jersey Point	-1.17	1.02	0.25	0.02	0.81
RE for Reach 15: OR_MidR to OR_Tracy or GLC	0.80	0.36	0.70	0.40	0.90
RE for Reach 16: OR_Tracy to MR_HWY4, OR_HWY4, CVP, or SWP	1.09	0.67	0.76	0.32	0.96
RE for Reach 17: OR_HWY4 to 3-mile or Jersey Point	-1.85	0.53	0.14	0.03	0.46
RE for Reach 18: GLC to MR_HWY4, OR_HWY4, CVP, or SWP	0.24	0.42	0.58	0.25	0.85
RE for Reach 19: CVP trash rack to Chipps Island	-1.47	0.53	0.20	0.05	0.55
RE for Reach 20: CCF_inlet to CCF_intake	-0.02	0.69	0.51	0.13	0.88
RE for Reach 21: CCF_intake to Chipps Island	-1.47	0.77	0.20	0.03	0.67
RE for Reach 22: 3-mile to Chipps Island	-0.28	0.74	0.45	0.10	0.86
RE for Reach 23: Jersey Point to Chipps Island	0.44	0.64	0.62	0.21	0.91
RE for Reach 24: Chipps Island to Benicia	1.32	0.64	0.80	0.39	0.96
RE for Reach 25: Benicia to Golden Gate E	1.43	0.72	0.82	0.38	0.97
Intercept for the survival mixed-effects regression	0.07	0.30			
Slope for the survival-length relationship*	0.52	0.04			
Log(SD) for Release-specific random effect hyperparameter*	0.43	0.25			
Log(SD) for Reach-specific random effect hyperparameter*	0.27	0.12			

Table C9. Mean routing random effects estimates (Est.) and standard errors (SE) on the logit-scale and mean transformed routing estimates with lower and upper 95% confidence intervals (L_{95} and U_{95}, respectively) from all release groups. Parameter estimates were obtained from the model using data processed with the multi-hit predator filter.

		Logit-Scale		Transformed Est.		
Par.	Parameter Description	Est.	SE	Mean	L_{95}	U_{95}
ρ_1	Prob. of entering CVP vs. SWP	0.21	0.24	0.55	0.43	0.66
ρ_2	Prob. of taking 3-mile vs. Jersey Point to Chipps Island	-1.49	0.35	0.18	0.10	0.31
ρ_3	Prob. of remaining in SJ @ HOR for DF release	-1.29	0.19	0.22	0.16	0.28
ρ_4	Prob. of taking SJ route for HOR release vs. OR route	-1.67	0.14	0.16	0.13	0.20
ρ_5	Prob. of going downstream @ ST release	0.09	0.19	0.52	0.43	0.61
ρ_6	Prob. of remaining in SJ @ Turner Cut	0.56	0.24	0.64	0.52	0.74
ρ_7	Prob. of heading to pumps after passing MAC	-2.53	0.60	0.07	0.02	0.20
ρ_8	Prob. of heading to pumps after entering Turner Cut	-0.53	0.59	0.37	0.16	0.65
ρ_9	Prob. of taking MR @ MR-OR split	-3.86	0.36	0.02	0.01	0.04
ρ_{10}	Prob. of heading to interior delta vs. pumps from MR	-1.16	1.05	0.24	0.04	0.71
ρ_{11}	Prob. of heading to interior via MR_HWY4 vs OR_HWY4 from MR	-1.18	1.05	0.24	0.04	0.70
ρ_{12}	Prob. of taking OR @ OR-GLC split	-1.18	0.13	0.24	0.19	0.28
ρ_{13}	Prob. of heading to interior delta vs. pumps from OR	-0.90	0.33	0.29	0.18	0.43
ρ_{14}	Prob. of heading to interior delta via MR_HWY4 vs. OR_Hwy4 from OR	-1.41	0.58	0.20	0.07	0.43
ρ_{15}	Prob. of heading to interior delta vs. pumps from GLC	0.35	0.21	0.59	0.49	0.68
ρ_{16}	Prob. of heading to interior delta via MR_HWY4 vs. OR_Hwy4 from GLC	-2.64	0.43	0.07	0.03	0.14

Table C10. Routing random effects estimates (Est.) and standard errors (SE) on the logit-scale and mean transformed routing estimates with lower and upper 95% confidence intervals (L_{95} and U_{95}, respectively) from the April release. The * indicates parameter held constant over release groups. Parameter estimates were obtained from the model using data processed with the multi-hit predator filter.

		Logit-Scale		Transformed Est.		
Par.	Parameter Description	Est.	SE	Mean	L_{95}	U_{95}
ρ_1	Prob. of entering CVP vs. SWP	0.15	0.49	0.54	0.31	0.75
ρ_2	Prob. of taking 3-mile vs. Jersey Point to Chipps Island	-2.44	0.79	0.08	0.02	0.29
ρ_3	Prob. of remaining in SJ @ HOR for DF release	-1.67	0.25	0.16	0.10	0.23
ρ_4	Prob. of taking SJ route for HOR release vs. OR route	-2.05	0.33	0.11	0.06	0.20
ρ_5	Prob. of going downstream @ ST release	0.44	0.34	0.61	0.44	0.75
ρ_6	Prob. of remaining in SJ @ Turner Cut	0.35	0.41	0.59	0.39	0.76
ρ_7	Prob. of heading to pumps after passing MAC	-2.58	1.16	0.07	0.01	0.42
ρ_8	Prob. of heading to pumps after entering Turner Cut	-0.15	0.92	0.46	0.12	0.84
ρ_9	Prob. of taking MR @ MR-OR split	-2.67	0.36	0.07	0.03	0.12
ρ_{10}	Prob. of heading to interior delta vs. pumps from MR	-1.16	1.78	0.24	0.01	0.91
ρ_{11}	Prob. of heading to interior via MR_HWY4 vs OR_HWY4 from MR	-1.19	1.76	0.23	0.01	0.91
ρ_{12}	Prob. of taking OR @ OR-GLC split	-1.28	0.25	0.22	0.14	0.31
ρ_{13}	Prob. of heading to interior delta vs. pumps from OR	-1.32	0.72	0.21	0.06	0.52
ρ_{14}	Prob. of heading to interior delta via MR_HWY4 vs. OR_Hwy4 from OR	-1.99	1.35	0.12	0.01	0.66
ρ_{15}	Prob. of heading to interior delta vs. pumps from GLC	1.04	0.42	0.74	0.55	0.87
ρ_{16}	Prob. of heading to interior delta via MR_HWY4 vs. OR_Hwy4 from GLC	-2.30	0.64	0.09	0.03	0.26
μ_ρ	Hyperparameter mean of transition probability in logit space*	-1.17	0.29			

Table C11. Routing random effects estimates (Est.) and standard errors (SE) on the logit-scale and mean transformed routing estimates with lower and upper 95% confidence intervals (L_{95} and U_{95}, respectively) from the April release. The * indicates parameter held constant over release groups. Parameter estimates were obtained from the model using data processed with the multi-hit predator filter.

		Logit-Scale		Transformed Est.		
Par.	Parameter Description	Est.	SE	Mean	L_{95}	U_{95}
ρ_1	Prob. of entering CVP vs. SWP	-0.23	0.28	0.44	0.31	0.58
ρ_2	Prob. of taking 3-mile vs. Jersey Point to Chipps Island	-1.19	0.49	0.23	0.10	0.44
ρ_3	Prob. of remaining in SJ @ HOR for DF release	-1.89	0.28	0.13	0.08	0.21
ρ_4	Prob. of taking SJ route for HOR release vs. OR route	-1.82	0.21	0.14	0.10	0.20
ρ_5	Prob. of going downstream @ ST release	-0.48	0.30	0.38	0.26	0.53
ρ_6	Prob. of remaining in SJ @ Turner Cut	0.42	0.41	0.60	0.41	0.77
ρ_7	Prob. of heading to pumps after passing MAC	-2.04	0.83	0.12	0.03	0.40
ρ_8	Prob. of heading to pumps after entering Turner Cut	-1.04	0.98	0.26	0.05	0.71
ρ_9	Prob. of taking MR @ MR-OR split	-4.24	0.55	0.01	0.00	0.04
ρ_{10}	Prob. of heading to interior delta vs. pumps from MR	-1.17	1.77	0.24	0.01	0.91
ρ_{11}	Prob. of heading to interior via MR_HWY4 vs OR_HWY4 from MR	-1.19	1.76	0.23	0.01	0.91
ρ_{12}	Prob. of taking OR @ OR-GLC split	-1.10	0.17	0.25	0.19	0.32
ρ_{13}	Prob. of heading to interior delta vs. pumps from OR	-0.67	0.41	0.34	0.19	0.53
ρ_{14}	Prob. of heading to interior delta via MR_HWY4 vs. OR_Hwy4 from OR	-1.36	0.73	0.21	0.06	0.52
ρ_{15}	Prob. of heading to interior delta vs. pumps from GLC	-0.15	0.25	0.46	0.35	0.58
ρ_{16}	Prob. of heading to interior delta via MR_HWY4 vs. OR_Hwy4 from GLC	-2.13	0.50	0.11	0.04	0.24
μ_ρ	Hyperparameter mean of transition probability in logit space*	-1.17	0.29			

Table C12. Routing random effects estimates (Est.) and standard errors (SE) on the logit-scale and mean transformed routing estimates with lower and upper 95% confidence intervals (L_{95} and U_{95}, respectively) from the May release. The * indicates parameter held constant over release groups. Parameter estimates were obtained from the model using data processed with the multi-hit predator filter.

		Logit-Scale		Transformed Est.		
Par.	Parameter Description	Est.	SE	Mean	L_{95}	U_{95}
ρ_1	Prob. of entering CVP vs. SWP	0.71	0.38	0.67	0.49	0.81
ρ_2	Prob. of taking 3-mile vs. Jersey Point to Chipps Island	-0.84	0.48	0.30	0.14	0.52
ρ_3	Prob. of remaining in SJ @ HOR for DF release	-0.31	0.41	0.42	0.25	0.62
ρ_4	Prob. of taking SJ route for HOR release vs. OR route	-1.13	0.14	0.24	0.20	0.30
ρ_5	Prob. of going downstream @ ST release	0.30	0.35	0.57	0.40	0.73
ρ_6	Prob. of remaining in SJ @ Turner Cut	0.92	0.41	0.72	0.53	0.85
ρ_7	Prob. of heading to pumps after passing MAC	-2.97	1.07	0.05	0.01	0.29
ρ_8	Prob. of heading to pumps after entering Turner Cut	-0.41	1.13	0.40	0.07	0.86
ρ_9	Prob. of taking MR @ MR-OR split	-4.68	0.83	0.01	0.00	0.05
ρ_{10}	Prob. of heading to interior delta vs. pumps from MR	-1.16	1.77	0.24	0.01	0.91
ρ_{11}	Prob. of heading to interior via MR_HWY4 vs OR_HWY4 from MR	-1.17	1.77	0.24	0.01	0.91
ρ_{12}	Prob. of taking OR @ OR-GLC split	-1.16	0.24	0.24	0.16	0.33
ρ_{13}	Prob. of heading to interior delta vs. pumps from OR	-0.72	0.49	0.33	0.16	0.56
ρ_{14}	Prob. of heading to interior delta via MR_HWY4 vs. OR_Hwy4 from OR	-0.89	0.79	0.29	0.08	0.66
ρ_{15}	Prob. of heading to interior delta vs. pumps from GLC	0.18	0.32	0.54	0.39	0.69
ρ_{16}	Prob. of heading to interior delta via MR_HWY4 vs. OR_Hwy4 from GLC	-3.50	0.98	0.03	0.00	0.17
μ_ρ	Prob. of heading to interior delta via MR_HWY4 vs. OR_Hwy4 from GLC	-1.17	0.29			

Table C13. Detection probability estimates (Est.) and standard errors (SE) on the logit-scale and and transformed estimates with lower and upper 95% confidence intervals (L_{95} and U_{95}, respectively). The bottom two parameters represent the hyperparameter mean and standard deviation (SD) for the distribution of random effects. Detection estimates represent detection at a single-line and detection of combined dual-line receivers so detection across both lines is $P = 1 - \left(1 - 1/e^{-lgt_p}\right)^2$. Parameter estimates were obtained from the model using data processed with the multi-hit predator filter.

Par.	Parameter Description	Logit-Scale Est.	Logit-Scale SE	Transformed Est. Mean	Transformed Est. L_{95}	Transformed Est. U_{95}	Dual-Line Est.
p_1	Logit Detection: DF_DS	3.49	0.32	0.97	0.95	0.98	
p_2	Logit Detection: SJ_BCA	4.05	0.45	0.98	0.96	0.99	
p_3	Logit Detection: Mossdale	3.95	0.45	0.98	0.96	0.99	
p_4	Logit Detection: SJ_HOR (Combined dual-line)	3.38	0.75	0.97	0.87	0.99	1.00
p_5	Logit Detection: Howard	2.57	1.43	0.93	0.44	1.00	
p_6	Logit Detection: SJG (Combined dual-line)	5.14	0.64	0.99	0.98	1.00	1.00
p_7	Logit Detection: MAC (Combined dual-line)	1.92	0.83	0.87	0.57	0.97	0.98
p_8	Logit Detection: Turner Cut (Combined dual-line)	1.33	0.46	0.79	0.61	0.90	0.96
p_9	Logit Detection: OR_HOR (Combined dual-line)	2.30	0.87	0.91	0.64	0.98	0.99
p_{10}	Logit Detection: MR_OR	1.33	0.39	0.79	0.64	0.89	
p_{11}	Logit Detection: MR_HWY4 (Combined dual-line)	0.89	0.34	0.71	0.56	0.83	0.92
p_{12}	Logit Detection: OR_MidR	2.18	0.54	0.90	0.76	0.96	
p_{13}	Logit Detection: OR_Tracy (Combined dual-line)	2.70	1.25	0.94	0.56	0.99	1.00
p_{14}	Logit Detection: OR_HWY4 (Combined dual-line)	2.84	1.15	0.94	0.64	0.99	1.00
p_{15}	Logit Detection: GLC (Combined dual-line)	2.64	1.31	0.93	0.52	0.99	1.00
p_{16}	Logit Detection: CVP_trash_rack	3.00	0.47	0.95	0.89	0.98	
p_{17}	Logit Detection: CCF_Inlet	2.42	1.57	0.92	0.34	1.00	
p_{18}	Logit Detection: CCF_Intake	1.58	0.49	0.83	0.65	0.93	
p_{19}	Logit Detection: 3-mile Slough (Combined dual-line)	0.40	0.39	0.60	0.41	0.76	0.84
p_{20}	Logit Detection: Jersey Point (Combined dual-line)	3.03	1.05	0.95	0.72	0.99	1.00
p_{21}	Logit Detection: Chipps Island (Combined dual-line)	2.49	1.47	0.92	0.40	1.00	0.99
p_{22}	Logit Detection: Benicia (Combined dual-line)	0.54	0.35	0.63	0.46	0.77	0.86
p_{23}	Logit Detection: Golden Gate E	1.93	0.56	0.87	0.70	0.95	
p_{24}	Logit Detection: Golden Gate W	2.93	1.10	0.95	0.69	0.99	
μ_p	Hyperparameter mean detection probability in logit space	2.46	0.37				
$log(\sigma_p)$	Hyperparameter log(SD) for detection random effect	0.38	0.20				