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Estimation of juvenile Steelhead survival and routing migrating through the Delta
2022 Six-Year Steelhead Survival Study: Statistical Methods and Results

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PI: Bryan Matthias, US Fish and Wildlife Service, Lodi. bryan_matthias@fws.gov
Co-PIs:
Lauren Yamane, US Fish and Wildlife Service, Lodi. lauren_yamane@fws.gov
Taylor Senegal, US Fish and Wildlife Service, Lodi. taylor_senegal@fws.gov

Executive summary

The 2022 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 2022, a multiagency collaboration between UCSC and USFWS-Lodi surgically implanted 976 juvenile steelhead from the Mokelumne River Hatchery with JSATS acoustic transmitters in March and April.

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 modified the multistate mark-recapture model from 2021 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. Updates to the 2022 multistate mark-recapture model included adjustments to active receiver locations along the Old River route, but otherwise the model was nearly identical to the prior version.

Survival was low for outmigrating steelhead smolts in 2022, regardless of release group or location. Through-Delta survival in 2022 (10-13%) was higher than those observed in 2021 (<5%), but were still on the low end compared with estimates from 2011-2016 (5-63%). Routing estimates at the HOR were comparable to dry and critically dry years without the rock HORB installed (<20% taking the SJR route at the HOR). Finally, detection rates were also comparable between studies with most detection estimates >80% for all studies. The 2022 water year was classified as critically dry, with mean SJR inflows from 846-1,320 cfs and exports ranging from 1,795-2,511 cfs. Additionally, water temperatures at Mossdale were 16.9-17.8°C during the study period. Future efforts will seek analytical methods to account for multiple covariates within the survival model.

Table of Contents

Acknowledgements

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Introduction

The 2022 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 2022, a multiagency collaboration between UCSC and USFWS-Lodi, surgically implanted 976 juvenile steelhead from the Mokelumne River Hatchery with JSATS acoustic transmitters in March and April (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 from 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 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 Fisheries Service 2019).

The 2022 water year was critically low for the San Joaquin and Sacramento Rivers (water year indices of 1.56 and 4.55, respectively, similar to 2021; 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 discharge (outlined in (U.S. National Marine Fisheries Service 2019), the releases for 2022 were planned to utilize and estimate the effects of a spring pulse flow in April. Thus, this study was intended to refine measures for protecting 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 two 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 last year's study and 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 from UCSC and USFWS performed the tagging operations during the two 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, while the other release team performed the third release.

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 (Figure 1) represent the receivers operational during the 2022 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 2022 study were deployed before the first releases of tagged steelhead. The receiver array in 2022 was the same as in 2021, except that no Grant Line Canal, Old River Tracy, Middle River at Old River (i.e., MR_OR), or Highway 4 (i.e., OR_hwy4, MR_hwy4) receivers were deployed for 2022.

Schedule

The fish were tagged and released over a 1-week period in each of March and April. 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 976 JSATs tags for this study, along with 50 tags for battery life tests. Daily fish released were distributed 50% to Durham Ferry, 29% to HOR, and 20% to Stockton. Therefore, in total, 976 fish were used over two weeks, so about 488 fish per week, and 118-123 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 3°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. The maximum tempering rate for 2022 was 1°C higher than 2021 to ensure fish were released close to their scheduled release times when water temperatures were high.

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 followed the previous year's analytical methods (Matthias et al. 2024) and used 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 used by Buchanan and coauthors (see Buchanan 2018c; Buchanan et al. 2021 and citations within).

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 4.3.2 (R Core Team 2023).

Data Processing

JSATS California Fish Tracking databases for this study were obtained from ERDDAP on April 15, 2024. 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_2022". 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_2022". 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 detections 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 format for the detection data was slightly updated in 2024, and affected the 2022 study data presented here. Two time stamps of the detection event correspond to the first time of tag transmission for the event (one is PST and one is UTC). Another time stamp corresponds to last time of tag transmission for the event in PST. 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. 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. 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 and Holland Cut Quimby receivers were removed from the analyses due to very limited detections and/or deployment dates during the study (see Figure 1). In 2021, detections from Old River and Middle River RR Bridge receivers (referred to as RT_Old River and RT_Middle River in the 2021 study plan) were removed due to limited detections, while in 2022, these detections were included in the analysis. Detections corresponding to one receiver (SJ_HOR_1_1) were completely removed due to high prevalence of false positive detections. Detection histories were scrutinized for individual implausible tag transmissions, and those detections were removed. Implausible detections were recorded at many receivers, although CVP Trash Rack was 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 (typically designated "1") and downstream (typically "2") lines of receivers or gates, which otherwise have the same site name (e.g., OR_HOR_1 and OR_HOR_2). 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 Reclamation (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, CC intake, Clifton Court). 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 therefore tags that are detected entering SWP and next at sites in the Western Delta (after transport) can be considered smolts. Although most steelhead predators are also too large to enter the CVP holding tanks, the trash rack preceding the holding tanks is occasionally cleaned and predators may swim through at those times (R. Buchanan, pers. comm.). However, repeated detections of a tag at the facilities 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 Reclamation (USBR) et al. 2018c). Although previous studies (e.g., U.S. Bureau of Reclamation (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 predator movements during the 2022 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= 3.57; p = 0.31). Of the three distributions tested (negative binomial, 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 and zero-inflated negative binomial distributions had the lowest AIC values (AIC = 1660.402).

The Poisson distribution had the highest AIC value (AIC = 1799.773). Estimation of the 0.95 quantile from the fitted negative binomial distributions corresponded to a median value of six detections at the facilities (μ= 1.39; Figure 5), and five detections at HOR sites (μ = 1.24; Figure 6) for the back transformed datasets. Thus, ≥ 6 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 composed 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 six 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, and therefore results are provided for all three datasets. 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. CliftonCourtRadialGates_1 and Clifton_Court_Radial_Gates_2 were combined. Detections for sites around the CVP Trash Rack (CentralValleyProjectTrashRack_1, CentralValleyProjectSalvageTank) 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 to match the model from the 2021 study (Matthias et al. 2024). See also 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

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

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

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

with a release-group-specific mean of $\mu_{\mathrm{B,g}}$ and a standard deviation of $\sigma_{\mathrm{B},x}$ 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 $\mathrm{B}_{k,1} = \mathrm{B}_{k,2}$, we are assuming survival for an individual of length L_i remains constant between the March and April releases. By setting $\mathrm{B}_{k,1} \neq \mathrm{B}_{k,2}$, 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 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 matrices, 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 13, 16, 18, 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.

- The 2021 model was developed to estimate migration characteristics along five major routing options for fish released at Durham Ferry 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. Both SJR routes have fish remaining in the SJR past the HOR where $CH = (1,4,5,6,7,8,9, \dots)$.
    - 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).
    - 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).
- The three OR routes have fish moving into OR after reach 6 where $CH = (1,4,5,6,12, \dots)$.

- 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 Railroad 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).
- 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).
- 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).

Due to differences in the receiver array along the Old River corridor in 2022, we were unable to estimate separate routing and survival probabilities associated with the Old River and GLC routes. Therefore, these two routes were combined into a single route within the model by assuming survival was equal between these two routes (i.e., estimating B_{15,g_i} and setting $\mathrm{B}_{16,g_i} = \mathrm{B}_{18,g_i} = 1.0$), arbitrarily assigning a 50% routing probability (i.e., $\rho_{12} = 0.5$), and assigning a 0% detection probability for these reaches (i.e., $p_{13} = p_{15} = 0.0$). In addition, there was no receiver along the Middle River route (i.e., $p_{10} = 0.0$), but we were still able to estimate routing into and survival through the MR route. These changes allowed us to keep the same model structure and routing probabilities as the 2021 model, while accounting for differences in receiver deployments.

For the DF transition matrix, we have three non-detection dummy states (Detection = 0% and survival = 100%; reaches 16, 18, 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

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

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
$$\psi_{g_i,r_i,10,22} = (1 - \rho_{g_i,6}) * \rho_{g_i,2} \tag{5}$$
2. stay in the central Delta and swim past Jersey Point to get to Chipps Island
$$\psi_{g_i,r_i,10,23} = (1 - \rho_{g_i,6}) * (1 - \rho_{g_i,2}) \tag{6}$$
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
$$\psi_{g_i,r_i,10,20} = \rho_{g_i,6} * (1 - \rho_{g_i,1}) \tag{8}$$

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 probabilities $\rho_{1,x} = \rho_{2,x} = \rho_{3,x}$, 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

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

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.

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. 2023). Briefly, a total of 50 tags were tested for battery life and tag retention. All tags made it to the estimated run-time of 79 days. Mean run time was 121 days with a range from 80-210. A total of 19 tags were shed (38.0%), with shed tags being found between 20-84 days post-surgery. Shed dates are only known for seven tags, with others found in the stomach of one steelhead (n = 6 tags) or not found (n = 6 tags; see Notch et al. 2023 for additional details). Given the high battery life, low tagging mortality, and difficulty in finding shed tags, we did not incorporate this information into the model. Further, incorporating tag loss into the model would require integrating time back into the model, similar to methods outlined in Hance et al. (2022) incorporating travel time into a space-for-time multistate model.

Analysis of Travel Time to Chipps Island

Travel times (in days) for all tags that made it to Chipps Island, including the 43 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. OR routes). 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), estimates from the 2021 study (Matthias et al. 2024) and the 2022 results from this study. All data utilized a predator filter, with the 2021 and 2022 data using the multi-hit filter (Tables B2, B3). 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]; Table 17). 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

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

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 covariates (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

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

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 covariates 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

Detections

A total of 487 fish were released at Durham Ferry. Of the 219 fish that were detected downstream of HOR, most fish selected the OR routes (n = 189) compared to the SJR routes (n = 30). A total of 33 fish were detected at Chipps Island. For the March releases, 13 were detected at Chipps Island, one taking the SJR mainstem route, 12 remaining in OR past MR. Of these fish that made it to Chipps Island, one took 3-Mile Slough, five went past Jersey Point, four were entrained into the CVP and three in the SWP. For the April releases, 20 were detected at Chipps Island with four taking the SJR routes (one via the SJR route and two via TC route, one unknown) and 16 taking the OR routes. Of the fish that made it to Chipps Island from the April releases, 12 fish passed through the pumping facilities (eight via the CVP and four via the SWP), four made it past Jersey Point, two via Three-Mile Slough, and two took an unknown route.

A total of 289 fish were released at HOR and most remained in the OR route (n = 235) compared to taking the SJR routes (n = 54). A total of 24 fish were detected at Chipps Island, 14 from the March release and nine from the April release. One additional fish from the March release was detected downstream of Chipps Island, but was not detected at Chipps Island. Of the fish that made it to Chipps Island, six fish took the SJR mainstem route and 18 took OR routes. Thirteen of the fish released at HOR that made it to Chipps Island were detected at the pumping facilities, seven detected at Jersey Point, two detected at Three-Mile Slough, and one made it to Chipps via an unknown route.

A total of 200 fish were released at Stockton, with 32 detected at Chipps (11 in March and 21 in April) and one fish released in March was detected at Benicia, but not Chipps Island. A total of 96 fish were detected downstream of release and 53 went upstream towards the HOR routes. Most fish that made it to Chipps Island were detected moving past Jersey Point (n = 24) or Three-Mile Slough (n = 6) and few were detected at the pumps (two at the SWP).

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 was 855 cfs in March and 1,363 cfs in April. Weekly mean temperature was 15.8°C in March and 16.6°C April. The daily flow range for the study period (March 08 – April 29) was 538 to 1,559 cfs and the daily temperature range was 11.9°C to 23.0°C.

Exports data were downloaded from the California Department of Water Resources Dayflow website. Weekly mean exports at the Central Valley Project were 1,391 cfs in March and 900 cfs in April. For the State Water Project, weekly mean exports were 595 cfs in March and 594 cfs in April. Weekly mean total exports were 2,119 cfs in March and 1,798 cfs April. The daily export range for the study period (March 08 – April 29) was 783 cfs to 2,705 cfs at the Central Valley Project, 0 cfs to 2,499 cfs at the State Water Project, and total daily exports ranged from, 884 cfs to 4,903 cfs. Weekly mean export to inflow ratio was 0.18 in March and 0.12 in April. The daily export to inflow ratio for the study period was 0.05 to 0.40.

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 0.48, through-Delta (Delta entry at Mossdale to Chipps Island) survival was 0.12, and through-Bay (Chipps Island to Golden Gate West) was 0.78 (Table 7). Fish taking the SJR Routes had 0.12 survival (Table 7). Survival for fish staying in the SJR was higher than those taking the TC route (0.14 and 0.10 respectively; Table 7). Fish taking the OR routes had survival rates of 0.11, with similarly low survival of fish taking the MR routes (0.09) or remaining to take the OR/GLC routes (0.11; Table 7). Post-release survival ranged from 0.93 for the HOR releases to 0.55 for the ST releases (Table 10). Reach-specific survival rates for an average-sized fish ranged from 0.93 for fish entering the Delta at Mossdale (reach 6) to 0.27 for fish entrained into the CVP (reach 19; Table 10).

March

Survival from Durham Ferry to Delta-entry was 0.39, through-Delta survival was 0.14, and through-Bay was 0.76 (Table 8). For fish taking the SJR Routes, survival was 0.06 and was the same for fish staying in the SJR or TC routes (Table 8). Fish taking the OR routes had survival rates of 0.14, with similar survival for fish taking the MR routes (0.15) compared to those staying in the OR/GLC routes (0.14; Table 8). Post-release survival ranged from 0.92 for the HOR releases to 0.51 for the ST releases (Table 11). Reach-specific survival rates for an average-sized fish ranged from 0.93 for fish traveling from Chipps Island to Benicia (reach 24) to 0.30 for fish entering the interior Delta from the MR Route (reach 14; Table 11).

April

Survival from Durham Ferry to Delta-entry was 0.57, through-Delta survival was 0.11, and through-Bay was 0.79 (Table 9). Survival for fish taking the SJR Routes was 0.21, with higher survival for fish staying in the SJR (0.27) compared to those taking the TC route (0.14; Table 9). Fish taking the OR routes had survival rates of 0.09, with lowest survival of fish taking the MR routes (0.05) compared to those staying in the OR/GLC routes (0.09; Table 9). Post-release survival ranged from 0.94 for the HOR releases to 0.58 for the ST releases (Table 12). Reach-specific survival rates for an average-sized fish ranged from 0.98 for fish traveling from Chipps Island to Benicia (reach 24) to 0.13 for fish transported from the CVP trash rack to Chipps Island (reach 19; Table 12).

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 263.1 mm (range 171-341 mm). Monthly size distributions were similar, with mean tagging length of 254.2 mm (range 171-318 mm) in March and 272.1 mm (range 215-341 mm) in April the mean was. The mean survival random effect, which can be interpreted as the mean release-specific intercept, showed lower values for March than April releases (mean values of 0.80 and 1.11, respectively; Tables 11-12). 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; mean estimate 0.18 with 95% confidence intervals of 0.13-0.22) positive relationship between length and survival (Tables 11-12).

Release/reach-specific Routing

All release groups combined

Routing probabilities across all release groups (reported in Table 13) showed few DF-released fish took SJR routes at the Head of OR (12% compared with 88% taking OR routes). For fish that took SJR routes, half remained in the SJR past TC (50%) and few of these fish headed towards the pumps after passing MacDonald Island (5%). For fish that took the TC route, 24% went towards the pumps. Very few fish took the MR route (3%) and 80% of those fish headed towards the pumps. Fish that took the OR/GLC routes often ended up at the pumping facilities (78%). Most fish released at the HOR remained in OR (80%) and most fish went downstream in the ST releases (67%).

Given the model structure, we modeled entrainment by the SWP or CVP as a constant across all routing options. For fish that were entrained at the pumping facilities, we estimated roughly half of fish were entrained by the CVP (44%) compared to the SWP (56%; Table 13). 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 (81%) to get to Chipps Island via the interior Delta (Table 13).

March

Routing probabilities for March (reported in Table 14) showed few DF released fish took SJR routes at the Head of OR (8%) compared to taking OR routes (92%). For fish that took SJR routes, half remained in the SJR past TC (50%) and few of these SJR route fish headed towards the pumps after passing MacDonald Island (7%). Few fish that took the TC route went towards the pumps (7%). Very few fish took the MR route (6%) and 81% of those fish that took the MR route headed towards the pumps. Fish that took OR/GLC routes at the split with MR often ended up at the pumping facilities (73%). Most fish released at the HOR remained in OR (77%) and just over half of fish went downstream in the ST releases (55%).

Given the model structure, we modeled entrainment by the SWP or CVP as a constant across all routing options. For fish that were entrained at the pumping facilities, we estimated less than half of fish were entrained by the CVP (37%) compared to the SWP (63%; Table 14). 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 (8%) to get to Chipps Island via the interior Delta (Table 14).

April

Routing probabilities for April (reported in Table 15) showed few DF released fish took SJR routes at the Head of OR (16%) compared to taking OR routes (84%; Table 15). For fish that took SJR routes, half remained in the SJR past TC (50%) and few of these fish headed towards the pumps after passing MacDonald Island (3%). Over half of the fish that took the TC route went towards the pumps (58%). Very few fish took the MR route (2%) and 78% of those fish that took the MR route headed towards the pumps. Fish that remained in OR at the split with MR often ended up at the pumping facilities (83%). Most fish released at the HOR remained in OR (83%) and most fish went downstream in the ST releases (77%; Table 15).

Given the model structure, we modeled entrainment by the SWP or CVP as a constant across all routing options. For fish that were entrained at the pumping facilities, we estimated roughly half of fish were entrained by the CVP (52%) compared to the SWP (48%; 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 (80%) to get to Chipps Island via the interior Delta (Table 15).

Detection Probabilities

Detection probabilities for single-line receiver gates were often >90% (9 of 21 gates; Table 16). Seven 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 >82% (i.e., the probability of being detected at the upstream gate, downstream gate, or both gates; i.e., SJ_HOR = 82%, SJG = 91%, Turner Cut = 95%, Jersey Point = 94%; Table 16). Exceptions with low detection probabilities were all from single-line receivers at Howard (detection rate of 66%), MR_RRB (detection rate of 76%), and CCF_inlet (detection rate of 55%; Table 16). 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 97 fish had detections that were removed due to exceeding predator thresholds for the 1-hit filter and 44 had detections removed for the multi-hit filter. Very few fish that made it to Chipps Island were flagged as predators. One fish released at DF was classified as exhibiting predator-type behaviors for the 1-hit filter, and two fish from the HOR release were flagged as a predator using the 1-hit filter. No fish identified as predators by the multi-hit filter made it to Chipps Island.

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 7-9, A1-A3, B1-B3). For the 1-hit filter, most derived survival rates showed little differences (estimates from the 1-hit filter within ± 0.03 of the unfiltered data). The exception was for fish taking the San Joaquin Routes, in which survival was 6% lower using the 1-hit filtered data along the SJR route and 3% lower for the Turner Cut Route compared to unfiltered data or data using the multi-hit predator filter (Tables 7-9, A1-A3, B1-B3). Overall, derived survival estimates using the multi-hit filter were very similar to those using the unfiltered data (Tables 7-9, A1-A3, B1-B3).

Reach-specific differences in reach-specific survival rates were generally within ± 0.05 units between the model with unfiltered data compared to model results using either predator filter (Tables 10-12, A4-A6, B4-B6). A few reaches in each release group had larger differences in survival between the unfiltered data and the 1-hit predator filter, (Tables 7-9, A1-A3)

- Reach 7 in the March release with survival rates of 0.55 (unfiltered) and 0.49 (1-hit filter),
- Reach 7 in the April release with survival rates of 0.80 (unfiltered) and 0.70 (1-hit filter),

- Reach 13 in the April release with survival rates of 0.46 (unfiltered) and 0.52 (1-hit filter), and
- Reach 14 in the March release with survival rates of 0.30 (unfiltered) and 0.48 (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) because so few fish flagged as predators made it to Chipps Island.

Estimates of routing and detection were also similar between models using all datasets (Tables 13-15, A7-A9, B7-B9). The only notable difference in routing were the probability of heading to the Interior Delta via MR_RRB or the OR_RRB for fish along the OR/GLC route (ρ_{14} & ρ_{16}). With the unfiltered data, 22% of the fish taking OR/GLC routes headed towards the interior Delta and this value was 14% with the 1-hit filter for the March releases. It should be noted that the 95% confidence intervals for these estimates overlap and are thus not statistically significant (Tables 13-15). Detection estimates were within $\pm$0.03 units between models using unfiltered vs. predator filtered data (Tables 16, A10, B10).

Travel Time

Travel times for the 89 tagged fish that made it to Chipps Island, based on the unfiltered dataset, are provided in Table 5. Across release months, fish released at Stockton that traveled along the OR routes to Chipps Island had the longest average travel time at 19.37 days (SE = 1.54 days). However, it should be noted that only two fish detected at Chipps Island took the OR routes after release at Stockton. The next longest average travel times to Chipps Island corresponded to HOR releases that used the OR routes (mean = 15.11 days; SE = 3.56 days) and Durham Ferry releases that used the SJR routes (mean = 15.12 days; SE = 1.44 days). For both HOR and Stockton released fish, it was faster to use the SJR routes to get to Chipps Island (mean = 14.30 days and SE = 8.12 days for HOR-released fsh, mean = 11.30 days and SE = 1.00 days for ST released fish) than OR routes. Fish released from Durham Ferry that took the OR routes to Chipps Island traveled approximately 2 fewer days (mean = 12.96 days, SE = 1.02 days) than those that took the SJR routes to Chipps Island.

Three fish spent six days enroute to Chipps Island, two by moving through the OR route from Durham Ferry and one by moving down SJR from Stockton. 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 69 days, by a HOR released fish that took on OR Route.

Based on the 1-hit predator filter, three tags that made it to Chipps Island were identified as having predator-type detections (SJSH2021-450, SJSH2021-462, and SJSH2021-749). Once the capture histories of these three tags were removed, travel times to Chipps Island only reduced slightly for Durham Ferry and HOR releases moving through the OR routes, Durham Ferry releases taking the SJR routes, and for fish released at Stockton traveling the SJR. Traveling time increased slightly for the HOR release group taking SJR routes (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 from 2022 (10-13%) were within the range estimated by Buchanan et al. (2021) between 2011 and 2016 (6-69%), and higher than those estimated in 2021 (2-5%; Figure 17). Environmental (SJR inflow and temperature) and managed (exports and IE ratio) conditions during 2022 were comparable to the prior studies for critically dry water years (Figures 17, 18). The multivariate analysis indicated that inflow (total Delta, SJR, and SAC inflow), Delta outflow, and exports were the best models describing variation in survival (i.e., ΔAIC < 6; Table 18) with the Delta inflow model having the lowest AIC. 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 18). Models using IE ratios and SAC inflow had some parameter estimates with very large standard errors and/or questionable estimates (extremely large positive and negative values; Table 18).

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 when the HORB was partially in place. It should be noted the HORB was under construction from March 15 to April 11 and fish were released from April 4-7 in 2012. 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 2022. These low survival rates were evident across each release group and release location. Estimates from 2022 (<10-13%) were also on the low end of prior estimates from 2011-2016 (5-63%; from Buchanan et al. 2021), but higher than 2021 (<5%). The 2022 study occurred during a critically low water year in both the Sacramento and SJR basins. Comparing estimates from 2022 to other critically dry years in 2013-2015 (6-45%; from Buchanan et al. 2021) and 2021 (2-5%), we see that survival in 2022 was within the range of past estimates. 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; Matthias et al. 2024), except for Jersey Point and the CCF inlet (53% and 76% respectively; Table B10). Note, the discussion focuses on results obtained from the multi-hit predator filter.

The 2022 water year was classified as critically dry, with mean SJR inflows from 846-1,320 cfs and exports ranging from 1,795-2,512 cfs, resulting in higher export rates than SJR inflow for each release group (SJR inflow/exports were 0.38 and 0.74 for the release groups). While more water was being pumped than entering via the SJR, OMR flows did not exceed the BiOp requirement during the release weeks (tidally averaged flows across the release groups were -2,725 and -1,858 cfs). Additionally, water temperatures at Mossdale increased from 16.9-17.8°C during the study period. Given the environmental conditions and low 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-recapture 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. (2021), 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 and lowest survival and highest temperatures in April. Unlike 2021, mean temperatures did not exceed 20°C during the release windows in 2022. These trends in survival and temperature were present when comparing to previous studies as well (Table 18; Figure 18; Buchanan et al. 2021; Matthias et al. 2024). Correlating the other covariates with survival showed higher survival with higher inflows, exports and IE ratios, similar to results from Buchanan et al. (2021). 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 regional scale, we see highest survival from Durham Ferry to Delta entry (39-60%) and from Delta exit to the Golden Gate Bridge (through-bay survival; 76-79%; Tables 8, 9). Survival rates from release to Delta entry were higher in April compared to March (which may be driven, in part, by the spring pulse flow; Figure 12). The increased to-Delta survival in April did not correspond with an increase in through-Delta survival, which was low across all release groups (Tables 8, 9). Similar to the 2021 study (Matthias et al. 2024), the 2022 results show relatively high survival of smolts that make it past Chipps Island (46-64% in 2021 and >76% in 2022).

Buchanan et al. (2021) and the 2021 study (Matthias et al. 2024) demonstrated that survival rates were not appreciably different for fish taking either the SJR and OR routes. The results from 2022 support these prior observations and show slightly higher survival of fish taking the OR routes in March (6% for SJR routes and 14% for OR routes) and the opposite pattern in April (15% for SJR routes and 9% for OR routes; Tables B2, B3). Taken together, the 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. 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. 2021). Looking at through-Delta survival for these routes, we found evidence that supports this for April (25% survival along the SJR route and 13% for the TC route; Table B3). Similar to the SJR routes, survival along the OR routes were low across the board (2-6%; Tables B2, B3). Overall, we detected similar route-specific patterns of 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 (73-93%). Survival for fish released at Stockton was lower across all release groups (50-58%). Similar to 2021, 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 facilities (reaches 19-21), particularly fish salvaged and trucked to releases near Chipps Island had low survival (<50%), especially in April (reaches 19 and 21 had 13% and 17% survival rates respectively). Given that each route modeled in this analysis had at least one reach with very low survival, it is hardly surprising that through-Delta survival rates were similar for all routes.

Similar to studies by R. Buchanan (Buchanan 2018a, 2018b, 2018c, USBR 2018a, 2018b, 2018c), the biggest driving factor in routing at the HOR was the presence/absence of the rock barrier (HORB). There was no HORB installed for the 2022 study and the majority of fish released at Durham Ferry took the OR routes (>84%). Comparing routing to the 2021 study, we see similar results with most fish taking OR at HOR. The exception was the May 2021 release where a higher proportion of fish (42%) remained in the SJR. The May 2021 estimate was similar to 2011 (the only wet year) and several releases where the HORB was partially installed (April 2012 and late-March 2015). As noted in the 2021 report (Matthias et al. 2024), the Durham Ferry release in May experienced very low survival from release to Delta-entry (12%, compared to >54% for the other releases) and this low sample size likely contributed to the high proportion of fish taking the SJR route for the May release.

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 estimates. 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 (surpassing thresholds for at least two of the following criteria at a station:

fish speed, residence time, upstream transitions, other unexpected transitions, travel time since release, and movements against flow; U.S. Bureau of Reclamation (USBR) et al. 2018c). 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 saw very high tag loss (38%) in the detection trials (Notch et al. 2023) and ignoring this may have influenced our estimates of survival. Assuming the travel time, survival, and routing were similar between fish with tags and those that shed tags, we would expect survival estimates to be biased low because fish that shed tags prior to passing Chipps Island would be undetectable. However, most fish that made it to Chipps Island took less than 30 days and the range of tag shedding was 20-84 days (mean 42). Therefore, we expect minimal bias in reach-specific survival estimates in reaches closer to the release sites, but increasing bias closer to Chipps Island and for through-Bay survival to Golden Gate Bridge. On the extreme end if we simply assume that 38% of the fish in the field experienced tag loss during the study, we can generate basic corrections for region-specific survival. As an example with through-Delta survival of Durham Ferry fish, we had

- 233 fish detected at or downstream of Mossdale,
- 33 fish detected at or downstream of Chipps Island, and
- 200 fish that were detected at or downstream of Mossdale, but not observed at or downstream of Chipps Island.

If 38% of those 200 fish had shed their tags and made it to Chipps Island, we would expect up to 73 additional fish at Chipps Island. Then, for "true" fish and "unobserved" fish that made it to Chipps (33 detected plus up to 76 undetected), we end up with 106 fish or, up to a 3.2 fold increase in the number of fish surviving to Chipps Island. If this 3.2 fold increase in the number of fish survival to Chipps Island holds for the other release sites, we could see through-Delta survival rates up to 38.4%. However, this assumes all fish that shed their tag would have made it to Chipps Island, which is very unlikely. Therefore, extreme caution should be used in interpreting this simple example. Methods such as those developed by Hance et al. (2022) should be used to account for many of the assumptions we made with this back of the envelope calculation.

Unlike survival, ignoring tag loss should have had minimal impact on detection and routing estimates. For these parameters we don’t expect shed tags to cause directional bias in estimates. At most, we would expect higher standard errors around detection and routing estimates because fewer active tags are able to be detected. However, this should cause the biggest impact at sites farther from the release locations and we don’t expect much impact on routing at major junctions (e.g., Head of Old River, Turner Cut, or entrainment into either pumping facility).

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 substitution, 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 the 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 low for fish taking either the SJR or OR routes in 2022. Survival estimates were comparable to those from the previous study from 2011-2016, even though environmental 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 976 fish were released during the study.

	March				April*			
Release Site	15	16	17	18	19	20	21	22
Durham Ferry	62	62	62	62	57	60	62	60
Head of OR	36	36	36	36	36	36	37	36
Stockton	25	25	25	25	25	25	24	26
Total	123	123	123	123	118	121	123	122

Table 2. Receiver general locations, and latitude and longitude coordinates used in 2022 study.

Receiver general location	Latitude	Longitude
DurhamFerry_Rel	37.68780	-121.2622
Durhamferry	37.69144	-121.2711
SJ_BCA	37.73285	-121.2956
Mossdale	37.79184	-121.3072
Head_of_Old_River	37.80789	-121.3295
SJ_HOR_1	37.81150	-121.3184
OldRiverHOR_1	37.81359	-121.3354
SJ_HOR_2	37.81377	-121.3184
OldRiverHOR_2	37.81545	-121.3342
CVP_Trash_Rack	37.81641	-121.5588
Old_River_at_Middle_River_Head_1	37.82061	-121.3776
GoldenGateW	37.82139	-122.4695
GoldenGateE	37.82523	-122.4616
Clifton_Court	37.82985	-121.5568
CC_intake_J	37.82824	-121.5942
SJHoward_1	37.87360	-121.3319
SJGarwood_1	37.93625	-121.3337
SJGarwood_2	37.93820	-121.3356
Stockton_Rel	37.93778	-121.3337
MiddleRiver_RR_Bridge (MR_RRB)	37.93935	-121.5330
OldRiver_RR_Bridge (OR_RRB)	37.93947	-121.5605
TurnerCut_3	37.98843	-121.4649
TurnerCut_2	37.99008	-121.4609
SJMac_1	38.02208	-121.4650
SJMac_2	38.02628	-121.4693
BeniciaW	38.04091	-122.1234
BeniciaE	38.04324	-122.1225
ChippsE	38.04594	-121.9098
ChippsW	38.04628	-121.9156
JerseyPoint_2	38.05065	-121.6939
JerseyPoint_1	38.05353	-121.6905
Three_Mile_South	38.10734	-121.6841
Three_Mile_North	38.11069	-121.6822

Table 3. Receiver locations, arrays used for the 2022 predator analysis, and the corresponding averaged latitude and longitude coordinates.

Receiver general location	Array	Averaged Latitude	Averaged Longitude
DurhamFerry_Rel	DurhamFerry_Rel	37.68780	-121.2622
Durhamferry	Durhamferry	37.69144	-121.2711
SJ_BCA	SJ_BCA	37.73285	-121.2956
Mossdale	Mossdale	37.79184	-121.3072
Head_of_Old_River	Head_of_Old_River	37.80789	-121.3295
SJ_HOR_1	SJ_HOR	37.81263	-121.3184
OldRiverHOR_1	OR_HOR	37.81452	-121.3348
SJ_HOR_2	SJ_HOR	37.81263	-121.3184
OldRiverHOR_2	OR_HOR	37.81452	-121.3348
CVP_Trash_Rack	CVP_Trash_Rack	37.81641	-121.5588
Old_River_at_Middle_River_Head_1	Old_River_at_Middle_River	37.82061	-121.3776
GoldenGateW	GoldenGate	37.82331	-122.4656
GoldenGateE	GoldenGate	37.82331	-122.4656
Clifton_Court	Clifton_Court	37.82985	-121.5568
CC_intake_J	CC_intake	37.82824	-121.5942
SJHoward_1	Howard	37.87360	-121.3319
SJGarwood_1	SJG	37.93723	-121.3347
SJGarwood_2	SJG	37.93723	-121.3347
Stockton_Rel	Stockton	37.93778	-121.3337
MiddleRiver_RR_Bridge (MR_RRB)	MiddleRiver_RR_Bridge	37.93935	-121.5330
OldRiver_RR_Bridge (OR_RRB)	OldRiver_RR_Bridge	37.93947	-121.5605
TurnerCut_3	TurnerCut	37.98925	-121.4629
TurnerCut_2	TurnerCut	37.98925	-121.4629
SJMac_1	Mac	38.02418	-121.4672
SJMac_2	Mac	38.02418	-121.4672
BeniciaW	Benicia	38.04207	-122.1231
BeniciaE	Benicia	38.04207	-122.1231
ChippsE	Chipps	38.04611	-121.9127
ChippsW	Chipps	38.04611	-121.9127
JerseyPoint_2	Jersey_Point	38.05209	-121.6922
JerseyPoint_1	Jersey_Point	38.05209	-121.6922
Three_Mile_South	Three_Mile	38.10902	-121.6831
Three_Mile_North	Three_Mile	38.10902	-121.6831

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)	Migration rate threshold (km/hr)
Benicia to GoldenGate	0.676	1.966
CC intake to Chipps	0.054	1.055
CVP Trash Rack to Chipps	0.897	2.452
Chipps to Benicia	0.743	2.102
Clifton Court to CC intake	-0.612	0.542
Durhamferry to SJ BCA	0.538	1.713
Howard to SJG	0.070	1.073
Howard to SJ HOR	0.460	1.584
Jersey Point to Chipps	0.326	1.385
Mac to Jersey Point	0.038	1.039
Mac to Middle River RR Bridge	-0.017	0.983
Mac to Three Mile	0.157	1.170
Middle River RR Bridge to Jersey Point	-1.681	0.186
Mossdale to Old River HOR	0.937	2.552
Mossdale to SJ HOR	0.839	2.314
Old River HOR to Old River at Middle River	0.391	1.478
Old River at Middle River to CVP Trash Rack	0.330	1.391
Old River at Middle River to Clifton Court	0.220	1.246
SJG to Howard	-0.333	0.717
SJG to Mac	0.038	1.039
SJG to TurnerCut	-0.090	0.914
SJ BCA to Mossdale	0.242	1.274
SJ HOR to Howard	-0.109	0.897
SJ HOR to Old River HOR	0.649	1.914
Three Mile to Chipps	0.187	1.206
TurnerCut to Jersey Point	-0.806	0.447
TurnerCut to Middle River RR Bridge	0.097	1.102

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	Old River	12.96	1.02
Durham Ferry	San Joaquin River	15.12	1.44
Head of Old River	Old River	15.11	3.56
Head of Old River	San Joaquin River	14.30	8.12
Stockton	Old River	19.37	1.54
Stockton	San Joaquin River	11.30	1.00

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	Old River	12.84	1.48
Durham Ferry	San Joaquin River	14.74	2.66
Head of Old River	Old River	13.03	2.04
Head of Old River	San Joaquin River	15.66	9.52
Stockton	Old River	19.37	1.54
Stockton	San Joaquin River	11.14	1.01

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	-0.07	0.09	0.48	0.44	0.53
Survival from Delta Entry to Chipps via San Joaquin Route	lphi_SJSJ	-1.86	0.29	0.14	0.08	0.22
Survival from Delta Entry to Chipps via Turner Cut Route	lphi_SJTC	-2.25	0.30	0.10	0.06	0.16
Survival from Delta Entry to Chipps via Middle River Route	lphi_ORMR	-2.34	0.72	0.09	0.02	0.29
Survival from Delta Entry to Chipps via Old River Route[1]	lphi_OROR	-2.06	0.14	0.11	0.09	0.14
Survival from Delta Entry to Chipps via Grant Line Canal Route[1]	lphi_ORGL	-2.06	0.14	0.11	0.09	0.14
Survival from Delta Entry to Chipps via San Joaquin River Routes (SJ and TC)	lphi_SJ	-2.03	0.26	0.12	0.07	0.18
Survival from Delta Entry to Chipps via Old River Routes (MR, OR, GLC)	lphi_OR	-2.06	0.14	0.11	0.09	0.14
Through-Delta Survial	lphi_TD	-1.98	0.13	0.12	0.10	0.15
Through-Bay Surival	lphi_TB	1.25	0.36	0.78	0.64	0.87
Survival from SJ downstream of HOR to Turner Cut	lphi_SJtTC	-0.63	0.27	0.35	0.24	0.47
Survial from Durham Ferry to Benicia	lphi_DFtB	-2.85	0.13	0.05	0.04	0.07
Survial from Head of Old River Release to Benicia	lphi_HORtB	-2.10	0.13	0.11	0.09	0.14
Survial from Stockton Release to Benicia	lphi_STtB	-1.82	0.15	0.14	0.11	0.18
Difference HOR release survival and HOR-reach survival *not logit space	dphi_HOR	0.00	0.02			
Difference in ST release survival and ST-reach survival *not logit space	dphi_ST	-0.19	0.07			

[1]These routes were combined in the analysis, but separate in the 2021 study

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	-0.44	0.13	0.39	0.33	0.46
Survival from Delta Entry to Chipps via San Joaquin Route	lphi_SJSJ	-2.74	0.51	0.06	0.02	0.15
Survival from Delta Entry to Chipps via Turner Cut Route	lphi_SJTC	-2.69	0.51	0.06	0.02	0.16
Survival from Delta Entry to Chipps via Middle River Route	lphi_ORMR	-1.74	0.50	0.15	0.06	0.32
Survival from Delta Entry to Chipps via Old River Route[1]	lphi_OROR	-1.79	0.20	0.14	0.10	0.20
Survival from Delta Entry to Chipps via Grant Line Canal Route[1]	lphi_ORGL	-1.79	0.20	0.14	0.10	0.20
Survival from Delta Entry to Chipps via San Joaquin River Routes (SJ and TC)	lphi_SJ	-2.71	0.47	0.06	0.03	0.14
Survival from Delta Entry to Chipps via Old River Routes (MR, OR, GLC)	lphi_OR	-1.79	0.20	0.14	0.10	0.20
Through-Delta Survial	lphi_TD	-1.85	0.19	0.14	0.10	0.19
Through-Bay Surival	lphi_TB	1.17	0.46	0.76	0.57	0.89
Survival from SJ downstream of HOR to Turner Cut	lphi_SJtTC	-1.69	0.46	0.16	0.07	0.31
Survival from Durham Ferry to Benicia	lphi_DFtB	-2.95	0.20	0.05	0.03	0.07
Survial from Head of Old River Release to Benicia	lphi_HORtB	-2.04	0.19	0.11	0.08	0.16
Survial from Stockton Release to Benicia	lphi_STtB	-1.98	0.25	0.12	0.08	0.19
Difference HOR release survival and HOR-reach survival *not logit space	dphi_HOR	0.00	0.03			
Difference in ST release survival and ST-reach survival *not logit space	dphi_ST	-0.07	0.12			

[1]These routes were combined in the analysis, but separate in the 2021 study

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	0.30	0.13	0.57	0.51	0.64
Survival from Delta Entry to Chipps via San Joaquin Route	lphi_SJSJ	-0.97	0.28	0.27	0.18	0.39
Survival from Delta Entry to Chipps via Turner Cut Route	lphi_SJTC	-1.82	0.32	0.14	0.08	0.23
Survival from Delta Entry to Chipps via Middle River Route	lphi_ORMR	-2.93	1.38	0.05	0.00	0.44
Survival from Delta Entry to Chipps via Old River Route[1]	lphi_OROR	-2.32	0.21	0.09	0.06	0.13
Survival from Delta Entry to Chipps via Grant Line Canal Route[1]	lphi_ORGL	-2.32	0.21	0.09	0.06	0.13
Survival from Delta Entry to Chipps via San Joaquin River Routes (SJ and TC)	lphi_SJ	-1.34	0.23	0.21	0.14	0.29
Survival from Delta Entry to Chipps via Old River Routes (MR, OR, GLC)	lphi_OR	-2.33	0.21	0.09	0.06	0.13
Through-Delta Survial	lphi_TD	-2.12	0.17	0.11	0.08	0.14
Through-Bay Surival	lphi_TB	1.33	0.48	0.79	0.59	0.91
Survival from SJ downstream of HOR to Turner Cut	lphi_SJtTC	0.42	0.28	0.60	0.47	0.72
Survial from Durham Ferry to Benicia	lphi_DFtB	-2.75	0.18	0.06	0.04	0.08
Survial from Head of Old River Release to Benicia	lphi_HORtB	-2.15	0.17	0.10	0.08	0.14
Survial from Stockton Release to Benicia	lphi_STtB	-1.67	0.21	0.16	0.11	0.22
Difference HOR release survival and HOR-reach survival *not logit space	dphi_HOR	0.00	0.03			
Difference in ST release survival and ST-reach survival *not logit space	dphi_ST	-0.32	0.07			

[1]These routes were combined in the analysis, but separate in the 2021 study

Table 10. Mean reach-specific survival random effects estimates (Est.), standard errors (SE), and lower and upper 95% confidence intervals (L_{95} and U_{95}, respectively) across all release groups for an average-sized fish. Parameter estimates were obtained from the model using data without a predator filter.

Parameter Description	Est.	SE	L_{95}	U_{95}
RE for Reach 1: DF release	0.78	0.02	0.74	0.82
RE for Reach 2: HOR release	0.93	0.02	0.90	0.96
RE for Reach 3: ST release	0.55	0.04	0.47	0.62
RE for Reach 4: DF_DS to SJ_BCA	0.71	0.02	0.66	0.76
RE for Reach 5: SJ_BCA to Mossdale	0.86	0.02	0.81	0.90
RE for Reach 6: Mossdale to SJ_HOR or OR_HOR	0.93	0.02	0.90	0.96
RE for Reach 7: SJ-HOR to Howard	0.67	0.05	0.57	0.77
RE for Reach 8: Howard to SJG	0.67	0.08	0.53	0.82
RE for Reach 9: SJG to MAC or TC	0.79	0.09	0.62	0.97
RE for Reach 10: MAC to 3-mile, Jersey Point, CVP or SWP	0.49	0.07	0.35	0.64
RE for Reach 11: Turner Cut to 3-mile, Jersey Point, CVP or SWP	0.51	0.08	0.36	0.66
RE for Reach 12: OR_HOR to OR_MR junction	0.84	0.02	0.80	0.89
RE for Reach 13: MR_OR to MR_RRB, OR_RRB, CVP, or SWP	0.59	0.32	-0.05	1.23
RE for Reach 14: MR_RRB to 3-mile or Jersey Point	0.28	0.11	0.06	0.50
RE for Reach 15: OR_MidR to OR_Tracy or GLC	0.76	0.03	0.70	0.82
RE for Reach 16: OR_Tracy to MR_RRB, OR_RRB, CVP, or SWP[1]	*1.00*	*0.00*	*1.00*	*1.00*
RE for Reach 17: OR_RRB to 3-mile or Jersey Point	0.35	0.09	0.17	0.52
RE for Reach 18: GLC to MR_RRB, OR_RRB, CVP, or SWP[1]	*1.00*	*0.00*	*1.00*	*1.00*
RE for Reach 19: CVP trash rack to Chipps Island	0.27	0.05	0.17	0.36
RE for Reach 20: CCF_inlet to CCF_intake	0.47	0.05	0.37	0.56
RE for Reach 21: CCF_intake to Chipps Island	0.29	0.06	0.17	0.41
RE for Reach 22: 3-mile to Chipps Island	0.90	0.07	0.76	1.04
RE for Reach 23: Jersey Point to Chipps Island	0.88	0.05	0.79	0.97
RE for Reach 24: Chipps Island to Benicia	0.95	0.02	0.91	1.00
RE for Reach 25: Benicia to Golden Gate E	0.82	0.06	0.70	0.93

[1]Survival in reaches 16 and 18 were not estimated, but were combined with reach 15 to estimate survival from the split with Middle River to the pumping facilities or MR/OR Railroad Bridge. These reaches were estimated in the 2021 study.

Table 11. 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	L_{95}	U_{95}
RE for Reach 1: DF release	0.99	0.15	0.73	0.67	0.78
RE for Reach 2: HOR release	2.43	0.30	0.92	0.86	0.95
RE for Reach 3: ST release	0.04	0.22	0.51	0.40	0.62
RE for Reach 4: DF_DS to SJ_BCA	0.73	0.17	0.68	0.60	0.74
RE for Reach 5: SJ_BCA to Mossdale	1.36	0.23	0.80	0.71	0.86
RE for Reach 6: Mossdale to SJ_HOR or OR_HOR	2.44	0.36	0.92	0.85	0.96
RE for Reach 7: SJ-HOR to Howard	0.19	0.33	0.55	0.39	0.70
RE for Reach 8: Howard to SJG	-0.21	0.57	0.45	0.21	0.71
RE for Reach 9: SJG to MAC or TC	0.79	0.78	0.69	0.32	0.91
RE for Reach 10: MAC to 3-mile, Jersey Point, CVP or SWP	-0.12	0.48	0.47	0.26	0.70
RE for Reach 11: Turner Cut to 3-mile, Jersey Point, CVP or SWP	-0.02	0.50	0.49	0.27	0.72
RE for Reach 12: OR_HOR to OR_MR junction	1.49	0.24	0.82	0.74	0.88
RE for Reach 13: MR_OR to MR_RRB, OR_RRB, CVP, or SWP	0.94	1.46	0.72	0.13	0.98
RE for Reach 14: MR_RRB to 3-mile or Jersey Point	-0.86	0.80	0.30	0.08	0.67
RE for Reach 15: OR_MidR to OR_Tracy or GLC	0.67	0.22	0.66	0.56	0.75
RE for Reach 16: OR_Tracy to MR_RRB, OR_RRB, CVP, or SWP			*1.00*	*1.00*	*1.00*
RE for Reach 17: OR_RRB to 3-mile or Jersey Point	-0.36	0.53	0.41	0.20	0.66
RE for Reach 18: GLC to MR_RRB, OR_RRB, CVP, or SWP			*1.00*	*1.00*	*1.00*
RE for Reach 19: CVP trash rack to Chipps Island	-0.39	0.39	0.40	0.24	0.59
RE for Reach 20: CCF_inlet to CCF_intake	-0.18	0.30	0.45	0.32	0.60
RE for Reach 21: CCF_intake to Chipps Island	-0.33	0.44	0.42	0.23	0.63
RE for Reach 22: 3-mile to Chipps Island	2.01	1.10	0.88	0.46	0.98
RE for Reach 23: Jersey Point to Chipps Island	1.89	0.63	0.87	0.66	0.96
RE for Reach 24: Chipps Island to Benicia	2.60	0.59	0.93	0.81	0.98
RE for Reach 25: Benicia to Golden Gate E	1.52	0.55	0.82	0.61	0.93
Mean of survival RE	0.80	0.33			
Slope for the survival-length relationship*	0.18	0.05			
Log(SD) for Release-specific random effect hyperparameter*	0.14	0.32			
Log(SD) for Reach-specific random effect hyperparameter*	0.43	0.14			

[1]Survival in reaches 16 and 18 were not estimated, but were combined with reach 15 to estimate survival from the split with Middle River to the pumping facilities or MR/OR Railroad Bridge. These reaches were estimated in the 2021 study.

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 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	L_{95}	U_{95}
RE for Reach 1: DF release	1.63	0.19	0.84	0.78	0.88
RE for Reach 2: HOR release	2.77	0.37	0.94	0.89	0.97
RE for Reach 3: ST release	0.33	0.21	0.58	0.48	0.68
RE for Reach 4: DF_DS to SJ_BCA	1.09	0.17	0.75	0.68	0.81
RE for Reach 5: SJ_BCA to Mossdale	2.43	0.32	0.92	0.86	0.96
RE for Reach 6: Mossdale to SJ_HOR or OR_HOR	2.70	0.35	0.94	0.88	0.97
RE for Reach 7: SJ-HOR to Howard	1.38	0.37	0.80	0.66	0.89
RE for Reach 8: Howard to SJG	2.20	0.63	0.90	0.72	0.97
RE for Reach 9: SJG to MAC or TC	2.17	0.59	0.90	0.73	0.97
RE for Reach 10: MAC to 3-mile, Jersey Point, CVP or SWP	0.08	0.32	0.52	0.37	0.67
RE for Reach 11: Turner Cut to 3-mile, Jersey Point, CVP or SWP	0.11	0.33	0.53	0.37	0.68
RE for Reach 12: OR_HOR to OR_MR junction	1.85	0.25	0.86	0.80	0.91
RE for Reach 13: MR_OR to MR_RRB, OR_RRB, CVP, or SWP	-0.16	2.33	0.46	0.01	0.99
RE for Reach 14: MR_RRB to 3-mile or Jersey Point	-1.05	0.76	0.26	0.07	0.61
RE for Reach 15: OR_MidR to OR_Tracy or GLC	1.79	0.30	0.86	0.77	0.92
RE for Reach 16: OR_Tracy to MR_RRB, OR_RRB, CVP, or SWP			*1.00*	*1.00*	*1.00*
RE for Reach 17: OR_RRB to 3-mile or Jersey Point	-0.95	0.53	0.28	0.12	0.53
RE for Reach 18: GLC to MR_RRB, OR_RRB, CVP, or SWP			*1.00*	*1.00*	*1.00*
RE for Reach 19: CVP trash rack to Chipps Island	-1.93	0.32	0.13	0.07	0.21
RE for Reach 20: CCF_inlet to CCF_intake	-0.08	0.25	0.48	0.36	0.60
RE for Reach 21: CCF_intake to Chipps Island	-1.59	0.41	0.17	0.08	0.31
RE for Reach 22: 3-mile to Chipps Island	2.41	1.07	0.92	0.58	0.99
RE for Reach 23: Jersey Point to Chipps Island	2.16	0.62	0.90	0.72	0.97
RE for Reach 24: Chipps Island to Benicia	3.68	0.85	0.98	0.88	1.00
RE for Reach 25: Benicia to Golden Gate E	1.46	0.52	0.81	0.61	0.92
Mean of survival RE	1.11	0.34			
Slope for the survival-length relationship*	0.18	0.05			
Log(SD) for Release-specific random effect hyperparameter*	0.14	0.32			
Log(SD) for Reach-specific random effect hyperparameter*	0.43	0.14			

[1]Survival in reaches 16 and 18 were not estimated, but were combined with reach 15 to estimate survival from the split with Middle River to the pumping facilities or MR/OR Railroad Bridge. These reaches were estimated in the 2021 study.

Table 13. 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	-0.23	0.15	0.44	0.37	0.51
ρ_2	Prob. of taking 3-mile vs. Jersey Point to Chipps Island	-1.46	0.34	0.19	0.11	0.31
ρ_3	Prob. of remaining in SJ @ HOR for DF release	-2.04	0.22	0.12	0.08	0.17
ρ_4	Prob. of taking SJ route for HOR release vs. OR route	-1.41	0.15	0.20	0.15	0.25
ρ_5	Prob. of going downstream @ ST release	0.71	0.22	0.67	0.57	0.76
ρ_6	Prob. of remaining in SJ @ Turner Cut	0.01	0.21	0.50	0.40	0.60
ρ_7	Prob. of heading to pumps after passing MAC	-2.98	0.77	0.05	0.01	0.19
ρ_8	Prob. of heading to pumps after entering Turner Cut	-1.14	0.62	0.24	0.09	0.52
ρ_9	Prob. of taking MR @ MR-OR split	-3.42	0.71	0.03	0.01	0.12
ρ_{10}	Prob. of heading to interior delta vs. pumps from MR	-1.37	0.99	0.20	0.04	0.64
ρ_{11}	Prob. of heading to interior via MR_RRB vs OR_RRB from MR	-0.60	1.13	0.35	0.06	0.84
ρ_{12}	Prob. of taking OR @ OR-GLC split			*0.50*	*0.50*	*0.50*
ρ_{13}	Prob. of heading to interior delta vs. pumps from OR	-1.29	0.20	0.22	0.16	0.29
ρ_{14}	Prob. of heading to interior delta via MR_RRB vs. OR_RRB from OR	-1.14	0.39	0.24	0.13	0.41
ρ_{15}	Prob. of heading to interior delta vs. pumps from GLC	-1.29	0.20	0.22	0.16	0.29
ρ_{16}	Prob. of heading to interior delta via MR_RRB vs. OR_RRB from GLC	-1.14	0.39	0.24	0.13	0.41

Table 14. 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 (L95 and U95, 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	L_{95}	U_{95}
ρ_1	Prob. of entering CVP vs. SWP	-0.54	0.24	0.37	0.27	0.48
ρ_2	Prob. of taking 3-mile vs. Jersey Point to Chipps Island	-1.53	0.52	0.18	0.07	0.38
ρ_3	Prob. of remaining in SJ @ HOR for DF release	-2.39	0.38	0.08	0.04	0.16
ρ_4	Prob. of taking SJ route for HOR release vs. OR route	-1.22	0.21	0.23	0.16	0.31
ρ_5	Prob. of going downstream @ ST release	0.21	0.30	0.55	0.40	0.69
ρ_6	Prob. of remaining in SJ @ Turner Cut	0.00	0.36	0.50	0.33	0.67
ρ_7	Prob. of heading to pumps after passing MAC	-2.63	1.15	0.07	0.01	0.41
ρ_8	Prob. of heading to pumps after entering Turner Cut	-2.61	1.15	0.07	0.01	0.41
ρ_9	Prob. of taking MR @ MR-OR split	-2.68	0.57	0.06	0.02	0.17
ρ_{10}	Prob. of heading to interior delta vs. pumps from MR	-1.46	0.96	0.19	0.03	0.60
ρ_{11}	Prob. of heading to interior via MR_RRB vs OR_RRB from MR	0.02	1.38	0.51	0.06	0.94
ρ_{12}	Prob. of taking OR @ OR-GLC split			*0.50*	*0.50*	*0.50*
ρ_{13}	Prob. of heading to interior delta vs. pumps from OR	-0.98	0.27	0.27	0.18	0.39
ρ_{14}	Prob. of heading to interior delta via MR_RRB vs. OR_RRB from OR	-1.25	0.53	0.22	0.09	0.45
ρ_{15}	Prob. of heading to interior delta vs. pumps from GLC	-0.98	0.27	0.27	0.18	0.39
ρ_{16}	Prob. of heading to interior delta via MR_RRB vs. OR_RRB from GLC	-1.25	0.53	0.22	0.09	0.45
μ_ρ	Hyperparameter mean of transition probability in logit space*	-1.17	0.34			

Table 15. 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	L_{95}	U_{95}
ρ_1	Prob. of entering CVP vs. SWP	0.08	0.16	0.52	0.44	0.60
ρ_2	Prob. of taking 3-mile vs. Jersey Point to Chipps Island	-1.38	0.42	0.20	0.10	0.36
ρ_3	Prob. of remaining in SJ @ HOR for DF release	-1.69	0.23	0.16	0.10	0.23
ρ_4	Prob. of taking SJ route for HOR release vs. OR route	-1.60	0.23	0.17	0.11	0.24
ρ_5	Prob. of going downstream @ ST release	1.21	0.31	0.77	0.65	0.86
ρ_6	Prob. of remaining in SJ @ Turner Cut	0.01	0.23	0.50	0.37	0.61
ρ_7	Prob. of heading to pumps after passing MAC	-3.33	1.00	0.03	0.00	0.20
ρ_8	Prob. of heading to pumps after entering Turner Cut	0.32	0.44	0.58	0.37	0.77
ρ_9	Prob. of taking MR @ MR-OR split	-4.15	1.29	0.02	0.00	0.16
ρ_{10}	Prob. of heading to interior delta vs. pumps from MR	-1.27	1.71	0.22	0.01	0.89
ρ_{11}	Prob. of heading to interior via MR_RRB vs OR_RRB from MR	-1.22	1.76	0.23	0.01	0.90
ρ_{12}	Prob. of taking OR @ OR-GLC split			*0.50*	*0.50*	*0.50*
ρ_{13}	Prob. of heading to interior delta vs. pumps from OR	-1.61	0.25	0.17	0.11	0.25
ρ_{14}	Prob. of heading to interior delta via MR_RRB vs. OR_RRB from OR	-1.04	0.49	0.26	0.12	0.48
ρ_{15}	Prob. of heading to interior delta vs. pumps from GLC	-1.61	0.25	0.17	0.11	0.25
ρ_{16}	Prob. of heading to interior delta via MR_RRB vs. OR_RRB from GLC	-1.04	0.49	0.26	0.12	0.48
μ_ρ	Hyperparameter mean of transition probability in logit space*	-1.17	0.34			

Table 16. 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	L_{95}	U_{95}	Line Est.
p_1	Logit Detection: DF_DS	2.62	0.24	0.93	0.90	0.96	
p_2	Logit Detection: SJ_BCA	2.59	0.25	0.93	0.89	0.96	
p_3	Logit Detection: Mossdale	2.46	0.25	0.92	0.88	0.95	
p_4	Logit Detection: SJ_HOR (Combined dual-line)	0.33	0.27	0.58	0.45	0.70	0.82
p_5	Logit Detection: Howard	0.66	0.26	0.66	0.54	0.76	
p_6	Logit Detection: SJG (Combined dual-line)	0.86	0.31	0.70	0.56	0.81	0.91
p_7	Logit Detection: MAC (Combined dual-line)	2.07	0.52	0.89	0.74	0.96	0.99
p_8	Logit Detection: Turner Cut (Combined dual-line)	1.23	0.45	0.77	0.59	0.89	0.95
p_9	Logit Detection: OR_HOR (Combined dual-line)	2.39	1.11	0.92	0.56	0.99	0.99
p_{10}	Logit Detection: MR_OR[1]			*0.00*	*0.00*	*0.00*	
p_{11}	Logit Detection: MR_RRB	1.18	0.49	0.76	0.55	0.89	
p_{12}	Logit Detection: OR_MidR	2.11	1.36	0.89	0.36	0.99	
p_{13}	Logit Detection: OR_Tracy[1]			*0.00*	*0.00*	*0.00*	
p_{14}	Logit Detection: OR_RRB	2.02	0.25	0.88	0.82	0.92	
p_{15}	Logit Detection: GLC[1]			*0.00*	*0.00*	*0.00*	
p_{16}	Logit Detection: CVP_trash_rack	4.57	0.76	0.99	0.96	1.00	
p_{17}	Logit Detection: CCF_Inlet	0.18	0.49	0.55	0.31	0.76	
p_{18}	Logit Detection: CCF_Intake	3.43	0.96	0.97	0.83	1.00	
p_{19}	Logit Detection: 3-mile Slough (Combined dual-line)	1.96	1.57	0.88	0.25	0.99	0.98
p_{20}	Logit Detection: Jersey Point (Combined dual-line)	1.14	0.42	0.76	0.58	0.88	0.94
p_{21}	Logit Detection: Chipps Island (Combined dual-line)	2.10	0.52	0.89	0.75	0.96	0.99
p_{22}	Logit Detection: Benicia (Combined dual-line)	2.87	0.89	0.95	0.75	0.99	1.00
p_{23}	Logit Detection: Golden Gate E	3.46	0.70	0.97	0.89	0.99	
p_{24}	Logit Detection: Golden Gate W	3.17	1.01	0.96	0.77	0.99	
μ_p	Hyperparameter mean detection probability in logit space	2.06	0.35				
$log\left(\sigma_p\right)$	Hyperparameter log(SD) for detection random effect	0.31	0.24				

[1]No receivers were deployed to monitor entry into these reaches and detection was set to zero in the model. Receivers were deployed and parameters were estimated in the 2021 model.

Table 17. 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
2022	3	15	18	0.14	0.10	0.19	10,796	846	9,525	7,719	2,512	4.8	0.4	4.3	17	0
2022	4	19	22	0.11	0.08	0.14	11,374	1,320	8,460	9,815	1,795	6.3	0.7	4.7	18	0

Table 18: 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.

Covariate	NLL	AIC	ΔAIC	Right Asymptote A	Left Asymptote κ	Intercept β_0	Barrier β_1	Covariate β_2	Temperature β_3	$\log(\sigma)$
Delta Inflow	22.9	59.7	0.0	1.03 (1.67)	-7.34 (13.58)	3.95 (8.06)	-0.75 (0.96)	-0.66 (0.87)	0.10 (0.14)	-0.47 (0.14)
Delta Outflow	23.4	60.8	1.1	1.37 (2.20)	-6.72 (10.17)	2.1 (4.85)	-0.75 (1.00)	-0.47 (0.62)	0.10 (0.14)	-0.44 (0.14)
Exports	28.2	70.4	10.7	-0.33 (0.24)	-2.36 (0.32)	30.32 (33.67)	-3.79 (6.13)	-8.71 (9.63)	2.25 (3.55)	-0.24 (0.14)
IE ratio	NA	NA	NA							
SJR Inflow	25.5	65.0	5.3	3.19 (9.51)	-15.21 (102)	-0.84 (5.86)	-0.29 (1.03)	-0.18 (0.63)	0.06 (0.23)	-0.36 (0.14)
SJR IE	30.5	75.0	15.3	0.75 (0.94)	-1.92 (0.50)	-5.72 (5.91)	-2.45 (2.38)	-1.62 (2.01)	0.44 (0.37)	-0.15 (0.14)
SAC Inflow	24.9	63.8	4.1	1.11 (2.16)	-3.74 (3.29)	5.44 (9.35)	-1.27 (1.88)	-0.87 (1.28)	0.18 (0.25)	-0.38 (0.14)
SAC IE	35.1	84.2	24.5	0.06 (--)	-1.49 (--)	133.16 (--)	526.19 (--)	-265.88 (--)	28.47 (--)	0.04 (--)

Figures

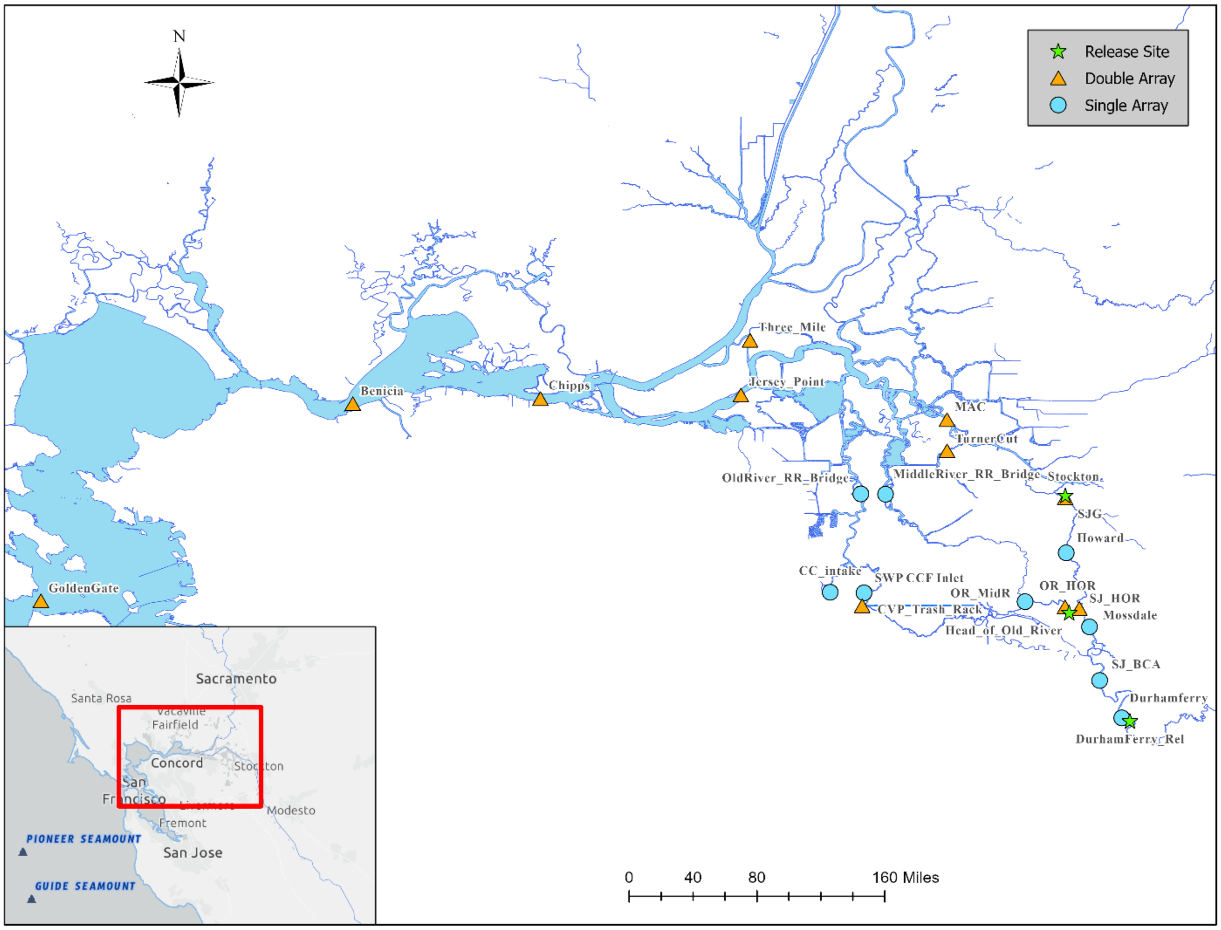

Figure 1. Receiver distribution and release locations in 2022.

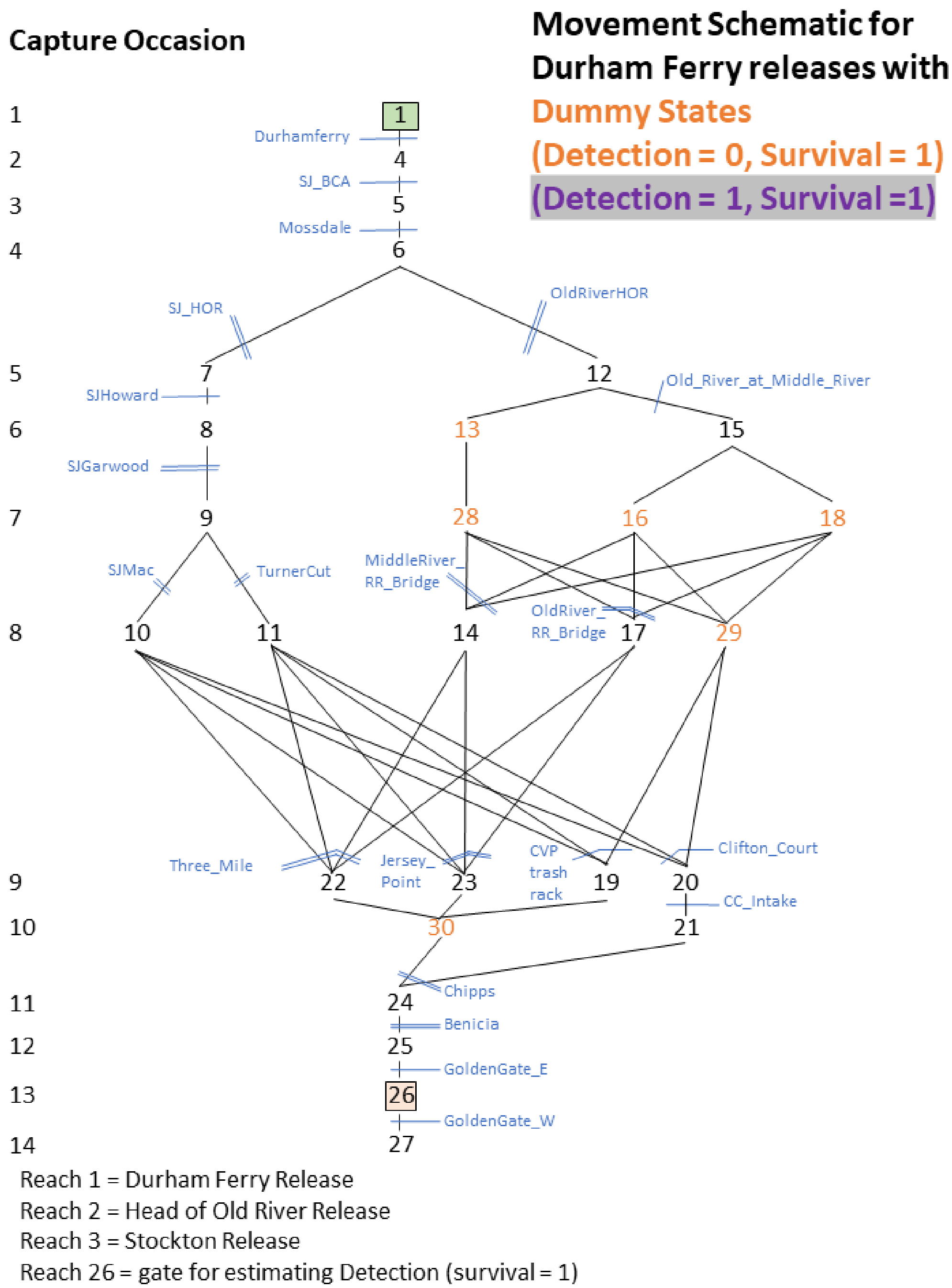

Figure 2. Movement schematic for 2022 releases at Durham Ferry. Numbers within the routing schematic are reaches (states) between receiver general locations indicated by blue single lines (single-arrays) or double lines (dual-arrays). Connecting (black) lines show downstream route options between states. 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.

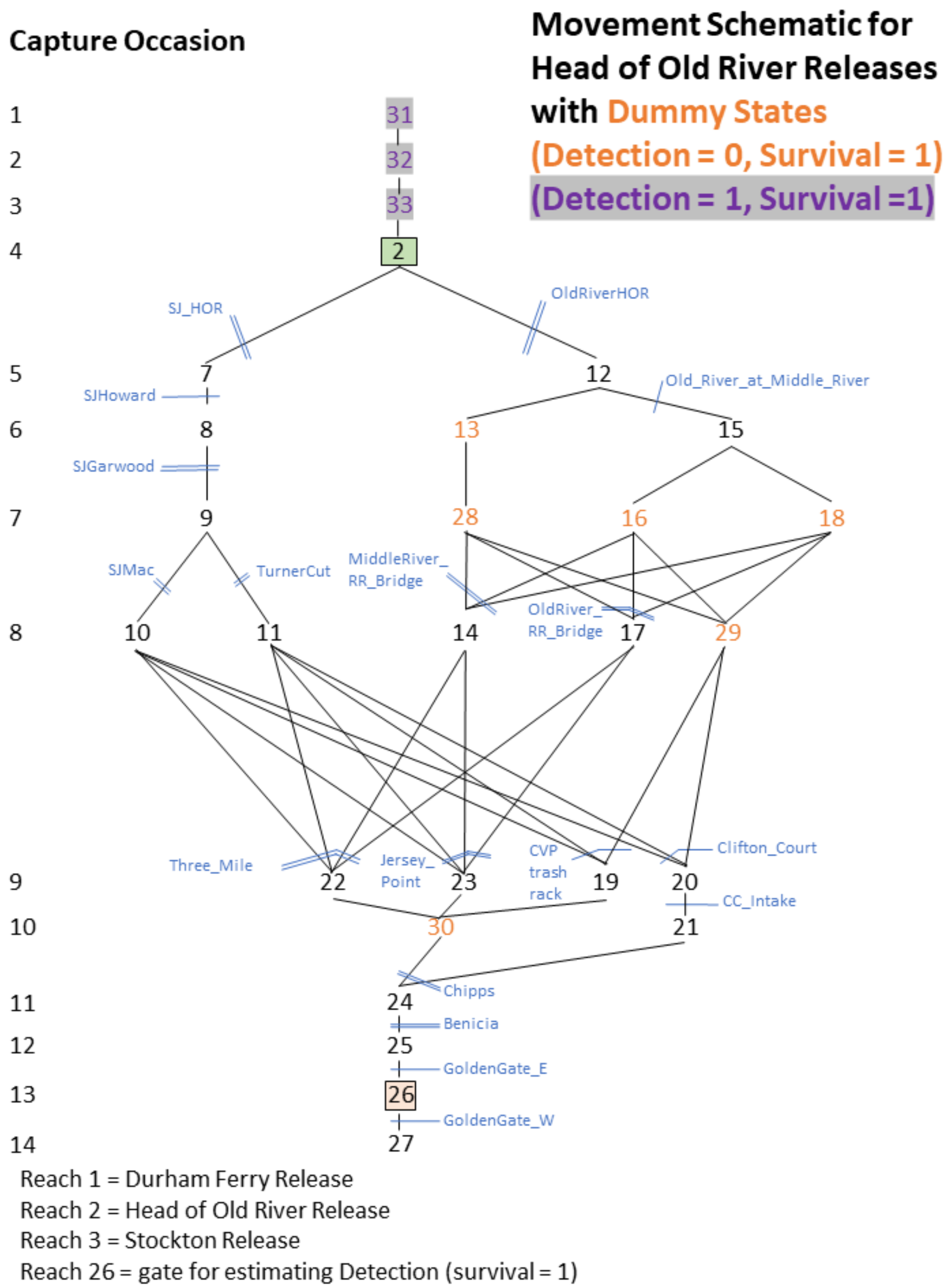

Figure 3. Movement schematic for 2022 releases at Head of Old River. Numbers within the routing schematic are reaches (states) between receiver general locations indicated by blue single lines (single-arrays) or double lines (dual-arrays). Connecting (black) lines show downstream route options between 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.

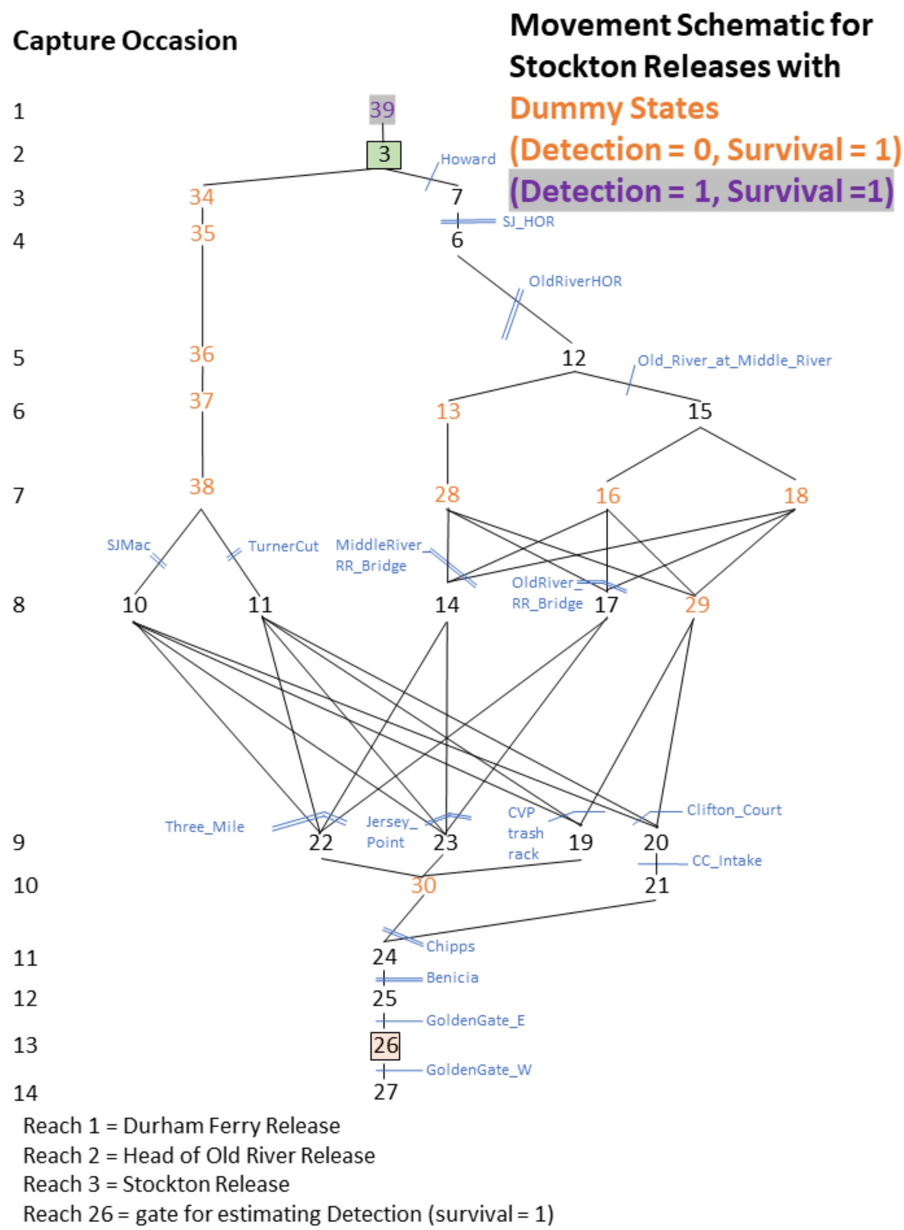

Figure 4. Movement schematic for 2022 releases at Stockton. Numbers within the routing schematic are reaches (states) between receiver general locations indicated by blue single lines (single-arrays) or double lines (dual-arrays). Connecting (black) lines show route options between states. Potential 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.

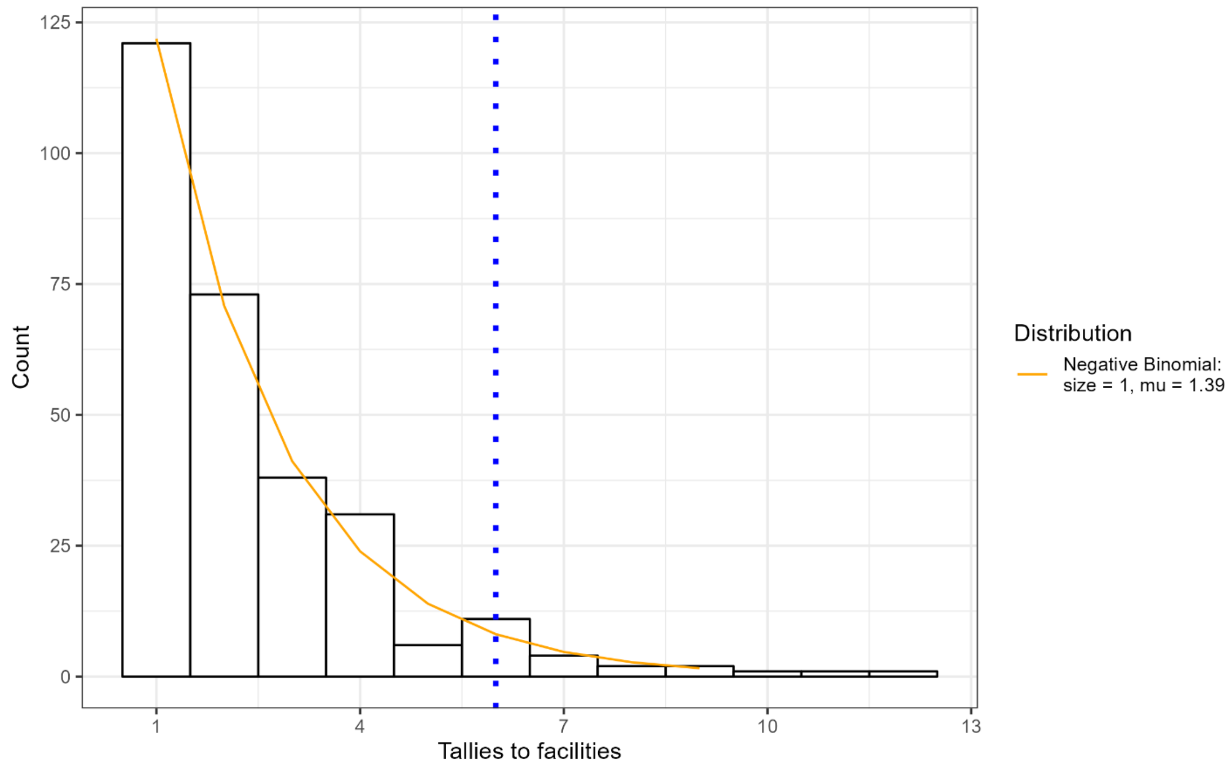

Figure 5. Negative binomial distribution (orange line) fit to the histogram of the number of detections of a tag at the SWP or CVP water export facilities. Estimated parameters for the fitted distribution are provided in the legend. The blue dotted line corresponds to 0.95 quantile for the number of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

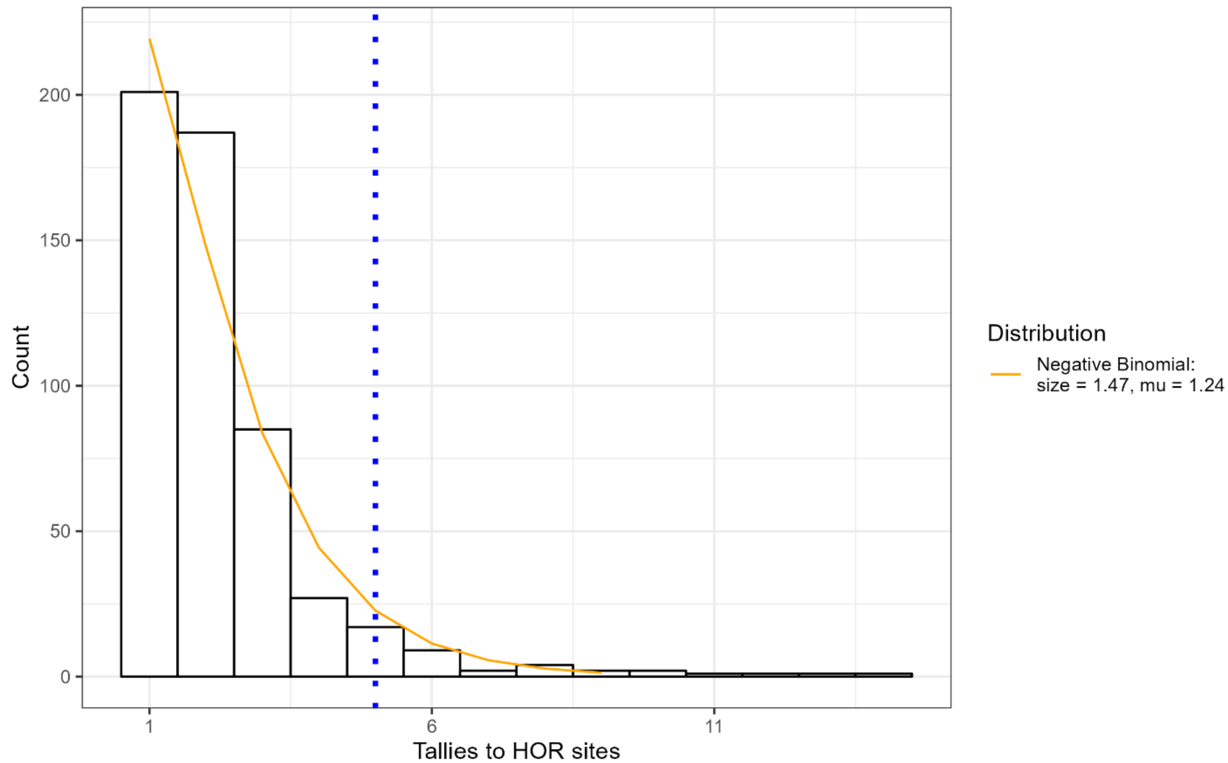

Figure 6. Negative binomial distribution (orange line) fit to the histogram of the number of detections of a tag at sites around the Head of Old River (HOR). Estimated parameters for the fitted distribution are provided in the legend. The blue dotted line corresponds to 0.95 quantile for the number of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

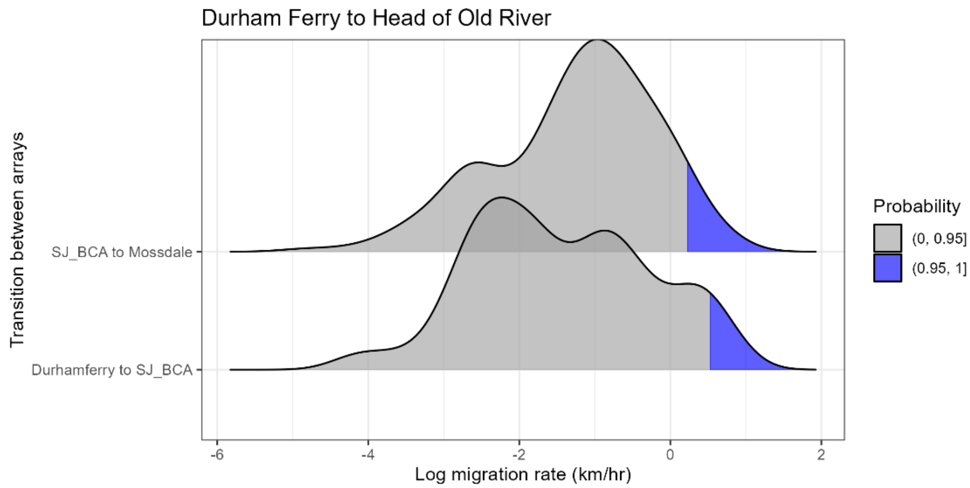

Figure 7. Smoothed histograms of counts of log migration rates (km/hr) at each transition between receiver arrays for the region between Durham Ferry and the Head of Old River. Shaded blue areas are the upper 0.05 quantile of migration rates observed per transition.

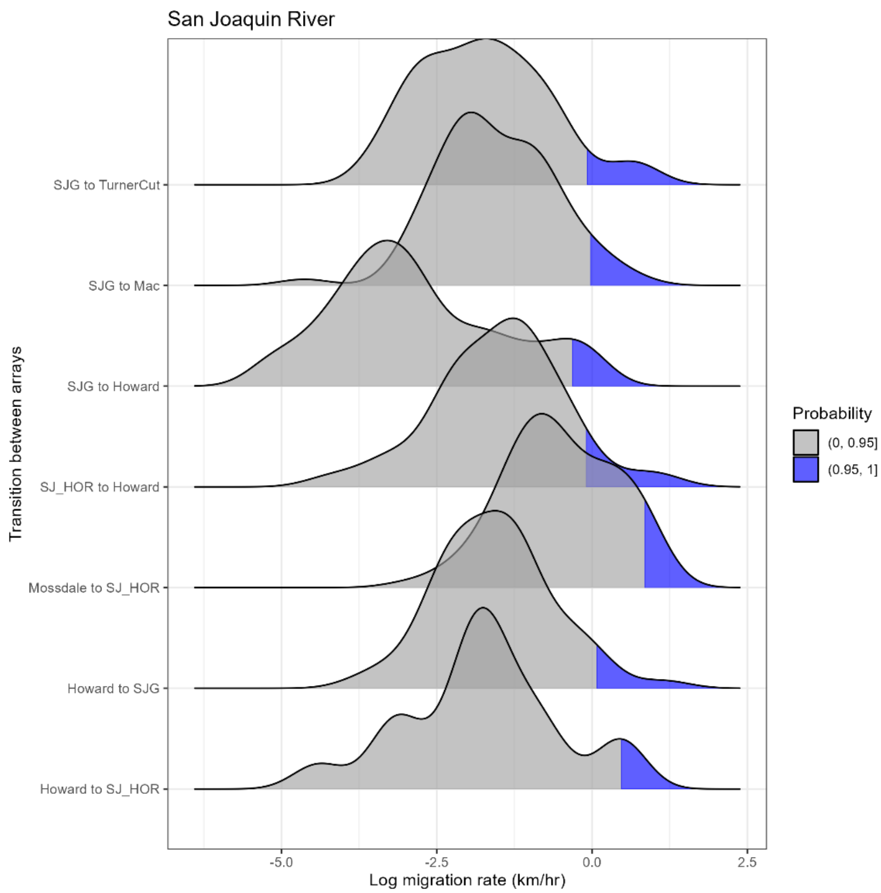

Figure 8. Smoothed histograms of counts of log migration rates (km/hr) at each transition between receiver arrays for the San Joaquin River region. Shaded blue areas are the upper 0.05 quantile of migration rates observed per transition.

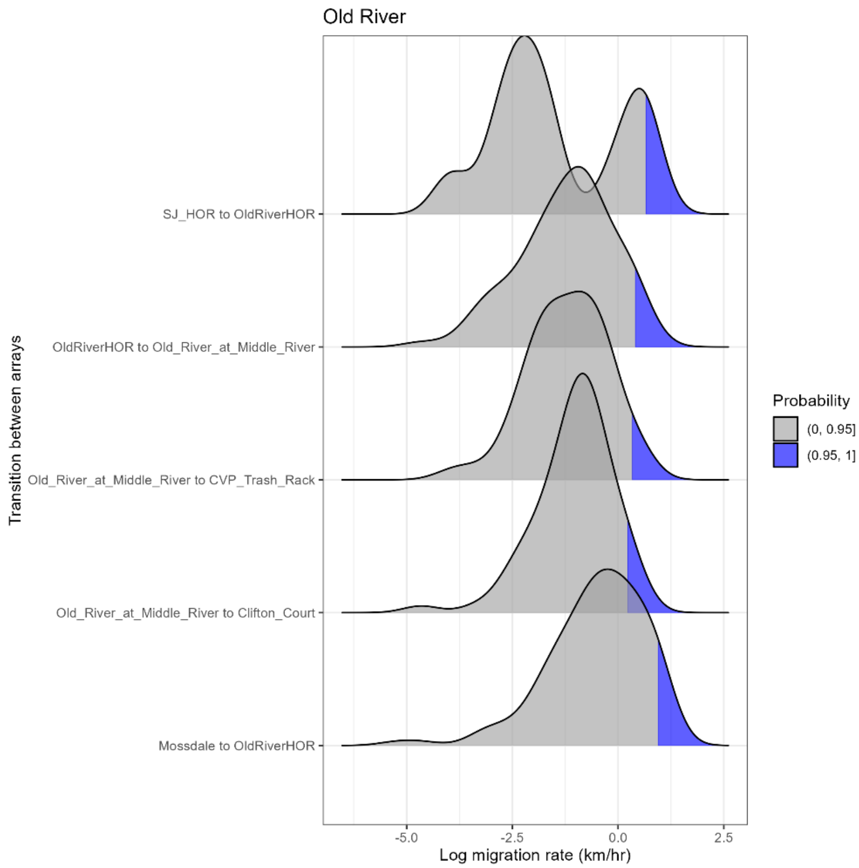

Figure 9. Smoothed histograms of counts of log migration rates (km/hr) at each transition between receiver arrays for the Old River region. Shaded blue areas are the upper 0.05 quantile of migration rates observed per transition.

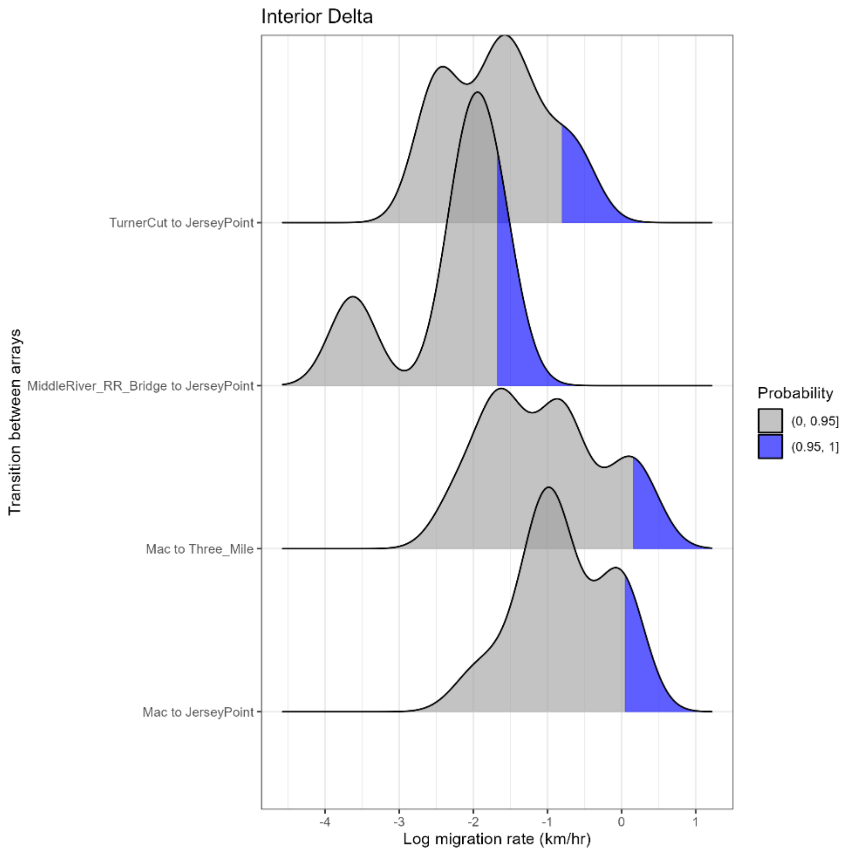

Figure 10. Smoothed histograms of counts of log migration rates (km/hr) at each transition between receiver arrays for the Interior Delta region. Shaded blue areas are the upper 0.05 quantile of migration rates observed per transition.

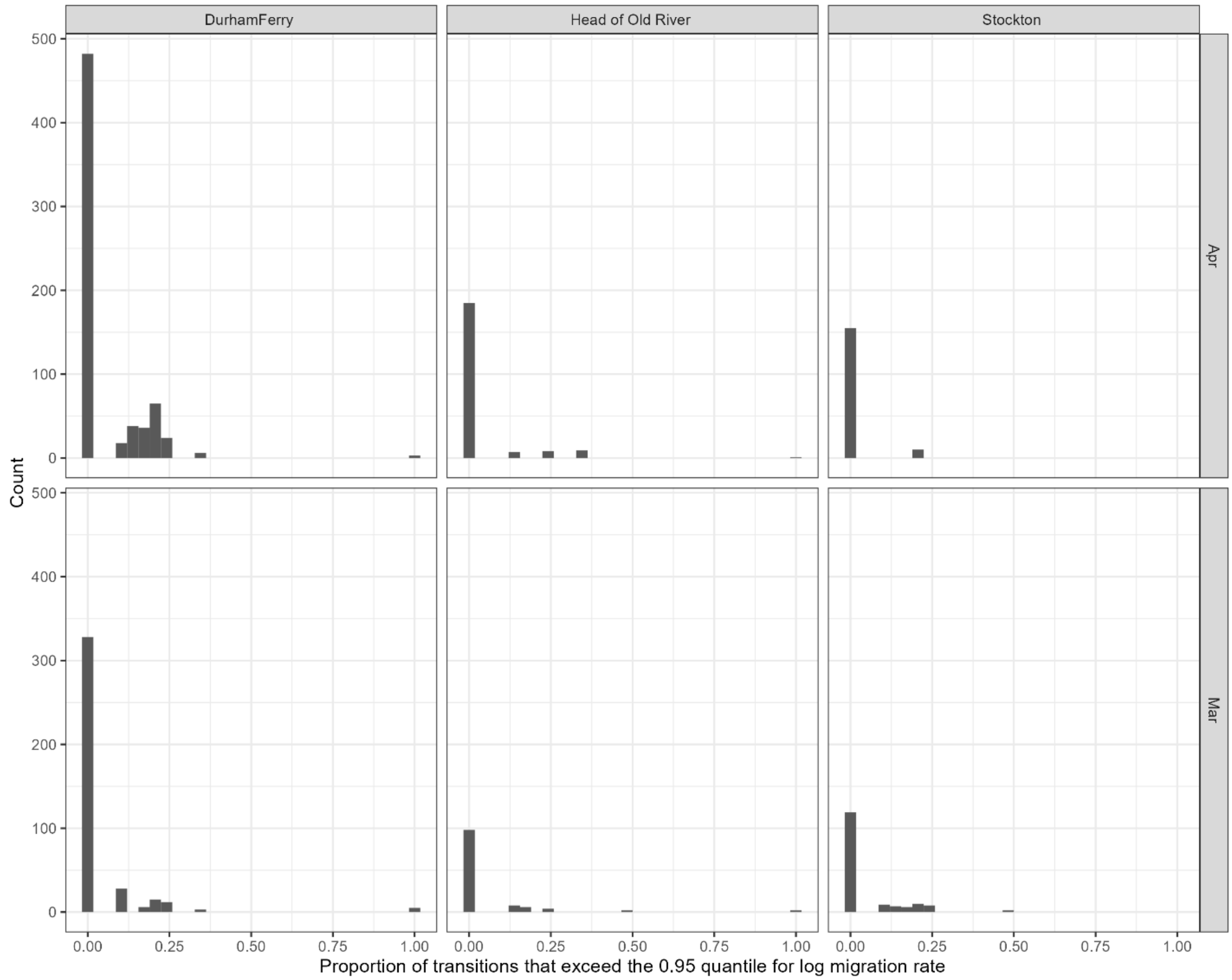

Figure 11. Histograms of the proportion of a tag's transitions between arrays that exceed the 0.95 quantile for log migration rate (km/hr), for each release group.

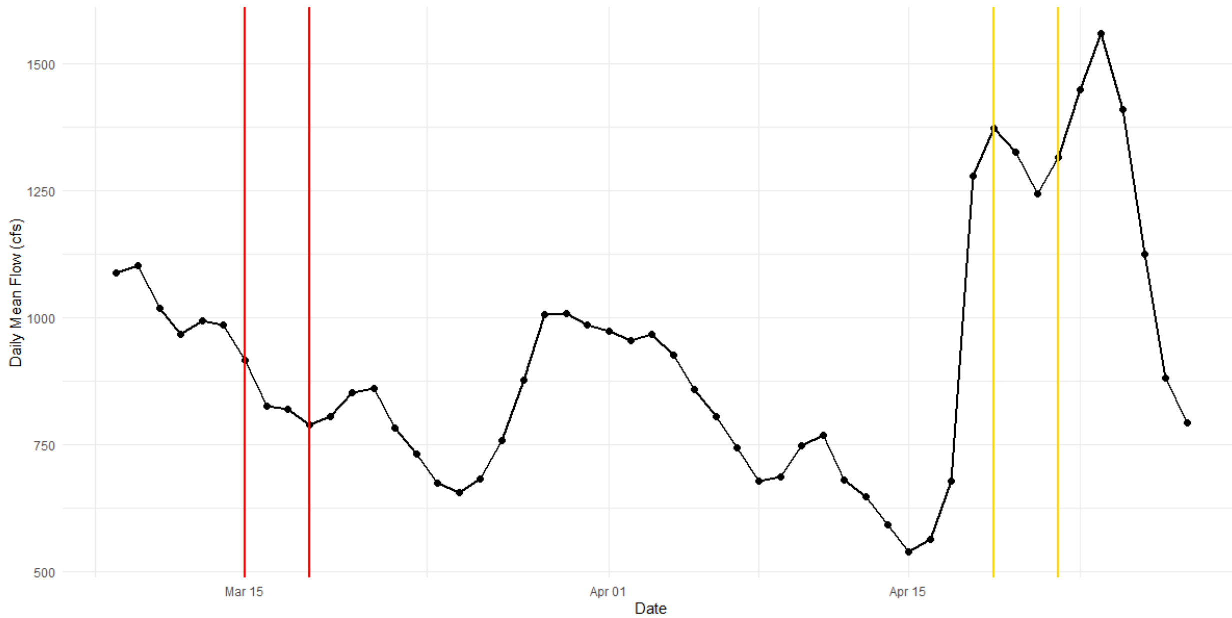

Figure 12. Daily mean flow (cubic feet per second, cfs) at Vernalis. Release weeks denoted by colors: March (red), April (yellow).

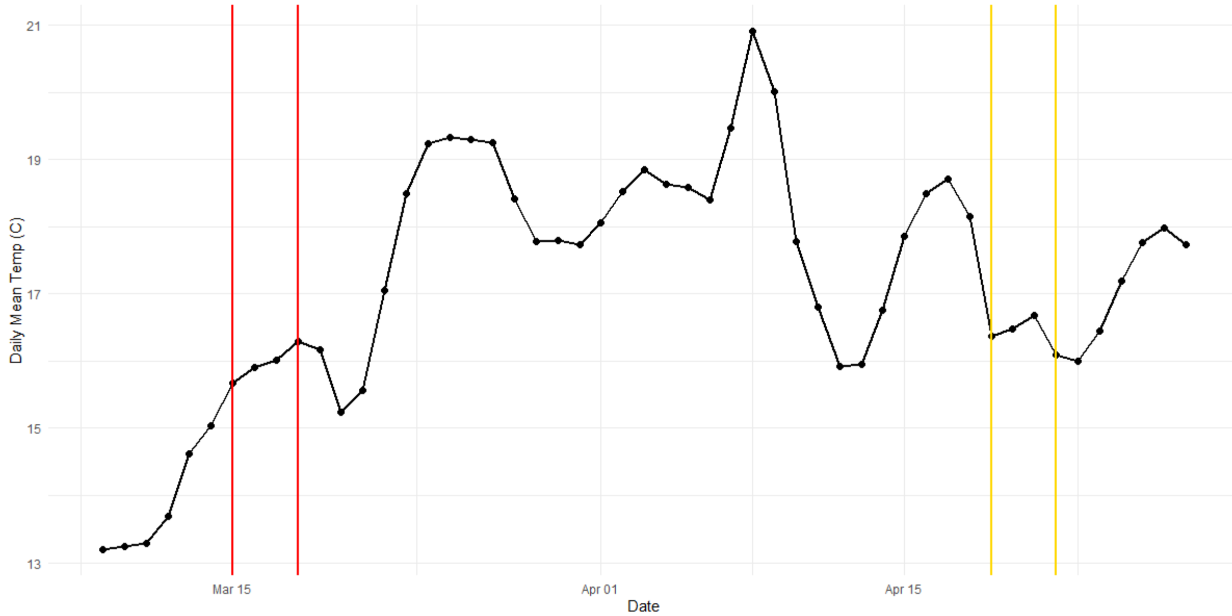

Figure 13. Daily mean water temperature (°C) at Vernalis. Release weeks denoted by colors: March (red), April (yellow).

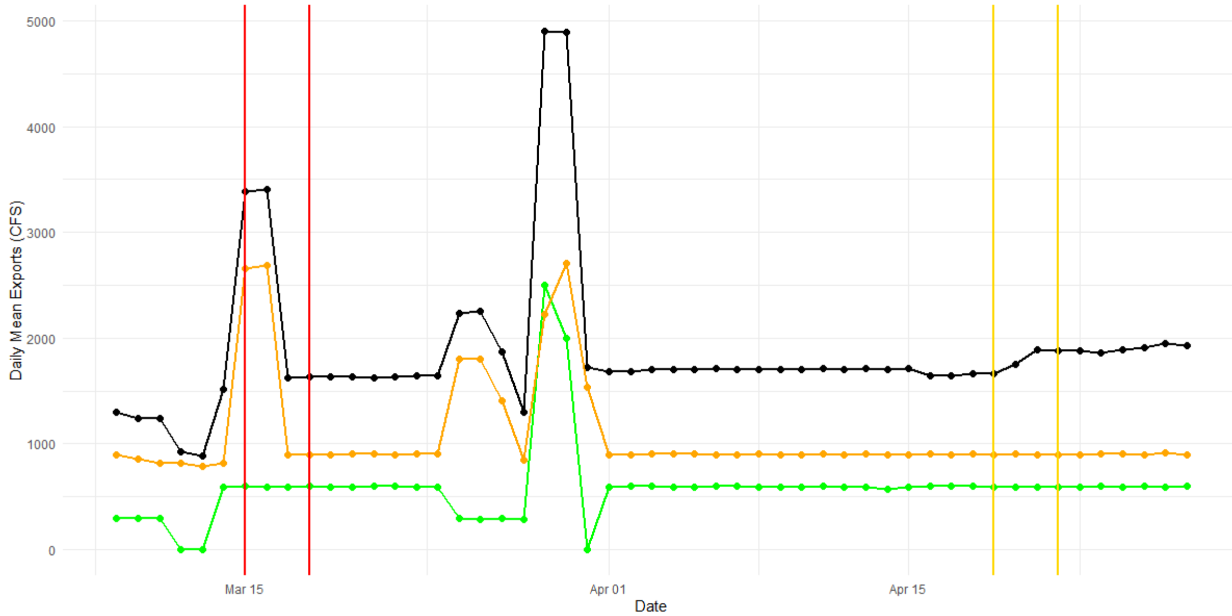

Figure 14. Daily mean Central Valley Project (orange), State Water Project (green), and total exports (black). Release weeks denoted by colors: March (red), April (yellow).

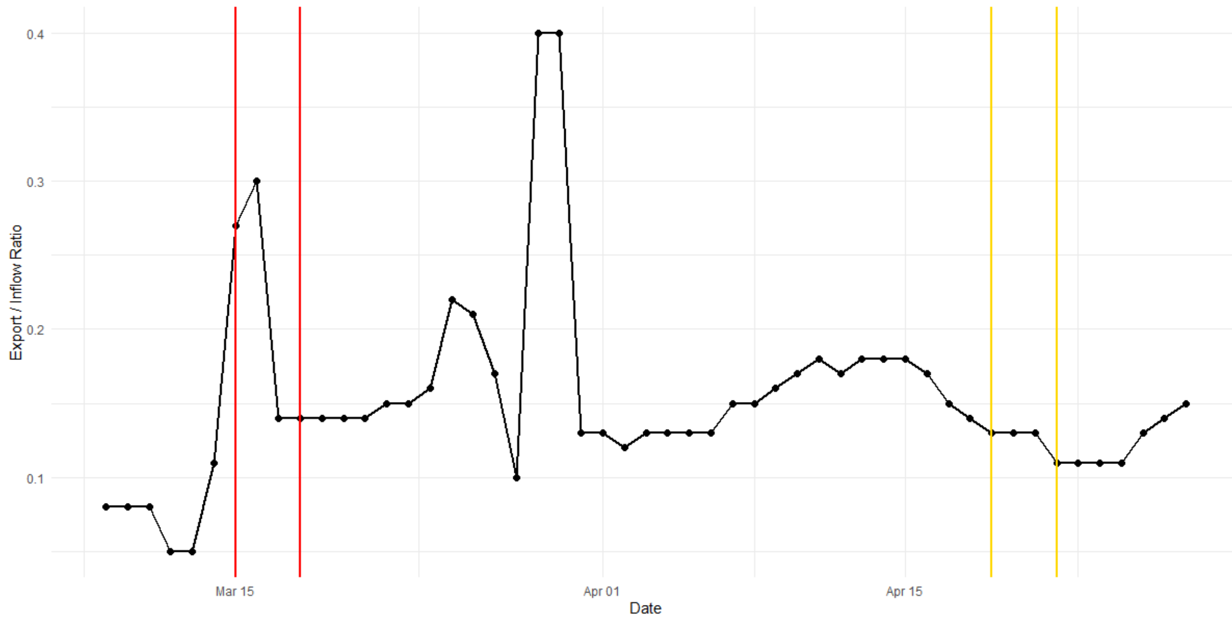

Figure 15. Daily mean export/inflow ratio. Release weeks denoted by colors: March (red), April (yellow).

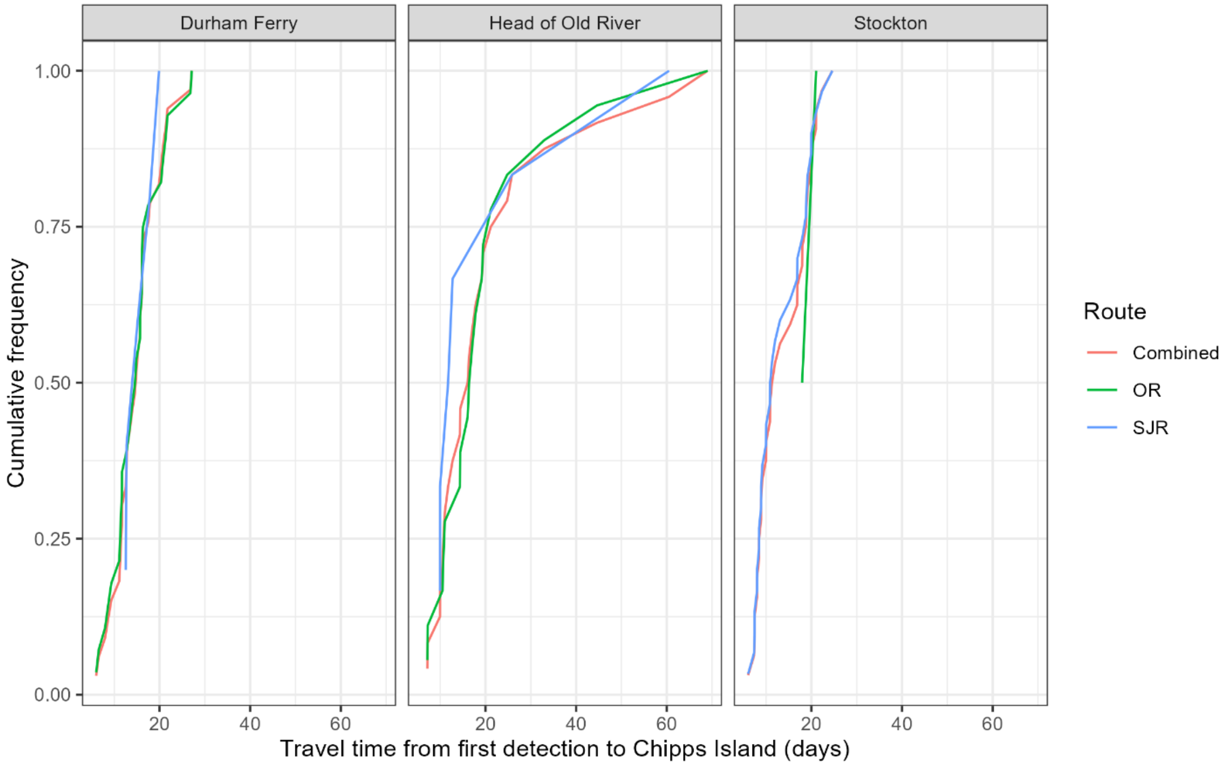

Figure 16. For those fish that made it to Chipps Island, the cumulative frequency of travel times (in days) from release to Chipps Island, based on the unfiltered dataset. Cumulative frequencies of travel times are displayed by route (San Joaquin River (SJR), Old River (OR), or Combined SJR and OR) and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

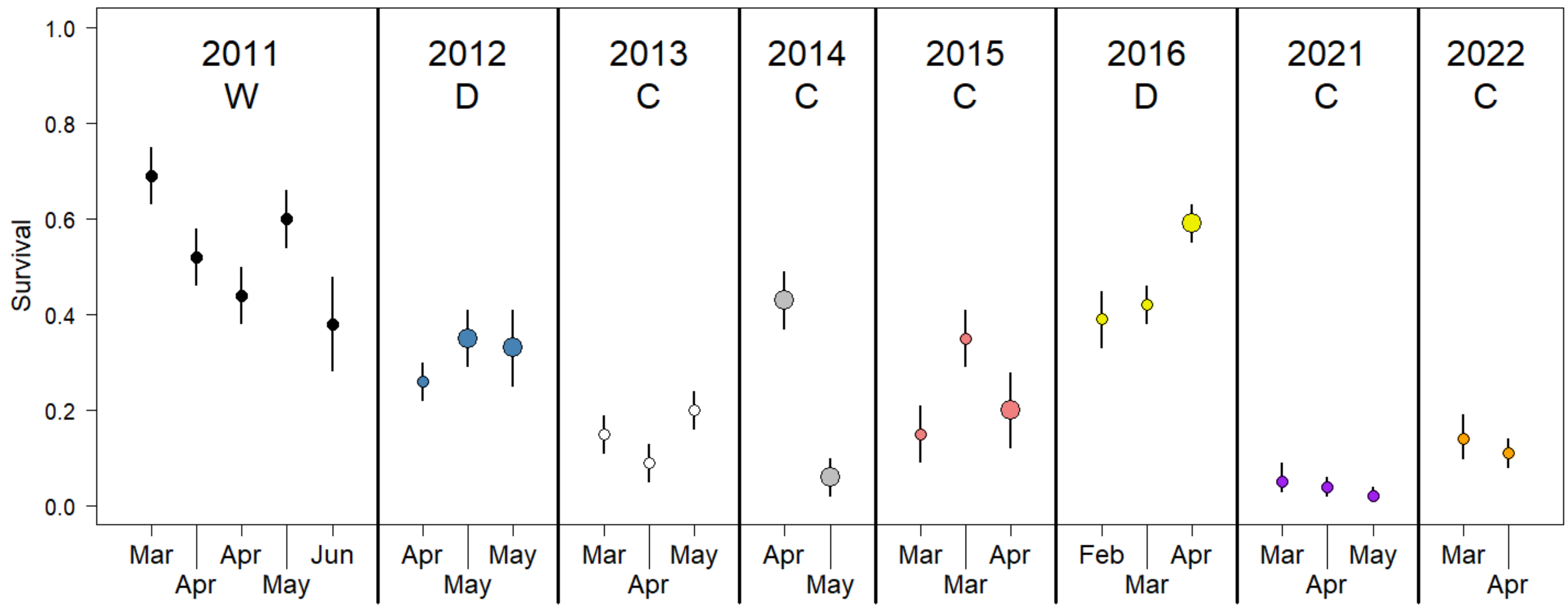

Figure 17. Juvenile steelhead through-Delta survival with 95% confidence intervals (from Mossdale to Chipps Island) from 2011-2016 (reported n Buchanan et al. 2021), 2021 (Matthias et al. 2024), and 2022. Water year types for the San Joaquin River Basin were wet (W), dry (D), and critically dry (C) during 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).

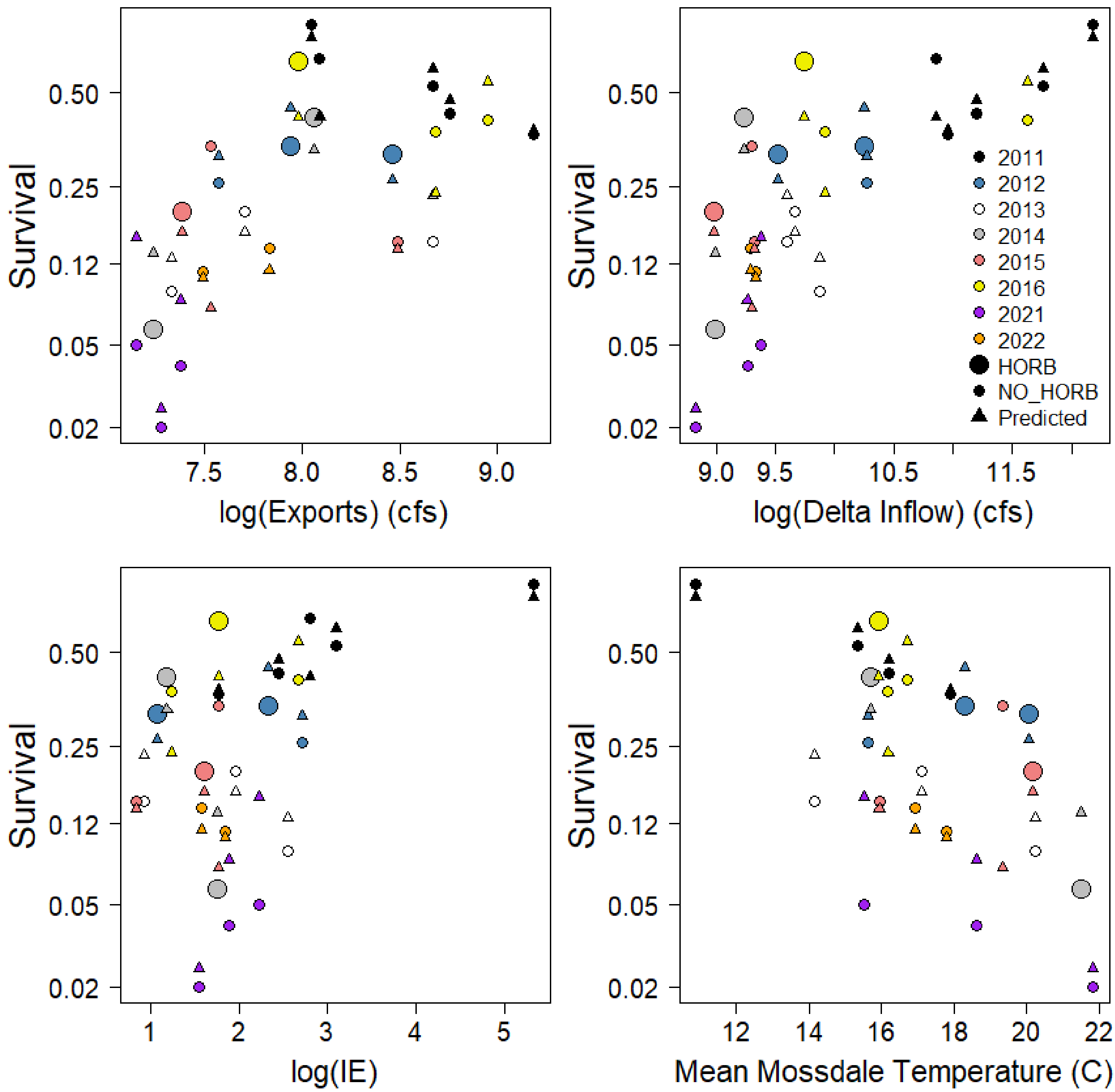

Figure 18. Juvenile steelhead through-Delta survival (from Mossdale to Chipps Island) from 2011-2016 (reported in Buchanan et al. 2021), 2021 (Matthias et al. 2024), and 2022. Environmental (total Delta inflow and mean temperature at Mossdale) and management (exports and Inflow:Export (IE) ratio) conditions were calculated as the mean values over the release period. The head of Old River barrier (HORB) was not installed in some years (2011, 2013, 2021, and 2022).

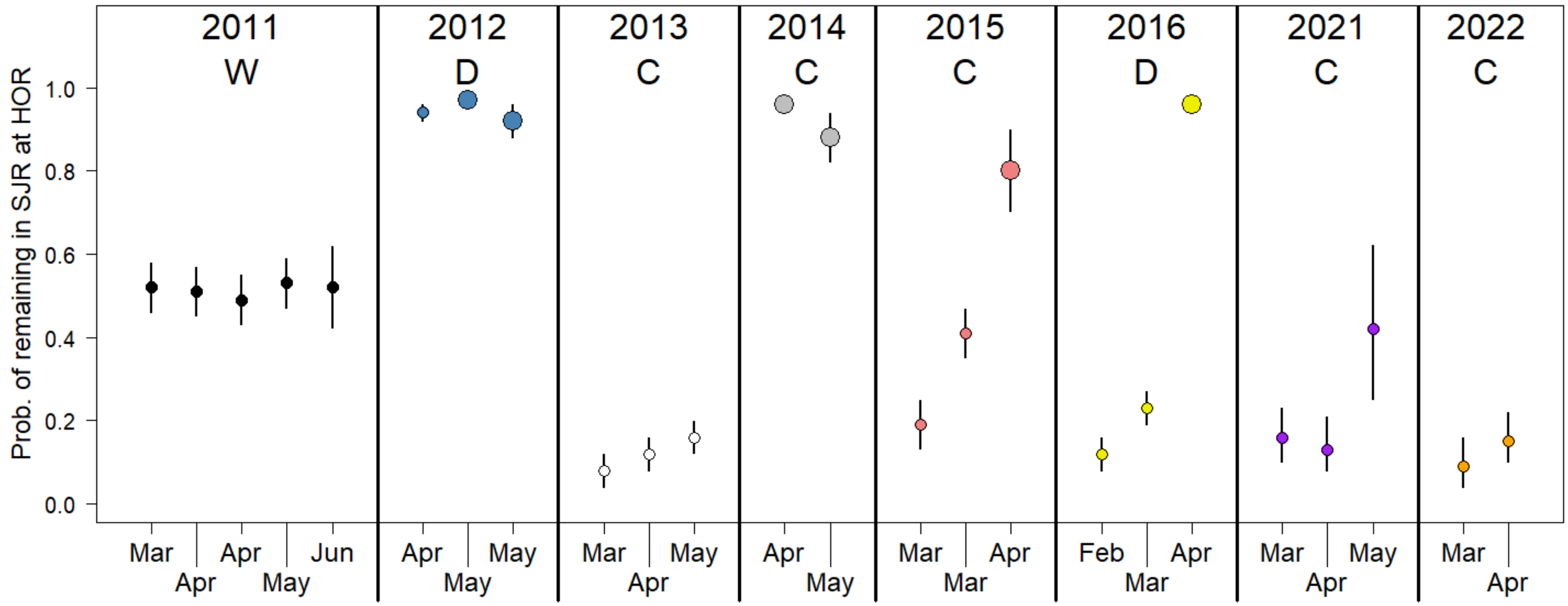

Figure 19. Juvenile steelhead routing at the Head of Old River (probability of remaining in the San Joaquin River) with 95% confidence intervals from 2011-2016 (reported in Buchanan 2018a, 2018b, 2018c, USBR 2018a, 2018b, 2018c), 2021 (Matthias et al. 2024), and 2022. Water year types for the San Joaquin 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).

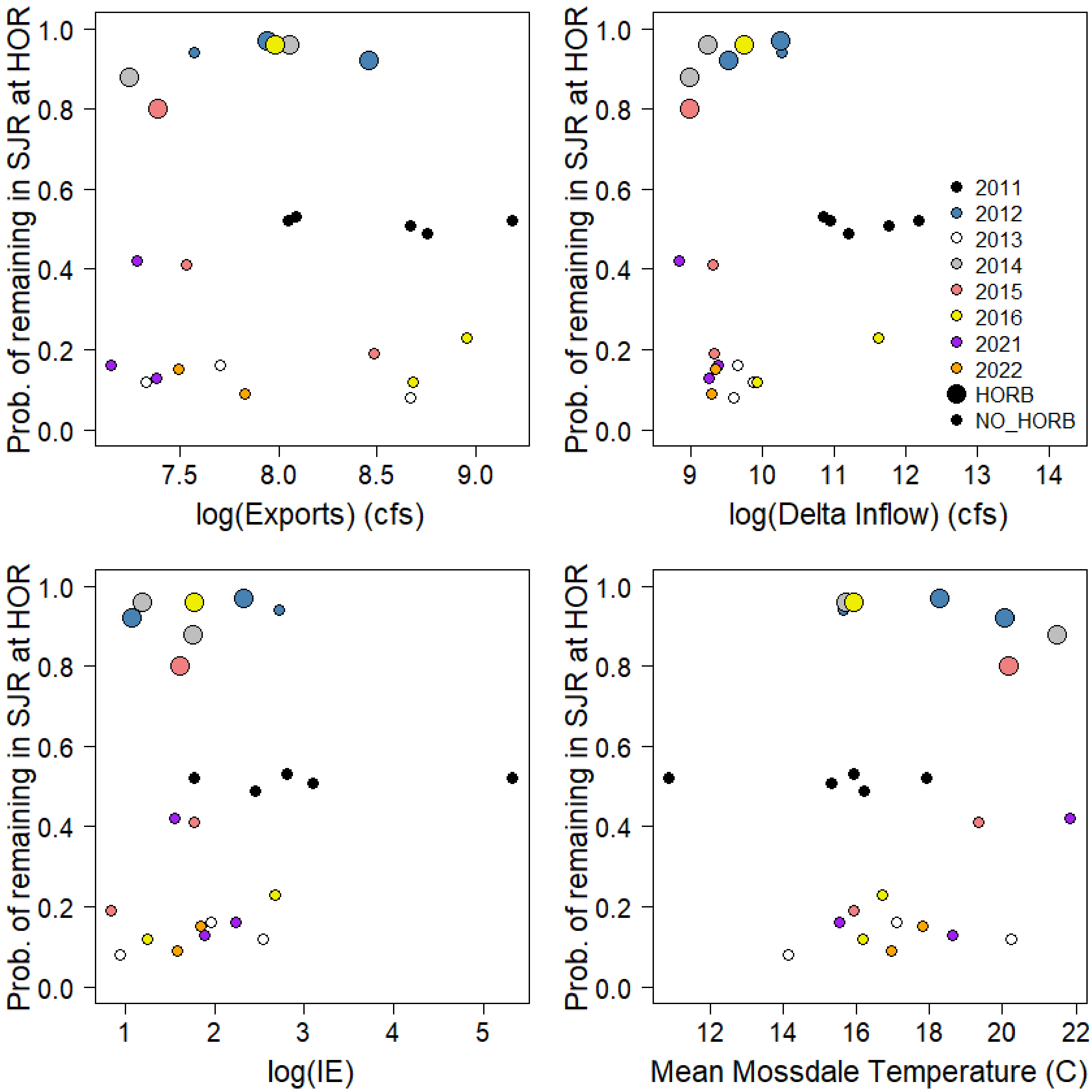

Figure 20. Juvenile steelhead routing at the Head of Old River from 2011-2016, 2021, and 2022. Environmental (total Delta inflow and mean temperature at Mossdale) and management (exports and Inflow:Export (IE) ratio) conditions were calculated as the mean values over the release period. The head of Old River barrier (HORB) was not installed in some years (2011, 2013, 2021, 2022).

Appendix

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

Table A1. 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	-0.05	0.09	0.49	0.44	0.53
Survival from Delta Entry to Chipps via San Joaquin Route	lphi_SJSJ	-2.06	0.28	0.11	0.07	0.18
Survival from Delta Entry to Chipps via Turner Cut Route	lphi_SJTC	-2.42	0.30	0.08	0.05	0.14
Survival from Delta Entry to Chipps via Middle River Route	lphi_ORMR	-2.32	0.59	0.09	0.03	0.24
Survival from Delta Entry to Chipps via Old River Route[1]	lphi_OROR	-2.10	0.15	0.11	0.08	0.14
Survival from Delta Entry to Chipps via Grant Line Canal Route[1]	lphi_ORGL	-2.10	0.15	0.11	0.08	0.14
Survival from Delta Entry to Chipps via San Joaquin River Routes (SJ and TC)	lphi_SJ	-2.21	0.26	0.10	0.06	0.15
Survival from Delta Entry to Chipps via Old River Routes (MR, OR, GLC)	lphi_OR	-2.10	0.15	0.11	0.08	0.14
Through-Delta Survival	lphi_TD	-2.05	0.13	0.11	0.09	0.14
Through-Bay Survival	lphi_TB	1.29	0.36	0.78	0.64	0.88
Survival from SJ downstream of HOR to Turner Cut	lphi_SJtTC	-0.97	0.26	0.28	0.19	0.39
Survival from Durham Ferry to Benicia	lphi_DFtB	-2.90	0.13	0.05	0.04	0.07
Survival from Head of Old River Release to Benicia	lphi_HORtB	-2.15	0.13	0.10	0.08	0.13
Survival from Stockton Release to Benicia	lphi_STtB	-1.81	0.17	0.14	0.11	0.18
Difference HOR release survival and HOR-reach survival *not logit space	dphi_HOR	0.02	0.03			
Difference in ST release survival and ST-reach survival *not logit space	dphi_ST	-0.18	0.07			

Table A2. 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	-0.46	0.13	0.39	0.33	0.45
Survival from Delta Entry to Chipps via San Joaquin Route	lphi_SJSJ	-2.81	0.50	0.06	0.02	0.14
Survival from Delta Entry to Chipps via Turner Cut Route	lphi_SJTC	-2.76	0.50	0.06	0.02	0.15
Survival from Delta Entry to Chipps via Middle River Route	lphi_ORMR	-1.76	0.50	0.15	0.06	0.31
Survival from Delta Entry to Chipps via Old River Route[1]	lphi_OROR	-1.86	0.21	0.13	0.09	0.19
Survival from Delta Entry to Chipps via Grant Line Canal Route[1]	lphi_ORGL	-1.86	0.21	0.13	0.09	0.19
Survival from Delta Entry to Chipps via San Joaquin River Routes (SJ and TC)	lphi_SJ	-2.78	0.47	0.06	0.02	0.13
Survival from Delta Entry to Chipps via Old River Routes (MR, OR, GLC)	lphi_OR	-1.85	0.20	0.14	0.10	0.19
Through-Delta Survival	lphi_TD	-1.91	0.20	0.13	0.09	0.18
Through-Bay Survival	lphi_TB	1.33	0.49	0.79	0.59	0.91
Survival from SJ downstream of HOR to Turner Cut	lphi_SJtTC	-1.77	0.45	0.15	0.07	0.29
Survival from Durham Ferry to Benicia	lphi_DFtB	-3.00	0.21	0.05	0.03	0.07
Survival from Head of Old River Release to Benicia	lphi_HORtB	-2.09	0.19	0.11	0.08	0.15
Survival from Stockton Release to Benicia	lphi_STtB	-1.98	0.26	0.24	0.08	0.19
Difference HOR release survival and HOR-reach survival *not logit space	dphi_HOR	0.01	0.04			
Difference in ST release survival and ST-reach survival *not logit space	dphi_ST	-0.09	0.13			

Table A3. 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	0.35	0.14	0.59	0.52	0.65
Survival from Delta Entry to Chipps via San Joaquin Route	lphi_SJSJ	-1.31	0.27	0.21	0.14	0.32
Survival from Delta Entry to Chipps via Turner Cut Route	lphi_SJTC	-2.08	0.32	0.11	0.06	0.19
Survival from Delta Entry to Chipps via Middle River Route	lphi_ORMR	-2.87	1.07	0.05	0.01	0.32
Survival from Delta Entry to Chipps via Old River Route[1]	lphi_OROR	-2.35	0.21	0.09	0.06	0.13
Survival from Delta Entry to Chipps via Grant Line Canal Route[1]	lphi_ORGL	-2.35	0.21	0.09	0.06	0.13
Survival from Delta Entry to Chipps via San Joaquin River Routes (SJ and TC)	lphi_SJ	-1.64	0.24	0.16	0.11	0.24
Survival from Delta Entry to Chipps via Old River Routes (MR, OR, GLC)	lphi_OR	-2.36	0.21	0.09	0.06	0.13
Through-Delta Survival	lphi_TD	-2.19	0.17	0.10	0.07	0.14
Through-Bay Survival	lphi_TB	1.25	0.46	0.78	0.59	0.90
Survival from SJ downstream of HOR to Turner Cut	lphi_SJtTC	-0.16	0.25	0.46	0.34	0.58
Survival from Durham Ferry to Benicia	lphi_DFtB	-2.80	0.18	0.06	0.04	0.08
Survival from Head of Old River Release to Benicia	lphi_HORtB	-2.21	0.17	0.10	0.07	0.13
Survival from Stockton Release to Benicia	lphi_STtB	-1.64	0.21	0.16	0.11	0.23
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	-0.27	0.07			

Table A4. Mean reach-specific survival random effects estimates (Est.), standard errors (SE), and lower and upper 95% confidence intervals (L_{95} and U_{95}, respectively) across all release groups for an average-sized fish. Parameter estimates were obtained from the model using data processed with the 1-hit predator filter.

Parameter Description	Est.	SE	L_{95}	U_{95}
RE for Reach 1: DF release	0.78	0.02	0.75	0.82
RE for Reach 2: HOR release	0.92	0.02	0.89	0.96
RE for Reach 3: ST release	0.55	0.04	0.47	0.62
RE for Reach 4: DF_DS to SJ_BCA	0.70	0.02	0.65	0.75
RE for Reach 5: SJ_BCA to Mossdale	0.87	0.02	0.83	0.92
RE for Reach 6: Mossdale to SJ_HOR or OR_HOR	0.90	0.02	0.86	0.94
RE for Reach 7: SJ-HOR to Howard	0.60	0.05	0.49	0.70
RE for Reach 8: Howard to SJG	0.66	0.08	0.50	0.83
RE for Reach 9: SJG to MAC or TC	0.77	0.09	0.60	0.95
RE for Reach 10: MAC to 3-mile, Jersey Point, CVP or SWP	0.50	0.07	0.36	0.64
RE for Reach 11: Turner Cut to 3-mile, Jersey Point, CVP or SWP	0.51	0.08	0.36	0.66
RE for Reach 12: OR_HOR to OR_MR junction	0.80	0.02	0.76	0.85
RE for Reach 13: MR_OR to MR_RRB, OR_RRB, CVP, or SWP	0.62	0.29	0.06	1.18
RE for Reach 14: MR_RRB to 3-mile or Jersey Point	0.37	0.14	0.10	0.64
RE for Reach 15: OR_MidR to OR_Tracy or GLC	0.76	0.03	0.70	0.83
RE for Reach 16: OR_Tracy to MR_RRB, OR_RRB, CVP, or SWP[1]	*1.00*	*0.00*	*1.00*	*1.00*
RE for Reach 17: OR_RRB to 3-mile or Jersey Point	0.35	0.09	0.17	0.53
RE for Reach 18: GLC to MR_RRB, OR_RRB, CVP, or SWP[1]	*1.00*	*0.00*	*1.00*	*1.00*
RE for Reach 19: CVP trash rack to Chipps Island	0.28	0.05	0.17	0.38
RE for Reach 20: CCF_inlet to CCF_intake	0.45	0.05	0.36	0.55
RE for Reach 21: CCF_intake to Chipps Island	0.30	0.06	0.18	0.43
RE for Reach 22: 3-mile to Chipps Island	0.88	0.08	0.72	1.04
RE for Reach 23: Jersey Point to Chipps Island	0.88	0.05	0.79	0.97
RE for Reach 24: Chipps Island to Benicia	0.96	0.02	0.92	1.00
RE for Reach 25: Benicia to Golden Gate E	0.82	0.06	0.70	0.93

[1]Survival in reaches 16 and 18 were not estimated, but were combined with reach 15 to estimate survival from the split with Middle River to the pumping facilities or MR/OR Railroad Bridge. These reaches were estimated in the 2021 study.

Table A5. 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	1.01	0.15	0.73	0.67	0.79
RE for Reach 2: HOR release	2.36	0.29	0.91	0.86	0.95
RE for Reach 3: ST release	0.04	0.23	0.51	0.40	0.62
RE for Reach 4: DF_DS to SJ_BCA	0.58	0.16	0.64	0.56	0.71
RE for Reach 5: SJ_BCA to Mossdale	1.57	0.26	0.83	0.74	0.89
RE for Reach 6: Mossdale to SJ_HOR or OR_HOR	2.20	0.33	0.90	0.83	0.94
RE for Reach 7: SJ-HOR to Howard	-0.04	0.32	0.49	0.34	0.65
RE for Reach 8: Howard to SJG	-0.09	0.60	0.48	0.22	0.75
RE for Reach 9: SJG to MAC or TC	0.79	0.77	0.69	0.33	0.91
RE for Reach 10: MAC to 3-mile, Jersey Point, CVP or SWP	-0.11	0.48	0.47	0.26	0.70
RE for Reach 11: Turner Cut to 3-mile, Jersey Point, CVP or SWP	-0.01	0.50	0.50	0.27	0.72
RE for Reach 12: OR_HOR to OR_MR junction	1.22	0.22	0.77	0.69	0.84
RE for Reach 13: MR_OR to MR_RRB, OR_RRB, CVP, or SWP	0.92	1.41	0.72	0.14	0.98
RE for Reach 14: MR_RRB to 3-mile or Jersey Point	-0.09	0.92	0.48	0.13	0.85
RE for Reach 15: OR_MidR to OR_Tracy or GLC	0.64	0.22	0.66	0.55	0.74
RE for Reach 16: OR_Tracy to MR_RRB, OR_RRB, CVP, or SWP			*1.00*	*1.00*	*1.00*
RE for Reach 17: OR_RRB to 3-mile or Jersey Point	-0.25	0.56	0.44	0.21	0.70
RE for Reach 18: GLC to MR_RRB, OR_RRB, CVP, or SWP			*1.00*	*1.00*	*1.00*
RE for Reach 19: CVP trash rack to Chipps Island	-0.36	0.40	0.41	0.24	0.61
RE for Reach 20: CCF_inlet to CCF_intake	-0.14	0.30	0.47	0.32	0.61
RE for Reach 21: CCF_intake to Chipps Island	-0.31	0.44	0.42	0.24	0.63
RE for Reach 22: 3-mile to Chipps Island	1.80	1.10	0.86	0.41	0.98
RE for Reach 23: Jersey Point to Chipps Island	1.87	0.62	0.87	0.66	0.96
RE for Reach 24: Chipps Island to Benicia	2.90	0.67	0.95	0.83	0.99
RE for Reach 25: Benicia to Golden Gate E	1.62	0.57	0.83	0.62	0.94
Mean of survival RE	0.82	0.32			
Slope for the survival-length relationship*	0.18	0.05			
Log(SD) for Release-specific random effect hyperparameter*	0.11	0.32			
Log(SD) for Reach-specific random effect hyperparameter*	0.37	0.15			

[1]Survival in reaches 16 and 18 were not estimated, but were combined with reach 15 to estimate survival from the split with Middle River to the pumping facilities or MR/OR Railroad Bridge. These reaches were estimated in the 2021 study.

Table A6. 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	1.62	0.19	0.84	0.78	0.88
RE for Reach 2: HOR release	2.65	0.35	0.93	0.88	0.97
RE for Reach 3: ST release	0.35	0.22	0.59	0.48	0.68
RE for Reach 4: DF_DS to SJ_BCA	1.17	0.18	0.76	0.70	0.82
RE for Reach 5: SJ_BCA to Mossdale	2.46	0.33	0.92	0.86	0.96
RE for Reach 6: Mossdale to SJ_HOR or OR_HOR	2.24	0.29	0.90	0.84	0.94
RE for Reach 7: SJ-HOR to Howard	0.85	0.31	0.70	0.56	0.81
RE for Reach 8: Howard to SJG	1.73	0.56	0.85	0.65	0.94
RE for Reach 9: SJG to MAC or TC	1.79	0.53	0.86	0.68	0.94
RE for Reach 10: MAC to 3-mile, Jersey Point, CVP or SWP	0.13	0.33	0.53	0.38	0.68
RE for Reach 11: Turner Cut to 3-mile, Jersey Point, CVP or SWP	0.11	0.34	0.53	0.36	0.69
RE for Reach 12: OR_HOR to OR_MR junction	1.61	0.21	0.83	0.77	0.88
RE for Reach 13: MR_OR to MR_RRB, OR_RRB, CVP, or SWP	0.07	1.98	0.52	0.02	0.98
RE for Reach 14: MR_RRB to 3-mile or Jersey Point	-0.99	0.75	0.27	0.08	0.62
RE for Reach 15: OR_MidR to OR_Tracy or GLC	1.88	0.32	0.87	0.78	0.92
RE for Reach 16: OR_Tracy to MR_RRB, OR_RRB, CVP, or SWP			*1.00*	*1.00*	*1.00*
RE for Reach 17: OR_RRB to 3-mile or Jersey Point	-1.04	0.55	0.26	0.11	0.51
RE for Reach 18: GLC to MR_RRB, OR_RRB, CVP, or SWP			*1.00*	*1.00*	*1.00*
RE for Reach 19: CVP trash rack to Chipps Island	-1.78	0.32	0.14	0.08	0.24
RE for Reach 20: CCF_inlet to CCF_intake	-0.24	0.25	0.44	0.33	0.56
RE for Reach 21: CCF_intake to Chipps Island	-1.48	0.41	0.19	0.09	0.34
RE for Reach 22: 3-mile to Chipps Island	2.22	1.04	0.90	0.55	0.99
RE for Reach 23: Jersey Point to Chipps Island	2.12	0.61	0.89	0.72	0.97
RE for Reach 24: Chipps Island to Benicia	3.55	0.82	0.97	0.87	0.99
RE for Reach 25: Benicia to Golden Gate E	1.39	0.50	0.80	0.60	0.91
Mean of survival RE	1.02	0.33			
Slope for the survival-length relationship*	0.18	0.05			
Log(SD) for Release-specific random effect hyperparameter*	0.11	0.32			
Log(SD) for Reach-specific random effect hyperparameter*	0.37	0.15			

[1]Survival in reaches 16 and 18 were not estimated, but were combined with reach 15 to estimate survival from the split with Middle River to the pumping facilities or MR/OR Railroad Bridge. These reaches were estimated in the 2021 study.

Table A7. 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	-0.35	0.15	0.41	0.34	0.49
ρ_2	Prob. of taking 3-mile vs. Jersey Point to Chipps Island	-1.65	0.36	0.16	0.09	0.28
ρ_3	Prob. of remaining in SJ @ HOR for DF release	-1.94	0.22	0.13	0.09	0.18
ρ_4	Prob. of taking SJ route for HOR release vs. OR route	-1.24	0.15	0.22	0.18	0.28
ρ_5	Prob. of going downstream @ ST release	0.69	0.22	0.67	0.56	0.75
ρ_6	Prob. of remaining in SJ @ Turner Cut	0.02	0.21	0.50	0.40	0.61
ρ_7	Prob. of heading to pumps after passing MAC	-3.00	0.77	0.05	0.01	0.18
ρ_8	Prob. of heading to pumps after entering Turner Cut	-1.20	0.62	0.23	0.08	0.51
ρ_9	Prob. of taking MR @ MR-OR split	-3.39	0.62	0.03	0.01	0.10
ρ_{10}	Prob. of heading to interior delta vs. pumps from MR	-1.40	0.99	0.20	0.03	0.63
ρ_{11}	Prob. of heading to interior via MR_RRB vs OR_RRB from MR	-0.62	1.13	0.35	0.06	0.83
ρ_{12}	Prob. of taking OR @ OR-GLC split			*0.50*	*0.50*	*0.50*
ρ_{13}	Prob. of heading to interior delta vs. pumps from OR	-1.41	0.21	0.20	0.14	0.27
ρ_{14}	Prob. of heading to interior delta via MR_RRB vs. OR_RRB from OR	-1.37	0.45	0.20	0.10	0.38
ρ_{15}	Prob. of heading to interior delta vs. pumps from GLC	-1.41	0.21	0.20	0.14	0.27
ρ_{16}	Prob. of heading to interior delta via MR_RRB vs. OR_RRB from GLC	-1.37	0.45	0.20	0.10	0.38

Table A8. 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	-0.64	0.25	0.35	0.24	0.46
ρ_2	Prob. of taking 3-mile vs. Jersey Point to Chipps Island	-1.78	0.57	0.14	0.05	0.34
ρ_3	Prob. of remaining in SJ @ HOR for DF release	-2.37	0.38	0.09	0.04	0.16
ρ_4	Prob. of taking SJ route for HOR release vs. OR route	-1.09	0.20	0.25	0.19	0.33
ρ_5	Prob. of going downstream @ ST release	0.22	0.31	0.55	0.40	0.69
ρ_6	Prob. of remaining in SJ @ Turner Cut	0.00	0.36	0.50	0.33	0.67
ρ_7	Prob. of heading to pumps after passing MAC	-2.65	1.16	0.07	0.01	0.41
ρ_8	Prob. of heading to pumps after entering Turner Cut	-2.63	1.16	0.07	0.01	0.41
ρ_9	Prob. of taking MR @ MR-OR split	-2.57	0.56	0.07	0.02	0.19
ρ_{10}	Prob. of heading to interior delta vs. pumps from MR	-1.47	0.94	0.19	0.04	0.59
ρ_{11}	Prob. of heading to interior via MR_RRB vs OR_RRB from MR	0.03	1.36	0.51	0.07	0.94
ρ_{12}	Prob. of taking OR @ OR-GLC split			*0.50*	*0.50*	*0.50*
ρ_{13}	Prob. of heading to interior delta vs. pumps from OR	-1.21	0.30	0.23	0.14	0.35
ρ_{14}	Prob. of heading to interior delta via MR_RRB vs. OR_RRB from OR	-1.78	0.66	0.14	0.04	0.38
ρ_{15}	Prob. of heading to interior delta vs. pumps from GLC	-1.21	0.30	0.23	0.14	0.35
ρ_{16}	Prob. of heading to interior delta via MR_RRB vs. OR_RRB from GLC	-1.78	0.66	0.14	0.04	0.38
μ_ρ	Hyperparameter mean of transition probability in logit space*	-1.23	0.34			

Table A9. 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	-0.05	0.17	0.49	0.41	0.57
ρ_2	Prob. of taking 3-mile vs. Jersey Point to Chipps Island	-1.53	0.45	0.18	0.08	0.34
ρ_3	Prob. of remaining in SJ @ HOR for DF release	-1.52	0.22	0.18	0.12	0.25
ρ_4	Prob. of taking SJ route for HOR release vs. OR route	-1.40	0.21	0.20	0.14	0.27
ρ_5	Prob. of going downstream @ ST release	1.17	0.31	0.76	0.63	0.86
ρ_6	Prob. of remaining in SJ @ Turner Cut	0.04	0.23	0.51	0.40	0.62
ρ_7	Prob. of heading to pumps after passing MAC	-3.35	1.01	0.03	0.00	0.20
ρ_8	Prob. of heading to pumps after entering Turner Cut	0.23	0.45	0.56	0.34	0.75
ρ_9	Prob. of taking MR @ MR-OR split	-4.20	1.10	0.01	0.00	0.11
ρ_{10}	Prob. of heading to interior delta vs. pumps from MR	-1.33	1.71	0.21	0.01	0.88
ρ_{11}	Prob. of heading to interior via MR_RRB vs OR_RRB from MR	-1.26	1.76	0.22	0.01	0.90
ρ_{12}	Prob. of taking OR @ OR-GLC split			*0.50*	*0.50*	*0.50*
ρ_{13}	Prob. of heading to interior delta vs. pumps from OR	-1.60	0.26	0.17	0.11	0.25
ρ_{14}	Prob. of heading to interior delta via MR_RRB vs. OR_RRB from OR	-0.95	0.51	0.28	0.13	0.51
ρ_{15}	Prob. of heading to interior delta vs. pumps from GLC	-1.60	0.26	0.17	0.11	0.25
ρ_{16}	Prob. of heading to interior delta via MR_RRB vs. OR_RRB from GLC	-0.95	0.51	0.28	0.13	0.51
μ_ρ	Hyperparameter mean of transition probability in logit space*	-1.23	0.34			

Table A10. 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	L95	U95	Line Est.
p_1	Logit Detection: DF_DS	2.55	0.23	0.93	0.89	0.95	
p_2	Logit Detection: SJ_BCA	2.36	0.23	0.91	0.87	0.94	
p_3	Logit Detection: Mossdale	2.44	0.25	0.92	0.88	0.95	
p_4	Logit Detection: SJ_HOR (Combined dual-line)	0.38	0.27	0.59	0.46	0.71	0.83
p_5	Logit Detection: Howard	0.54	0.26	0.63	0.50	0.74	
p_6	Logit Detection: SJG (Combined dual-line)	0.86	0.31	0.70	0.56	0.81	0.91
p_7	Logit Detection: MAC (Combined dual-line)	2.06	0.52	0.89	0.74	0.96	0.99
p_8	Logit Detection: Turner Cut (Combined dual-line)	1.17	0.46	0.76	0.57	0.89	0.94
p_9	Logit Detection: OR_HOR (Combined dual-line)	2.36	1.08	0.91	0.56	0.99	0.99
p_{10}	Logit Detection: MR_OR	0.00	0.00	0.00	0.00	0.00	
p_{11}	Logit Detection: MR_RRB	1.15	0.49	0.76	0.55	0.89	
p_{12}	Logit Detection: OR_MidR	2.00	1.37	0.88	0.34	0.99	
p_{13}	Logit Detection: OR_Tracy (Combined dual-line)			*0.00*	*0.00*	*0.00*	
p_{14}	Logit Detection: OR_RRB	1.97	0.25	0.88	0.82	0.92	
p_{15}	Logit Detection: GLC (Combined dual-line)			*0.00*	*0.00*	*0.00*	
p_{16}	Logit Detection: CVP_trash_rack	4.48	0.76	0.99	0.95	1.00	
p_{17}	Logit Detection: CCF_Inlet	0.27	0.52	0.57	0.32	0.79	
p_{18}	Logit Detection: CCF_Intake	3.37	0.94	0.97	0.82	0.99	
p_{19}	Logit Detection: 3-mile Slough (Combined dual-line)	1.89	1.57	0.87	0.23	0.99	0.98
p_{20}	Logit Detection: Jersey Point (Combined dual-line)	1.13	0.41	0.76	0.58	0.87	0.94
p_{21}	Logit Detection: Chipps Island (Combined dual-line)	2.08	0.51	0.89	0.75	0.96	0.99
p_{22}	Logit Detection: Benicia (Combined dual-line)	2.84	0.87	0.94	0.76	0.99	1.00
p_{23}	Logit Detection: Golden Gate E	3.40	0.69	0.97	0.89	0.99	
p_{24}	Logit Detection: Golden Gate W	3.11	0.99	0.96	0.76	0.99	
μ_p	Hyperparameter mean detection probability in logit space	2.02	0.34				
$\log(\sigma_p)$	Hyperparameter log(SD) for detection random effect	0.29	0.25				

Appendix B: Model Results from the Multi-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 multi-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	-0.07	0.09	0.48	0.44	0.53
Survival from Delta Entry to Chipps via San Joaquin Route	lphi_SJSJ	-1.88	0.29	0.13	0.08	0.21
Survival from Delta Entry to Chipps via Turner Cut Route	lphi_SJTC	-2.27	0.30	0.09	0.05	0.16
Survival from Delta Entry to Chipps via Middle River Route	lphi_ORMR	-2.32	0.69	0.09	0.02	0.28
Survival from Delta Entry to Chipps via Old River Route	lphi_OROR	-2.05	0.14	0.11	0.09	0.15
Survival from Delta Entry to Chipps via Grant Line Canal Route	lphi_ORGL	-2.05	0.14	0.11	0.09	0.15
Survival from Delta Entry to Chipps via San Joaquin River Routes (SJ and TC)	lphi_SJ	-2.04	0.26	0.11	0.07	0.18
Survival from Delta Entry to Chipps via Old River Routes (MR, OR, GLC)	lphi_OR	-2.06	0.14	0.11	0.09	0.14
Through-Delta Survival	lphi_TD	-1.98	0.13	0.12	0.10	0.15
Through-Bay Survival	lphi_TB	1.25	0.35	0.78	0.64	0.87
Survival from SJ downstream of HOR to Turner Cut	lphi_SJtTC	-0.67	0.27	0.34	0.23	0.46
Survival from Durham Ferry to Benicia	lphi_DFtB	-2.85	0.13	0.05	0.04	0.07
Survival from Head of Old River Release to Benicia	lphi_HORtB	-2.10	0.13	0.11	0.09	0.14
Survival from Stockton Release to Benicia	lphi_STtB	-1.82	0.16	0.14	0.11	0.18
Difference HOR release survival and HOR-reach survival *not logit space	dphi_HOR	0.00	0.02			
Difference in ST release survival and ST-reach survival *not logit space	dphi_ST	-0.19	0.07			

Table B2. Derived survival estimates for the March releases. Parameter estimates were obtained from the model using data processed with the multi-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	0.13	0.39	0.33	0.45
Survival from Delta Entry to Chipps via San Joaquin Route	lphi_SJSJ	-2.77	0.51	0.06	0.02	0.15
Survival from Delta Entry to Chipps via Turner Cut Route	lphi_SJTC	-2.72	0.51	0.06	0.02	0.15
Survival from Delta Entry to Chipps via Middle River Route	lphi_ORMR	-1.76	0.51	0.15	0.06	0.32
Survival from Delta Entry to Chipps via Old River Route	lphi_OROR	-1.79	0.20	0.14	0.10	0.20
Survival from Delta Entry to Chipps via Grant Line Canal Route	lphi_ORGL	-1.79	0.20	0.14	0.10	0.20
Survival from Delta Entry to Chipps via San Joaquin River Routes (SJ and TC)	lphi_SJ	-2.74	0.47	0.06	0.02	0.14
Survival from Delta Entry to Chipps via Old River Routes (MR, OR, GLC)	lphi_OR	-1.79	0.20	0.14	0.10	0.20
Through-Delta Survival	lphi_TD	-1.85	0.19	0.14	0.10	0.19
Through-Bay Survival	lphi_TB	1.17	0.45	0.76	0.57	0.89
Survival from SJ downstream of HOR to Turner Cut	lphi_SJtTC	-1.73	0.46	0.15	0.07	0.30
Survival from Durham Ferry to Benicia	lphi_DFtB	-2.96	0.20	0.05	0.03	0.07
Survival from Head of Old River Release to Benicia	lphi_HORtB	-2.04	0.19	0.12	0.08	0.16
Survival from Stockton Release to Benicia	lphi_STtB	-1.98	0.25	0.12	0.08	0.19
Difference HOR release survival and HOR-reach survival *not logit space	dphi_HOR	0.01	0.04			
Difference in ST release survival and ST-reach survival *not logit space	dphi_ST	-0.07	0.12			

Table B3. Derived survival estimates for the April releases. Parameter estimates were obtained from the model using data processed with the multi-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	0.32	0.13	0.58	0.51	0.64
Survival from Delta Entry to Chipps via San Joaquin Route	lphi_SJSJ	-0.99	0.28	0.27	0.18	0.39
Survival from Delta Entry to Chipps via Turner Cut Route	lphi_SJTC	-1.81	0.32	0.14	0.08	0.24
Survival from Delta Entry to Chipps via Middle River Route	lphi_ORMR	-2.88	1.29	0.05	0.00	0.41
Survival from Delta Entry to Chipps via Old River Route	lphi_OROR	-2.32	0.21	0.09	0.06	0.13
Survival from Delta Entry to Chipps via Grant Line Canal Route	lphi_ORGL	-2.32	0.21	0.09	0.06	0.13
Survival from Delta Entry to Chipps via San Joaquin River Routes (SJ and TC)	lphi_SJ	-1.35	0.24	0.21	0.14	0.29
Survival from Delta Entry to Chipps via Old River Routes (MR, OR, GLC)	lphi_OR	-2.33	0.21	0.09	0.06	0.13
Through-Delta Survival	lphi_TD	-2.12	0.17	0.11	0.08	0.14
Through-Bay Survival	lphi_TB	1.32	0.48	0.79	0.59	0.91
Survival from SJ downstream of HOR to Turner Cut	lphi_SJtTC	0.39	0.28	0.60	0.46	0.72
Survival from Durham Ferry to Benicia	lphi_DFtB	-2.74	0.18	0.06	0.04	0.08
Survival from Head of Old River Release to Benicia	lphi_HORtB	-2.17	0.17	0.10	0.08	0.14
Survival from Stockton Release to Benicia	lphi_STtB	-1.66	0.21	0.16	0.11	0.22
Difference HOR release survival and HOR-reach survival *not logit space	dphi_HOR	0.00	0.03			
Difference in ST release survival and ST-reach survival *not logit space	dphi_ST	-0.31	0.07			

Table B4. Mean reach-specific survival random effects estimates (Est.), standard errors (SE), and lower and upper 95% confidence intervals (L_{95} and U_{95}, respectively) across all release groups for an average-sized fish. Parameter estimates were obtained from the model using data processed with the multi-hit predator filter.

Parameter Description	Est.	SE	L_{95}	U_{95}
RE for Reach 1: DF release	0.78	0.02	0.74	0.82
RE for Reach 2: HOR release	0.93	0.02	0.90	0.96
RE for Reach 3: ST release	0.55	0.04	0.47	0.62
RE for Reach 4: DF_DS to SJ_BCA	0.72	0.02	0.67	0.77
RE for Reach 5: SJ_BCA to Mossdale	0.85	0.02	0.80	0.89
RE for Reach 6: Mossdale to SJ_HOR or OR_HOR	0.92	0.02	0.89	0.96
RE for Reach 7: SJ-HOR to Howard	0.66	0.05	0.57	0.77
RE for Reach 8: Howard to SJG	0.66	0.08	0.52	0.82
RE for Reach 9: SJG to MAC or TC	0.79	0.09	0.62	0.96
RE for Reach 10: MAC to 3-mile, Jersey Point, CVP or SWP	0.50	0.07	0.35	0.64
RE for Reach 11: Turner Cut to 3-mile, Jersey Point, CVP or SWP	0.50	0.08	0.36	0.65
RE for Reach 12: OR_HOR to OR_MR junction	0.83	0.02	0.78	0.88
RE for Reach 13: MR_OR to MR_RRB, OR_RRB, CVP, or SWP	0.60	0.32	-0.03	1.22
RE for Reach 14: MR_RRB to 3-mile or Jersey Point	0.30	0.12	0.07	0.53
RE for Reach 15: OR_MidR to OR_Tracy or GLC	0.76	0.03	0.70	0.82
RE for Reach 16: OR_Tracy to MR_RRB, OR_RRB, CVP, or SWP[1]	*1.00*			
RE for Reach 17: OR_RRB to 3-mile or Jersey Point	0.37	0.09	0.19	0.55
RE for Reach 18: GLC to MR_RRB, OR_RRB, CVP, or SWP[1]	*1.00*			
RE for Reach 19: CVP trash rack to Chipps Island	0.27	0.05	0.17	0.37
RE for Reach 20: CCF_inlet to CCF_intake	0.47	0.05	0.37	0.56
RE for Reach 21: CCF_intake to Chipps Island	0.29	0.06	0.17	0.41
RE for Reach 22: 3-mile to Chipps Island	0.90	0.07	0.76	1.04
RE for Reach 23: Jersey Point to Chipps Island	0.88	0.05	0.79	0.97
RE for Reach 24: Chipps Island to Benicia	0.95	0.02	0.91	1.00
RE for Reach 25: Benicia to Golden Gate E	0.82	0.06	0.70	0.93

[1]Survival in reaches 16 and 18 were not estimated, but were combined with reach 15 to estimate survival from the split with Middle River to the pumping facilities or MR/OR Railroad Bridge. These reaches were estimated in the 2021 study.

Table B5. 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	0.99	0.15	0.73	0.67	0.78
RE for Reach 2: HOR release	2.43	0.30	0.92	0.86	0.95
RE for Reach 3: ST release	0.05	0.22	0.51	0.41	0.62
RE for Reach 4: DF_DS to SJ_BCA	0.71	0.17	0.67	0.59	0.74
RE for Reach 5: SJ_BCA to Mossdale	1.34	0.24	0.79	0.71	0.86
RE for Reach 6: Mossdale to SJ_HOR or OR_HOR	2.31	0.34	0.91	0.84	0.95
RE for Reach 7: SJ-HOR to Howard	0.16	0.33	0.54	0.38	0.69
RE for Reach 8: Howard to SJG	-0.22	0.57	0.45	0.21	0.71
RE for Reach 9: SJG to MAC or TC	0.79	0.78	0.69	0.32	0.91
RE for Reach 10: MAC to 3-mile, Jersey Point, CVP or SWP	-0.12	0.48	0.47	0.26	0.70
RE for Reach 11: Turner Cut to 3-mile, Jersey Point, CVP or SWP	-0.02	0.50	0.49	0.27	0.72
RE for Reach 12: OR_HOR to OR_MR junction	1.40	0.23	0.80	0.72	0.87
RE for Reach 13: MR_OR to MR_RRB, OR_RRB, CVP, or SWP	0.91	1.47	0.71	0.12	0.98
RE for Reach 14: MR_RRB to 3-mile or Jersey Point	-0.68	0.82	0.34	0.09	0.72
RE for Reach 15: OR_MidR to OR_Tracy or GLC	0.68	0.21	0.66	0.57	0.75
RE for Reach 16: OR_Tracy to MR_RRB, OR_RRB, CVP, or SWP[1]			*1.00*	*1.00*	*1.00*
RE for Reach 17: OR_RRB to 3-mile or Jersey Point	-0.20	0.55	0.45	0.22	0.71
RE for Reach 18: GLC to MR_RRB, OR_RRB, CVP, or SWP[1]			*1.00*	*1.00*	*1.00*
RE for Reach 19: CVP trash rack to Chipps Island	-0.39	0.39	0.40	0.24	0.59
RE for Reach 20: CCF_inlet to CCF_intake	-0.18	0.30	0.46	0.32	0.60
RE for Reach 21: CCF_intake to Chipps Island	-0.33	0.44	0.42	0.23	0.63
RE for Reach 22: 3-mile to Chipps Island	1.99	1.09	0.88	0.46	0.98
RE for Reach 23: Jersey Point to Chipps Island	1.88	0.63	0.87	0.66	0.96
RE for Reach 24: Chipps Island to Benicia	2.59	0.59	0.93	0.81	0.98
RE for Reach 25: Benicia to Golden Gate E	1.51	0.55	0.82	0.61	0.93
Mean of survival RE	0.81	0.33			
Slope for the survival-length relationship*	0.17	0.05			
Log(SD) for Release-specific random effect hyperparameter*	0.11	0.32			
Log(SD) for Reach-specific random effect hyperparameter*	0.41	0.14			

[1]Survival in reaches 16 and 18 were not estimated, but were combined with reach 15 to estimate survival from the split with Middle River to the pumping facilities or MR/OR Railroad Bridge. These reaches were estimated in the 2021 study.

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 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	1.62	0.19	0.84	0.78	0.88
RE for Reach 2: HOR release	2.65	0.35	0.93	0.88	0.97
RE for Reach 3: ST release	0.33	0.21	0.58	0.48	0.68
RE for Reach 4: DF_DS to SJ_BCA	1.21	0.18	0.77	0.70	0.83
RE for Reach 5: SJ_BCA to Mossdale	2.20	0.29	0.90	0.84	0.94
RE for Reach 6: Mossdale to SJ_HOR or OR_HOR	2.70	0.35	0.94	0.88	0.97
RE for Reach 7: SJ-HOR to Howard	1.36	0.37	0.80	0.65	0.89
RE for Reach 8: Howard to SJG	2.15	0.63	0.90	0.71	0.97
RE for Reach 9: SJG to MAC or TC	2.13	0.59	0.89	0.72	0.96
RE for Reach 10: MAC to 3-mile, Jersey Point, CVP or SWP	0.08	0.32	0.52	0.37	0.67
RE for Reach 11: Turner Cut to 3-mile, Jersey Point, CVP or SWP	0.05	0.34	0.51	0.35	0.67
RE for Reach 12: OR_HOR to OR_MR junction	1.78	0.23	0.86	0.79	0.90
RE for Reach 13: MR_OR to MR_RRB, OR_RRB, CVP, or SWP	-0.08	2.25	0.48	0.01	0.99
RE for Reach 14: MR_RRB to 3-mile or Jersey Point	-1.03	0.76	0.26	0.07	0.61
RE for Reach 15: OR_RRB to OR_Tracy or GLC	1.78	0.30	0.86	0.77	0.91
RE for Reach 16: OR_Tracy to MR_RRB, OR_RRB, CVP, or SWP[1]			*1.00*	*1.00*	*1.00*
RE for Reach 17: OR_RRB to 3-mile or Jersey Point	-0.94	0.53	0.28	0.12	0.53
RE for Reach 18: GLC to MR_RRB, OR_RRB, CVP, or SWP[1]			*1.00*	*1.00*	*1.00*
RE for Reach 19: CVP trash rack to Chipps Island	-1.90	0.32	0.13	0.07	0.22
RE for Reach 20: CCF_inlet to CCF_intake	-0.08	0.25	0.48	0.36	0.60
RE for Reach 21: CCF_intake to Chipps Island	-1.59	0.41	0.17	0.08	0.31
RE for Reach 22: 3-mile to Chipps Island	2.37	1.05	0.91	0.58	0.99
RE for Reach 23: Jersey Point to Chipps Island	2.15	0.62	0.90	0.72	0.97
RE for Reach 24: Chipps Island to Benicia	3.64	0.84	0.97	0.88	0.99
RE for Reach 25: Benicia to Golden Gate E	1.45	0.52	0.81	0.61	0.92
Mean of survival RE	1.09	0.33			
Slope for the survival-length relationship*	0.17	0.05			
Log(SD) for Release-specific random effect hyperparameter*	0.11	0.32			
Log(SD) for Reach-specific random effect hyperparameter*	0.41	0.14			

[1]Survival in reaches 16 and 18 were not estimated, but were combined with reach 15 to estimate survival from the split with Middle River to the pumping facilities or MR/OR Railroad Bridge. These reaches were estimated in the 2021 study.

Table B7. 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	-0.25	0.15	0.44	0.37	0.51
ρ_2	Prob. of taking 3-mile vs. Jersey Point to Chipps Island	-1.46	0.34	0.19	0.11	0.31
ρ_3	Prob. of remaining in SJ @ HOR for DF release	-2.04	0.22	0.12	0.08	0.17
ρ_4	Prob. of taking SJ route for HOR release vs. OR route	-1.41	0.15	0.20	0.15	0.25
ρ_5	Prob. of going downstream @ ST release	0.70	0.22	0.67	0.57	0.76
ρ_6	Prob. of remaining in SJ @ Turner Cut	0.02	0.21	0.50	0.40	0.61
ρ_7	Prob. of heading to pumps after passing MAC	-2.99	0.77	0.05	0.01	0.19
ρ_8	Prob. of heading to pumps after entering Turner Cut	-1.19	0.62	0.23	0.08	0.51
ρ_9	Prob. of taking MR @ MR-OR split	-3.41	0.68	0.03	0.01	0.11
ρ_{10}	Prob. of heading to interior delta vs. pumps from MR	-1.38	0.99	0.20	0.03	0.64
ρ_{11}	Prob. of heading to interior via MR_RRB vs OR_RRB from MR	-0.60	1.13	0.35	0.06	0.83
ρ_{12}	Prob. of taking OR @ OR-GLC split			*0.50*	*0.50*	*0.50*
ρ_{13}	Prob. of heading to interior delta vs. pumps from OR	-1.35	0.20	0.21	0.15	0.28
ρ_{14}	Prob. of heading to interior delta via MR_RRB vs. OR_RRB from OR	-1.19	0.40	0.23	0.12	0.40
ρ_{15}	Prob. of heading to interior delta vs. pumps from GLC	-1.35	0.20	0.21	0.15	0.28
ρ_{16}	Prob. of heading to interior delta via MR_RRB vs. OR_RRB from GLC	-1.19	0.40	0.23	0.12	0.10

Table B8. 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 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	-0.54	0.24	0.37	0.27	0.48
ρ_2	Prob. of taking 3-mile vs. Jersey Point to Chipps Island	-1.53	0.52	0.18	0.07	0.37
ρ_3	Prob. of remaining in SJ @ HOR for DF release	-2.38	0.38	0.09	0.04	0.16
ρ_4	Prob. of taking SJ route for HOR release vs. OR route	-1.18	0.20	0.24	0.17	0.31
ρ_5	Prob. of going downstream @ ST release	0.20	0.30	0.55	0.40	0.69
ρ_6	Prob. of remaining in SJ @ Turner Cut	0.00	0.36	0.50	0.33	0.67
ρ_7	Prob. of heading to pumps after passing MAC	-2.63	1.15	0.07	0.01	0.41
ρ_8	Prob. of heading to pumps after entering Turner Cut	-2.62	1.16	0.07	0.01	0.41
ρ_9	Prob. of taking MR @ MR-OR split	-2.64	0.57	0.07	0.02	0.18
ρ_{10}	Prob. of heading to interior delta vs. pumps from MR	-1.47	0.95	0.19	0.03	0.60
ρ_{11}	Prob. of heading to interior via MR_RRB vs OR_RRB from MR	0.03	1.38	0.51	0.06	0.94
ρ_{12}	Prob. of taking OR @ OR-GLC split			*0.50*	*0.50*	*0.50*
ρ_{13}	Prob. of heading to interior delta vs. pumps from OR	-1.10	0.28	0.25	0.16	0.37
ρ_{14}	Prob. of heading to interior delta via MR_RRB vs. OR_RRB from OR	-1.35	0.56	0.21	0.08	0.44
ρ_{15}	Prob. of heading to interior delta vs. pumps from GLC	-1.10	0.28	0.25	0.16	0.37
ρ_{16}	Prob. of heading to interior delta via MR_RRB vs. OR_RRB from GLC	-1.35	0.56	0.21	0.08	0.44
μ_ρ	Hyperparameter mean of transition probability in logit space*	-1.19	0.34			

Table B9. 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	0.05	0.16	0.51	0.43	0.59
ρ_2	Prob. of taking 3-mile vs. Jersey Point to Chipps Island	-1.38	0.42	0.20	0.10	0.36
ρ_3	Prob. of remaining in SJ @ HOR for DF release	-1.70	0.23	0.15	0.10	0.22
ρ_4	Prob. of taking SJ route for HOR release vs. OR route	-1.65	0.23	0.16	0.11	0.23
ρ_5	Prob. of going downstream @ ST release	1.21	0.31	0.77	0.64	0.86
ρ_6	Prob. of remaining in SJ @ Turner Cut	0.04	0.23	0.51	0.40	0.62
ρ_7	Prob. of heading to pumps after passing MAC	-3.34	1.00	0.03	0.00	0.20
ρ_8	Prob. of heading to pumps after entering Turner Cut	0.24	0.45	0.56	0.35	0.75
ρ_9	Prob. of taking MR @ MR-OR split	-4.18	1.23	0.02	0.00	0.15
ρ_{10}	Prob. of heading to interior delta vs. pumps from MR	-1.29	1.71	0.22	0.01	0.89
ρ_{11}	Prob. of heading to interior via MR_RRB vs OR_RRB from MR	-1.24	1.76	0.23	0.01	0.90
ρ_{12}	Prob. of taking OR @ OR-GLC split			*0.50*	*0.50*	*0.50*
ρ_{13}	Prob. of heading to interior delta vs. pumps from OR	-1.60	0.25	0.17	0.11	0.25
ρ_{14}	Prob. of heading to interior delta via MR_RRB vs. OR_RRB from OR	-1.04	0.49	0.26	0.12	0.48
ρ_{15}	Prob. of heading to interior delta vs. pumps from GLC	-1.60	0.25	0.17	0.11	0.25
ρ_{16}	Prob. of heading to interior delta via MR_RRB vs. OR_RRB from GLC	-1.04	0.49	0.26	0.12	0.48
μ_ρ	Hyperparameter mean of transition probability in logit space*	-1.19	0.34			

Table B10. 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.

		Logit-Scale		Transformed Est.			
Par.	Parameter Description	Est.	SE	Mean	L_{95}	U_{95}	Dual-Line Est.
p_1	Logit Detection: DF_DS	2.57	0.23	0.93	0.89	0.95	
p_2	Logit Detection: SJ_BCA	2.46	0.24	0.92	0.88	0.95	
p_3	Logit Detection: Mossdale	2.45	0.25	0.92	0.88	0.95	
p_4	Logit Detection: SJ_HOR (Combined dual-line)	0.33	0.27	0.58	0.45	0.70	0.82
p_5	Logit Detection: Howard	0.63	0.26	0.65	0.53	0.76	
p_6	Logit Detection: SJG (Combined dual-line)	0.86	0.31	0.70	0.56	0.81	0.91
p_7	Logit Detection: MAC (Combined dual-line)	2.06	0.52	0.89	0.74	0.96	0.99
p_8	Logit Detection: Turner Cut (Combined dual-line)	1.21	0.45	0.77	0.58	0.89	0.95
p_9	Logit Detection: OR_HOR (Combined dual-line)	2.39	1.10	0.92	0.56	0.99	0.99
p_{10}	Logit Detection: MR_OR	0.00	0.00	0.00	0.00	0.00	
p_{11}	Logit Detection: MR_RRB	1.16	0.49	0.76	0.55	0.89	
p_{12}	Logit Detection: OR_MidR	2.09	1.36	0.89	0.36	0.99	
p_{13}	Logit Detection: OR_Tracy (Combined dual-line)			*0.00*	*0.00*	*0.00*	
p_{14}	Logit Detection: OR_RRB	2.01	0.25	0.88	0.82	0.92	
p_{15}	Logit Detection: GLC (Combined dual-line)			*0.00*	*0.00*	*0.00*	
p_{16}	Logit Detection: CVP_trash_rack	4.55	0.76	0.99	0.96	1.00	
p_{17}	Logit Detection: CCF_Inlet	0.18	0.49	0.55	0.31	0.76	
p_{18}	Logit Detection: CCF_Intake	3.42	0.95	0.97	0.82	0.99	
p_{19}	Logit Detection: 3-mile Slough (Combined dual-line)	1.94	1.57	0.87	0.24	0.99	0.98
p_{20}	Logit Detection: Jersey Point (Combined dual-line)	1.14	0.42	0.76	0.58	0.88	0.94
p_{21}	Logit Detection: Chipps Island (Combined dual-line)	2.10	0.52	0.89	0.75	0.96	0.99
p_{22}	Logit Detection: Benicia (Combined dual-line)	2.86	0.89	0.95	0.75	0.99	1.00
p_{23}	Logit Detection: Golden Gate E	3.45	0.70	0.97	0.89	0.99	
p_{24}	Logit Detection: Golden Gate W	3.16	1.00	0.96	0.77	0.99	
μ_p	Hyperparameter mean detection probability in logit space	2.05	0.35				
$\log(\sigma_p)$	Hyperparameter log(SD) for detection random effect	0.31	0.24				