2016 Six-Year Acoustic Telemetry Steelhead Study: Statistical Methods and Results

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Executive Summary

A total of 1,440 acoustic-tagged steelhead were released into the San Joaquin River at Durham Ferry in February, March, and April of 2016: 480 in February, 480 in March, and 480 in late April. Detection data were also available from 300 acoustic tags implanted into several species of predatory fish released in the Delta in April and May of 2014 and 2015. Acoustic tags were detectable on VEMCO hydrophones located at 44 stations throughout the lower San Joaquin River and Delta to Chipps Island (i.e., Mallard Slough) and Benicia Bridge. A rock barrier was installed at the head of Old River in early April 2016. Tagging and observation data were processed to construct detection histories, and data were passed through a predator filter to identify and remove detections thought to come from predators. Detection history data were analyzed using a multi-state release-recapture model to estimate survival, route selection, and transition probabilities throughout the Delta; receiver station detection probabilities were estimated concurrently from the release-recapture model. The survival and transition probabilities were adjusted for premature tag failure based on modeled tag survival from three tag-life studies. For all release groups, survival estimates included both the probability of migrating downriver and surviving, so that the complement included the probability of residualization as well as mortality.

Using only those detections classified as coming from juvenile steelhead by the predator filter, the estimates of total survival from Mossdale to Chipps Island, S_{Total}, ranged from 0.39 ($\widehat{SE} = 0.03$) for the February release group to 0.59 ($\widehat{SE} = 0.02$) for the April release group; the overall population estimate from all three releases (weighted average) was 0.47 ($\widehat{SE} = 0.02$). The estimated probability of entering Old River at its head was highest for the February release group (0.88, $\widehat{SE} = 0.02$), which passed mostly before the Head of Old River barrier was installed on April 1; estimates were still high (0.77, $\widehat{SE} = 0.02$) for the March release group, most of which passed before the barrier installation was complete, and were noticeably lower for the April release (0.04, $\widehat{SE} = 0.01$). The population estimate of Old River route selection over all three releases was 0.56 ($\widehat{SE} = 0.01$). There was a statistically significant preference for the Old River route for the February and March releases, and for the San Joaquin River route for the April release ($P<0.0001$ for each release group). Estimates of survival from Mossdale to Chipps Island via the San Joaquin River route $\left(S_A\right)$ ranged from 0.23 ($\widehat{SE} = 0.08$) for the February release group to 0.61 ($\widehat{SE} = 0.02$) for the April release; the population estimate, averaged over all three release groups, was 0.45 ($\widehat{SE} = 0.03$) overall. In the Old River route, estimates of survival from Mossdale to Chipps Island (S_B) ranged from 0.17 ($\widehat{SE} = 0.06$) for the April release to 0.41 ($\widehat{SE} = 0.04$) for the February release (population average = 0.33, $\widehat{SE} = 0.03$). The route-specific survival to Chipps Island was significantly different (at the 5% level) between routes for the April release group, when survival was higher in the San Joaquin River route than in the Old River route (P=0.0002). For the March release group, the point estimate of San Joaquin River route survival (0.50) was also higher than for the Old River route (0.40), but the difference was statistically significant only at the 10% level (P=0.0612). There was no significance difference in survival to Chipps Island between routes for the February release (P=0.1216). When combined over all three release groups, the population estimate of route-specific survival to Chipps Island was higher for the San Joaquin River route than for the Old River route (P=0.0034).

Travel time from release at Durham Ferry to Chipps Island ranged from 2.8 days to 41.2 days, and averaged 8.32 days ($\widehat{SE} = 0.19$ days) for all three release groups combined. Average travel time to Chipps Island was longest for the February release group (13.2 days), and shortest for the March release group (6.6 days); the April group had travel time similar to March (8.8 days). Average travel time to all detection sites was longest for the February release group. Travel time from release to the Mossdale receivers averaged approximately 6 days for the February release group, compared to 1.0 to 1.6 days for the March and April release groups. Travel time to the Turner Cut junction (i.e., receivers at either Turner Cut or MacDonald Island) ranged from 1.7 days to 32.8 days, and averaged 17.6 days for the February release, and approximately 5 days for the March and April releases.

A barrier was in place (i.e., after barrier closure during installation) at the head of Old River for passage of approximately 42% of the tagged steelhead in the 2016 tagging study. Of the 569 tagged steelhead that arrived at the head of Old River before the barrier closure during installation, 463 (81%) entered Old River. A route analysis was performed for the head of Old River using fish that arrived before barrier closure, using covariates measuring river discharge (flow), water velocity, export rates, fish length, river stage, and time of day of fish arrival at the river junction. Covariates that had significant associations with route selection at the head of Old River included a modeled estimate of flow at SJL (P<0.0001), river stage at MSD (P=0.0001), flow at MSD (P=0.0006), stage at OH1 (P=0.0009), OH1:MSD flow ratio (P=0.0015), and stage at SJL (P=0.0017) (Table 18). The regression model that accounted for the most variation in route selection at the head of Old River used river stage at MSD and the 15-minute change in river stage at SJL. The model predicted that fish that arrived at the junction at higher river stages had a lower probability of entering Old River, and a higher probability of remaining in the San Joaquin River, whereas fish that arrived at the junction at higher levels of 15-minute change in river stage at SJL were more likely to enter Old River.

Route selection was analyzed at the Turner Cut junction using 389 tags, of which 24% entered Turner Cut, using measures of flow, water velocity, and river stage, export rates, fish length, and time of day of arrival at the junction. Covariates that had statistically significant associations with route selection at this river junction were the 15-minute change in river stage at the TRN gaging station in Turner Cut ($P<0.0001$) and both flow and velocity at TRN ($P=0.0003$). The regression model that accounted for the most variability in route selection at Turner Cut included the 15-minute change in river stage at TRN and flow at TRN. The modeled predicted that fish that arrived at the junction (i.e., passed the SJS receivers) at higher levels of the 15-minute change in river stage or higher levels of flow at TRN had a lower probability of entering Turner Cut.

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Introduction

A total of 1,440 acoustic-tagged juvenile steelhead were released into the San Joaquin River at Durham Ferry in February, March, and April of 2016; 480 were released in each of these months. Each steelhead was surgically implanted with a VEMCO V5 microacoustic tag. Each acoustic tag transmitted two unique identification codes: a traditional Pulse Position Modulation (PPM) code and a High Residence (HR) code, which provided detections on high residence receivers. The acoustic tags were detectable on hydrophones located at 44 stations throughout the lower San Joaquin River and Delta to Chipps Island (i.e., Mallard Slough) and Benicia Bridge. Detection data were also available from 300 acoustic tags implanted into several species of predatory fish released in the Delta in April and May of 2014 and 2015. A rock barrier was installed at the head of Old River in early April 2016; closure of the barrier was on 1 April 2016, and the barrier was breached on 1 June 2016.

VEMCO acoustic hydrophones and receivers were installed at 44 stations throughout the lower San Joaquin River and Delta in 2016 (Figure 1, Table 1). All of the receiver stations used in 2015 (Buchanan 2018b) were also used in 2016. One new receiver station was used in 2016, in the San Joaquin River near the Calaveras River (SJC = model code A10).

Statistical Methods

Data Processing for Survival Analysis

The University of Washington received the database of tagging and release data from the US Fish and Wildlife Service. The tagging database included the date and time of tag activation and tagging surgery for each tagged steelhead released in 2016, as well as the name of the surgeon (i.e., tagger), and the date and time of release of the tagged fish to the river. Fish size (length and weight), tag size, and any notes about fish condition were included, as well as the survival status of the fish at the time of release. Tag serial number and two unique tagging codes were provided for each tag, representing codes for various types of signal coding. Tagging data were summarized according to release group and tagger, and were cross-checked with Pat Brandes (USFWS) and Josh Israel (USBR) for quality control. All tags used in the survival study were activated only once.

Acoustic tag detection data collected at individual monitoring sites (Table 1) were transferred to the US Geological Survey (USGS) in Sacramento, California. A multiple-step process was used to identify and verify detections of fish in the data files and produce summaries of detection data suitable for converting to tag detection histories. Detections were classified as valid if two or more pings were recorded within a 30 minute time frame on the hydrophones comprising a detection site from either of two tag codes associated with the tag; at the Central Valley Project trashrack receivers, a minimum of four pings were required within a 30 minute time frame for detections to be considered valid. The University of Washington received the primary database of autoprocessed detection data from the USGS. These data included the date, time, location, and tag codes and serial number of each valid detection of the acoustic steelhead tags on the fixed site receivers. The tag serial number indicated the acoustic tag ID, and were used to identify tag activation time, tag release time, and release group from the tagging database.

The autoprocessed database was cleaned to remove obviously invalid detections. The University of Washington identified potentially invalid detections based on unexpected travel times or unexpected transitions between detections, and queried the USGS processor about any discrepancies. All corrections were noted and made to the database. All subsequent analysis was based on this cleaned database.

The information for each tag in the database included the date and time of the beginning and end of each detection event when a tag was detected. Unique detection events were distinguished by detection on a separate hydrophone or by a time delay of 30 minutes between repeated hits on the same receiver. Separate events were also distinguished by unique signal coding schemes (i.e., PPM vs. HR). The cleaned detection event data were converted to detections denoting the beginning and end of receiver "visits;" consecutive visits to a receiver were separated either by a gap of at least 12 hours between detections on the receiver, or by detection on a different receiver array. Detections from receivers in dual or redundant arrays were pooled for this purpose, as were detections using different tag coding schemes.

The same data structure and data processing procedure were used to summarize detections of the acoustic-tagged predatory fish. Detections of the predatory fish were compared to detections of the steelhead tags to assist in distinguishing between detections of steelhead and detections of predators (see below).

Distinguishing between Detections of Steelhead and Predators

The possibility of predatory fish eating tagged study fish and then moving past one or more fixed site receivers complicated analysis of the detection data. The steelhead survival model depended on the assumption that all detections of the acoustic tags represented live juvenile steelhead, rather than a mix of live steelhead and predators that temporarily had a steelhead tag in their gut. Without removing the detections that came from predators, the survival model would produce potentially biased estimates of survival of actively migrating juvenile steelhead through the Delta. The size of the bias depends on the amount of predation by predatory fish and the spatial distribution of the predatory fish after eating the tagged steelhead. To minimize bias, the detection data were filtered for predator detections, and detections assumed to come from predators were identified.

The predator filter used for analysis of the 2016 data was based on the predator filter designed and used in the analysis of the 2011–2015 data (USBR 2018a, 2018b, 2018c; Buchanan 2018a, 2018b). The 2011 predator filter was based on predator analyses presented by Vogel (2010, 2011), as well as conversations with fisheries biologists familiar with the San Joaquin River and Delta regions. The 2011 filter served as the basis for construction of the predator filters used in later years. The 2016 filter was applied to all detections of all tags implanted in steelhead. Two datasets were then constructed: the full steelhead-tag dataset of all detections, including those classified as coming from predators (i.e., “predator-type”), and the reduced dataset, restricted to those detections classified as coming from live steelhead smolts (i.e., “smolt-type”). The survival model was fit to both datasets separately. The results from the analysis of the reduced “smolt-type” dataset are presented as the final results of the 2016 tagging study. Results from analysis of the full dataset including “predator-type” detections were used to indicate the degree of uncertainty in survival estimates arising from the predator decision process.

The predator filter used for steelhead tagging data must account for both the possibility of extended rearing by steelhead in the Delta before eventual outmigration, and the possibility of residualization. These possibilities mean that some steelhead may have long residence or transition times, or they may move upstream either with or against the flow. Nevertheless, it was assumed that steelhead could not move against very high flow, and that their upstream excursions would be limited after entering the Delta at the head of Old River. Maximum residence times and transition times were imposed for most regions of the Delta, even allowing for extended rearing.

Even with these flexible criteria for steelhead, it was impossible to perfectly distinguish between a residualizing or extended rearing steelhead and a resident predator. A truly residualizing steelhead that is classified as a predator should not bias the overall estimate of successfully leaving the Delta at Chipps Island, because a residualizing steelhead would not be detected at Chipps Island. However, the case of a steelhead exhibiting extended rearing or delayed migration before finally outmigrating past Chipps Island is more complicated. Such a steelhead may be classified as a predator based on long residence times, long transition times, and atypical movements within the Delta, or a combination of all three of these characteristics. Such a classification would negatively bias the overall estimate of true survival out of the Delta for steelhead. On the other hand, the survival model assumes common survival and detection probabilities for all steelhead, and thus is implicitly designed for actively migrating steelhead. With that understanding, the "survival" parameter estimated by the survival model is more properly interpreted as the joint probability of migration and survival, and its complement includes both mortality and extended rearing or residualization. The possibility of classifying steelhead with extended rearing times in the Delta as predators does not bias the survival model under this interpretation of the model parameters, and in fact is likely to improve model performance (i.e., fit) when these non-actively migrating steelhead detections are removed. In short, it was necessary either to limit survival analysis to actively migrating steelhead, or to assume that all detections came from steelhead. The first approach used the outcome of the predator filter described here for analysis. The second approach used all detection data.

The predator filter was based on assumed behavioral differences between actively migrating steelhead smolts and predators such as striped bass and channel catfish. For each steelhead tag, all detections were considered when implementing the filter, including detections from acoustic receivers that were not otherwise used in the survival model. As part of the decision process, environmental data including river flow, river stage, and water velocity were examined from several points throughout the Delta (Table 2), as available. Hydrologic data were downloaded from the California Data Exchange Center website (http://cdec.water.ca.gov/selectQuery.html) on 25 April 2017, and from the California Water Data Library (www.water.ca.gov/waterdatalibrary/) on 25–26 April 2017. Environmental data were reviewed for quality, and obvious errors were omitted. Daily pumping rates at the CVP and CCFB reservoir inflow rates were also used, downloaded from CDEC on 25 April 2016.

For each tag detection, several steps were performed to determine if it should be classified as predator or steelhead. Initially, all detections were assumed to be of live smolts. A tag was classified as a predator upon the first exhibition of predator-type behavior, with the acknowledged uncertainty that the steelhead smolt may actually have been eaten sometime before the first obvious predator-type detection. Once a detection was classified as coming from a predator, all subsequent detections of that tag were likewise classified as predator detections. The assignment of predator status to a detection was made conservatively, with doubtful detections classified as coming from live steelhead.

A tag could be given a predator classification at a detection site on either arrival or departure from the site. A tag classified as being in a predator because of long travel time or movement against the flow was generally assigned a predator classification upon arrival at the detection site. On the other hand, a tag classified as being in a predator because of long residence time was assigned a predator classification upon departure from the detection site. Because the survival analysis estimated survival within reaches between sites, rather than survival during detection at a site, the predator classifications on departure from a site did not result in removal of the detection at that site from the reduced data set. However, all subsequent detections were removed from the reduced data set.

The predator filter used various criteria that addressed several spatial and temporal scales and fit under several categories (see USBR 2018a for more details): fish speed, residence time, upstream transitions, other unexpected transitions, travel time since release, and movements against flow. A predator score of at least 2 (i.e., failure to meet criteria of two or more predator filter components) was required to classify a tag as in a predator for a given transition if all previous detections had been classified as steelhead (USBR 2018a). If a previous detection had been classified as a predator, then all subsequent detections were classified as predators, also. The criteria used in the 2011–2015 studies were updated to reflect river conditions and observed tag detection patterns in 2016, and to represent transitions observed among the 2016 detection sites (Table 1). All receiver sites used in the 2015 study (Buchanan 2018b) were used in the 2016 study (Table 1). Additionally, there was a new receiver site installed in 2016 that was added to the predator filter: the San Joaquin River site near Calaveras River (SJC, site A10; Table 1).

Criteria for distinguishing between steelhead detections and predator detections were partially based on observed behavior of tags in fish that were presumed to have been transported from the holding tanks at either the State Water Project (SWP) or the Central Valley Project (CVP) to release sites in the lower San Joaquin River or Sacramento River, upstream of Chipps Island, under the assumption that such tags must have been in steelhead smolts rather than in steelhead predators. More weight was given to the data from tags that were presumed to have passed through the SWP than through the CVP, because steelhead predators can enter the CVP holding tank but are thought to be too large to pass through the louvers at the SWP (personal communication, Kevin Clark, California Department of Water

Resources). Tags presumed to have been transported from either SWP or CVP were used to identify the range of possible steelhead movement through the rest of the Delta. This was most helpful for detection sites in the western portion of the study area. This method mirrors that used for the 2011–2015 predator filters (USBR 2018a, 2018b, 2018c; Buchanan 2018a, 2018b).

Acoustic receivers were stationed inside the holding tanks at CVP, and tags that were observed in the holding tanks and then next observed at either Chipps Island (i.e., Mallard Island), Benicia Bridge, Jersey Point, False River, or Montezuma or Spoonbill sloughs (i.e., JPE/JPW–BBR) were assumed to have been transported. Acoustic receivers were not placed in the holding tanks at SWP, and so fish transported from SWP were identified with less certainty. It was presumed that tags were transported from SWP if they were detected either inside or outside the radial gates at the entrance to the Clifton Court Forebay (CCFB; the final receivers encountered before the SWP holding tank) and next detected at one of the JPE/JPW–BBR sites. This group may include tagged fish that migrated from the CCFB entrance to the JPE/JPW–BBR region in-river, evading detection at the multiple Old River and Middle River receivers north of the CCFB. While this in-river pathway was possible, it was deemed less likely than the SWP transport pathway for fish with no detections between CCFB and the downstream sites (i.e., JPE/JPW–BBR). More definitive information on transportation from the SWP was available in 2016 than in previous years, because the acoustic-tagged steelhead in the 2016 study were also PIT-tagged. The SWP release pipes that are used to return salvaged and transported fish to the San Joaquin River or Sacramento River at Sherman Island are outfitted with PIT-tag antennae. Thus, PIT-tag detections were available from 38 steelhead tags in 2016, detected 3–80 days after release at Durham Ferry; these detections were used to identify detections from steelhead, under the assumption that steelhead predators could not be transported from the SWP. Although not physically recaptured, the PIT-tag detection event is referred to as a “recapture event” and the acoustic tags associated with the detection PIT tags are referred to as “recapture tags” in what follows.

In addition to the PIT-tag detections, 17 acoustic-tagged steelhead were physically recaptured in the CVP holding tank, and 1 acoustic-tagged steelhead was recaptured in the Mossdale trawl[1]. The CVP holding tank recaptures occurred 3–19 days after initial release at Durham Ferry; the tag recaptured in

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[1] One tagged steelhead was recaptured in the CVP holding tank at 2200 hours on 13 March 2016, with fork length 225 mm. The tag serial number was recorded as 1232894. This record was removed as inaccurate based on (1) the lack of detections of this tag downstream of the Durham Ferry receivers, (2) the fact that no other tags detected downstream of Mossdale passed Mossdale without detection, and (3) the large negative difference observed between fork length at tagging (237 mm) and fork length at recapture (225).

the Mossdale trawl was recaptured there 2 days after release at Durham Ferry. These recapture events provided evidence that the steelhead acoustic tag was still in a live steelhead at the time of recapture, rather than in a predator's gut. Combined over the tags recaptured in the CVP holding tank or in the Mossdale trawl and those associated with PIT-tag detections from the SWP transport truck release pipe, there were a total of 56 recaptured tags in 2016. The fixed site receiver detections of the recaptured steelhead tags that occurred prior to the recapture event provided information on the range of steelhead behavior, and were used to calibrate the predator filter for the regions represented by pre-recapture detections. In particular, the total score from the predator filter for each pre-recapture detection was required to be either 0 or 1, so that each pre-recapture detection was classified as coming from a likely steelhead rather than a likely predator. There was no limit placed on the predator score for detections of recaptured tags that occurred after the recapture event.

The criteria used in the predator filter were spatially explicit, with different limits defined for different receivers and transitions (Table 3). The overall approach used in the 2013–2015 studies was also used for the 2016 study; no new criteria were developed for the 2016 study. As in the 2014 and 2015 predator filters, the 2016 filter did not require upstream-directed transitions to have migration rate or body length per second (BLPS) less extreme than that observed on the downstream transition through the same reach. Components of the filter that are broadly applicable are described below, along with general criteria and/or exceptions for individual detection sites. This information largely complements that in Table 3, which provides detailed information on criteria for individual transitions. Only those transitions actually observed among either steelhead tags or predator tags (described below) are addressed. More information on the predator filter structure can be found in reports on the 2011–2015 studies in USBR (2018a, 2018b, 2018c), and Buchanan (2018a, 2018b).

The 2016 predator filter continued use of criteria relating to the maximum total visit length at a site (combined over multiple visits), time between visits to the same site, and large-scale movements from different regions of the study area. The maximum allowed time for detections anywhere since release at Durham Ferry was 1,000 hours. Although there was a PIT-tag detection in the SWP release pipes 80 days (approximately 1,929 hours) after Durham Ferry release, 37 of the 38 tags detected in the SWP release pipes were detected there <1,000 hours after Durham Ferry release. To the extent that steelhead may exhibit longer travel times or residencies in the study area, such steelhead are not actively migrating and are not well-represented by the survival model, as described above; thus, such detections were interpreted as more likely to indicate a predator than a migrating steelhead. The default maximum total visit length at a site was 500 hours (approximately 21 days), although longer visits were allowed upstream of the head of Old River and at the radial gates (D1, D2). The maximum total visit length was further limited to the maximum of the mid-field residence time (i.e., duration from the first detection at a site without intervening detections elsewhere) or of the far-field (i.e., regional) residence time, if less than the default limit for the site. The maximum regional residence time that was allowed for transitions depended on the maximum values allowed for the mid-field residence time, travel time for the transition, and the regional residence time at previously detected sites in the region, if the tagged fish was coming from a site in the same region (see Table 4 for a description of the regions); if the tagged fish was coming from a different region, then the maximum allowed regional residence time was determined based only on the maximum mid-field residence time. More generally, regional residence times were limited to 1,000 hours upstream of the head of Old River and at the CVP (E1, E2), 800 hours in the vicinity of WCL (B3), OR4 (B4), and RGU/RGD (D1, D2), and 500 hours elsewhere in the study area; exceptions to this rule are indicated in Table 3. Unless otherwise specified, the maximum allowed length of an upstream foray (i.e., upstream directed movement that is uninterrupted by detections that indicated downstream movement between sites) was 20 km. The other criteria are specified below and in Table 3.

Detections in the San Joaquin River, Burns Cutoff (Rough and Ready Island, R1), and near the heads of Old and Middle Rivers (B1, B2, C1) after previous entry to the Interior Delta (sites B3, B4, C2, C3, D1, D2, E1, and E2) from near Stockton or sites farther downstream in the San Joaquin River ("lower San Joaquin River"; sites N6, N7, A8–A14, R1, F1, F2, and B5) were generally not allowed. The exceptions were at the San Joaquin River Shipping Channel (A11), MacDonald Island (A12), Turner Cut (F1), Medford Island (A13), and Disappointment Slough (A14). Once a tag had been detected arriving at either the CVP or the radial gates from the lower San Joaquin River, subsequent detection was allowed only at the CVP (E1, E2), the radial gates (D1/D2), Jersey Point (G1), False River (H1), Old River at its mouth (B5), Disappointment Slough (A14), Threemile Slough (T1), and the other sites downstream of Threemile Slough (T2, T3, G2, and G3). An exception was for West Canal (B3), for which post-facility transitions were allowed coming from the radial gates and Old River at Highway 4 (B4) for fish that came via the lower San Joaquin River. These restrictions were based on the assumption that juvenile steelhead that leave the lower San Joaquin River for the Interior Delta are not expected to return to the San Joaquin River, and those that leave the lower San Joaquin River for the water export facilities are not expected to subsequently leave the facilities other than through salvage and transport. Maximum travel times were imposed on transitions in the Interior Delta and at the facilities for steelhead observed leaving the lower San Joaquin River for these regions. In general, travel time in the Interior Delta after entry to that region from the lower San Joaquin River was limited to 120 hours. For fish that entered the Interior Delta from the lower San Joaquin River and were then detected at the facilities, travel time in the Interior Delta after leaving the facilities was further limited to 100 hours; exceptions are noted below. Transitions from the northern Delta sites (G1, G2, G3, H1, T1, T2, T3) or western Delta sites (B2, B3, B4, C1, C2, D, E1, E2) back to the regions of the San Joaquin River upstream of Turner Cut were not allowed. Finally, transitions from ORS (B2) or the head of Middle River (C1) upstream to the head of Old River (B1) were not expected following detection in the lower San Joaquin River, whether the tagged fish used the Interior Delta or the head of Old River to move from the lower San Joaquin River to the B2/C1 region. More site-specific details and exceptions to these general rules are described below, and in Table 3.

DFU, DFD = Durham Ferry Upstream (A0) and Durham Ferry Downstream (A2): allow long residence and transition times and multiple visits; maximum total visit length (summed over visits that were separated by detections elsewhere) = 1,000 hours.

BDF1, BDF2 = Below Durham Ferry 1 (A3) and Below Durham Ferry 2 (A4): allow long transition times and multiple visits; maximum total visit length = 1,000 hours.

BCA, MOS, and HOR = Banta Carbona (A5), Mossdale (A6), and Head of Old River (B0): allow longer residence time if next transition is directed downstream (BCA, MOS); may have extra visits to A5, A6, and B0, or longer travel times to A6 and B0, if arrival flow is low. Transitions from Old River East (B1) are not allowed if the HOR barrier is installed. Maximum total visit length = 1,000 hours.

SJL = San Joaquin River near Lathrop (A7): transitions from Old River East (B1) are not allowed if the HOR barrier is in place. Maximum total visit length = 483 hours.

RS4–RS10 = Removal Study 4 (N1) through Removal Study 10 (N7): generally increasing regional residence times allowed for sites further downstream. Maximum total visit length = 75 hours.

ORE = Old River East (B1): require shorter residence times and/or fewer visits if the HOR barrier is in place; maximum total visit length = 324 hours. For transitions from ORS, no prior detections in the lower San Joaquin River.

SJG = San Joaquin River at Garwood Bridge (A8): repeat visits require arrival flow/velocity to be opposite direction from flow/velocity on previous departure. Maximum total visit length = 75 hours.

SJNB and RRI = San Joaquin River at Navy Bridge Drive (A10) and Rough and Ready Island (R1): fast transitions moving downstream require positive water velocity. Maximum total visit length = 40 hours.

SJC = San Joaquin River at the Calaveras River (A10): allow longer residence time if transition water velocity was low and positive for downstream transitions. Should not move against flow if coming from downstream; repeat visits require arrival flow/velocity to be opposite direction from flow/velocity on previous departure. Maximum total visit length = 85 hours.

SJS = San Joaquin River Shipping Channel (A11): should not move against flow if coming from downstream; repeat visits require arrival flow/velocity to be opposite direction from flow/velocity on previous departure. Maximum total visit length = 40 hours. No prior transition to the Interior Delta from the lower San Joaquin River if coming from upstream of SJS.

MAC = San Joaquin River at MacDonald Island (A12): allow more flexibility (longer regional residence time, transition time) if transition water velocity was low and positive for downstream transitions. Maximum total visit length = 60 hours. No prior transition to the Interior Delta from the lower San Joaquin River if coming from upstream of MAC.

MFE/MFW = Medford Island (A13): allow more flexibility (longer transition time) if transition water velocity was low and positive for downstream transitions; should not move against for transitions from downstream. Maximum total visit length = 500 hours. If coming from MID, no prior transition to Interior Delta from the lower San Joaquin River.

SJD = San Joaquin River at Disappointment Slough (A14): should not move against flow; repeat visits require arrival flow/velocity to be opposite direction from flow/velocity on previous departure. Maximum total visit length = 265 hours. No prior transition to facilities from the lower San Joaquin River if coming from MID, COL, or the San Joaquin River upstream of SJD.

TCE/TCW = Turner Cut (F1): should not move against flow. Maximum total visit length = 60 hours. If coming from SJS or MAC, no prior transition to the Interior Delta from the lower San Joaquin River.

COL = Columbia Cut (F2): no flow or velocity restrictions. Maximum total visit length = 500 hours.

OSJ = Old River at the San Joaquin (B5): should not move against flow; repeat visits require arrival flow/velocity to be opposite direction from flow/velocity on previous departure. Maximum total visit length = 325 hours. If coming from MFE/MFW or TCE/TCW, no prior transition to the facilities from the lower San Joaquin River. If coming from TCE/TCW, no prior detection in northwest Delta.

ORS = Old River South (B2): maximum total visit length = 500 hours. If coming from ORE, no prior detection in the northwest Delta. If coming from CVP, no prior detection in the lower San Joaquin River.

MRH = Middle River Head (C1): shorter residence times than at ORS; repeat visits are not allowed; maximum total visit length = 47 hours. If coming from ORE, no prior detection in the northwest Delta.

MR4 = Middle River at Highway 4 (C2): maximum total visit length = 80 hours. If coming from ORS, CVP, or WCL, no prior detections in the lower San Joaquin River. Maximum travel time in Interior Delta after detection at the facilities via the lower San Joaquin River = 10 hours.

MID = Middle River near Mildred Island (C3): should not move against flow; maximum total visit length = 134 hours. If coming from RS10, MFE/MFW, or TCE/TCW, no prior detection in northwest Delta. Maximum travel time in Interior Delta after detection at the facilities via the lower San Joaquin River = 10 hours.

CVP = Central Valley Project (E1): allow multiple visits; transitions from downstream Old River should not have departed Old River site against flow or arrived during low pumping. Maximum total visit length = 500 hours. Maximum cumulative upstream foray length = 23 km. If coming from ORS, no prior transition to Interior Delta or facilities from the lower San Joaquin River. Maximum travel time in the Interior Delta after entering that region from the lower San Joaquin River is unrestricted if coming from CVPtank, 180 hours for consecutive CVP transitions (i.e., CVP–CVP) and for transitions from WCL, MR4, and RGU/RGD, and 120 hours otherwise.

CVPtank = Central Valley Project holding tank (E2): assume that steelhead can leave tank and return (personal communication, Brent Bridges, USBR). Maximum total visit length = 500 hours. Maximum cumulative upstream foray length = 23 km.

WCL = West Canal (B3): allow many visits; should not arrive against flow or water velocity, or have departed RGU/RGD against strong inflow or CVP against strong pumping. Maximum total visit length = 40 hours. No prior transition to facilities from the lower San Joaquin River if coming from CVP, ORS, or MR4; no prior transition to Interior Delta from the lower San Joaquin River if coming from CVP or ORS.

OR4 = Old River at Highway 4 (B4): should not arrive move against flow or water velocity; maximum total visit length = 60 hours.

RGU/RGD = Radial Gates (D1, D2 = D): see OCAP 2015 [2013 report] for a general description of the residence time criteria at the radial gates. Maximum total visit length = 800 hours. Should not have moved against strong flow or CVP pumping. No prior transition to Interior Delta or facilities from the lower San Joaquin River if coming from ORS.

JPE/JPW and FRE/FRW = Jersey Point (G1) and False River (H1): no flow/velocity restrictions; maximum total visit length = 140 hours for JPE/JPW, and 83 hours for FRE/FRW. Maximum cumulative upstream foray length = 25 km if coming from JPE/JPW, FRE/FRW, or MAE/MAW. No prior transition to facilities from the lower San Joaquin River if coming from MFE/MFW, MID, MR4, OR4, or TCE/TCW; no prior detection in northwest Delta if coming from MFE/MFW or TCE/TCW.

TMS/TMN = Threemile Slough (T1): should not move against flow on departing from San Joaquin River sites. Maximum total visit length = 47 hours. Maximum cumulative upstream foray length = 25 km.

MTZ, SBS = Montezuma Slough (T2) and Spoonbill Slough (T3): No flow or velocity restrictions. Maximum total visit length = 10 hours for MTZ, and 4 hours for SBS; maximum cumulative upstream foray = 25 km.

MAE/MAW, BBR = Chipps Island (G2) and Benicia Bridge (G3): should not arrive from upstream against strong negative water velocity/flow (MAE/MAW). Maximum total visit length = 50 hours; maximum cumulative upstream foray = 25 km. No prior transition to facilities from the lower San Joaquin River if coming from MFE/MFW or TCE/TCW.

Fixed-site receiver detections were available from up to 150 predatory fish that had been implanted with acoustic tags as part of a predation study conducted by NMFS in 2014 and 2015: 78 Striped Bass *Morone saxatilis*, 128 Largemouth Bass *Micropterus salmoides*, 60 White Catfish *Ameiurus* *catus*, and 34 Channel Catfish *Ictalurus punctatus*. Releases of tagged predatory fish took place in spring of 2014 and 2015, in reaches of the San Joaquin River between MOS (A6) and RS9 (N6) (Smith et al. 2016). The predator detections were used to assess the sensitivity (i.e., true positive rate) of the predator filter. A "positive" outcome was a predator score of two or more on at least one detection on the visit spatiotemporal scale during the detection history; earning a predator score ≥2 on every detection of the predator tag was not required. Filter sensitivity was measured as the proportion of the predator tags that were classified as in a predator at some point during their detection history within 2016. The sensitivity assessment excluded the "time since release" component of the predator filter because all predators were tagged before the current study year, and the observed time since release for the predator tags was outside the range observable for the steelhead tags for which the filter was designed. Only predator tags that were detected on at least one fixed site receiver were used in the sensitivity assessment. Some components of the predator filter use information from multiple detections, with the result that tags that have more observations are more likely to be classified as in a predator. Thus, the filter sensitivity was measured first using all detected predator tags, and then using only those that had at least five detections on the "visit" spatiotemporal scale. A sensitivity of 100% indicates a perfect ability to classify predators correctly, although it is still possible that live steelhead may be erroneously classified as predators.

The filter specificity (true negative rate) is the ability of the filter to correctly classify detections of steelhead as coming from steelhead rather than predatory fish. Assessing the filter specificity requires tags that are known to be in steelhead at some point after their initial release. There were 56 steelhead tags recaptured or detected via PIT tag after initial release in 2016. These 56 tags were used in calibrating the filter, however, and so it was not appropriate to use them also for assessing the filter specificity. No attempt was made to monitor filter specificity.

Constructing Detection Histories

For each tag, the detection data summarized on the "visit" scale were converted to a detection history (i.e., capture history) that indicated the chronological sequence of detections on the fixed site receivers throughout the study area. In cases in which a tag was observed passing a particular receiver array or river junction multiple times, the detection history represented the final route of the tagged fish past the array or junction. In particular, if a fish was observed even far downstream in one route but then returned to the river junction and finally selected the other route, then survival and detection in the later route were modeled. Detections from the receivers comprising certain dual arrays were pooled to improve model fit, thereby converting the dual arrays to redundant arrays, which were treated as single arrays in the survival model: the San Joaquin River receivers at Durham Ferry Downstream (A2), Banta Carbona (A5), Mossdale (A6), Garwood Bridge (A8), and Calaveras River (A10); the Central Valley Project trash racks (E1); the radial gates receivers both outside (D1) and inside (D2) the Clifton Court Forebay; and Chipps Island (G2). For some release groups, it was necessary to pool detections across the lines in the dual array at Jersey Point (G1) to fit the model. The acoustic station on the San Joaquin River at the Navy Drive Bridge (A9) was designed as a dual array, but because no data were retrieved from one of the receivers within that array, the Navy Drive Bridge site was also treated as a single array in the model. One release group required pooling across the lines of the dual array at the Old River site at Highway 4 (B4) for fish that reached that site via the Old River route, although it was possible to use the full data from the dual array for fish that arrived there via from the San Joaquin River route. Treating the Chipps Island receivers as a redundant array rather than a dual array was possible because of the presence of the Benicia Bridge receivers (G3). The status of the radial gates (opened or closed) upon detection at the receivers just outside the radial gates (D1) was included in the detection history. Detections on receivers at the Head of Old River site (B0), the predator removal study sites (N1–N7), Montezuma Slough (T2), and Spoonbill Slough (T3) were used in determining the detection history, but were omitted from the survival model. Detections at Threemile Slough (T1) were included in the detection histories to represent the Sacramento River route to Chipps Island from the San Joaquin River receiver at Disappointment Slough (A14). Detections at West Canal (B3) were included in the model for the Old River from the head of Old River, but excluded from the San Joaquin River route.

Survival Model

A two-part multi-state statistical release-recapture model was developed and used to estimate perceived juvenile steelhead survival and migration route parameters throughout the study area. The release-recapture model was a modified version of the models used in the 2011–2015 steelhead analyses (USBR 2018a, 2018b, 2018c; Buchanan 2018a, 2018b), and similar to the model developed by Perry et al. (2010) and the model developed for the 2009–2011 VAMP studies (SJRGA 2010, 2011, 2013). Figure 1 shows the layout of the receivers using both descriptive labels for site names and the code names used in the survival model (Table 1). The survival model represented movement and perceived survival throughout the study area to the primary exit point at Chipps Island (i.e., Mallard Island) and on to Benicia Bridge (Figure 2, Figure 3). Individual receivers comprising dual arrays were identified separately, using “a” and “b” to represent the upstream and downstream receivers, respectively.

The statistical model depended on the assumption that all tagged steelhead in the study area were actively migrating, and that any residualization occurred upstream of the Durham Ferry release site. If, on the contrary, tagged steelhead residualized downstream of Durham Ferry, and especially within the study area (downstream of the Mossdale receiver, A6), then the multi-state statistical release-recapture model estimated perceived survival rather than true survival, where perceived survival is the joint probability of migrating and surviving. The complement of perceived survival includes both the probability of mortality and the probability of halting migration to rear or residualize. Unless otherwise specified, references to "survival" below should be interpreted to mean "perceived survival."

Fish moving through the Delta toward Chipps Island may have used any of several routes. The two primary routes modeled were the San Joaquin River route (Route A) and the Old River route (Route B). Route A followed the San Joaquin River past the distributary point with Old River near the town of Lathrop, CA, and past the city of Stockton, CA. Downstream of Stockton, fish in the San Joaquin River route (route A) may have remained in the San Joaquin River past its confluence with the Sacramento River and on to Chipps Island. Alternatively, fish in Route A may have exited the San Joaquin River for the interior Delta at any of several places downstream of Stockton, including Turner Cut, Columbia Cut (just upstream of Medford Island), and the confluence of the San Joaquin River with either Old River or Middle River, at Mandeville Island. Three of these four exit points from the San Joaquin River between Stockton and Jersey Point were monitored and used in the survival model: Turner Cut, Columbia Cut, and the Old River mouth (TCE/TCW, COL, and OSJ, respectively). Turner Cut and Columbia Cut were assigned route F, and treated as a subroute of route A. The Old River mouth route was treated as a subroute of route A, although as a site in Old River, it was given a model code name starting with "B" (B5). Fish that entered the interior Delta from the lower San Joaquin River may have either moved north through the interior Delta and reached Chipps Island by returning to the San Joaquin River and passing Jersey Point and the junction with False River, or they may have moved south through the interior Delta to the state or federal water export facilities, where they may have been salvaged and trucked to release points on the San Joaquin or Sacramento rivers just upstream of Chipps Island. All of these possibilities were included in both subroute F and route A. Another subroute of route A was Burns Cutoff around Rough and Ready Island, near Stockton, assigned subroute R; fish taking subroute R returned to the main stem San Joaquin River near the Calaveras River (SJC).

For fish that entered Old River at its distributary point on the San Joaquin River just upstream of Lathrop, CA (route B), there were several pathways available to Chipps Island. These fish may have migrated to Chipps Island either by moving northward in either the Old or Middle rivers through the interior Delta, or they may have moved to the state or federal water export facilities to be salvaged and trucked. The Middle River route (subroute C) was monitored and contained within Route B. Passage through the State Water Project via Clifton Court Forebay was monitored at the entrance to the Forebay and assigned a route (subroute D). Likewise, passage through the federal Central Valley Project was monitored at the entrance trashracks and in the facility holding tank and assigned a route (subroute E). Subroutes D and E were both contained in subroutes C (Middle River) and F (Turner Cut), as well as in primary routes A (San Joaquin River) and B (Old River). All routes and subroutes included multiple unmonitored pathways for passing through the Delta to Chipps Island.

Several exit points from the San Joaquin River were monitored and given route names for convenience, although they did not determine unique routes to Chipps Island. The first exit point encountered was False River, located off the San Joaquin River just upstream of Jersey Point. Fish entering False River from the San Joaquin River entered the interior Delta at that point, and would not be expected to reach Chipps Island without subsequent detection in another route. Thus, False River was considered an exit point of the study area, rather than a waypoint on the route to Chipps Island. It was given a route name (H) for convenience. Likewise, Jersey Point and Chipps Island were not included in unique routes. Jersey Point was included in many of the previously named routes (in particular, routes A and B, and subroutes C and F), whereas Chipps Island (the final exit point) was included in all previously named routes and subroutes except route H. Thus, Jersey Point and Chipps Island were given their own route name (G). Benicia Bridge was monitored in 2016; located downstream of Chipps Island, it was considered to be outside the study area, but facilitated estimating survival to Chipps Island; Benicia Bridge was also assigned route G. Several additional sets of receivers located in the San Joaquin River upstream of Stockton (Route A), Middle River (Subroute C) near Mildred Island, and in Montezuma and Spoonbill sloughs (Route T) were not used in the survival model. Threemile Slough (Route T) was used to represent a subroute of the San Joaquin River route (route A), namely a passage route from the lower San Joaquin to Chipps Island that uses the Sacramento River, rather than the San Joaquin River and Jersey Point, to pass Sherman Island. The routes, subroutes, and study area exit points are summarized as follows:

A = San Joaquin River: survival

B = Old River: survival

C = Middle River: survival

D = State Water Project: survival

E = Central Valley Project: survival

F = Turner Cut and Columbia Cut: survival

G = Jersey Point, Chipps Island, Benicia Bridge: survival, exit point

H = False River: exit point

N = Predator Removal Study: not used in survival model

R = Rough and Ready Island: survival

T = Threemile, Montezuma, and Spoonbill sloughs: survival (Threemile) or not used in survival model (Montezuma, Spoonbill)

The release-recapture model used parameters denoting the probability of detection (P_{hi}), route selection ("route entrainment", ψ_{hl}), perceived steelhead survival (the joint probability of migrating and surviving; S_{hi}), and transition probabilities equivalent to the joint probability of directed movement and survival ($\phi_{kj,hi}$) (Figure 2, Figure 3, Table A1). For each dual array, unique detection probabilities were estimated for the individual receivers in the dual array: P_{hia} represented the detection probability of the upstream receiver line at station i in route h, and P_{hib} represented the detection probability of the downstream receiver line.

The model parameters are:

P_{hi} = detection probability: probability of detection at telemetry station i within route h, conditional on surviving to station i, where i = ia, ib for the upstream, downstream receiver lines in a dual array, respectively.

S_{hi} = perceived survival probability: joint probability of migration and survival from telemetry station i to i+1 within route h, conditional on surviving to station i.

ψ_{hl} = route selection probability: probability of a fish entering route h at junction l (l =1, 2, 3), conditional on fish surviving to junction l.

$\phi_{kj,hi}$ = transition probability: joint probability of migration, route selection, and survival; the probability of migrating, surviving, and moving from station j in route k to station i in route h, conditional on survival to station j in route k.

The transition parameters involving the receivers outside Clifton Court Forebay (site D1, RGU) depended on the status of the radial gates upon tag arrival at D1. Although fish that arrive at D1 when the gates are closed cannot immediately enter the gates to reach site D2 (RGD), they may linger in the area until the gates open. Thus, the parameters $\phi_{kj,D1O}$ and $\phi_{D1O,D2}$ represent transition to and from site D1 when the gates are open, and parameters $\phi_{kj,D1C}$ and $\phi_{D1C,D2}$ represent transition to and from D1 when the gates are closed. It was not possible to estimate unique detection probabilities at site D1 for open and closed gates, so a common probability of detection, P_{D1}, was assumed at that site regardless of gate status upon arrival.

A variation on the parameter naming convention was used for parameters representing the transition probability to the junction of False River with the San Joaquin River, just upstream of Jersey Point (Figure 1). This river junction marks the distinction between routes G and H, so transition probabilities to this junction are named $\phi_{kj,GH}$ for the joint probability of surviving and moving from station j in route k to the False River junction. Fish may arrive at the junction either from the San Joaquin River or from the interior Delta. The complex tidal forces present in this region prevent distinguishing between individuals using False River as an exit from the San Joaquin and individuals using False River as an entrance to the San Joaquin from Frank's Tract. Regardless of which approach the fish used to reach this junction, the $\phi_{kj,GH}$ parameter (e.g. $\phi_{A14,GH}$) is the transition probability to the junction of False River with the San Joaquin River via any route; ψ_{G1} is the probability of moving downstream toward Jersey Point from the junction; and $\psi_{H1} = 1 - \psi_{G1}$ is the probability of exiting (or re-exiting) the San Joaquin River to False River from the junction (Figure 2, Figure 3). In the event that sparse detections at False River prevented separate estimation of $\phi_{kj,GH}$ and ψ_{G1}, the parameter $\phi_{kj,G1} = \phi_{kj,GH}\psi_{G1}$ was estimated directly and used to compute estimates of Mid-Delta survival (defined below).

For fish that reached the interior receivers at the State Water Project (D2) or the Central Valley Project (E2), the parameters $\phi_{D2,G2}$ and $\phi_{E2,G2}$, respectively, represent the joint probability of migrating and surviving to Chipps Island, including survival during and after collection and transport (Figure 2). Some salvaged and transported fish were released in the San Joaquin River between Jersey Point and Chipps Island, and others were released in the Sacramento River upstream of the confluence with the San Joaquin River; records of the release location were not available for individual fish. Because salvaged fish were not required to pass Jersey Point and the False River junction, and in particular those released in the Sacramento River, it was not possible to estimate the transition probability to Chipps Island via Jersey Point for salvaged fish. Thus, only the overall probability of making the transition to Chipps Island was estimated for fish passing through the water export facilities.

Because of the complexity of routing in the vicinity of MacDonald Island on the San Joaquin River, Turner Cut, Columbia Cut, Medford Island, and Disappointment Slough, and the possibility of reaching the interior Delta via either route A or route B, the full survival model that represented all routes was decomposed into two submodels for analysis, as in the 2011–2015 analyses (USBR 2018a, 2018b, 2018c; Buchanan 2018a, 2018b). Submodel I modeled the overall migration from release at Durham Ferry to arrival at Chipps Island without modeling the specific routing from the lower San Joaquin River (i.e., from the Turner Cut Junction) through the interior Delta to Chipps Island, although it included detailed subroutes in route B for fish that entered Old River at its upstream junction with the San Joaquin River (Figure 2). In Submodel I, transitions from MacDonald Island (A12) and Turner Cut (F1) to Chipps Island were interpreted as survival probabilities ($S_{A12,G2}$ and $S_{F1,G2}$) because they represented all possible pathways from these sites to Chipps Island. Submodel II, on the other hand, focused entirely on Route A, and used a virtual release of tagged fish detected at the San Joaquin River receiver array near Lathrop (A7, SJL) to model the detailed routing from the lower San Joaquin River near MacDonald Island and Turner Cut through or around the interior Delta to Jersey Point and Chipps Island (Figure 3). Submodel II included the Medford Island and Disappointment Slough detection sites (A13 and A14), as well as Columbia Cut (F2) and the northern Old River site (B5), all of which were omitted from Submodel I because of complex routing in that region. Submodel II also included the Old and Middle River receivers near Highway 4 (B4 and C2), as well as the water export facilities (D1, D2, E1, E2), Jersey Point/False River (G1/H1), and Threemile Slough (T1) (Figure 3).

The two submodels I and II were fit concurrently using common detection probabilities at certain shared receivers: D1 (RGU), D2 (RGD), E1 (CVP), E2 (CVP holding tank), G1 (JPE/JPW), and H1 (FRE/FRW). While submodels I and II both modeled detections at these receivers, actual detections modeled at these receivers came from different tagged fish in the two submodels: detections from Route B fish were used in Submodel I, and detections from Route A fish were used in Submodel II. Detections at all other sites included in Submodel II either included the same fish as in Submodel I (i.e., sites SJG, SJNB, RRI, SJC, SJS, MAC, TCE/TCW, MAE/MAW, and BBR, model codes A8–A12, R1, F1, G2, and G3), or else were unique to Submodel II (i.e., sites MFE/MFW, COL, SJD, OSJ, TMN/TMS = A13, F2, A14, B5, T1). Detection probabilities at sites that shared detections between the submodels were estimated separately for submodels I and II to avoid double-counting. As in the 2011 study (USBR 2018a), unique transition parameters through the water export facility sites (i.e., $\phi_{D1O,D2}$, $\phi_{D1C,D2}$, $\phi_{D2,G2}$, $\phi_{E1,E2}$, and $\phi_{E2,G2}$) were estimated for Submodels I and II, under the assumption that fish that arrive outside the CVP or the Clifton Court Forebay coming from the head of Old River might have a different likelihood of reaching the interior receivers than fish that came from the lower San Joaquin River.

In addition to the model parameters, performance metrics measuring migration route probabilities and survival were estimated as functions of the model parameters. Both route selection probabilities and route-specific survival were estimated for the two primary routes determined by routing at the head of Old River (routes A and B). Route selection and route-specific survival were also estimated for the major subroutes of routes A and B, when possible from the available data. These subroutes were identified by a two-letter code, where the first letter indicates routing used at the head of Old River (A or B), and the second letter indicates routing used at the next river junction encountered: A or F at the Turner Cut Junction, and B or C at the head of Middle River. Thus, the route selection probabilities for the subroutes were:

$\psi_{AA} = \psi_{A1}\psi_{A3}$: probability of remaining in the San Joaquin River past both the head of Old River and the Turner Cut Junction,

$\psi_{AF} = \psi_{A1}\psi_{F3}$: probability of remaining in the San Joaquin River past the head of Old River, and exiting to the interior Delta at Turner Cut,

$\psi_{BB} = \psi_{B1}\psi_{B2}$: probability of entering Old River at the head of Old River, and remaining in Old River past the head of Middle River,

$\psi_{BC} = \psi_{B1}\psi_{C2}$: probability of entering Old River at the head of Old River, and entering Middle River at the head of Middle River,

where $\psi_{B1} = 1 - \psi_{A1}$, $\psi_{F3} = 1 - \psi_{A3}$, and $\psi_{C2} = 1 - \psi_{B2}$.

The probability of surviving from the entrance of the Delta near Mossdale Bridge (site A6, MOS) through an entire migration pathway to Chipps Island was estimated as the product of survival probabilities that trace that pathway:

$S_{AA} = S_{A6}S_{A7}S_{A8,A10}S_{A10}S_{A11}S_{A12,G2}$: Delta survival for fish that remained in the San Joaquin River past the head of Old River,

$S_{AF} = S_{A6}S_{A7}S_{A8,A10}S_{A10}S_{A11}S_{F1,G2}$: Delta survival for fish that entered Turner Cut from the San Joaquin River,

$S_{BB} = S_{A6}S_{B1}S_{B2,G2}$: Delta survival for fish that entered Old River at its head, and remained in Old River past the head of Middle River,

$S_{BC} = S_{A6}S_{B1}S_{C1,G2}$: Delta survival for fish that entered Old River at its head, and entered Middle River at its head.

The measure $S_{A8,A10}$ is the probability of surviving from Garwood Bridge (A8) to the receivers in the San Joaquin River near the Calaveras River (A10 = SJC), and includes both passing Rough and Ready Island via the San Joaquin River (ψ_{A2}) and passing it via Burns Cutoff ($\psi_{R2} = 1 - \psi_{A2}$):

$$S_{A8,A10} = S_{A8}\left(\psi_{A2}S_{A9} + \psi_{R2}S_{R1}\right).$$

In cases where detections were sparse at site C1 in route B, Delta survival could not be estimated for the Middle River subroute of route B.

The parameters $S_{A12,G2}$ and $S_{F1,G2}$ represent the probabilities of getting to Chipps Island (i.e., Mallard Island, site MAE/MAW) from sites A12 and F1, respectively. Both parameters represent multiple pathways around or through the Delta to Chipps Island (Figure 1). Fish that were detected at the A12 receivers (MacDonald Island) may have remained in the San Joaquin River all the way to Chipps Island, or they may have entered the interior Delta downstream of Turner Cut. Fish that entered the interior Delta either at Turner Cut or farther downstream may have migrated through the interior Delta to Chipps Island via Frank's Tract or Fisherman's Cut, False River, and Jersey Point; returned to the San Joaquin River via its downstream confluence with either Old or Middle River at Mandeville Island; or gone through salvage and trucking from the water export facilities. All such routes are represented in the $S_{A12,G2}$ and $S_{F1,G2}$ parameters, which were estimated directly using Submodel I (Figure 2).

Survival probabilities $S_{B2,G2}$ and $S_{C1,G2}$ represent survival to Chipps Island for fish that remained in Old River at B2 (ORS), or entered the Middle River at C1 (MRH), respectively. Fish in both these routes may have subsequently been salvaged and trucked from the water export facilities, or have migrated through the interior Delta to Jersey Point and on to Chipps Island (Figure 1). Because there were many unmonitored river junctions within the "reach" between sites B2 or C1 and Chipps Island, it was impossible to separate the probability of taking a specific pathway from the probability of survival along that pathway. Thus, only the joint probability of movement and survival to the next receivers along a route (i.e., the $\phi_{kj,hi}$ parameters defined above and in Figure 2) could be estimated. However, the overall survival probability from B2 ($S_{B2,G2}$) or C1 ($S_{C1,G2}$) to Chipps Island was estimable by summing products of the $\phi_{kj,hi}$ parameters:

$$\begin{aligned} S_{B2,G2} \quad = \quad & \left(\phi_{B2,D1O}\phi_{D1O,D2} + \phi_{B2,D1C}\phi_{D1C,D2}\right)\phi_{D2,G2} + \phi_{B2,E1}\phi_{E1,E2}\phi_{E2,G2} + \\ & \left(\phi_{B2,B3}\phi_{B3,B4}\phi_{B4,GH} + \phi_{B2,C2}\phi_{C2,GH}\right)\psi_{G1}\phi_{G1,G2} \end{aligned}$$

and

$$\begin{aligned} S_{C1,G2} \quad = \quad & \left(\phi_{C1,D1O}\phi_{D1O,D2} + \phi_{C1,D1C}\phi_{D1C,D2}\right)\phi_{D2,G2} + \phi_{C1,E1}\phi_{E1,E2}\phi_{E2,G2} + \\ & \left(\phi_{C1,B3}\phi_{B3,B4}\phi_{B4,GH} + \phi_{C1,C2}\phi_{C2,GH}\right)\psi_{G1}\phi_{G1,G2}. \end{aligned}$$

In cases where detections were sparse at site C1, the survival parameter $S_{C1,G2}$ was estimated directly from the model, and no attempt was made to decompose it into individual transition parameters.

Fish in the Old River route that successfully bypassed the water export facilities and reached the receivers in Old River or Middle River near Highway 4 (sites B4 or C2, respectively) may have used any of several subsequent routes to reach Chipps Island. In particular, they may have remained in Old or Middle rivers until they rejoined the San Joaquin downstream of Medford Island, and then migrated in the San Joaquin, or they may have passed through Frank's Tract and False River or Fisherman's Cut to rejoin the San Joaquin River. As described above, these routes were all included in the transition probabilities $\phi_{B4,GH}$ and $\phi_{C2,GH}$, which represent the probability of moving from site B4 or C2, respectively, to the False River junction with the San Joaquin.

Both route selection and route-specific survival were also estimated on the large routing scale, focusing on routing only at the head of Old River. The route selection parameters were defined as:

$\psi_A = \psi_{A1}$: probability of remaining in the San Joaquin River at the head of Old River

$\psi_B = \psi_{B1}$: probability of entering Old River at the head of Old River.

The probability of surviving from the entrance of the Delta (site A6, MOS) through an entire large-scale migration pathway to Chipps Island was defined as a function of the finer-scale route-specific survival probabilities and route selection probabilities:

$S_A = \psi_{A3} S_{AA} + \psi_{F3} S_{AF}$: Delta survival (from Mossdale to Chipps Island) for fish that remained in the San Joaquin River at the head of Old River, and

$S_B = \psi_{B2} S_{BB} + \psi_{C2} S_{BC}$: Delta survival for fish that entered Old River at the head of Old River.

Using the estimated migration route probabilities and route-specific survival for these two primary routes (A and B), survival of the population from A6 (Mossdale) to Chipps Island was defined as:

$$S_{Total} = \psi_A S_A + \psi_B S_B .$$

Survival was also estimated from Mossdale to the Jersey Point/False River junction, both by route and overall. Survival through this region ("Mid-Delta" or MD) was estimated only for fish that migrated entirely in-river, without being trucked from either of the water export facilities, because trucked fish were not required to pass the Jersey Point/False River junction in order to reach Chipps

Island. The route-specific Mid-Delta survival for the large-scale San Joaquin River and Old River routes was defined as follows:

$S_{A(MD)} = \psi_{A3} S_{AA(MD)} + \psi_{F3} S_{AF(MD)}$: Mid-Delta survival for fish that remained in the San Joaquin River past the head of Old River, and

$S_{B(MD)} = \psi_{B2} S_{BB(MD)} + \psi_{C2} S_{BC(MD)}$: Mid-Delta survival for fish that entered Old River at its head, where

$$S_{AA(MD)} = S_{A6} S_{A7} S_{A8,A10} S_{A10} S_{A11} S_{A12(MD)},$$

$$S_{AF(MD)} = S_{A6} S_{A7} S_{A8,A10} S_{A10} S_{A11} \phi_{F1,GH},$$

$$S_{BB(MD)} = S_{A6} S_{B1} \left(\phi_{B2,B3} \phi_{B3,B4} \phi_{B4,GH} + \phi_{B2,C2} \phi_{C2,GH} \right), \text{ and}$$

$$S_{BC(MD)} = S_{A6} S_{B1} \left(\phi_{C1,B3} \phi_{B3,B4} \phi_{B4,GH} + \phi_{C1,C2} \phi_{C2,GH} \right).$$

The parameter $S_{A12(MD)}$ is derived from the parameters of Submodel II:

$$S_{A12(MD)} = \phi_{A12,A13} S_{A13(MD)} + \phi_{A12,F2} S_{F2(MD)},$$

where

$$S_{A13(MD)} = \phi_{A13,GH} + \phi_{A13,A14} \phi_{A14,GH} + \phi_{A13,B4} \phi_{B4,GH} + \phi_{A13,C2} \phi_{C2,GH} + \phi_{A13,B5} S_{B5(MD)},$$

$$S_{F2(MD)} = \phi_{F2,GH} + \phi_{F2,A14} \phi_{F2,GH} + \phi_{F2,B4} \phi_{B4,GH} + \phi_{F2,C2} \phi_{C2,GH} + \phi_{F2,B5} S_{B5(MD)},$$

and

$$S_{B5(MD)} = \phi_{B5,GH} + \phi_{B5,B4} \phi_{B4,GH} + \phi_{B5,C2} \phi_{C2,GH}.$$

In cases where detections were sparse at sites downstream of A13 and at F2, the parameter $S_{A12(MD)}$ was derived as follows:

$$S_{A12(MD)} = \phi_{A12,GH} + \phi_{A12,A13} \phi_{A13,GH},$$

where $\phi_{A12,GH}$ represents the probability of moving directly from A12 to the Jersey Point/False River junction without passing A13, and $\phi_{A13,GH}$ represents the total probability of moving from A13 to the Jersey Point/False River junction. In cases where detections were sparse at the Highway 4 sites (B4, C2) in the Old River route, the subroute-specific estimates of Mid-Delta survival within the Old River route were derived as:

$$S_{BB(MD)} = S_{A6}S_{B1}\phi_{B2,GH}\text{, and}$$

$$S_{BC(MD)} = S_{A6}S_{B1}\phi_{C1,GH}\text{,}$$

where $\phi_{B2,GH}$ and $\phi_{C1,GH}$ were estimated in the model directly.

Total Mid-Delta survival (i.e., from Mossdale to the Jersey Point/False River junction) was defined as $S_{Total(MD)} = \psi_A S_{A(MD)} + \psi_B S_{B(MD)}$. Mid-Delta survival was estimated only for those release groups with sufficient tag detections to model transitions through the entire south Delta and lower San Joaquin River and to the Jersey Point/False River junction. In cases where detections at False River were too sparse to be modeled, the estimate of survival through the Mid-Delta region should be interpreted as survival to Jersey Point, rather than to the Jersey Point/False River junction. In cases where detections were too sparse at the Middle River Head (C1) receivers in the Old River route to estimate transition probabilities from that site, no estimate was available of Mid-Delta survival for the Middle River component of the Old River route.

Survival was also estimated through the southern portions of the Delta (“South Delta” or SD), both within each primary route and overall:

$$S_{A(SD)} = S_{A6}S_{A7}S_{A8,A10}S_{A10}S_{A11}\text{, and}$$

$$S_{B(SD)} = S_{A6}S_{B1}\left(\psi_{B2}S_{B2(SD)} + \psi_{C2}S_{C1(SD)}\right)\text{,}$$

where $S_{B2(SD)}$ and $S_{C1(SD)}$ are defined as:

$$S_{B2(SD)} = \phi_{B2,B3}\phi_{B3,B4} + \phi_{B2,C2} + \phi_{B2,D1O} + \phi_{B2,D1C} + \phi_{B2,E1}\text{, and}$$

$$S_{C1(SD)} = \phi_{C1,B3}\phi_{B3,B4} + \phi_{C1,C2} + \phi_{C1,D1O} + \phi_{C1,D1C} + \phi_{C1,E1} .$$

Total survival through the South Delta was defined as:

$$S_{Total(SD)} = \psi_A S_{A(SD)} + \psi_B S_{B(SD)} .$$

In cases where detection data were too sparse in the Old River route to estimate transitions to the water export facilities or Highway 4 from both Old River South (B2) and Middle River Head (C1) (e.g., first release group), estimates of South Delta survival were not available for either the Old River route or overall.

The probability of reaching Mossdale from the release point at Durham Ferry, $\phi_{A1,A6}$, was defined as the product of the intervening reach survival probabilities:

$$\phi_{A1,A6} = \phi_{A1,A2} S_{A2} S_{A3} S_{A4} S_{A5} .$$

This measure reflects a combination of mortality and residualization upstream of Old River.

Individual detection histories (i.e., capture histories) were constructed for each tag as described above. More details and examples of detection history construction and model parameterization are available in USBR (2018a). Under the assumptions of common survival, route selection, and detection probabilities and independent detections among the tagged fish in each release group, the likelihood function for the survival model for each release group is a multinomial likelihood with individual cells denoting the possible capture histories.

Parameter Estimation

The multinomial likelihood model described above was fit numerically to the observed set of detection histories according to the principle of maximum likelihood using Program USER software, developed at the University of Washington (Lady et al. 2009). Point estimates and standard errors were computed for each parameter. Standard errors of derived performance measures were estimated using the delta method (Seber 2002: 7-9). Sparse data prevented some parameters from being freely estimated for some release groups. Transition, survival, detection, and route selection probabilities were fixed to 1 or 0 in the USER model as appropriate, based on the observed detections. The model was fit separately for each release group. For each release group, the complete data set that included possible detections from predatory fish was analyzed separately from the reduced data set that was restricted to detections classified as steelhead detections. Population-level estimates of parameters and performance measures were estimated as weighted averages of the release-specific estimates, using weights proportional to release size.

In cases in which a survival or transition parameter was estimated at 0, the 95% upper bound on survival was estimated using a binomial error structure (Louis 1981); correction for tag failure was calculated using an assumed travel time that was based on travel time either from other release groups, from previous years, or to nearby sites, together with the fitted tag survival model. Likewise, in cases in which a survival parameter was estimated at 1, the 95% lower bound on survival was estimated.

The significance of the radial gates status on arrival at the outside receiver (RGU, site D1) was assessed for the each release group separately using a likelihood ratio test to indicate a significant difference in model fit (Sokal and Rohlf 1995). If the effect of the gates was found to be insignificant using this criterion, then a simplified model was used for parameter estimation in which $\phi_{kj,D1O} = \phi_{kj,D1C}$ for station k in route j, and $\phi_{D1O,D2} = \phi_{D1C,D2}$. The overall probability of transitioning from station k in route j to site D1 was modeled as $\phi_{kj,D2} = \phi_{kj,D1O} + \phi_{kj,D1C}$ under this simplified model. A likelihood ratio test was also used to test for the significance of route effects on the transition probabilities through the water export facilities: $\phi_{D1O,D2}$, $\phi_{D1C,D2}$ (or $\phi_{D1,D2}$ if the gate effect test was not significant), $\phi_{E1,E2}$, and $\phi_{E2,G2}$. Likewise, a likelihood ratio test was used to test for the significance of route effects on the transition probability from Jersey Point to Chipps Island ($\phi_{G1,G2}$). Only parameters that could be estimated separately in both routes were included in testing. All testing was performed at the 95% level (α=0.05). For each model, goodness-of-fit was assessed visually using Anscombe residuals (McCullagh and Nelder 1989). The sensitivity of parameter and performance metric estimates to inclusion of detection histories with large absolute values of Anscombe residuals was examined for each release group individually.

For each release group, the effect of primary route (San Joaquin River or Old River) on estimates of survival to Chipps Island was tested with a two-sided Z-test on the log scale:

$$\mathrm{Z} = \frac{\ln\left(\hat{S}_A\right) - \ln\left(\hat{S}_B\right)}{\sqrt{\hat{V}}},$$

where

$$V = \frac{Var\left(\hat{S}_A\right)}{\hat{S}_A^2} + \frac{Var\left(\hat{S}_B\right)}{\hat{S}_B^2} - \frac{2Cov\left(\hat{S}_A, \hat{S}_B\right)}{\hat{S}_A \hat{S}_B}.$$

The parameter *V* was estimated using Program USER. Estimates of survival to Jersey Point and False River (i.e., $S_{A(MD)}$ and $S_{B(MD)}$) were also compared in this way. Also tested was whether tagged steelhead showed a route preference at the head of Old River, using a two-sided *Z*-test with the test statistic:

$$\mathrm{Z} = \frac{\hat{\psi}_A - 0.5}{SE\left(\hat{\psi}_A\right)}.$$

Statistical significance was tested at the 5% level (α=0.05). Tests that were significant only at the 10% level (α=0.10) were noted.

Analysis of Tag Failure

Three in-tank tag-life studies of VEMCO V5 tags were implemented for the 2016 steelhead survival study. Each study used 33 acoustic tags. Tags in the February study were activated on 24 February 2016, and were last detected on 10 May 2016. The April tag-life study used tags that were activated on 5 April 2016, and last detected on 11 June 2016. The tags in the May tag-life study were activated on 8 May 2016, and last detected on 18 July 2016. Total time of battery activation was used in the tag-life study. Tags were monitored in tanks using fixed-site hydrophones and receivers, and were pooled across tanks for analysis.

Six acoustic hydrophones and receivers were used in the 2016 tag-life study. Receiver 300959 failed in the May tag-life study, resulting in missing failure times for the 17 tags monitored on this receiver. The last detection times for these 17 tags was at day 55.82 after tag activation, compared to a median tag failure time among the remaining 82 tags of approximately 64 days (pooled over all three studies). Because receiver 300959 failed relatively early compared to observed failure of tags monitored on other receivers, and because the equipment failure was in the monitoring equipment rather than the tag battery, the last detection times recorded for these 17 tags were expected to have been unrelated to the actual failure time. These 17 tags were omitted from analysis of tag failure.

For each tag-life study, the observed tag survival was modeled using the 4-parameter vitality curve (Li and Anderson, 2009). Tag failure times were truncated at day 69 to improve model fit (USBR 2018b). The improvement in model fit attained by stratifying by tag-life study was assessed using the Akaike Information Criterion (AIC; Burnham and Anderson, 2002).

The fitted tag survival model from the tag failure data was used to adjust estimated fish survival and transition probabilities for premature tag failure using methods adapted from Townsend et al. (2006). In Townsend et al. (2006), the probability of tag survival through a reach is estimated based on the average observed travel time of tagged fish through that reach. For this study, travel time and the probability of tag survival to Chipps Island were estimated separately for the different routes (e.g., San Joaquin route vs. Old River route). Subroutes using truck transport were handled separately from subroutes using only in-river travel. Standard errors of the tag-adjusted fish survival and transition probabilities were estimated using the inverse Hessian matrix of the fitted joint fish-tag survival model. The additional uncertainty introduced by variability in tag survival parameters was not estimated, with the result that standard errors may have been slightly low. In previous studies, however, variability in tag-survival parameters has been observed to contribute little to the uncertainty in the fish survival estimates when compared with other, modeled sources of variability (Townsend et al. 2006); thus, the resulting bias in the standard errors was expected to be small.

Analysis of Surgeon Effects

The potential effects of different surgeons (i.e., taggers) on steelhead survival were analyzed in several ways. The simplest method used contingency tests of independence on the number of tag detections at key detection sites throughout the study area. Specifically, a lack of independence (i.e., heterogeneity) between the detections distribution and surgeon was tested using a chi-squared test (α=0.05; Sokal and Rohlf, 1995). Lack of independence may be caused by differences in survival, route selection, or detection probabilities among surgeons. Detections from those downstream sites with sparse data were omitted for this test in order to achieve adequate cell counts.

A second method of assessing possible surgeon effects visually compared estimates of cumulative steelhead survival throughout the study area among surgeons; an F-test was used to test for a surgeon effect on cumulative survival through each major route (routes A and B). Although differences in cumulative survival can provide compelling indication of possible surgeon effects on survival, they are inconclusive alone, because survival differences in the first few reaches can persist in estimates of cumulative survival even if individual reach survival estimates are equal among surgeons in those downstream reaches. Thus, it is necessary to augment the cumulative survival assessment with additional evidence. Accordingly, a third method of assessment used Analysis of Variance to test for a surgeon effect on individual reach survival estimates. Finally, the nonparametric Kruskal-Wallis rank sum test (Sokal and Rohlf 1995, ch. 13) was used to test for whether one or more surgeons performed consistently more poorly than others, based on individual reach survival or transition probabilities through key reaches. In the event that survival was different for the steelhead tagged by a particular surgeon, the model was refit to the pooled release groups without tags from the surgeon in question, and the difference in survival estimates due to the surgeon was tested using a two-sided Z-test on the lognormal scale. The reduced data set (without predator detections), pooled over release groups, was used for these analyses.

Analysis of Travel Time

Travel time was measured from release at Durham Ferry to each detection site. Travel time was also measured through each reach for tags detected at the beginning and end of the reach, and summarized across all tags with observations. Travel time between two sites was defined as the time delay between the beginning of the detections at the first site and the first detection at the second site. In cases where the tagged fish was observed to make multiple visits to a site, the final visit was used for travel time calculations. When possible, travel times were measured separately for different routes through the study area. Detection sites, routes, or transitions that were omitted from the survival model because of sparse data were also omitted from the travel time analysis. The harmonic mean was used to summarize travel times.

Route Selection Analysis

A temporary rock barrier was installed at the head of Old River through part of the 2016 tagging study, effectively blocking most access to the upper reaches of Old River when the barrier was in place. Culverts in the barrier allowed water and fish to pass through the barrier, but few (10) tagged steelhead were observed at the upper Old River detection sites when the barrier was in place in 2016. Analysis of route selection at the head of Old River used those fish that passed before the barrier was installed. Route selection was also analyzed for the Turner Cut junction. In both cases, acoustic tag detections used in these analysis were restricted to those detected at the acoustic receiver arrays located just downstream of the junction in question: SJL (model code A7) or ORE (B1) for the head of Old River junction, and MAC (A12) or TCE/TCW (F1) for the Turner Cut junction. Tags were further restricted to those whose final pass of the junction came from either upstream sites or from the opposite leg of the junction; tags whose final pass of the junction came either from downstream sites or from a previous visit to the same receivers (e.g., repeated visits to the SJL receivers for the head of Old River junction) were excluded from this analysis. Tags were restricted in this way to limit the delay between initial arrival at the junction, when hydrologic covariates were measured, and the tagged fish's final route selection at the junction. Predator-type detections were excluded.

As in previous years (USBR 2018a, 2018b, 2018c; Buchanan 2018a, 2018b), the effects of variability in hydrologic conditions on route selection at the head of Old River and Turner Cut were explored using statistical generalized linear models (GLMs) with a binomial error structure and logit link (McCullagh and Nelder, 1989). Hydrologic metrics used in the analyses are defined below for each junction. In addition to the hydrologic metrics, fork length at tagging (L), release group $\left(RG\right)$, and time of day of arrival at the junction were also considered as factors potentially affecting route selection. Time of day of arrival was measured as dawn, day, dusk, or night. Dawn was assumed to end at sunrise, and dusk began at sunset. A separate measure indicated whether fish arrived at the junction during the day.

Head of Old River

The head of Old River barrier closure date during installation was 1 April 2016; only those tag detections from either the San Joaquin River receivers at Lathrop (SJL, site A7) or the Old River receivers at Old River East (ORE, site B1) from before 1500 hours on that date were used in the covariate analysis of route selection at the head of Old River. The estimated detection probabilities at both these sites were 1.0 for all release groups, so no detections from downstream sites in either route were needed to augment the route selection data. All tags detected at SJL or ORE before barrier closure date came from the February and March release groups. Tags used in the analysis were restricted to those estimated to have spent no more than 3 hours between passing the head of Old River junction and being detected at the receivers at either SJL or ORE on their final pass through the river junction, using linear interpolation and the average travel rate through that reach for the tag in question. Tags were restricted in this way to limit the time delay between arrival at the junction and final route selection. When restricted to this set of the tags observed passing the head of Old River before barrier closure, there were 88 tags detected at the San Joaquin River receiver (SJL), and 442 tags detected at the Old River receiver (ORE), providing at most 88 degrees of freedom for the route selection analysis.

The same set of possible covariates were formatted for the simple route selection analysis at the head of Old River in 2016 as in previous years: measures of flow, water velocity, and river stage at the estimated time of arrival at the head of Old River junction, the 15-minute change in these measures, daily export rates from the Central Valley Project and State Water Project on the day of arrival at the junction, fish fork length at the time of tagging, and time of day at fish arrival at the junction. Methods used to compile and format the data were those used in previous years; see USBR (2018c) for more details. As in 2014 and 2015, no flow or water velocity data were available from the Lathrop gaging station (SJL) in the San Joaquin River in 2016; this lack of data meant that the flow proportion into the San Joaquin River was also missing for 2016. Flow, velocity, and river stage data were available from the Mossdale gaging station (MSD), and these data were used as covariates in 2016 (Table 2). The OH1 gaging station was located 0.86–0.92 km upstream of the ORE receivers; the SJL gaging station was located 0.30–0.40 km from the SJL receivers. The covariates considered were:

- C_{SJL}, ΔC_{SJL} = SJL river stage (C) and the 15-minute change in SJL river stage at the estimated time of tag passage of the head of Old River junction;
- Q_{OH1}, ΔQ_{OH1}, V_{OH1}, ΔV_{OH1}, C_{OH1}, ΔC_{OH1} = OH1 river flow (i.e., discharge: Q), water velocity (V), and river stage (C), and the 15-minute changes in OH1 flow, water velocity, and river stage at the estimated time of tag passage of the head of Old River junction;
- Q_{MSD}, ΔQ_{MSD}, V_{MSD}, ΔV_{MSD}, C_{MSD}, ΔC_{MSD} = MSD river flow (i.e., discharge: Q), water velocity (V), and river stage (C), and the 15-minute changes in MSD flow, water velocity, and river stage at the estimated time of tag passage of the head of Old River junction;
- E_{CVP}, E_{SWP} = Daily export rate at the CVP and SWP at the estimated time of tag passage of the head of Old River junction, as reported by Dayflow (https://water.ca.gov/Programs/Environmental-Services/Compliance-Monitoring-And-Assessment/Dayflow-Data);
- P_{CVP} = Percent of combined daily CVP/SWP export rate that was attributable to the CVP; = E_{CVP} /($E_{CVP} + E_{SWP}$);
- *day* = Indicator variable defined to be 1 if tag was estimated to have passed the head of Old River junction during the day, and 0 otherwise;
- *Time of day* = Categorical variable for the time of day of tag passage of the head of Old River, defined as *dawn*, *day*, *dusk*, or *night*;
- L = Fork length at tagging;
- RG = Release group (categorical variable).

In addition to the covariates that represented environmental conditions measured at individual monitoring stations, two additional covariates were developed that combined flow measures at the MSD and OH1 monitoring stations. The difference between the flow at MSD and flow at OH1 at the time of estimated passage of head of Old River junction was used as a first-order approximation of flow at the SJL station at the same time, in the absence of measured flow data from SJL:

$$qQ_{SJL} = Q_{MSD} - Q_{OH1},$$

where "qQ" indicates a modeled approximation of flow (Q). This modeled flow at SJL makes the simplifying assumption that there was no loss or gain in flow between the MSD station and the SJL and OH1 stations.

Another new covariate is the signed ratio of flow at OH1 to the flow at MSD, r_Q. To avoid complications of interpretation when flow at these two stations was measured as moving in different directions (i.e., positive flow measure at one station and negative flow measure at the other station), this ratio measure was defined to be 0 when the two flow measurements had different signs:

$$r_Q = \begin{cases} \dfrac{Q_{OH1}}{Q_{MSD}}, & Q_{MSD}, Q_{OH1} \text{ both } > 0; \\ -1 \times \dfrac{Q_{OH1}}{Q_{MSD}}, & Q_{MSD}, Q_{OH1} \text{ both } < 0; \\ 0, & Q_{MSD} < 0 \text{ or } Q_{OH1} < 0 \text{ but not both.} \end{cases}$$

If all flow passing the OH1 gaging station in Old River either came from or went to the San Joaquin River upstream of the MSD gaging station, then the magnitude of the measure r_Q is always ≤ 1 and can be interpreted as the OH1 proportion of MSD flow, approximately. However, under some stages of the tidal cycle, water directed downstream in Old River past the OH1 station may have come partially from the San Joaquin River past MSD and partially from the lower San Joaquin River past the SJL gaging station; in this case, r_Q is sometimes > 1, and it is misleading to interpret it as a proportion of MSD flow. For this reason, the measure r_Q is more properly referred to as the OH1:MSD flow ratio, or more simply the "flow ratio."

The route selection analysis in previous years included a factor variable (U) that indicated whether flow at OH1 was negative at the time of tag arrival at the river junction. In 2016, OH1 flow was positive for all but 4 records used in the route selection analysis, and so this variable was omitted from analysis.

As in previous years, all continuous covariates were standardized, i.e.,

$$\tilde{x}_{ij} = \frac{x_{ij} - \overline{x}_j}{s(x_j)}$$

for the observation x of covariate j from tag i. Categorical variables (e.g., release group, time of day) were not standardized.

The form of the generalized linear model was

$$\ln\left(\frac{\psi_{iA}}{\psi_{iB}}\right) = \beta_0 + \beta_1\left(\tilde{x}_{i1}\right) + \beta_2\left(\tilde{x}_{i2}\right) + \cdots + \beta_p\left(\tilde{x}_{ip}\right)$$

where $\tilde{x}_{i1}, \tilde{x}_{i2}, \ldots, \tilde{x}_{ip}$ are the observed values of standardized covariates for tag i (covariates 1, 2, …, *p*, see below), ψ_{iA} is the predicted probability that the fish with tag i selected route A (San Joaquin River route), and $\psi_{iB} = 1 - \psi_{iA}$ (B = Old River route). Route choice for tag i was determined based on detection of tag i at either site A7 (route A) or site B1 (route B).

Single-variate regression was performed first, and covariates were ranked by P-values from the appropriate F-test (if the model was over-dispersed) or χ^2 test otherwise (McCullagh and Nelder 1989). Significance was determined at the experimentwise level of 5%; the Bonferroni correction for multiple comparisons was used within each step of the stepwise regression (Sokal and Rohlf 1995). In the event that significant associations were found from the single-variate models, covariates were then analyzed together in a series of multiple regression models. Because of high correlation between flow and velocity measured from the same site, the covariates flow and velocity were analyzed in separate models. River stage was analyzed both separately from flow, velocity, and the OH1:MSD flow ratio, and together with flow. A flow ratio model was developed using the OH1:MSD flow ratio, r_Q. The general forms of the various multivariate models were:

Flow model: $Q_{OH1} + \Delta Q_{OH1} + Q_{MSD} + \Delta Q_{MSD} + day + E_{CVP} + E_{SWP} + P_{CVP} + L + RG$

Flow ratio model: $r_Q + day + E_{CVP} + E_{SWP} + P_{CVP} + L + RG$

Velocity model: $V_{OH1} + V_{MSD} + \Delta V_{OH1} + \Delta V_{MSD} + day + E_{CVP} + E_{SWP} + P_{CVP} + L + RG$

Stage model:

$$C_{MSD} + \Delta C_{MSD} + C_{SJL} + \Delta C_{SJL} + C_{OH1} + \Delta C_{OH1} + day + E_{CVP} + E_{SWP} + P_{CVP} + L + RG$$

Flow + Stage model:

$$\begin{aligned} &Q_{OH1} + Q_{MSD} + \Delta Q_{OH1} + \Delta Q_{MSD} + C_{MSD} + \Delta C_{MSD} + C_{SJL} + \Delta C_{SJL} + C_{OH1} + \Delta C_{OH1} + day \\ &\quad + E_{CVP} + E_{SWP} + P_{CVP} + L + RG. \end{aligned}$$

An alternative flow model was developed that used the modeled SJL flow (qQ_{SJL}) in place of Q_{OH1} and Q_{MSD}.

Backwards selection with F-tests was used to find the most parsimonious model in each category (flow, flow ratio, velocity, stage, and stage + flow) that explained the most variation in the data (McCullagh and Nelder 1989). Main effects were considered using the full model; two-way interaction effects were considered using the reduced model found from backwards selection on the main effects model. The model that resulted from the selection process in each model category was compared using an F-test to the full model (or a χ^2-test if the data were not overdispersed from the model) from that category to ensure that all significant main effects were included. AIC and assessment of model fit were used to select among the flow, flow ratio, velocity, stage, and flow + stage models (Burnham and Anderson 2002). Model fit was assessed by grouping data into discrete classes according to the independent covariate, and comparing predicted and observed frequencies of route selection into the San Joaquin using the Pearson chi-squared test (Sokal and Rohlf 1995). The variance inflation factor (VIF) for each covariate was also calculated as a measure of multicollinearity among the covariates, and models with maximum VIF greater than 10 or mean VIF considerably greater than 1 were excluded (Kutner et al. 2004).

Turner Cut Junction

The acoustic receiver arrays MAC (A12) and TCE/TCW (F1) were located 1.2–3.4 km downstream of the Turner Cut junction; detections at the SJS receiver array (A11), 0.39 km upstream of the Turner Cut junction, were also used. In addition to the data restrictions described above, tags were limited to those whose observed travel time from the SJS receiver to either MAC or TCE/TCW was ≤ 8 hours. Also excluded were tags whose last detection before their final visit to the MAC or TCE/TCW receivers came from the opposite leg of the river junction. These requirements were used to ensure that environmental conditions measured at the time of departure from SJS represented conditions when fish reached the Turner Cut junction.

The covariates used in previous years were again used for the 2016 analysis: measures of river discharge (flow), river velocity, and river stage measured at the TRN gaging station at the time of tag departure from SJS (model code A11), the 15-minute change in flow, velocity, and stage at TRN, measures of the average magnitude (i.e., the Root Mean Square, or RMS) of flow and velocity at the SJG gaging station (Table 2) during the tagged individual's transition from the SJG telemetry station (model code A8) to SJS, daily export rates at the CVP and SWP upon tag departure from SJS, the CVP proportion of combined exports from the CVP and SWP, fork length at tagging, release group, and time of day of arrival at the junction. The covariates considered were:

- Q_{TRN}, ΔQ_{TRN}, V_{TRN}, ΔV_{TRN}, C_{TRN}, ΔC_{TRN} = TRN river flow (i.e., discharge: Q), water velocity (V), and river stage (C), and the 15-minute changes in TRN flow, water velocity, and river stage at the observed time of tag departure from the SJS receivers;
- Q_{SJG}, V_{SJG} = Root Mean Square (RMS) of San Joaquin River flow (Q) and water velocity (V) measured at the SJG gaging station at Garwood Bridge, from the time of the final tag detection at the SJG telemetry station (site A8) until the observed time of tag departure from SJS;
- U = Indicator variable defined to be 1 if flow at TRN was negative, and 0 otherwise
- E_{CVP}, E_{SWP} = Daily export rate at the CVP and SWP on the day of tag departure from the SJS receivers, as reported by Dayflow;
- P_{CVP} = Percent of combined daily CVP/SWP export rate that was attributable to the CVP; = E_{CVP} /($E_{CVP} + E_{SWP}$);
- day = Indicator variable defined to be 1 if tag departed the SJS receivers during the day, and 0 otherwise;

- *Time of day* = Categorical variable for the time of day of tag departure from the SJS receivers, defined as *dawn*, *day*, *dusk*, or *night*;
- *L* = Fork length at tagging;
- *RG* = Release group (categorical variable).

The TRN gaging station was located 0.13–0.19 km northeast of the TCE and TCW receivers (i.e., between the Turner Cut junction with the San Joaquin River and the TCE/TCW receivers (Table 2). Negative flow at the TRN station was interpreted as being directed into the interior Delta, away from the San Joaquin River (Cavallo et al. 2013). No gaging station was available in the San Joaquin River close to the MAC receivers. Thus, although measures of hydrologic conditions were available in Turner Cut, measures of flow proportion into Turner Cut were not available. The SJG gaging station was approximately 14 km upstream from the Turner Cut junction. More details on the definition and construction of the covariates are available in the report for the 2012 study (USBR 2018b). One change was made in the data formatting procedure from the 2012 analysis. In the 2012 analysis, environmental conditions were measured at the estimated time of arrival at the Turner Cut junction, based on observed travel time and travel distance to the TCE/TCW or MAC receivers. For the 2016 analysis, environmental conditions were measured instead at the observed time of tag departure from the SJS (A11) receivers, which exhibited less uncertainty than estimates of junction arrival time; this approach mirrors that used in 2015 (Buchanan 2018b).

As in previous years, all continuous covariates were standardized, i.e.,

$$\tilde{x}_{ij} = \frac{x_{ij} - \overline{x}_j}{s(x_j)}$$

for the observation x of covariate j from tag i. Categorical variables (e.g., release group, time of day) were not standardized.

The form of the generalized linear model was

$$\ln\left(\frac{\psi_{iA}}{\psi_{iF}}\right) = \beta_0 + \beta_1\left(\tilde{x}_{i1}\right) + \beta_2\left(\tilde{x}_{i2}\right) + \cdots + \beta_p\left(\tilde{x}_{ip}\right)$$

where $\tilde{x}_{i1}, \tilde{x}_{i2}, \ldots, \tilde{x}_{ip}$ are the observed values of standardized covariates for tag i (covariates 1, 2, …, p, see below), ψ_{iA} is the predicted probability that the fish with tag i selected route A (San Joaquin River route), and $\psi_{iF} = 1 - \psi_{iA}$ (F = Turner Cut route). Route choice for tag i was determined based on detection of tag i at either site A12 (route A) or site F1 (route F).

Single-variate regression was performed first, and covariates were ranked by P-values from the appropriate F-test (if the model was over-dispersed) or χ-square test otherwise (McCullagh and Nelder 1989). Significance was determined at the experimentwise level of 5%; the Bonferroni correction for multiple comparisons was used within each step of the stepwise regression (Sokal and Rohlf 1995). If individual covariates were found to have significant associations with route selection, covariates were then analyzed together in a series of multiple regression models. Because of high correlation between flow and velocity measured from the same site, the covariates flow and velocity were analyzed in separate models. River stage was analyzed both separately from flow and velocity, and together with flow. The exception was that the flow index in the reach from SJG to the TCE/TCW or MAC receivers (Q_{SJG}) was included in the river stage models. The general forms of the three multivariate models were:

Flow model: $Q_{TRN} + Q_{SJG} + \Delta Q_{TRN} + U + day + E_{CVP} + E_{SWP} + P_{CVP} + L + RG$

Velocity model: $V_{TRN} + V_{SJG} + \Delta V_{TRN} + U + day + E_{CVP} + E_{SWP} + P_{CVP} + L + RG$

Stage model: $C_{TRN} + \Delta C_{TRN} + Q_{SJG} + day + E_{CVP} + E_{SWP} + P_{CVP} + L + RG$

Flow + Stage model:

$$Q_{TRN} + Q_{SJG} + \Delta Q_{TRN} + U + C_{TRN} + \Delta C_{TRN} + day + E_{CVP} + E_{SWP} + P_{CVP} + L + RG.$$

Backwards selection with F-tests was used to find the most parsimonious model in each category (flow, velocity, stage, and flow + stage) that explained the most variation in the data (McCullagh and Nelder 1989). Main effects were considered using the full model; two-way interaction effects were considered using the reduced model found from backwards selection on the main effects model. The model that resulted from the selection process in each category (flow, velocity, stage, or flow + stage) was compared using an F-test to the full model (or a χ^2-test if the data were not overdispersed from the model) from that category to ensure that all significant main effects were included. AIC was used to select among the flow, velocity, and stage models (Burnham and Anderson 2002). Model fit was assessed by grouping data into discrete classes according to the independent covariate, and comparing predicted and observed frequencies of route selection into the San Joaquin using the Pearson chi-squared test (Sokal and Rohlf 1995).

Survival through Facilities

A supplemental analysis was performed to estimate the probability of survival of tagged fish from the interior receivers at the water export facilities through salvage to release on the San Joaquin or Sacramento rivers. Overall salvage survival from the interior receivers at site $k2$, $S_{k2(salvage)}$ (k=D, E), was defined as

$$S_{k2(salvage)} = \phi_{k2,GH} + \phi_{k2,G2} + \phi_{k2,T1} + \phi_{k2,T2} + \phi_{k2,T3},$$

where $\phi_{k2,G2}$ is as defined above, and $\phi_{k2,GH}$, $\phi_{k2,T1}$, $\phi_{k2,T2}$, and $\phi_{k2,T3}$ are the joint probabilities of surviving and moving from site $k2$ to the Jersey Point/False River junction (GH), Threemile Slough (T1), Montezuma Slough (T2), and Spoonbill Slough (T3), respectively, without going on to Chipps Island. The subset of detection histories that included detection at site $k2$ (k=D, E) was used for this analysis; predator-type detections were excluded. Detections from the full data set were used to estimate the detection probability at sites G1, G2, H1, T1, T2, and T3, although only data from tags detected at either D2 or E2 were used to estimate salvage survival. Because there were many tags detected at H1 that were later detected elsewhere such that their H1 detections were not used in the full survival model, all presumed steelhead tags ever detected at H1 were used to estimate the detection probability at H1; only detections from the final visit to H1 were used for detection probability estimation. The same procedure was used for estimating the detection probability at sites T1, T2, and T3. Detections at G1 and G2 were treated in the same way as in the full survival model, namely, detections from the lines forming the dual array at each site were pooled and these sites were treated as single arrays in the salvage survival model. The detection probability at Chipps Island was estimated based on all tags detected at Benicia Bridge (G3), as in the full survival model. Profile likelihood was used to estimate the 95% confidence intervals for both $S_{D2(salvage)}$ and $S_{E2(salvage)}$ when those parameters were estimated freely; in the event that the parameter estimates were on the boundary of the permissible interval (i.e., either 0 or 1), the sample size and the 95% upper bound (for a point estimate of 0) or the 95% lower bound (for a point estimate of 1) were reported.

Comparison among Release Groups

In order to address the issue of whether a single release group consistently had higher or lower survival and transition probability estimates compared to the other two release groups, parameter estimates were compared using a two-way analysis of variance and F-test (Sokal and Rohlf 1995). Only survival parameters representing non-overlapping regions, and transition probabilities for non-competing reaches, were used in this analysis; reaches considered were further limited to those with at least 5 tags detected per release group at the upstream end of the reach. The parameters considered were: transition probability from the release site at Durham Ferry to the first downstream detection site ($\phi_{A1,A2}$), reach-specific survival from Durham Ferry Downstream (A2) to the Turner Cut junction (A12, F1) ($S_{A2},\ldots,S_{A11}$), overall survival from MacDonald Island (A12) to Chipps Island ($S_{A12,G2}$) and from Turner Cut (F1) to Chipps Island ($S_{F1,G2}$), survival in Old River from the receivers near its head (B1) to the receivers near the head of Middle River (B2, C1) (S_{B1}), and overall survival from the Old River South receivers (B2) to Chipps Island ($S_{B2,G2}$). Both parameter and release group were treated as factors. In the event of a significant F-test indicating a consistent effect of release group on parameter estimates, three two-sided pairwise *t*-tests were used to test for comparisons between pairs of release groups. Significance was assessed at the testwise 10% level.

Linear contrasts were used to test whether estimates of survival in key regions and routes were different for one release group compared to the others. In particular, for release group i ($i=1,2,3$) and survival parameter θ, the linear contrast $L_{i\theta}$ was estimated as:

$$\hat{L}_{i\theta}=\hat{\theta}_i-0.5\sum_{j\neq i}\hat{\theta}_j\ .$$

For each release group i, $\hat{L}_{i\theta}$ was compared to 0 using a Z-test. The survival parameters considered were the composite parameters $\phi_{A1,A6}$, S_A, S_B, and overall survival S_{Total}. The Bonferroni multiple comparison correction was used for 12 tests with a 10% experimentwise significance level (Sokal and Rohlf, 1995). A contrast that is positive (negative) and significantly different from 0 indicates that the release in question had higher (lower) survival than the other two release groups.

Results

Detections of Acoustic-Tagged Fish

A total of 1,440 tags were released in juvenile steelhead at Durham Ferry in 2016 and used in the survival study. Of these, 1,331 (92%) were detected on one or more receivers either upstream or downstream of the release site (Table 5), including any predator-type detections. A total of 1,300 (90%) were detected at least once downstream of the release site, and 1,020 (71%) were detected in the study area from Mossdale to Chipps Island (Table 5). One hundred thirty (130) tags were detected upstream of the release site; 99 of these were also detected downstream of the release site. A total of 21 tags were detected at Mossdale or downstream without having been detected between the Durham Ferry release site and Mossdale.

Overall, there were 630 tags detected on one or more receivers in the San Joaquin River route downstream of the head of Old River, including possible predator detections (Table 5). In general, tag detections decreased within each migration route as distance from the release point increased, after fish reached Mossdale. Of the 630 tags detected in the San Joaquin River route, all but one were detected on the receivers near Lathrop, CA (SJL); the single tag that was not detected at SJL was observed at Turner Cut (F1) and Calaveras River (A10) after taking the Old River route at the head of Old River and passing the Highway 4 receiver on Middle River (MR4). A total of 572 tags were detected on one or more of the receivers used in the predator removal study (RS4–RS10); 496 were detected on one or more receivers near Stockton, CA (SJG, SJNB, or RRI); 481 were detected on the receivers at Calaveras River or near the Turner Cut (SJC, SJS, MAC, or TCE/TCW); and 328 were detected at Medford Island or Columbia Cut (MFE/MFW or COL) (Table 6). A total of 289 tags were detected at either Disappointment Slough or the northern Old River site (SJD or OSJ) (Table 6); 2 of those tags had been observed taking the Old River route at the head of Old River. The majority of the tags from the February release group (release 1) that were detected in the San Joaquin River downstream of the head of Old River were not assigned to the San Joaquin River route for the survival model, because they were subsequently detected in the Old River route or upstream of Old River (Table 5). Most of the tags detected in the San Joaquin River route from the March and April release groups (releases 2 and 3) were also assigned to that route for survival analysis (Table 5). Overall, 521 tags were assigned to the San Joaquin River route for the survival model, mostly from the April release group (Table 5). One additional tag was detected in the San Joaquin River route but was captured in the Mossdale trawl before its San Joaquin River route detections, and its detection history was right-censored (i.e., truncated) at site A6 (MOS); this tag was not included in the total 521 tags assigned to the San Joaquin River route. Of the 521 tags, 143 were detected at the receivers in Turner Cut, although 16 of those tags were subsequently detected in the San Joaquin River, and so were not assigned to the Turner Cut route for analysis. Of the 521 tags assigned to the San Joaquin River route, 71 were detected in Columbia Cut (COL, site F2), 57 at the northern Middle River receivers (MID, site C3), 48 at the northern Old River receivers (OSJ, site B5), 60 at the Old or Middle River receivers near Highway 4 (OR4 and MR4, sites B4 and C2), 49 at West Canal (WCL, site B3), and 50 at the water export facilities (including the radial gates at the entrance to the Clifton Court Forebay) (Table 6). A total of 293 San Joaquin River route tags were detected at the Jersey Point/False River receivers, including 65 on the False River receivers (Table 6). However, most of the tags detected at False River were later detected either at Jersey Point or Chipps Island, and so only one tag detected at False River from the San Joaquin River route was available for use in the survival model (Table 7). Forty-four (44) tags from the San Joaquin River route were detected at Threemile Slough; all but two had come from the Disappointment Slough receivers, although some had intervening detections at Jersey Point. One Threemile Slough tag came from the northern Old River site (OSJ), and one came from the CVP holding tank. A total of 291 San Joaquin River route tags were eventually detected at Chipps Island, including predator-type detections, mostly from the April release group (Table 6).

The majority of the tags from the February and March release groups that were detected downstream of the head of Old River were detected in the Old River route (472 tags); the April release group had many fewer tags detected in the Old River route compared to the San Joaquin River route (19 vs 415) (Table 5). All 491 tags detected in the Old River route were detected at the Old River East receivers near the head of Old River; 479 were detected near the head of Middle River, 417 at the receivers at the water export facilities, 118 at West Canal, and 21 at the Old or Middle River receivers near Highway 4 in the interior Delta (Table 6). The majority of the tags detected at West Canal entered the interior Delta from the head of Old River, while the majority of the tags detected at Highway 4 (OR4, MR4) entered the interior Delta from the San Joaquin River downstream of Stockton (Table 6).

The large majority of tags detected in the Old River route were also assigned to that route for the survival model, although up to three tags in each release group were detected in the Old River route but assigned to the San Joaquin River route because of subsequent detections in that route. One tag detected in the Old River route was subsequently detected upstream of the head of Old River, and was not assigned to the Old River route. In all, 483 tags were assigned to the Old River route at the head of Old River based on the full sequence of tag detection (Table 5). Of these 483 tags, 341 were detected at the CVP trash racks, although only 285 such tags were used in the survival model for the CVP because the others were subsequently detected at the radial gates, Old River, or Middle River (Table 6, Table 7). Likewise, 231 of the tags assigned to the Old River route were detected at the radial gates, and only 113 of those detections were available for use in the survival model (Table 6, Table 7). A total of 31 of the Old River route tags were detected at either Jersey Point or False River (Table 6), 21 of which came via the CVP, 6 via the CCFB, and 4 via Old River at Highway 4, before being detected at Jersey Point or False River. Ten tags from the Old River route were detected at False River, but all were later detected at Jersey Point, Chipps Island, Benicia Bridge, or Threemile Slough, so there were no False River detections available for the survival model from the Old River route (Table 6, Table 7). Of the 483 tags assigned to the Old River route at the head of Old River, 184 were detected at Chipps Island, including predator-type detections (Table 6, Table 7).

In addition to the northern Middle River receivers (MID), tag detections were recorded at the Montezuma Slough and Spoonbill Slough receivers but were purposely omitted from the survival model. Two tags were detected at the Montezuma Slough receivers (both from the Old River route), and nine tags were detected at the Spoonbill Slough receivers (six from the Old River route); all were subsequently detected at Chipps Island. Threemile Slough was used only in the San Joaquin River route; four tags from the Old River route were detected at Threemile Slough after detection at either the water export facilities (three tags) or the Old River receivers near Highway 4 (one tag) (Table 6).

The predator filter used to distinguish between detections of juvenile steelhead and detections of predatory fish that had eaten the tagged steelhead classified 161 of the 1,440 tags (11%) released as being detected in a predator at some point during the study (Table 8). Of the 1,020 tags detected in the study area (i.e., at Mossdale or points downstream), 139 tags (14%) were classified as being in a predator, although some had also been identified as a predator before entering the study area. A total of 131 tags (13% of 1,020) were first classified as a predator within the study area. Relatively few (31, 2%) of the 1,310 tags detected upstream of Mossdale were assigned a predator classification in that region; 1 of those 31 tags was first classified as a predator downstream of Mossdale, and then returned to the upstream region.

The detection site with the most first-time predator classifications was the CVP trashrack (E1; 33 of 351, 9.4%) (Table 8). The detection site upstream of Durham Ferry (A0) also had a high number of first-time predator classifications (14 of 130, 10.8%). Within the study area, the detection sites with the largest number of first-time predator-type detections, aside from the CVP trashrack (E1), were the

Radial Gates Upstream receivers (D1; 11 of 268, 4.1%) and Predator Removal Study 6 (N3; 7 of 524, 1.3%) (Table 8). The majority of the first-time predator classifications assigned within the study area were assigned to tags on departure from the site in question (77) rather than on arrival at the site (54). Predator classifications on arrival were typically due to unexpected travel time, unexpected transitions between detection sites, or lengthy detection histories at individual sites, and were most common at Durham Ferry Upstream (A0), the CVP trashrack (E1), Banta Carbona (A5), and the third and fourth predator removal study sites (N3, N4) (Table 8). Predator classifications on departure were typically due to long residence times, and were most prevalent at the CVP trashrack (E1) and outside the radial gates (D1) (Table 8). Only detections classified as from predators on arrival were removed from the survival model, along with any detections subsequent to the first predator-type detection for a given tag.

The predator filter performance was assessed using acoustic telemetry detections of predatory fish including Striped Bass, Largemouth Bass, White Catfish, and Channel Catfish. A total of 89 tagged predatory fish were detected in the 2016 steelhead survival study: 22 that had been released in 2014, and 67 that had been released in 2015. Of the 89 predator tags detected, a total of 71 tags were classified as being in a predator at some point during their detection history, based on a score of at least 2 from the predator filter, resulting in a filter sensitivity of 79.8%. When predator tags that had fewer than 5 detections events on the visit scale were omitted, the filter sensitivity increased to 98.5%: 66 of 67 predator tags tested positive as a predator.

When the detections classified as coming from predators were removed from the detection data, there was little change in the overall number of tags detected, although the patterns of detections changed somewhat (Table 9, Table 10, and Table 11). With the predator-type detections removed, 1,297 of the 1,440 (90%) tags released were detected downstream of the release site, and 1,012 (70% of those released) were detected in the study area from Mossdale to Chipps Island (Table 9). A total of 122 tags were detected upstream of the release site with steelhead-type detections; 90 of these were also detected downstream of the release site. With or without the predator-type detections, the April release group had the most detections in the study area, and the February release group had the fewest (Table 5, Table 9).

The Old River route was used more than the San Joaquin River route for the February and March release groups, while the April release group used the San Joaquin River route more (Table 9). Most detection sites had fewer detections in the reduced, steelhead-only data set (Table 10 vs Table 6). However, because some tags were observed moving upriver or to an alternate route after the predator classification from the predator filter, the number of detections available for use in the survival model was actually higher in the steelhead-only data set for some detection sites (DFD, WCL, and MRH; Table 11 vs Table 7). The largest change in the number of detections available for the survival analysis occurred at the Navy Drive Bridge (SJNB), where the reduced data set had 19 fewer detections than the full data set that included the predator-type detection (Table 11 vs Table 7). Comparable reductions in the number of detections were observed at the Calaveras River (SJC; reduction = 18), Chipps Island (reduction = 17), and Benicia Bridge (reduction = 16) (Table 11 vs Table 7). The number of tags detected at Chipps Island changed from 461 when the predator-type detections were included, to 444 when such detections were excluded (Table 6 vs Table 10). Of the 518 tags that were assigned to the San Joaquin River route at the head of Old River when predator-type detections were excluded, 93 were subsequently detected in the interior Delta, 131 were detected in Turner Cut, 68 were detected in Columbia Cut, and 46 were detected at the northern Old River site (OSJ), compared to 275 tags that were detected only in the main stem San Joaquin River downstream of the head of Old River; 277 (53%) of the tags assigned to the San Joaquin River route were detected at Jersey Point, and 276 (53%) were detected at Chipps Island (Table 10). Of the 479 tags assigned to the Old River route at the head of Old River, 304 (63%) were detected at the CVP trash racks, 224 (47%) at the radial gates, 30 (6%) at Jersey Point, and 182 (38%) at Chipps Island (Table 10). Detection counts used in the survival model largely follow a similar pattern (Table 11).

Survival Model Modifications for Individual Release Groups

Modifications to the survival model were required for the individual release groups because of sparse data.

Modifications for February Release Group

Most of the fish from the February release group that reached the head of Old River arrived at that junction before the temporary rock barrier was installed, and the majority of tags from this release were observed using the Old River route through the Delta. Detections were too sparse in the San Joaquin River route to fit the full reach-specific survival model to those data. Survival could be estimated along the San Joaquin River to Turner Cut, MacDonald Island, and Medford Island, and from those sites to Chipps Island, but the finer-grained spatial detail between those sites and Chipps Island could not be estimated. No attempt was made to estimate transition probabilities from the lower San Joaquin River to the Highway 4 sites (OR4, MR4) or the water export facility sites (RGU, RGD, CVP, CVPtank), or to Chipps Island specifically via Columbia Cut, the northern Old River site (OSJ), or

Disappointment Slough (SJD). Detection sites A14, B4, B5, C2, D1, D2, E1, E2, F2, G1, and T1 were all omitted from Submodel II because of sparse detections (Figure 4). False River was omitted entirely from both submodels.

In the Old River route, only one tag was detected at the Middle River Head (MRH, C1) site; the detection history for that tag was right-censored (i.e., truncated) at that site, so that it contributed to estimation of survival to that site but no attempt was made to estimate transition probabilities starting at site C1. The majority of the Old River route tags observed downstream of the Old River South station (ORS, B2) were detected at the water export facilities (CVP, CVP tank, RGU, and RGD). Too few tags were detected at the Highway 4 sites (OR4, MR4) to estimate transition probabilities from those sites, although transition probabilities were estimated to those sites, under the assumption of 100% detection. There were also too few tags detected at West Canal (WCL, B3) to estimate the transition probability from that site; WCL was omitted from Submodel I. No Old River route tags were detected at Jersey Point (JPE/JPW, G1), so that site was omitted from the model. The estimates of total Delta survival in both routes and overall estimated from the full model were confirmed by fitting a simplified model that estimated survival from the Old River East (ORE = B1) site to Chipps Island directly.

Modifications for March Release Group

The majority of tags detected downstream of the head of Old River from the March release group were observed taking the Old River route. Within the Old River route, the majority of tags were observed taking the routes through the water export facilities rather than past Highway 4. The sparse detections at the Old River receivers at Highway 4 (OR4 = B4) required pooling the detections from the dual array at that site and treating it as a single array for Submodel I. Sparse detection data in the San Joaquin River route at the water export facilities and Highway 4 receivers (OR4, MR4) required removing those sites from Submodel II. This resulted in parameters $\phi_{A13,GH}$, $\phi_{B5,GH}$, $\phi_{F1,GH}$, and $\phi_{F2,GH}$ encompassing not only the probability of directly moving from sites MFE/MFW (A13), OSJ (B5), TCE/TCW (F1), and COL (F2) directly to the Jersey Point/False River junction as implied in the full Submodel II (Figure 3), but also the probability of moving first to the Highway 4 region (OR4, MR4) before moving on to Jersey Point or False River (Figure 5). It was also necessary to pool detections across the dual array at Jersey point (G1) for both major routes, and at Old River South (ORS = B2) in the Old River route. Only one tag was detected using the Threemile Slough route, but that tag was subsequently detected downstream at Benicia Bridge (BBR = G3), so it was necessary to retain Threemile Slough in the model to avoid biasing estimates of transitions past Jersey Point. It was also necessary to assume 100% detection probability at Threemile Slough and complete transitions from that site to Chipps Island (i.e., $\phi_{T1,G2} = 1$); the limitations of these assumptions were explored. False River was omitted entirely from both submodels. Through-Delta survival estimates from the full model were confirmed using a simpler model that estimated survival directly from ORS to Chipps Island in the Old River route.

Modifications for April Release Group

The head of Old River barrier was installed for passage of the majority of fish from the April release group. The presence of the barrier resulted in few April tags detected in the Old River route, and sparse detections downstream of the Old River South/Middle River Head receivers (ORS = B2, MRH = C1). The majority of tag detections at the water export facilities, and all detections at the Highway 4 sites (OR4 = B4, MR4 = C2) and Jersey Point (JPE/JPW = G1), came from tags observed taking the San Joaquin River route at the head of Old River. Under the assumption of common detection probabilities regardless of route, it was possible to retain most detection sites in both submodels, although it was not possible to estimate all transition probabilities in the Old River route. In particular, because there were no detections at the stations at West Canal (WCL = B3) or Highway 4, it was not possible to estimate transition probabilities from those sites ($\phi_{B3,B4}$, $\phi_{B4,GH}$, and $\phi_{C2,GH}$) and WCL was omitted from the model. Estimates of mid-Delta survival in the Old River route ($S_{B(MD)}$) and overall ($S_{Total(MD)}$) could nevertheless be estimated based on the pattern of detections at upstream sites (ORE, ORS, and MR4) and Jersey Point (JPE/JPW), using the Jersey Point detection probability from the San Joaquin River route fish. Sparse detections at the Middle River Head station (MRH = C1) required right-censoring (i.e., truncating) detection histories at that site; no attempt was made to estimate transition probabilities or survival from that site. The estimates of through-Delta survival and mid-Delta from the Old River route (S_B and $S_{B(MD)}$) and overall (S_{Total} and $S_{Total(MD)}$) were all based on the assumption that no tags successfully reached either Jersey Point or Chipps Island via the MR4 detection site. Although it was not possible to estimate transition probabilities from the MRH site, the low observed usage of that site across all release groups, and the lack of any subsequent detections of MRH tags, provides support for that assumption. Because the sparse detection data in the Old River route presented challenges in fitting the full model in that route, the estimates of through-Delta survival in the Old River route and overall were confirmed by fitting a simplified model that omitted all detailed transitions between the Old River East (ORE = B1) site near the head of Old River and Chipps Island.

False River was omitted entirely from both submodels. It was necessary to pool detections within the dual array at Columbia Cut (COL = F2) when the predator-type detections were removed, and at Jersey Point with and without the predator-type detections. Model fit was improved by pooling detections within the lines comprising the dual arrays at MacDonald Island (MAC = A12); each of these sites was treated as a single array in the model.

Tag-Survival Model and Tag-Life Adjustments

Observed tag failure times ranged from 22.92 days to 76.01 days; all but 1 of the 82 tags with failure times survived at least 57 days. Model fit was improved by right-censoring (i.e., truncating) failure time data at 69 days; there were 15 tags with tag failure times > 69 days. Model fit comparisons using AIC to compare analyses that pooled over tag-life study resulted in selection of the pooled model (ΔAIC = 30.15). Thus, a single tag survival model was fitted and used to adjust fish survival estimates for premature tag failure. The estimated mean time to failure from the pooled data was 63.9 days ($\widehat{SE} =$ 6.4 days) (Figure 6).

The complete set of acoustic-tag detection data from those tags released in steelhead to the river at Durham Ferry, including any detections that may have come from predators, contained several detections that occurred after the tags began dying (Figure 7, Figure 8). The sites with the latest detections were the CVP trashracks, Durham Ferry Downstream, Medford Island, and Chipps Island (Figure 7, Figure 8). Some of these late-arriving detections may have come from predators, or from residualizing steelhead. Without the predator-type detections, the late-arriving detections were largely removed (e.g., Figure 9). Tag-life corrections were made to survival estimates to account for the premature tag failure observed in the tag-life studies. All of the estimates of reach tag survival were greater than or equal to 0.9812, and most were greater than 0.998, out of a possible range of 0 to 1; cumulative tag survival to Chipps Island was estimated at 0.9955 without predator-type detections (0.9950 with predator-type detections). Thus, there was little effect of either premature tag failure or corrections for tag failure on the estimates of steelhead reach survival in 2016.

Surgeon Effects

Steelhead in the release groups were evenly distributed across surgeon (Table 12). Additionally, for each surgeon, the number of steelhead tagged was well-distributed across release group. A chi-squared test found no evidence of lack of independence of surgeon across release group (χ^2 = 0.533, df = 4, P = 0.9702). The distribution of tags detected at various key detection sites was also well-distributed across surgeons and showed no evidence of a surgeon effect on survival, route selection, or detection probabilities at these sites (χ^2 = 17.253, df = 52, P > 0.9999; Table 13).

Estimates of cumulative fish survival throughout the San Joaquin River route to Chipps Island showed similar patterns of survival across all surgeons. Surgeon A had consistently lower point estimates of cumulative survival through the San Joaquin River route, and in the Old River route through Old River South and the head of Middle River (Figure 10, Figure 11). The estimate of cumulative survival to the Turner Cut junction (i.e., to the MacDonald Island or Turner Cut receivers) in the San Joaquin River route was 0.56 ($\widehat{SE} = 0.03$) for fish tagged by surgeon A, compared to 0.62 ($\widehat{SE} = 0.03$) for surgeon B, and 0.60 ($\widehat{SE} = 0.03$) for surgeon C (Figure 10). Survival to Chipps Island via the San Joaquin River route was estimated at 0.37 surgeon A, compared to 0.41 and 0.42 for surgeons B and C, respectively ($\widehat{SE} = 0.03$ for each surgeon). Despite the lower point estimates of survival in the San Joaquin River route for fish tagged by surgeon A, there was no significant difference in cumulative survival to any sites in that route among surgeons (P≥0.2019, Figure 10). In the Old River route, the differences between the surgeons were smaller, and had disappeared by the export facilities, West Canal, and Highway 4; no differences were statistically significant (P≥0.6312; Figure 11). In particular, there was no difference in survival to Chipps Island in the Old River route (P=0.7049; Figure 11). Analysis of variance found no effect of surgeon on reach survival in the two routes collectively (P=0.2070). Rank tests found no evidence of consistent differences in reach survival for fish from different surgeons either upstream of the Head of Old River (P=0.9810), in the San Joaquin River route (P=0.6977), or in the Old River route (P=0.9810).

Survival and Route Selection Probabilities

Likelihood ratio tests found that transitions to the exterior receivers at the Clifton Court Forebay, and on to the interior receivers of the Forebay, depended on whether the radial gates were open or closed at the time of arrival at the exterior receivers (P≤0.0036) for the February and March release groups. No strong gate effect was observed for the April release group (P=0.0575), so the April model was fit without differentiating between open and closed gates. Model fit was not significantly improved by including an effect of route selection at the head of Old River on the transition probabilities from the water export facility detection sites ($\phi_{D1,D2}$, $\phi_{D2,G2}$, $\phi_{E1,E2}$, and $\phi_{E2,G2}$ for the April release group (P=0.6139); detection data at the water export facility sites from the San Joaquin River tags were too sparse to include those sites in the February and March models. Model fit was also not improved by including an effect of route selection on the transition probability from Jersey Point to Chipps Island ($\phi_{G1,G2}$) for the March release group (P=0.5949); detections at Jersey Point were too sparse in one or both routes for testing in the February and April release groups.

Some parameters were unable to be estimated because of sparse detection data; see above for details on modifications to the release-recapture model required for each release group. For all release groups, detections at the Middle River Head site (C1) were too sparse to estimate transition probabilities from that site to telemetry stations downstream. Estimates of survival through the South Delta were available only when there was no evidence of tags selecting the Middle River route (i.e., $\psi_{BC} = 0$; March release without predator-type detections, and March and April releases with predator-type detections) (Table 14, Table 15), and estimates of survival through the South Delta, Mid-Delta region (i.e., to Jersey Point), or total (i.e., to Chipps Island) depended on the assumption (consistent with the data) that either use of the Middle River route or survival in that route was 0. Selection of the Middle River route was based on the assumption of 100% detection probability at site C1. While this assumption could not be tested within each release group, it is consistent with the pattern of detections observed over all release groups (i.e., all tags detected at the C1 array were detected on both lines of the array).

Sparse detection data at the Highway 4 sites (OR4, MR4) in the February and April release groups prevented estimation of transition probabilities from those sites to Jersey Point and Chipps Island; estimates of Old River route survival to either Jersey Point or Chipps Island depended on the assumption that the Highway 4 routes were not viable, which was consistent with the data. Sparse detection data at Jersey Point from the February release group prevented estimation of survival through the Mid-Delta region for both primary routes (Table 14, Table 15). No transition probabilities could be estimated to or from the Highway 4 sites and the water export facility sites for fish that took the San Joaquin River route at the head of Old River from the February and March release groups, because of sparse detections at those sites. Likewise, detection counts in the San Joaquin River route were too low for the February release to estimate transition probabilities among the detection sites between the region around MacDonald Island, Medford Island, and Turner Cut, and Chipps Island.

Although the full survival model separately estimates the transition probabilities to the Jersey Point/False River junction ($\phi_{kj,GH}$) and the route selection probability at that junction $\left(\psi_{G1}\right)$, it was not possible to estimate these two parameter separately for any release group in 2016. Of the 75 steelhead tags observed on the False River receivers, all but one of them were later detected at either Jersey Point or Chipps Island. There were too few detections available in the modeled detection histories at False River to reliably estimate the detection probability at that site. This meant that it was not possible to separately estimate the survival transition parameters $\phi_{kj,GH}$ from the route selection probability ψ_{G1}, for transitions from station j in route k. Instead, only their product was estimable: $\phi_{kj,G1} = \phi_{kj,GH}\psi_{G1}$, for kj = A12, A13, A14, B4, B5, C2, F1, and F2. However, in some cases, even those parameters could not be estimated because of sparse data. Because there were some detections at the H1 receivers, it is must be that $\psi_{G1} < 1$ and $\phi_{kj,G1} \neq \phi_{kj,G1}$. Although not possible to estimate the difference between these parameters, the fact that 74 of 75 (99%) of the tags detected at H1 were later detected at G1 or G2 suggests that the difference between $\phi_{kj,G1}$ and $\phi_{kj,GH}$ was small. Omitting H1 meant also that the estimates of survival through the Mid-Delta region should be interpreted as survival to Jersey Point, rather than to the Jersey Point/False River junction.

Few tags were detected using the Burns Cutoff route around Rough and Ready Island (i.e., passing the RRI = R1 telemetry station), and no tags were detected at that site from the February and March release groups (Table 11). The estimates of route selection at Burns Cutoff (ψ_{A2}) were based on the assumption of 100% detection probability at site R1 for the February and March release groups. No estimate of survival from the R1 site to the Calaveras River detection site (SJC = A10) was available for the February and March release groups. Likewise, the estimate of the transition probability to Threemile Slough ($\phi_{A14,T1}$) was based on the assumption of 100% detection probability at Threemile Slough for the March release group. Alternative assumptions of 50% detection probability at Threemile Slough raised the estimate of $\phi_{A14,T1}$ by 0.01, a difference which was less than the standard error.

Using only those detections classified as coming from juvenile steelhead by the predator filter, the estimates of total survival from Mossdale to Chipps Island, S_{Total}, ranged from 0.39 ($\widehat{SE} =$ 0.03) for the February release group to 0.59 ($\widehat{SE} =$ 0.02) for the April release group; the overall population estimate from all three releases (weighted average) was 0.47 ($\widehat{SE} =$ 0.02) (Table 14). The estimated probability of entering Old River at its head was highest for the February release group (0.88, $\widehat{SE} =$ 0.02), which passed mostly before the Head of Old River barrier was installed on April 1; estimates were still high (0.77, $\widehat{SE} = 0.02$) for the March release group, most of which passed before the barrier installation was complete, and were noticeably lower for the April release (0.04, $\widehat{SE} = 0.01$). The population estimate of Old River route selection over all three releases was 0.56 ($\widehat{SE} = 0.01$) (Table 14). There was a statistically significant preference for the Old River route for the February and March releases, and for the San Joaquin River route for the April release (P<0.0001 for each release group). Estimates of survival from Mossdale to Chipps Island via the San Joaquin River route $\left(S_A\right)$ ranged from 0.23 ($\widehat{SE} = 0.08$) for the February release group to 0.61 ($\widehat{SE} = 0.02$) for the April release; the population estimate, averaged over all three release groups, was 0.45 ($\widehat{SE} = 0.03$) overall (Table 14). In the Old River route, estimates of survival from Mossdale to Chipps Island $\left(S_B\right)$ ranged from 0.17 ($\widehat{SE} = 0.06$) for the April release to 0.41 ($\widehat{SE} = 0.04$) for the February release (population average = 0.33, $\widehat{SE} = 0.03$) (Table 14). The route-specific survival to Chipps Island was significantly different (at the 5% level) between routes for the April release group, when survival was higher in the San Joaquin River route than in the Old River route (P=0.0002; Table 14). For the March release group, the point estimate of San Joaquin River route survival (0.50) was also higher than for the Old River route (0.40), but the difference was statistically significant only at the 10% level (P=0.0612). There was no significance difference in survival to Chipps Island between routes for the February release (P=0.1216; Table 14). When combined over all three release groups, the population estimate of route-specific survival to Chipps Island was higher for the San Joaquin River route than for the Old River route (P=0.0034; Table 14).

Survival was estimated to the Jersey Point/False River junction for routes that did not pass through the holding tanks at the CVP or the CCFB. This survival measure ($S_{Total(MD)}$) was estimable only for the March and April release groups: $\hat{S}_{Total(MD)} = 0.14$ ($\widehat{SE} = 0.02$) for March, and 0.53 ($\widehat{SE} = 0.02$) for April (Table 14). This was a minimum estimate, because it excluded the possibility of going to False River rather than to Jersey Point; however, no tags from these two release groups were detected at False River without also being detected at either Jersey Point or Chipps Island (Table 11), suggesting that the bias in the estimate of $S_{Total(MD)}$ was small. Survival to Jersey Point was different for the two routes for both the March and April releases (P<0.0001), and was higher for fish in the San Joaquin River route (Table 14). However, over 75% of the Old River route fish from the March release group were detected at the radial gates at the entrance to the Clifton Court Forebay or at the CVP trashracks (Table 11); the survivors of these fish would not have contributed to survival to Jersey Point or False River, because those sites were not on the migration route downstream from the CVP or SWP holding tanks. Because $S_{Total(MD)}$ does not reflect survival to downstream regions via salvage, it does not necessarily indicate overall survival to Chipps Island (S_{Total}), in particular in the absence of a barrier at the head of Old River. The barrier was absent for the majority of fish passing the head of Old River from the March release, and approximately 77% of fish used the Old River route from that release group. Only 4% of fish from the April release group used the Old River route, and the estimates of mid-Delta survival and total Delta survival were similar for that group (0.53 ($\widehat{SE} = 0.02$) for mid-Delta survival and 0.59 ($\widehat{SE} = 0.02$) for total Delta survival; Table 14).

Survival was estimated through the South Delta for San Joaquin River route fish ($S_{A(SD)}$) for all three release groups, and for Old River route fish only for the March release group ($S_{B(SD)}$). The "South Delta" region corresponded to the region studied for Chinook salmon survival in the 2009 VAMP study (SJRGA 2010). Survival through the San Joaquin River portion of the South Delta, i.e. from Mossdale to the Turner Cut or MacDonald Island receivers, had estimates ranging from 0.58 ($\widehat{SE} = 0.09$; February) to 0.89 ($\widehat{SE} = 0.02$; April); the population level estimate was 0.73 ($\widehat{SE} = 0.04$; Table 14). Survival through the Old River portion of the South Delta, i.e., from Mossdale to the CVP trashracks (CVP), radial gates exterior receivers (RGU), and Highway 4 receivers (OR4, MR4), was estimated only for the March release: 0.0.83 ($\widehat{SE} = 0.02$; Table 14). Total estimated survival through the entire South Delta region ($S_{Total(SD)}$) was estimable only for the March group (0.81, $\widehat{SE} = 0.02$; Table 14).

Including the predator-type detections in the analysis had a negligible effect on the survival estimates in most regions for the February and March release groups, and moderate effects for the April release group (Table 15). The measures of through-Delta survival and Mid-Delta survival had higher estimates for the April release group when predators were included (Table 15) than when they were excluded (Table 14); the increases ranged from 0.03 for Mid-Delta survival through the San Joaquin River Route ($S_{A(MD)}$) to 0.08 for the Old River route survival from Mossdale to Chipps Island $\left(S_B\right)$. Also notable was the ability to estimate South Delta survival in the Old River route ($S_{B(SD)}$) for the April release when predator-type detections were included, although with only moderate precision (0.67,

$\widehat{SE} = 0.12$; Table 15). The differences in April through-Delta survival estimates when the predator-type detections were included arose from additional tags detected at Chipps Island, along with small increases in detection counts at sites throughout the study area (Table 7, Table 11, Table 14, Table 15).

Estimates of survival through the South Delta tended to be higher when predator-type detections were included, if survival was estimable at all, for all release groups. The estimates of South Delta survival in the San Joaquin River route for the three release groups increased from 0.58 ($\widehat{SE} =$ 0.09), 0.74 ($\widehat{SE} = 0.05$), and 0.89 ($\widehat{SE} = 0.02$) without the predator-type detections to 0.65 ($\widehat{SE} = 0.09$), 0.77 ($\widehat{SE} = 0.05$) and 0.93 ($\widehat{SE} = 0.01$) when predator-type detections were included (Table 14, Table 15). For the March release group, estimates of South Delta survival in the Old River route and overall both increased by 0.03 when predator-type detections were included. For the April release group, South Delta survival in the Old River route ($S_{B(SD)}$) could be estimated only when the predator-type detections were included (0.67, $\widehat{SE} = 0.12$; Table 15). No estimates of Old River route South Delta survival could be estimated for the February release group, whether or not predator-type detections were included.

Detection probability estimates were high (>0.95) at most receiver arrays throughout the Delta (Table A2). However, some detection sites upstream of Mossdale had estimated detection probabilities as low as 0.30 (BDF1 = A3 for the April release; Table A2). The estimated probability of detection at Chipps Island ranged from 0.93 ($\widehat{SE} = 0.02$) for the April release to 0.95 ($\widehat{SE} = 0.03$) for the February release (Table A2), based on the pattern of detections at Chipps Island and Benicia Bridge. The estimates of survival to Chipps Island are adjusted for imperfect detection, so detection probabilities < 1.0 are not expected to bias the survival estimates.

Survival estimates in reaches varied throughout the study. For most reaches upstream of the San Joaquin River Navy Drive Bridge (SJNB = A9), the estimated survival was highest for the April release, and lowest for the February release (Table A2). The estimated total probability of survival from release at Durham Ferry to Mossdale was considerably lower for the February release (0.44, $\widehat{SE} = 0.02$) compared to March (0.78, $\widehat{SE} = 0.02$) or April (0.89, $\widehat{SE} = 0.01$) (Table 14). This pattern of lower perceived survival to Mossdale in February was observed both with and without the predator-type detections (Table 14, Table 15). The probability of turning upstream from the release site ($\phi_{A1,A0}$) had similar estimates for all three releases (0.02 to 0.08; Table A2), suggesting that the lower estimate of cumulative survival to Mossdale for February was due either to mortality or to permanent rearing between Durham Ferry and Mossdale rather than farther upstream.

Reach-specific estimates in the San Joaquin River route tended to be less precise (larger standard errors) for the February release group, when relatively few tags were observed in that route compared to the March and April release groups (Table A2). Survival from Mossdale through the head of Old River, to the SJL or ORE receivers, had high estimates all three release groups, ranging from 0.96 ($\widehat{SE} = 0.01$) for February to 1.00 ($\widehat{SE} < 0.01$) for April (Table A2). Survival in the San Joaquin River from Lathrop (SJL) to Garwood Bridge (SJG, site A8) varied from 0.72 ($\widehat{SE} = 0.09$) for the February release group to 0.96 ($\widehat{SE} = 0.01$) for the April release group (Table A2). Reach-specific survival estimates in the reaches between Garwood Bridge and the MacDonald Island/Turner Cut receivers were consistently high (0.92 to 1.00) across the release groups (Table A2). From MacDonald Island, most fish continued in the San Joaquin River to Medford Island, represented by the transition parameter $\phi_{A12,A13}$; estimates were higher for the later release groups (0.97, $\widehat{SE} = 0.05$ for March, and 0.75, $\widehat{SE} = 0.03$ for April) than for February (0.44, $\widehat{SE} = 0.17$) (Table A2). Most fish from the March and April release groups that were observed at Medford Island continued down the San Joaquin to Disappointment Slough ($\hat{\phi}_{A13,A14} = 0.72$ to 0.81, $\widehat{SE} \le 0.07$), although some moved past the northern Old River receivers (OSJ, site B5) instead ($\hat{\phi}_{A13,B5} = 0.10$ to 0.21, $\widehat{SE} \le 0.06$ (Table A2). Total survival from Disappointment Slough to either Jersey Point (G1) or Threemile Slough (T1) was > 0.95 for both the March and April release groups. The probability of moving from OSJ to Jersey Point was also high (≥0.93) for March and April, whereas the estimated transition probability from Jersey Point to Chipps Island ranged from 0.84 to 0.98 ($\widehat{SE} \le 0.05$) (Table A2). Too few tags from the February release were detected in the San Joaquin River route to monitor detailed migration pathways downstream of MacDonald Island and Turner Cut for that release. Most tags detected coming from Disappointment Slough past Threemile Slough were later detected at Chipps Island ($\hat{\phi}_{T1,G2} = 0.95$, $\widehat{SE} = 0.03$ population estimate, Table A2). Consistent with the relatively low survival in the upstream reaches for the February release group compared to the March and April releases, the February release had the lowest estimate of total survival to Chipps Island from MacDonald Island: 0.34 ($\widehat{SE} = 0.16$), compared to 0.81 to 0.83 for the March and April releases (Table A2). On the other hand, the February group had the highest estimated survival from Turner Cut to Chipps Island but with low precision because of small sample size: 0.50, $\widehat{SE} = 0.21$ for February, compared to 0.31 to 0.33 ($\widehat{SE} = 0.05$ to 0.11) for March and April (Table A2). The February group also had the highest probability of leaving the San Joaquin River for Turner Cut (0.40; $\widehat{SE} = 0.13$; Table A2).

In the Old River route, the estimated probability of surviving from the first detection site (ORE, site B1) to the head of Middle River (S_{B1}) was very high (≥0.97) for all three release groups; the February and March estimates had high precision ($\widehat{SE} = 0.01$), while the smaller sample size in April resulted in lower precision (95% lower bound = 0.82; Table A2). For all release groups, the estimate of S_{B1} was dependent on the assumption of 100% detection at the Middle River site MRH (site C1); pooling detections across all three release groups, the dual array estimate of the detection probability at that site was 1.0. No tags observed taking the Middle River route had subsequent detections. All release groups had a low estimated probability of moving and surviving from ORS to the Highway 4 sites (≤0.04 for each release group for OR4 and MR4; Table A2); because no February tags were detected at MR4, the MR4 transition probability for that group was based on the untested assumption of 100% detection probability. The estimated probability of moving from the Old River site at Highway 4 (OR4) to Jersey Point was highest for March (0.38, $\widehat{SE} = 0.17$), and either very low (0.04, $\widehat{SE} = 0.04$) or unestimable for the other release groups (Table A2). No tags detected at the Middle River Highway 4 site (MR4) were later detected at Jersey Point (95% upper bound = 0.56 for March and 0.14 for April for $\phi_{C2,G1}$; Table A2). The transition probability from ORS to the CCFB radial gates (exterior site, D1) had similar estimates for the three release groups (0.21 to 0.39), while the estimated transition probability from ORS to the CVP was considerably lower for April (0.23, $\widehat{SE} = 0.12$) than for February (0.67, $\widehat{SE} =$ 0.04) or March (0.57, $\widehat{SE} = 0.03$) (Table A2). The majority of tags that were detected at the exterior radial gate receivers (D1) and did not return to either the CVP or Highway 4 were eventually observed entering Clifton Court Forebay and were detected on the interior receivers (D2): 0.82 to 1.04. The transition probability from the interior radial gate receivers to Chipps Island, presumably through the Forebay and salvage, ranged from 0.33 ($\widehat{SE} = 0.12$) for April, to 0.56 ($\widehat{SE} = 0.06$) for March (Table A2). Of the February and March tagging steelhead that reached the CVP trashracks (E1) without later being detected at the CCFB radial gates (D1, D2) or Highway 4 receivers, just over half were estimated to have survived to the holding tank (0.54 to 0.59, $\widehat{SE} \le 0.05$), whereas under half were observed entering the CVP holding tank from the April release (0.44, $\widehat{SE} = 0.10$) (Table A2). From the holding tank to Chipps Island, the transition probability estimate ranged from 0.85 ($\widehat{SE} = 0.05$) for February to 0.92 ($\widehat{SE} = 0.08$) for April (Table A2). Although including predator-type detections resulted in modified transition and survival probabilities for some reaches, similar overall patterns of movement and survival were estimated whether or not predator-type detections were included (Table A3).

Travel Time

For tags classified as being in steelhead, travel time through the system from release at Durham Ferry to Chipps Island ranged from 2.8 days to 41.2 days, and averaged 8.32 days ($\widehat{SE} = 0.19$ days) for all three release groups combined (Table 16a). Average travel time to Chipps Island was longest for the February release group (13.2 days), and shortest for the March release group (6.6 days); the April group had travel time similar to March (8.8 days) (Figure 12). Average travel time to Chipps Island was slightly longer for fish in the San Joaquin River route than for the Old River route: combined over all releases, fish in the San Joaquin River route took an average of 8.92 days ($\widehat{SE} =$ 0.21 days) from release at Durham Ferry, compared to an average of 7.52 days ($\widehat{SE} = 0.33$ days) for fish in the Old River route (Table 16a). However, variability between release groups complicates comparisons of route effects on travel time. For example, although the average travel time was shorter for the Old River route within each release group, the average travel time in the Old River route for the February release (12.8 days, $\widehat{SE} = 0.9$ days) was considerably longer than the average San Joaquin River travel time for either the March (9.1 days, $\widehat{SE} = 0.4$ days) or April (8.8 days, $\widehat{SE} = 0.2$ days) release group (Table 16a). Over 80% of the tags that were observed at Chipps Island arrived within 15 days of release at Durham Ferry. There were 56 tags that took 16–41 days, evenly split between the San Joaquin River route and the Old River route. Travel time from release at Durham Ferry to Chipps Island via salvage at the CVP ranged from 2.8 days to 38.3 days, and was observed in all release groups. Of the 123 tags that took this migration route, 19 had travel time > 15 days from Durham Ferry to Chipps Island: 17 were released at Durham Ferry in February and 2 were released in April, and all but 4 used the Old River route to the CVP. Travel time from Durham Ferry to Chipps Island via presumed salvage at the SWP ranged from 4.0 days to 41.2 days. Of the 57 tags observed taking this route, 11 had travel time > 15 days, all from the Old River migration route and all but 3 from the February release group.

Average travel time to all detection sites was longest for the February release group (Table A16a). For most detection sites, the March release group had lower average travel time than the April release, but the difference was typically small (average difference = 1.2 days). However, the average travel time to the CCFB radial gates was approximately 6 days longer for April (10.0 days, $\widehat{SE} = 1.2$ days) than for March (3.5 days, $\widehat{SE} = 0.2$ days) (Table 16a), while the April release tended to arrive at Columbia Cut or Disappointment Slough approximately 1 day faster than the March release (approximately 5 to 7 days for both releases) (Table 16a). Travel time from release to the Mossdale receivers averaged approximately 6 days for the February release group, compared to 1.0 to 1.6 days for the March and April release groups (Table 16a). Travel time to the Turner Cut junction (i.e., either Turner Cut receivers or MacDonald Island receivers) ranged from 1.7 days to 32.8 days, and averaged 17.6 days for the February release, approximately 5 days for the March and April releases. The majority (362 of 439, 82%) of the tags detected at the Turner Cut or MacDonald Island receivers came from the April release group (Table 16a). Travel time from release to the CVP trash racks ranged from 1.4 days to 37.1 days, and averaged 10.1 days, 4.0 days, and 8.9 days ($\widehat{SE} \leq 0.9$ days) for the February, March, and April release groups, respectively (Table 16a). Travel time to the radial gates receivers outside Clifton Court Forebay (RGU) followed a similar distribution as to the CVP trash racks (Table 16a). For both the CVP trash racks and the CCFB exterior receivers, travel time from Durham Ferry was longer for the San Joaquin River route than for the Old River route for the April release, and too few San Joaquin River route tags were detected from February and March to estimate travel time.

Few tags were detected at the Highway 4 detection sites (OR4, MR4) from the February release group from either route, and from the March release group from the San Joaquin River route. For tags taking the Old River route from the March release, average travel times were approximately 6.5 days to MR4 and 9.6 days to OR4 ($\widehat{SE} \leq 1.7$ days) (Table 16a). Considerably more tags were detected at the Highway 4 sites from the April release, all from the San Joaquin River route, and travel times averaged 8 – 10 days at both sites (Table 16a). Too few tags were detected at Jersey Point coming from either route to estimate travel time to that site for the February release group. The majority of tags observed at Jersey Point from March and April came from the San Joaquin River site, and had an average travel time of approximately 7-8 days (Table 16a). The three tags observed at Jersey Point from the Old River route (all from March) had travel times ranging from 9.8 days to 19.7 days.

Including detections from tags classified as predators tended to lengthen average travel times slightly, but the general pattern across routes and release groups was the same as without predator-type detections (Table 16b). The average travel time from release to Chipps Island via all routes, including the predator-type detections, was 8.49 days ($\widehat{SE} = 0.20$) (Table 16b). Increases in travel time with the predator-type detections reflect the travel time criteria in the predator filter, which assumes that predatory fish may move more slowly through the study area than migrating steelhead. Travel time increases may also reflect multiple visits to a site by a predator, because the measured travel time reflects time from release to the start of the final visit to the site. The Old River site at Highway 4 (OR4) had lower average travel times when the predator-type detections were included; this can happen when the predator filter removes repeat movement to sites that were previously visited.

Average travel time through reaches for tags classified as being in steelhead ranged from 0.008 days (approximately 12 minutes) from the entrance channel receivers at the Clifton Court Forebay (RGU) to the interior forebay receivers (RGD), to 4.48 days from Turner Cut (TCE/TCW) to Chipps Island (Table 17a; all releases). The "reach" from the exterior to the interior radial gate receivers (RGU to RGD) was the shortest, so it is not surprising that it would have the shortest travel time, as well. Travel times from the San Joaquin River receiver near Lathrop (SJL) to Garwood Bridge (SJG) averaged 1 day over all tags (~18 rkm); for tags released in February and March, average travel time through this reach was approximately 1.6 to 1.7 days (Table 17a). Average travel time from Old River South (ORS) to the CVP trashracks was approximately 1.4 day over all tags (~18 rkm). Average travel time to Chipps Island was approximately 2.9 days from MacDonald Island (~54 rkm via the San Joaquin River), and approximately 4.5 days from Turner Cut (also ~54 rkm via Frank's Tract) (Table 17a; all releases). From Jersey Point to Chipps Island was approximately 1 day (~26 rkm). Including the predator-type detections had little effect on average travel time through reaches (Table 17b).

Route Selection Analysis

Head of Old River

A total of 997 tags were detected at either the ORE or SJL telemetry receiver sites in 2018. Estimated detection probabilities were 1.0 for both sites A7 and B1 for all releases, without predator-type detections (Appendix Table A2). Of these 997 tags, 569 were estimated to have arrived at the head of Old River junction before closure of the barrier during installation ("before barrier installation"). The majority of the tags that arrived before barrier installation selected the Old River route (463 tags = 82%).

When slow-moving tags and tags coming from either downstream or making repeated visits to the ORE or SJL receiver sites were removed, route selection data were available for 919 tags. Of these 919 tags, 530 were estimated to have arrived at the head of Old River junction before barrier installation. A total of 88 of the tags that arrived before barrier installation selected the San Joaquin River route (16.6%), whereas 374 tags arriving after barrier installation (and before barrier opening) selected the San Joaquin River route (97.4%) (Figure 13). The remaining analysis used only those tags that arrived before barrier installation.

San Joaquin River flow (discharge) at the MSD gaging station (near Mossdale Bridge), at the estimated time of arrival of the tagged juvenile steelhead at the head of Old River, ranged from -1,073 cfs to 5,114 cfs (average = 2,866 cfs), for study fish that arrived at the river junction before barrier closure on 1 April 2016. The flow at MSD was negative for 9 of 530 (1.7%) tags upon arrival at the river junction. Water velocity ranged from -0.48 ft/s to 1.8 ft/s (average = 1.22 ft/s) at tag arrival at the junction. Flow and velocity at MSD were highly correlated (r=0.92). At the Old River gaging station OH1, flow at estimated time of fish arrival at the river junction ranged from -114 cfs to 3,441 cfs (average = 1,829 cfs), and was negative for arrival of 4 of 530 (0.7%) tags at the junction. Water velocity at OH1 ranged from -0.06 ft/s to 1.93 ft/s (average = 1.13 ft/s) at tag arrival at the junction. Flow and velocity at OH1 were highly correlated (r=0.94), whereas flow at the MSD and OH1 stations were only moderately correlated (r=0.64). There was high correlation between river stage measurements from the different gaging stations (MSD, SJL, and OH1; r≥0.98), and low correlation between stage and the 15-minute change in stage for each station ($\left|r\right| \leq$ 0.21). Export rates averaged 3,334 cfs at CVP, and 3,159 cfs at SWP, and the average CVP proportion of combined (CVP + SWP) export rates was 52%, on the days of fish arrival at the head of Old River. There was moderate correlation between total Delta exports and flow at OH1 (r=0.72) and flow at MSD (r=0.76) upon fish arrival at the river junction.

Of the 530 tags detected at SJL or ORE and used in the route selection analysis at the head of Old River, 19 were estimated to have arrived at head of Old River junction at dawn, 233 during the day, 6 during dusk, and 272 at night. Thirty-four of the 88 tagged steelhead that selected the San Joaquin River route arrived during the day, 48 arrived at night, one at dusk, and 5 at dawn. Steelhead that entered Old River tended to have more variable measures of flow and OH1 flow proportion, river stage, 15-minute change in river stage, and SWP export rates (Figure 14). Those that entered Old River also tended to have lower flow at MSD and lower modeled SJL flow, lower SJL river stage, higher 15-minute change in river stage, and lower SWP export rates (Figure 14). Similar patterns of river stage and route selection were observed for the OH1 and MSD gaging stations as for the SJL gaging station (not shown). Flow and velocity measures at the same stations were highly correlation ($r \geq 0.92$) at the estimated time of tag arrival at the head of Old River junction; thus, no velocity plot is shown.

Although the majority of tagged steelhead that arrived at the head of Old River junction before barrier closure in 2016 selected the Old River route, the proportion of fish selecting the San Joaquin River route tended to be highest in the middle of March, which was also when flow, velocity, river stage, and SWP exports were highest (Figure 15–Figure 18). Of the 530 tags used in the route selection analysis at the head of Old River, 442 (83%) selected Old River. This left a maximum of 87 degrees of freedom for the regression models.

The single-variate analyses found significant associations (experimentwise $\alpha=0.05$) between route selection at the head of Old River and modeled flow at SJL ($P<0.0001$), river stage at MSD ($P=0.0001$), flow at MSD ($P=0.0006$), stage at OH1 ($P=0.0009$), OH1:MSD flow ratio ($P=0.0015$), and stage at SJL ($P=0.0017$) (Table 18). The 15-minute change in river stage SJL, OH1, and MSD, velocity and 15-minute change in velocity at MSD, SWP export rate and total export rate throughout the Delta, and CVP proportion of CVP and SWP exports all had associations with route selection that were significant at the testwise 5% level ($P<0.05$), but not at the more stringent experimentwise 5% level ($P<0.0021$ required). The other measures all had associations with route selection that were non-significant even at the testwise 5% level ($P \geq 0.0928$) (Table 18).

Multiple regression found significant associations between route selection and measures of flow at OH1 and MSD, the OH1:MSD flow ratio, water velocity at OH1, stage at MSD and OH1 and the 15-minute change in stage at SJL, and the SWP export rate (Table 19). The flow + stage model had the lowest AIC, and used river stage from two different stations (OH1 and MSD). River stage from these two stations was highly correlated ($r=0.98$), and the maximum variance inflation factor (VIF) for this model was 34.7, indicating that the level of multicollinearity among the covariates may be influencing the regression coefficient estimates to a large extent (Kutner et al. 2004). When river stage from either OH1 or MSD was omitted from the flow + stage model, the flow measure at OH1 no longer accounted for a significant amount of variation in route selection (P≥0.0901), suggesting that the flow + stage model was over-fitting the data.

The best-fitting stage model used the measure of river stage at the MSD station (C_{MSD}) and the 15-minute change in river stage at the SJL station (ΔC_{SJL}), and fit almost as well as the flow + stage model based on AIC (ΔAIC=0.80; Table 19). The stage model also had acceptable fit based on the Pearson chi-squared test (P=0.6550), and both the mean and maximum VIF was 1.0 (acceptable). Model fit was better for lower levels of the predicted probability of taking the San Joaquin River route, compared to higher levels (Figure 19: Stage Model 1). All other models had ΔAIC≥8.46. An alternate stage model was considered that used river stage and the 15-minute change in river stage measured from the same station, SJL. This model made similar predictions as the river stage model that used river stage at MSD and the change in river stage from SJL, but had markedly lower fit based on AIC (ΔAIC=7.75; Figure 19: Stage Model 2). Thus, the stage model that used river stage at MSD and change in river stage at SJL was selected as the final model for route selection at the head of Old River.

The stage model predicted the probability of remaining in the San Joaquin River at the head of Old River according to:

$$\hat{\psi}_A = \frac{\exp\left(-11.37 + 1.60 C_{MSD} - 16.99 \Delta C_{SJL}\right)}{1 + \exp\left(-11.37 + 1.60 C_{MSD} - 16.99 \Delta C_{SJL}\right)},$$

where C_{MSD} and ΔC_{SJL} represent the river stage at MSD and 15-minute change in river stage at SJL, respectively, measured upon estimated time of tagged fish arrival at the head of Old River junction (Table 19). Equivalently, the probability of entering Old River was modeled as

$$\hat{\psi}_B = \left[1 + \exp\left(-11.37 + 1.60 C_{MSD} - 16.99 \Delta C_{SJL}\right)\right]^{-1}.$$

This model shows an effect of both river stage and the 15-minute change in river stage on the probability of entering Old River: fish that arrived at the junction at higher river stages had a lower probability of entering Old River, and a higher probability of remaining in the San Joaquin River, whereas fish that arrived at the junction at higher levels of 15-minute change in river stage at SJL were more likely to enter Old River (Figure 20, Figure 21). If the 15-minute change in river stage can be interpreted as a surrogate for the phase of the tidal cycle, the stage model indicates that fish are more likely to take the Old River route if they reach the head of Old River on an incoming tide (Figure 21).

Turner Cut Junction

A total of 440 tags were detected at the MAC (A12) and TCE/TCW (F1) telemetry receiver arrays in 2016. Estimated detection probabilities were 0.995 to 1.0 for site A12, and 1.0 for site F1 for all release groups (Appendix Table A2). Overall, 39 tags were excluded from the route selection analysis because of transition type (i.e., repeated visits at MAC or TCE/TCW, transitions between MAC and TCE/TCW, or transitions from downstream or the interior Delta), and 12 tags were excluded because of slow travel. Detections from a total of 389 tags were used in this analysis: 13 from the February release group, 54 from the March release group, and 322 from the April release group. Of these 389 tags, 93 (24%) selected the Turner Cut route, and 296 (76%) selected the San Joaquin River route.

River flow (discharge) at the Turner Cut gaging station (TRN) at the time of tag passage of the SJS receivers ranged from -4,447 cfs to 2,851 cfs (average = -796 cfs) in 2016. The flow in Turner Cut was negative (directed into Turner Cut from the San Joaquin River) for 236 of 389 (61%) of the tags detected. Water velocity at TRN ranged from -0.79 ft/s to 0.58 ft/s (average = -0.13 ft/s) at the time of SJS passage in 2016; there was high correlation between river flow and water velocity at the TRN station (r=0.999). River stage at TRN ranged from 6.3 ft to 11.1 ft (average = 9.0 ft) at tag passage of SJS; correlation between river stage and either flow or water velocity was moderate (r=-0.85). The average magnitude (root mean square, RMS) of river flow at Garwood Bridge (gaging station SJG) in the San Joaquin River during fish travel from the SJG telemetry station to SJS ranged from 2,163 cfs to 4,113 cfs (average = 2,854 cfs). Daily export rates at CVP ranged from 414 cfs to 3,439 cfs (average = 1,714 cfs); SWP export ranged from 393 cfs to 4,595 cfs, and averaged 1,404 cfs. The CVP proportion of combined export rates ranged from 37% to 68% (average = 56%). There was moderate correlation between either CVP exports or SWP exports and flow at Turner Cut ($\left|r\right| \leq 0.12$ for both).

Of the 389 tags detected at MAC or TCE/TCW and used in the route selection analysis at the Turner Cut junction, 7 were estimated to have passed the SJS receivers at dawn, 326 during the day, 7 at dusk, and 49 at night. Only 1 (14%) of the 7 tags passing at dawn, and 2 (29%) of the 7 tags passing at dusk, selected the Turner Cut route; 74 (23%) and 16 (33%) of those passing SJS during the day and night, respectively, selected the Turner Cut route. Steelhead that selected the San Joaquin River route tended to have passed SJS with more positive river flow at TRN than those that selected the Turner Cut route (Figure 22); positive flow at TRN indicated flow directed out of Turner Cut into the San Joaquin River. Fish that selected the Turner Cut route tended to have passed SJS when the river stage at TRN was higher than for fish that selected the alternate route, but there was considerable overlap in river stage values between the two routes (Figure 22). The 15-minute change in river stage at TRN was considerably less variable and lower (i.e., more negative, indicating falling river stage levels) for fish that selected the San Joaquin River route than for those that selected the Turner Cut route (Figure 22). There was little difference in the RMS of river flow at SJG during transition from the SJG telemetry station to SJS for fish that eventually took the two routes, or in exports or fork length at tagging (Figure 22).

The majority of the tagged steelhead detected at either Turner Cut or MacDonald Island in 2016 were observed at MacDonald Island, and most were detected there in the second week of May; smaller groups were detected there in the third week of May and the fourth week of March (Figure 23). There was little obvious pattern in variations in route selection and either flow (Figure 23), velocity (Figure 24), river stage (Figure 25), or exports (Figure 26), summarized on the weekly time scale. Although the average values of flow at TRN for steelhead detected at the junction varied considerably between weeks, the extreme values of TRN flow were observed in weeks when only one or two fish were detected (Figure 23). There was lower variation in the RMS of flow at SJG during the steelhead transition from the SJG telemetry station to SJS (Figure 23). Similar patterns were seen with velocity (Figure 24). River stage at TRN tended to be slightly higher for fish that selected the San Joaquin River route than those that selected the Turner Cut route, but the pattern was not wholly consistent (Figure 25). For fish arriving at the Turner Cut junction in March and April, fish that stayed in the San Joaquin River tended to pass SJS when the combined CVP and SWP exports were higher; for fish that arrived at the junction in May, the pattern was reversed but weak, when viewed on the weekly scale (Figure 26). Overall, the tendency of the tagged steelhead to arrive at the Turner Cut junction in only a few weeks meant that the weekly time scale had little ability to highlight patterns in the data.

Of the 389 tags used in the Turner Cut route selection analysis, 296 (76%) selected the San Joaquin River route, and 93 (24%) selected the Turner Cut route. This left a maximum of 92 degrees of freedom for the regression models. Observations of the 15-minute change in river flow, river stage, and water velocity at the TRN gaging station were missing for 8 records, of which 3 tags were observed in the Turner Cut route; for those covariates and for the multiple regression models, there were only 89 degrees of freedom available.

The single-variate analyses found significant associations (experimentwise α=0.05) between route selection at the Turner Cut junction and the 15-minute change in river stage at TRN ($P<0.0001$), and both flow and velocity at TRN (P=0.0003) (Table 20). The 15-minute change in flow and velocity at TRN and the presence of negative flow at TRN (i.e., directed into the interior Delta) each had associations with route selection that were significant at the testwise 5% level (P<0.05), but not at the more stringent experimentwise 5% level (P<0.0029 required). The other measures all had associations with route selection that were non-significant even at the testwise 5% level (P≥0.0928) (Table 20).

Multiple regression found significant associations between route selection and measures of flow, velocity, and the 15-minute change in river stage at TRN (Table 21). The flow + stage model had the lowest AIC (ΔAIC≥13.53), although the F-test of the significance of the effect of flow at TRN was significant only at the testwise 5% level rather than the experimentwise 5% level (P=0.0364 vs P<0.0250 required). The strongly improved model fit indicated by the AIC compared to the stage-only model (ΔAIC=13.53), combined with the nearly significant flow effect, suggests that flow at TRN was a moderately important component in route selection in 2016, although not as important as the 15-minute change in river stage (P=0.0004). The model that used measures of flow instead of measures of river stage ("flow model") used the 15-minute change in flow and the indicator variable for negative flow as well as the measure of flow itself at TRN, but was not selected by AIC (ΔAIC=15.95 compared to the flow + stage model) (Table 21). Both models had adequate fit based on the Pearson chi-squared test (P≥0.9998), but the strong relationship between the observations of flow at TRN and the presence of negative flow at that station made the flow model unreliable. For the flow + stage model, the VIF was 1.2, which indicates an acceptably low level of multicollinearity between the covariates. Model fit was markedly better for the flow + stage model compared to the other models (Figure 27). Thus, the flow + stage model was selected as the final model for route selection at the Turner Cut Junction.

The flow + stage model predicted the probability of remaining in the San Joaquin River at the Turner Cut junction according to:

$$\hat{\psi}_A = \frac{\exp\left(-1.21 - 9.92\Delta C_{TRN} + 0.0003 Q_{TRN}\right)}{1 + \exp\left(-1.21 - 9.92\Delta C_{TRN} + 0.0003 Q_{TRN}\right)},$$

where ΔC_{TRN} and Q_{TRN} represent the 15-minute change in river stage at TRN and the flow at TRN, respectively, measured upon the final tag detection at the SJS telemetry station (Table 21). Equivalently, the probability of entering Turner Cut was modeled as

$$\hat{\psi}_F = \left[1 + \exp\left(-1.21 - 9.92\Delta C_{TRN} + 0.0003 Q_{TRN}\right)\right]^{-1}.$$

This model shows an effect both of the 15-minute change in river stage at TRN and flow at TRN on the probability of entering Turner Cut: fish that passed SJS at higher levels of the 15-minute change in river stage at TRN or lower levels of flow at TRN had a higher probability of entering Turner Cut (Figure 28, Figure 29). If the 15-minute change in river stage can be interpreted as a surrogate for the phase of the tidal cycle, the stage model indicates that fish are more likely to enter Turner Cut if they pass SJS (e.g., arrive at the function) on an incoming tide (Figure 28) and when flow is directed into Turner Cut (Figure 29).

Survival through Facilities

Survival through the water export facilities was estimated as the overall probability of reaching Chipps Island, Jersey Point, False River, Threemile Slough, Montezuma Slough, or Spoonbill Slough after being last detected in the CVP holding tank (site E2, for the federal facility) or the interior receivers at the radial gates at the entrance to the Clifton Court Forebay (site D2, for the receivers closest to the SWP state facility). Thus, survival for the federal facility (CVP) is conditional on being entrained in the holding tank, while survival for the state facility (SWP) is conditional on entering and not leaving the Clifton Court Forebay, and includes survival through the Forebay to the holding tanks. Results are reported for the individual release groups, and also for the pooled data set from all release groups (population estimate); predator-type detections were excluded. Conditional detection probabilities were estimated for all sites used.

Estimated survival from the CVP holding tank to the receivers located near the salvage release sites (Chipps Island, Jersey Point, False River, Threemile Slough, Montezuma Slough, and Spoonbill Slough) ranged from 0.86 ($\widehat{SE} = 0.05$) for the February release group, with a 95% profile likelihood interval of (0.75, 0.93), to 1.00 (95% lower bound = 0.78) for the April release group (Table 22). For the state facility, estimated survival from the radial gates to the receivers near the release sites ranged from 0.33 ($\widehat{SE} = 0.12$) for April release group (95% profile likelihood interval = (0.13, 0.58)), to 0.56 ($\widehat{SE} = 0.06$) for the March release group (95% profile likelihood interval = (0.44, 0.68); Table 22). Release-specific sample sizes ranged from 12 to 79 for the CVP analysis, and from 15 to 66 for the SWP analysis. Estimated survival to receivers after release was consistently higher for the CVP holding tank compared to the Clifton Court Forebay radial gate (SWP); this is consistent with the estimates of the probability of successfully moving from those sites to Chipps Island that were calculated from the full survival model: $\hat{\phi}_{D2,G2} =$ 0.33 to 0.56 ($\widehat{SE} \leq 0.12$), and $\hat{\phi}_{E2,G2} =$ 0.85 to 0.92 ($\widehat{SE} \leq 0.08$) (Table A2).

Comparison among Release Groups

Analysis of variance found that the effect of release group on parameter estimates of reach-specific survival and transition probability parameters was just non-significant at the 10% level ($F_{2,28} =$ 2.452, P=0.1044). Pairwise *t*-tests found a significant difference between estimates from the February release and those from the March and April releases ($t_{28} =$ 1.845, P=0.0756 for February vs March, and $t_{28} =$1.983, P=0.0573 for February vs April). The effect of the February release group was negative in both cases, indicating that survival estimates for February tended to be lower than those from the latter two release groups. There was no significant difference found in estimates between the March and April release groups ($t_{28} =$0.138, P=0.8915).

Linear contrasts found differences in survival from Durham Ferry to Mossdale among all three release groups, with estimates from February being lower than the other releases (P<0.0001) (Table 23). Survival from Mossdale to Chipps Island via the San Joaquin River route was lower in February and higher in April (P≤0.0003), whereas survival from Mossdale to Chipps Island via the Old River route was lower in April (P=0.0003). Overall survival from Mossdale to Chipps Island followed the pattern for the San Joaquin River route, and was lower in February and higher in April (P≤0.0025) (Table 23).

Discussion

Predator Filter and Predator-type Detections

The 2016 predator filter had similar sensitivity to the 2015 filter, and lower sensitivity than the 2014 filter. As in the case of the 2015 filter, this is partly a result of the modifications to the calibration of the 2016 filter to reflect the detection histories of the recapture tags prior to the recapture event. When predator tags that had fewer than 5 detection events were omitted, the 2016 filter had higher sensitivity (98.%) than either the 2014 (92.9%) or 2015 (87.1%) filters. Because some components of the predator filter use the pattern of detections over multiple detection sites and time periods, it is reasonable that the filter sensitivity was improved for tags with longer detection histories.

The increase in total Delta survival seen when predator-type detections were included for the April release (i.e., increase of 0.04), but not for the February or March releases, suggests either that steelhead predators were leaving the Delta in April, or that steelhead were more likely to engage in temporary Delta rearing or delayed migration behavior in April than earlier in the spring. A comparable increase (i.e., increase of 0.03) was observed for survival through the South Delta survival for the March release group when predators were observed, but not through the Mid-Delta or the entire Delta; this pattern is consistent with high predation activity around the water export facilities or Highway 4 in March, but not further downstream. In general, the spatial patterns in the survival differences with and without predator-type detections may reflect a reduced ability to distinguish between behavior of steelhead and predators from the available tagging data as fish approach Jersey Point and Chipps Island, especially from the Old River route.

Comparison among Release Groups

The estimate of total Delta survival from Mossdale to Chipps Island was lower for the February release group than for the later groups (P=0.0025; Table 23). Examination of the reach-specific survival estimates suggests that it was primarily survival between MacDonald Island and Chipps Island that accounted for the lower Delta survival estimate for the February release (Table A2). That release group also had lower survival from Durham Ferry to Mossdale than the other groups (P<0.0001; Table 23), driven by lower transition probabilities from Durham Ferry to Banta Carbona (Table A2). The April release group, on the other hand, had the highest total Delta survival estimate (P<0.0001) and the highest survival from Durham Ferry to Mossdale (P<0.0001), but the lowest estimated survival to Chipps Island via the Old River route (P=0.0003; Table 14, Table 23).

There was considerable variation in river conditions among the time periods when fish from the different release groups were migrating through the Delta. Measures of Delta inflow, export rates, the I:E ratio, and water temperature were averaged for each release group through the time period that extended from the first day of release through the last day of release, and further extended by the median observed travel time from release to Chipps Island for the release group: 15 days for the February release, 8 days for the March release, and 10 days for the April release (Figure 30–Figure 33). Delta inflow measured at Vernalis (VNS gaging station) was lowest for the February release (average = 1,209 cfs) compared to average VNS flows of 2,508 cfs and 2,649 cfs for the March and April releases, respectively (Figure 30). Delta inflow was highest (up to 6,100 cfs) immediately before and during the first day of the March release period, before a steep decline through the 8 days over which conditions were summarized (Figure 30). Exports were highest for the February and March releases (average combined CVP-SWP export rate = 5,900 cfs for February, and 6,030 cfs for March), and lowest for the April release (2,553 cfs; Figure 31). The I:E ratio (ratio of Delta inflow at VNS to total Delta exports, measured on daily time scale) was lowest for the February release and highest for the April release

(Figure 32). The highest daily I:E ratio values occurred in mid-April, shortly before the start of the April release period (Figure 32). Average I:E values for the three release groups were 0.20, 0.39, and 0.93, respectively. Water temperatures measured at the MSD gaging station near Mossdale tended to be highest for the March release group (average = 16.6°C). The February and April groups experienced similar temperatures (average = 17.8°C and 16.4°C, respectively), but there was more variability during the April summarization period (Figure 33). The highest water temperatures occurred between the March and April releases, when water temperature at MSD reached 22.2°C (Figure 33).

The prevailing conceptual model of how water project operations and river conditions influence survival through the Delta is that survival is higher during periods of higher Delta inflow, lower export rates, higher I:E, and lower water temperatures (SST 2017). The survival estimates from the 2016 six-year study support the conceptual model regarding Delta inflow, exports, and the I:E ratio. In particular, the release group that experienced the lowest Delta inflow (February) had the lowest total survival to Chipps Island, and the release group that experienced the lowest export rates (April) had the highest total survival through the Delta. However, the March release group experienced similarly high Delta inflow compared to the April release on average (Figure 30), but had lower survival. Also, the March release group experienced export rates as high as the February release (Figure 31), but had higher survival. It may be that the high export rates experienced by the March release prevented the full benefit of high Delta inflow for that group, or that the high inflow may have partially offset potential negative effects of high export rates. Alternatively, despite the very high Delta inflow experienced by the first fish released in March, the steep decline in Delta inflow shortly after the beginning of the March release period may have resulted in lower survival compared with the more moderate but also more stable Delta inflow conditions experienced by the April release group. It is notable that when compared to the I:E ratio, which combines both Delta inflow and export conditions, the expected pattern of higher survival associated with higher I:E was observed when comparing all three release groups (Figure 32).

Within the Old River route, the February and March release groups had higher survival than the April release (P=0.0003; Table 14). These first two release groups also experienced higher levels of combined export rates from the SWP and CVP facilities, and migrated before installation of the barrier at the head of Old River was complete (Figure 31). This pattern suggests that for fish that enter Old River at its head, higher export rates may provide some benefit by drawing migrants into the salvage tanks faster. However, the estimates of the transition probability from the CVP trashrack into the holding tank (≤0.59), and from the entrance of the Clifton Court Forebay through the Forebay and salvage facility to Chipps Island (≤0.56) (Table A2) indicate that the salvage routes have considerable mortality risks, even at relatively high export rates. It is also notable that even with the high export rates in February and March, survival to Chipps Island was not higher in the Old River route than in the San Joaquin River route (Table 14).

Within the San Joaquin River route, the April release group had the highest survival to Chipps Island ($P<0.0001$), and survival was higher in this route than in the Old River route ($P=0.0002$) (Table 14). In addition to experiencing low combined export rates, the April release group was the only release that passed the head of Old River with the barrier in place. The rock barrier diverted both fish and river flow away from Old River and into the San Joaquin River route, and in this way may have extended the protective effect of increased Delta inflow further downstream in the San Joaquin River.

Water temperature may also have contributed to differences in survival among the three release groups. Despite the initially high Delta inflows experienced by the March release group, fish from that release also migrated with consistently higher water temperatures than the February or April groups (Figure 33). The warmer water temperatures may have limited the benefit of the higher inflow for the March group. The February and April releases had similar average water temperatures, but the longer travel time of the February release meant that the February fish had longer exposure to warmer water than for the April release (Figure 33), which may have then contributed to the lower survival of that release group. Despite the higher survival estimated for the April release group during this study, the high water temperatures (up to 22°C) and low flow in early and mid-April suggest that run-of-river (untagged) steelhead migrating in the interval between the March release and the April release were likely to have had lower survival than those study fish that migrated in late April.

Survival Through Central Valley Project

Survival through the water export facilities was estimable for all three release groups (Table 22). Pooled over all release groups, the large majority of tags detected at either facility came from the Old River route (Table 11), and the head of Old River barrier prevented most access to the Old River route for the April release group. More tags were detected at the facilities from the San Joaquin River route from the April release group compared to earlier releases, possibly reflecting the larger number of tags observed taking the San Joaquin River route when the barrier was in place. Based on tag detections in regions near the transport release sites (Jersey Point, False River, Chipps Island, Benicia Bridge, Threemile Slough, Montezuma Slough, and Spoonbill Slough), survival was higher through the CVP facility than through the SWP (Table 22). However, the SWP survival included survival through the

Clifton Court Forebay, whereas the CVP survival started from the trashracks located just outside the facility.

The probability of successfully reaching the CVP holding tank from the trashracks ($\phi_{E1,E2}$) was estimated at 0.44 to 0.59 ($\widehat{SE} \leq 0.10$) for each release group (Table A2). The transition parameter $\phi_{E1,E2}$ is the product of the probability of moving from the trashracks toward the louvers and holding tank, and the probability of surviving during that process. Its complement includes both mortality before passing the louvers and within the facility, and the possibility of returning from the trashracks to Old River and moving either upstream toward Middle River or downstream toward the Clifton Court Forebay and Highway 4. Tagged fish whose modeled detection histories included the CVP trashracks (i.e., as tabulated in Table 11) were those fish that were not detected at Old River, Middle River, or radial gate sites (i.e., Clifton Court Forebay) after their CVP detection (excluding the predator-type detections), which means that the extent to which the probability $1-\phi_{E1,E2}$ includes leaving the trashracks for non-CVP sites is limited by the probability of non-detection at those sites (conditional on tag presence), and the possibility of mortality before reaching those sites. The estimated conditional probability of detection was 1.0 for most Old River route sites outside the CVP (Table A2), but was 0.75 at Highway 4 (site B4) for the March release group, and ≥ 0.93 at the exterior receiver at Clifton Court Forebay (RGU, site D1). Additionally, there were too few detections at the Middle River sites in some releases to freely estimate the detection probability at those sites (Table A2). The imperfect detection probabilities at some sites means that some component of the estimated value of $1-\phi_{E1,E2}$ includes the probability of exiting the CVP into the interior Delta and reaching Old and Middle River sites without detection. Nevertheless, the moderate to high estimates of the conditional detection probabilities in Old and Middle Rivers suggest that the majority of the probability $1-\phi_{E1,E2}$ reflects mortality either between the CVP trashracks and those interior Delta sites, or between the CVP trashracks and the CVP holding tank. The complex Delta routing and tidal influence in the southwest region of the Delta prevent estimating the probability of mortality outside the CVP for fish that may have left the trashracks, or to separate that mortality from mortality outside the louvers or within the facility. Comparison of Table 10 and Table 11 shows that of the 336 tags were detected at the CVP trashracks (site E1), 91% (305) were assigned the trashracks detection for the survival model. The other 9% (31 tags) were subsequently observed at non-CVP sites (i.e., B2, B3, B4, C1, C2, D1, D2). While not a reliable estimate of the final probability of leaving the CVP for the interior Delta, the relatively low rate of total CVP tags that were later detected elsewhere in the interior Delta suggests that most tagged steelhead detected at the CVP trashracks in 2016 attempted to pass into the facility. This result is similar to the pattern observed in 2014, when 96% of the CVP tags were assigned to the CVP route, but considerably different from 2015, when only 59% of the CVP tags were assigned to that route (Buchanan 2018a, 2018b). The estimates of $\phi_{E1,E2}$ in 2016 were similar to those from 2014 (0.50–0.51) and higher than in 2015 (0.36–0.37), implying continued high mortality between the CVP trashracks and either the holding tank or in the Delta following CVP exit.

Once in the CVP holding tank, the probability of successfully reaching Chipps Island ($\phi_{E2,G2}$) was estimated at 0.85–0.92 ($\widehat{SE} \leq$ 0.08) for the three release groups (Table A2). Thus, the majority of the perceived loss between the CVP trashrack receivers and Chipps Island occurred between detection at the trashracks and arrival in the holding tanks; survival during and after salvage was relatively high (0.86–1.00; Table 22).

The daily export rate at the CVP, on the day of tag detection at the trashracks (site E1), was between 3,000 cfs and 3,500 cfs for 202 of the 305 (66%) tags used to estimate $\phi_{E1,E2}$; all tags that arrived when the CVP export rate was > 3,000 cfs came from the February and March release groups (Figure 31). The other 103 tags detected at the CVP trashracks were detected there on days when the daily export rate was between 956 cfs and 2,746 cfs. A likelihood ratio test found a difference in estimates of $\phi_{E1,E2}$ for conditions of export rates >3,000 cfs versus <1,000 cfs at tag detection at the CVP trashracks (P=0.0179), pooled over all releases. Combined over releases, the estimated transition probability from the CVP trashracks to the holding tank ($\hat{\phi}_{E1,E2}$) was 0.60 ($\widehat{SE} =$ 0.03) for tags that arrived the CVP export rate >3,000, and 0.46 ($\widehat{SE} =$ 0.05) when the export rate ≤3,000 cfs.

The route via the Old River route through the CVP to Chipps Island accounted for 0.5% to 66% of the total survival to Chipps Island in 2016, depending on the release group. The estimate of the probability of getting from Mossdale to Chipps Island via Old River and the CVP was unavailable for the February release group because of sparse data at certain sites; however, of the 79 tags detected at either Chipps Island or Benicia Bridge from the February release group, 52 (66%) had been detected in the CVP holding tank. For the March release group in 2016, the route via the CVP to Chipps Island accounted for approximately 45% of the total survival to Chipps Island: total Delta survival was estimated at 0.42 ($\widehat{SE} = 0.02$), and the total probability of getting from Mossdale to Chipps Island via Old River and the CVP was 0.20 ($\widehat{SE} = 0.02$). The head of Old River barrier was installed for the April release group, and the Old River route via the CVP contributed considerably less to total Delta survival for that group: the probability of getting from Mossdale to Chipps Island via the Old River route and the CVP was <0.01, whereas the total Delta survival was higher than for the other groups (0.59, $\widehat{SE} = 0.02$) (Table 11, Table 14). The proportion of the total Delta survival that represents the CVP salvage route depends on a variety of factors: the probability of taking the Old River route at the head of Old River, the probability of entering the CVP rather than migrating past it to the radial gates or Highway 4, and relative survival in both Old River between its head and the CVP, within the CVP, and during and after salvage, compared to survival throughout the San Joaquin River to Chipps Island. If a barrier blocks most access to Old River, then the CVP is unlikely to represent a significant migration route to Chipps Island, unless survival is also very low in the San Joaquin River. In 2016, the February release group had both a relatively high probability of entering Old River at its head (0.88, $\widehat{SE} = 0.02$) and relatively low survival in the San Joaquin River route (0.23, $\widehat{SE} = 0.08$), compared to the later release groups (Table 14); these two factors contributed to the CVP representing a higher proportion of total Delta survival for February release groups compared to the March and April releases.

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Figures

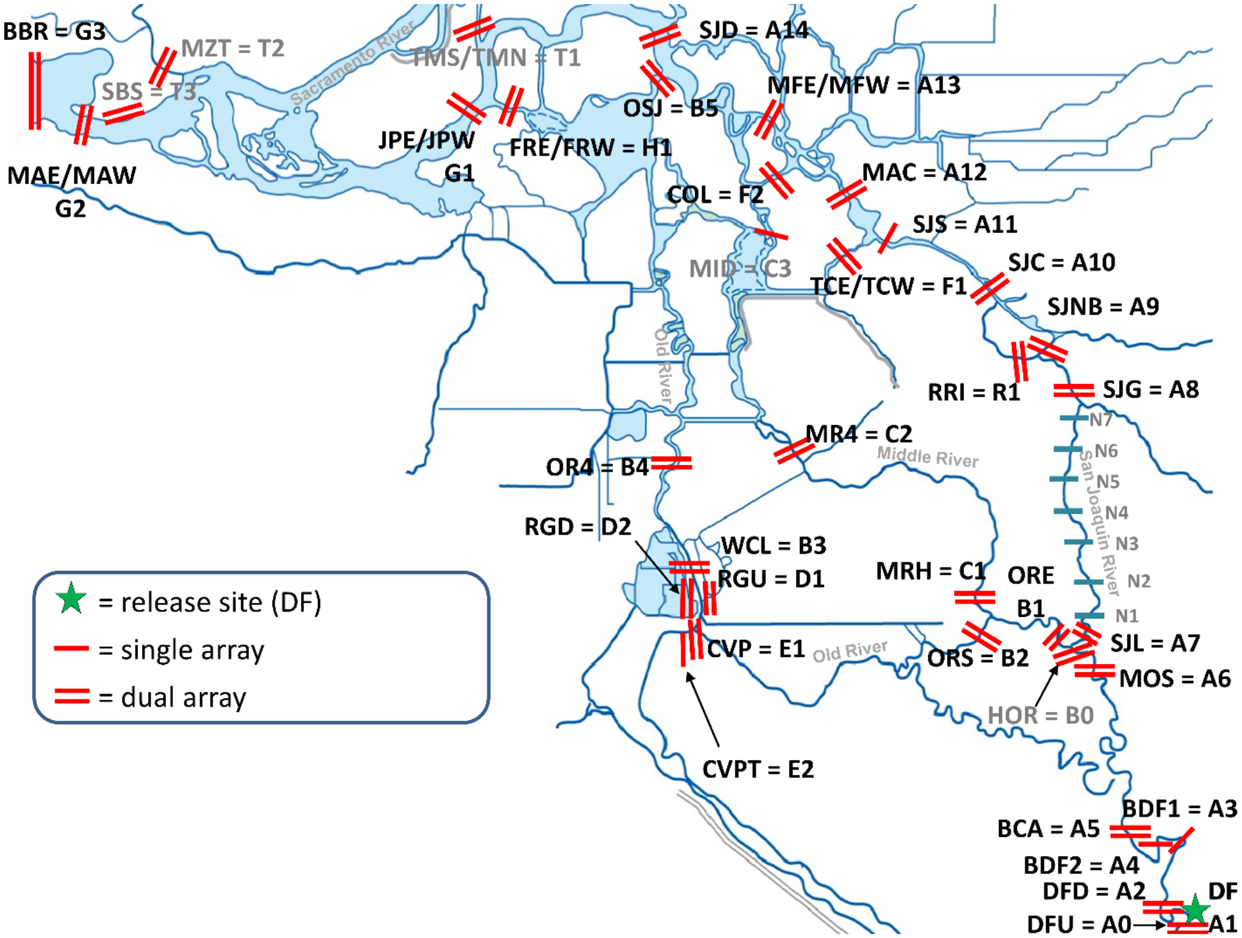

Figure 1. Locations of acoustic receivers and release site used in the 2016 steelhead tagging study, with site code names (3- or 4-letter code) and model code (letter and number string). Site A1 is the release site at Durham Ferry. Sites in gray were omitted from the survival model.

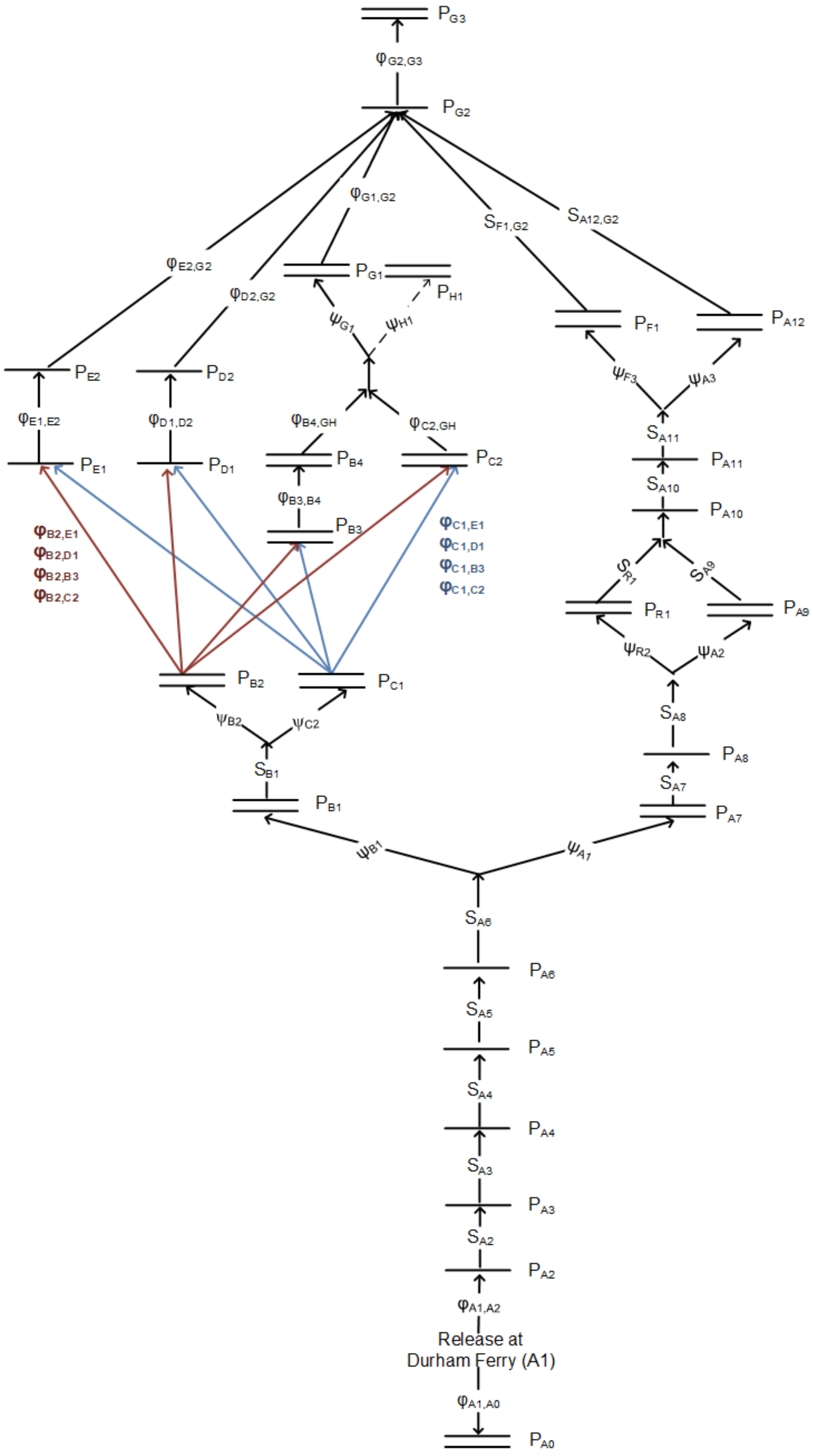

Figure 2. Schematic of 2016 mark-recapture Submodel I with estimable parameters. Single lines denote single-array or redundant multi-line telemetry stations, and double lines denote dual-array telemetry stations, respectively. Names of telemetry stations correspond to site labels in Figure 1. Migration pathways to sites B3 (WCL), C2 (MR4), D1 (RGU), and E1 (CVP) are color-coded by departure site.

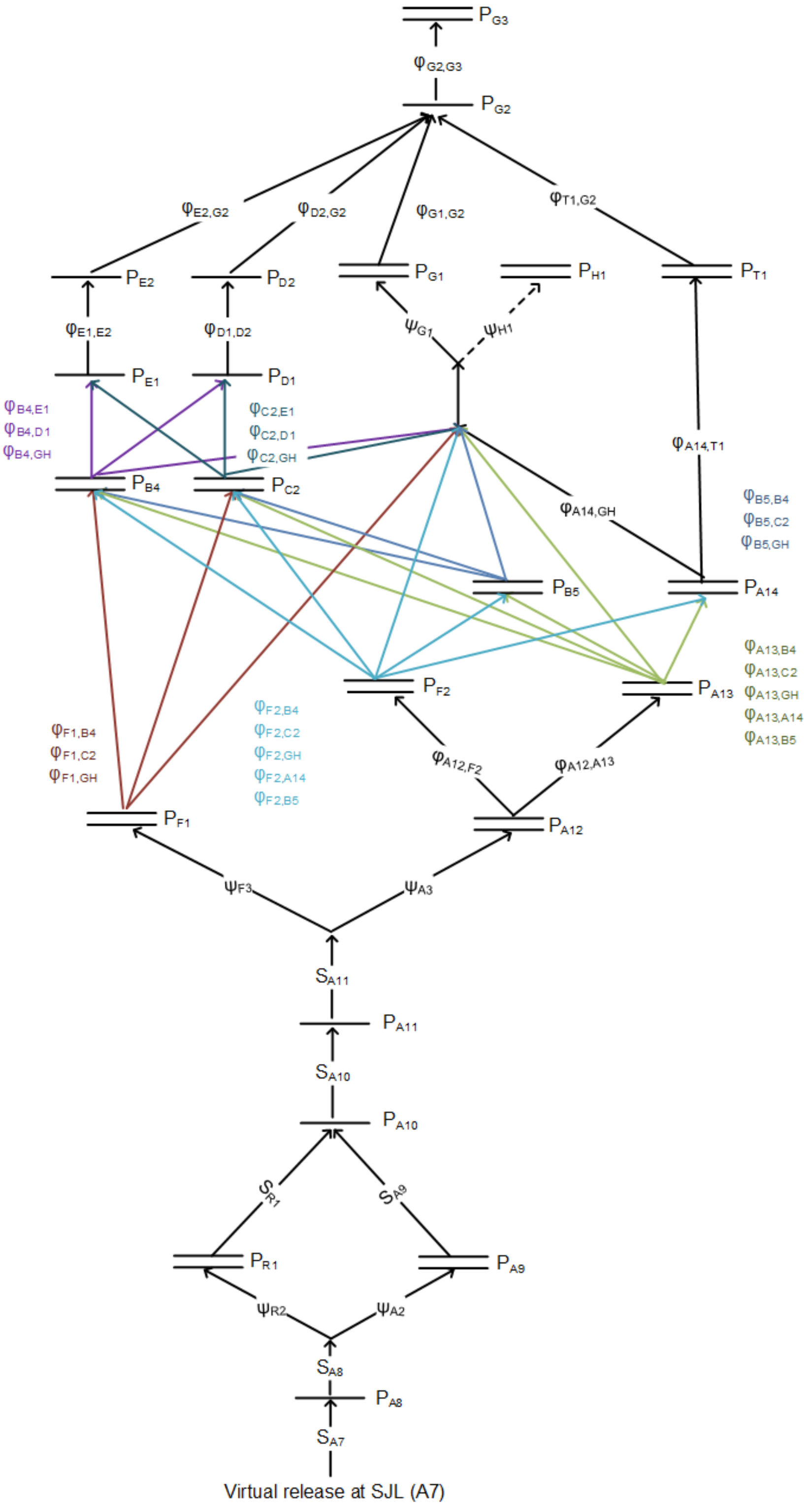

Figure 3. Schematic of 2016 mark-recapture Submodel II with estimable parameters. Single lines denote single-array or redundant multi-line telemetry stations, and double lines denote dual-array telemetry stations. Names of telemetry stations correspond to site labels in Figure 1. Migration pathways to sites A14 (SJD), B4 (OR4), B5 (OSJ), C2 (MR4), D1 (RGU), E1 (CVP), and the G1-H1 junction (JPE/JPW – FRE/FRW) are color-coded by departure site.

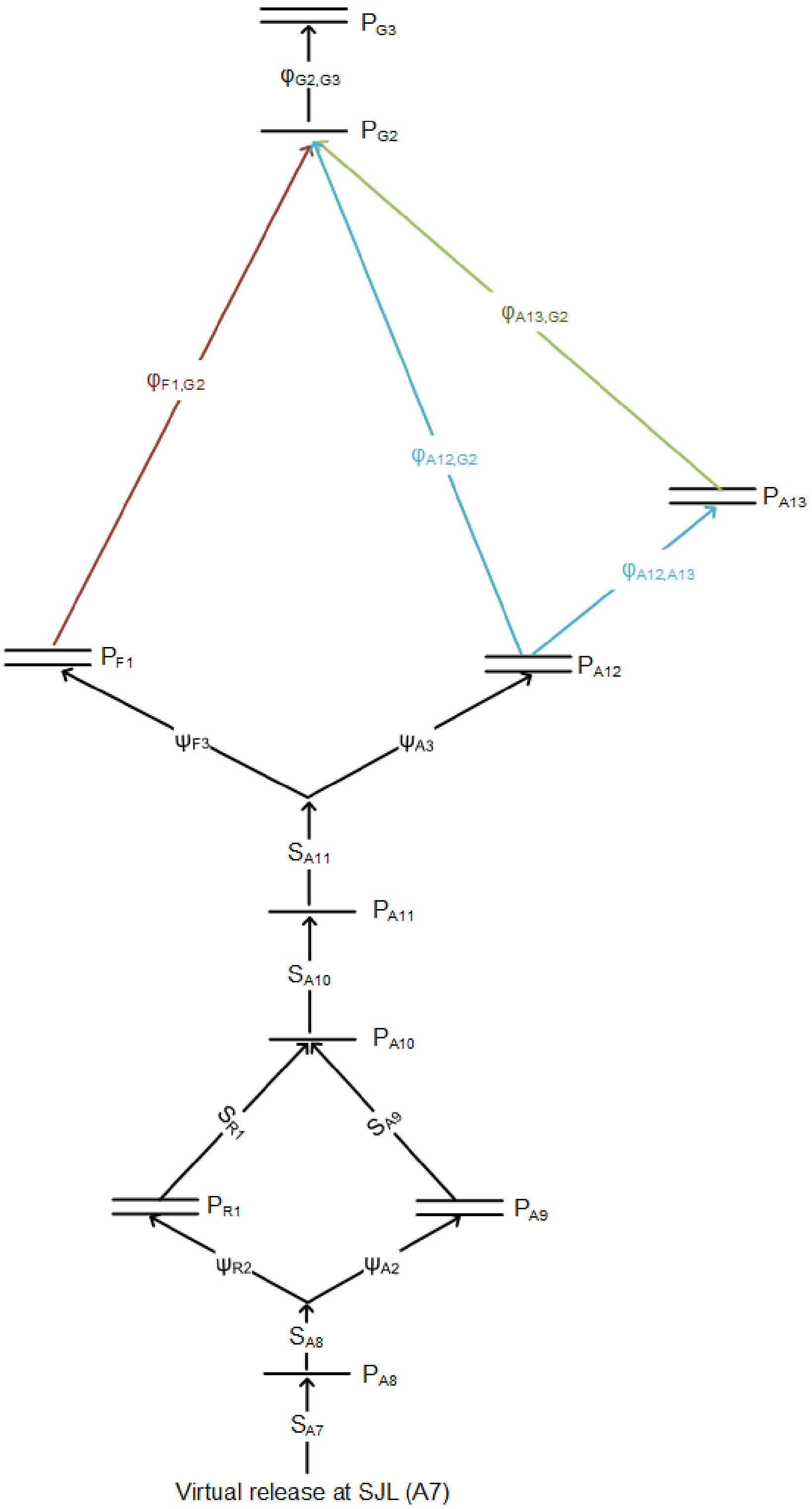

Figure 4. Schematic of simplified 2016 mark-recapture Submodel II with estimable parameters, used for the February release group (release 1). Single lines denote single-array or redundant multi-line telemetry stations, and double lines denote dual-array telemetry stations. Names of telemetry stations correspond to site labels in Figure 1. Migration pathways from sites A12 (MAC), A13 (MFE/MFW), and F1 (TCE/TCW) are color-coded by departure site.

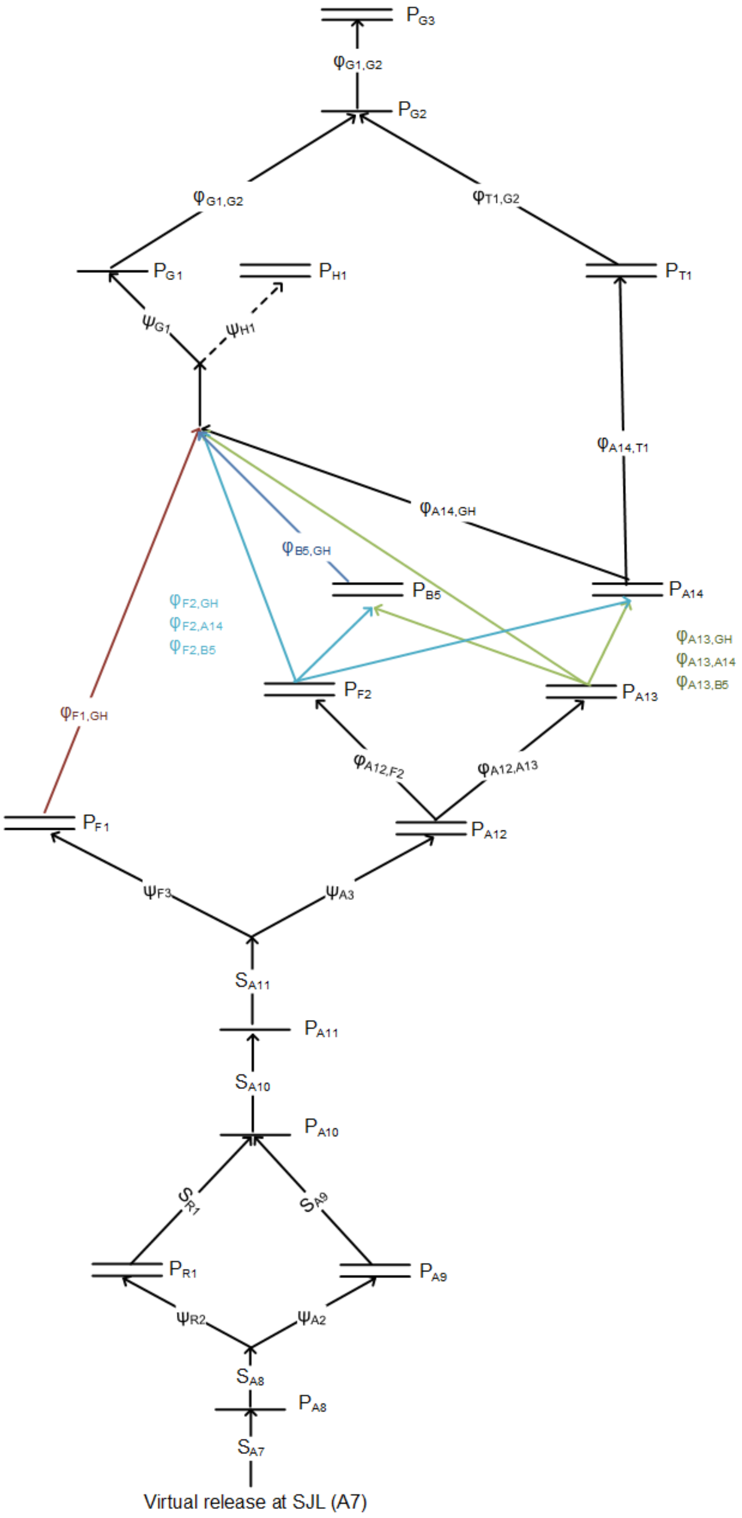

Figure 5. Schematic of simplified 2016 mark-recapture Submodel II with estimable parameters, used for the March release group (release 2). Single lines denote single-array or redundant multi-line telemetry stations, and double lines denote dual-array telemetry stations. Names of telemetry stations correspond to site labels in Figure 1. Migration pathways to sites A14 (SJD), B5 (OSJ), and the G1-H1 junction (JPE/JPW – FRE/FRW) are color-coded by departure site.

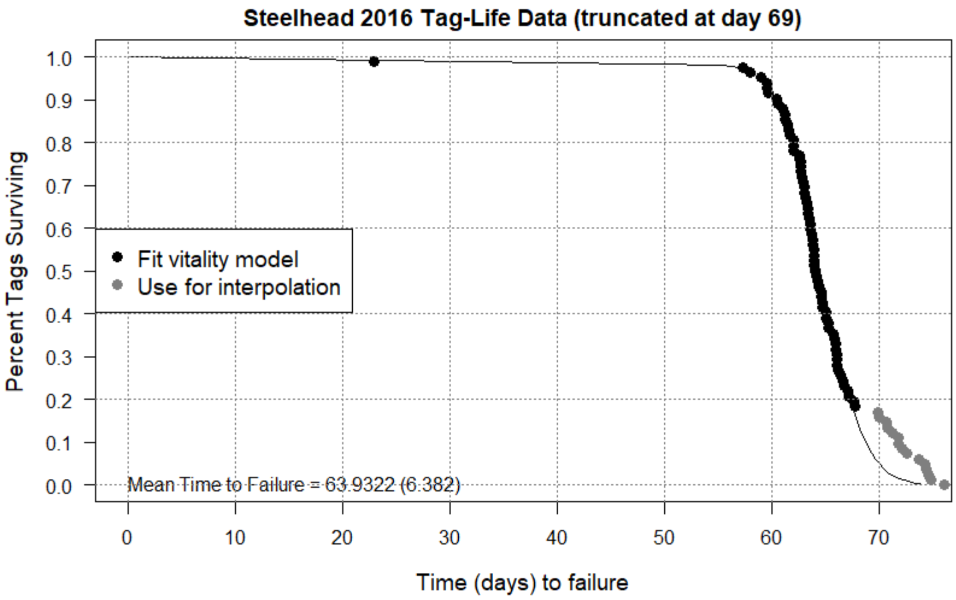

Figure 6. Observed tag failure times from the 2016 tag-life studies (pooled over the February, April, and May studies), and fitted four-parameter vitality curve. Tags without final failure times were omitted (17 tags). Failure times were truncated at day 69 to improve fit of the model. Tag failure times used to fit the model are represented by black dots; failure times past the truncation point are in gray.

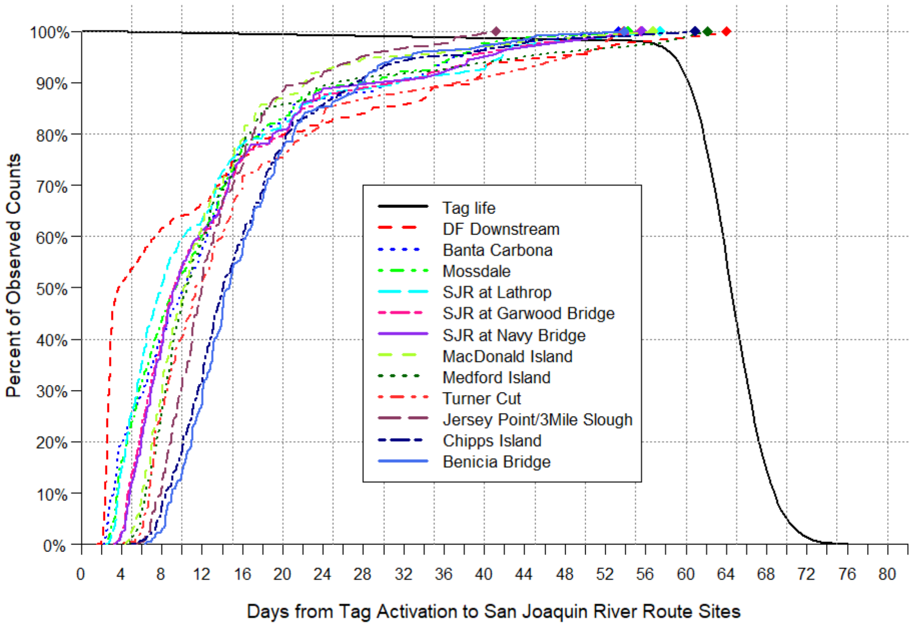

Figure 7. Four-parameter vitality survival curve for tag survival, and the cumulative arrival timing of acoustic-tagged juvenile steelhead at receivers in the San Joaquin River route to Chipps Island in 2016, including detections that may have come from predators; tag-life data were pooled across tag-life studies, and arrival time data were pooled across releases. The tag survival curve was estimated only to day 69, to improve model fit.

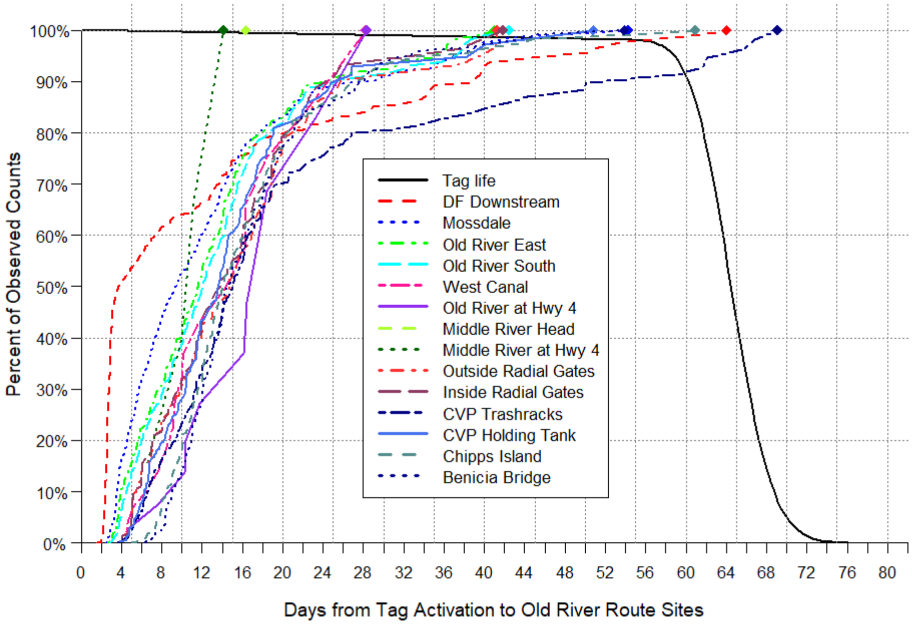

Figure 8. Four-parameter vitality survival curve for tag survival, and the cumulative arrival timing of acoustic-tagged juvenile steelhead at receivers in the Old River route to Chipps Island in 2016, including detections that may have come from predators; tag-life data were pooled across tag-life studies, and arrival time data were pooled across releases. The tag survival curve was estimated only to day 69, to improve model fit.

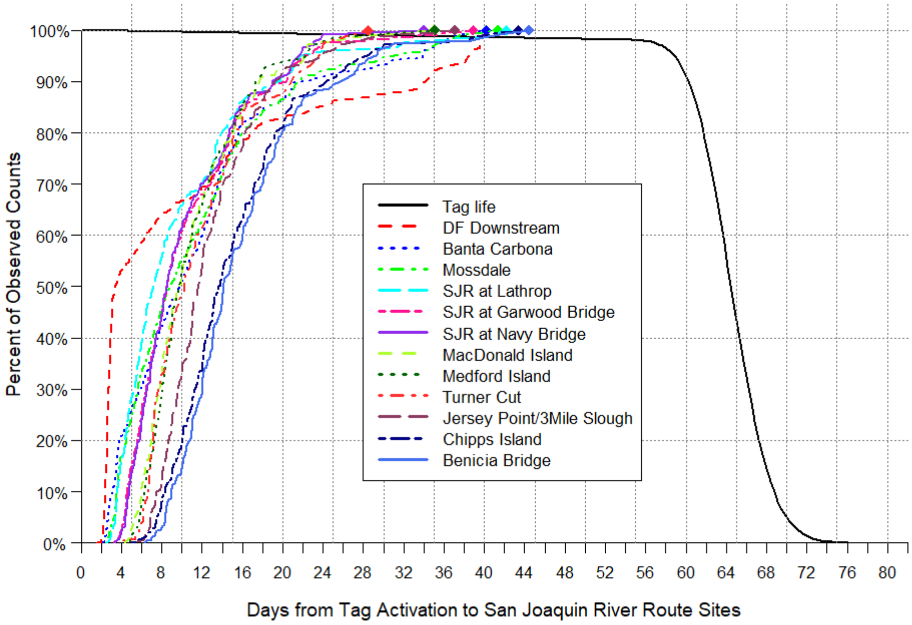

Figure 9. Four-parameter vitality survival curve for tag survival, and the cumulative arrival timing of acoustic-tagged juvenile steelhead at receivers in the San Joaquin River route to Chipps Island in 2016, excluding detections that were deemed to have come from predators; tag-life data were pooled across tag-life studies, and arrival time data were pooled across releases. The tag survival curve was estimated only to day 69, to improve model fit.

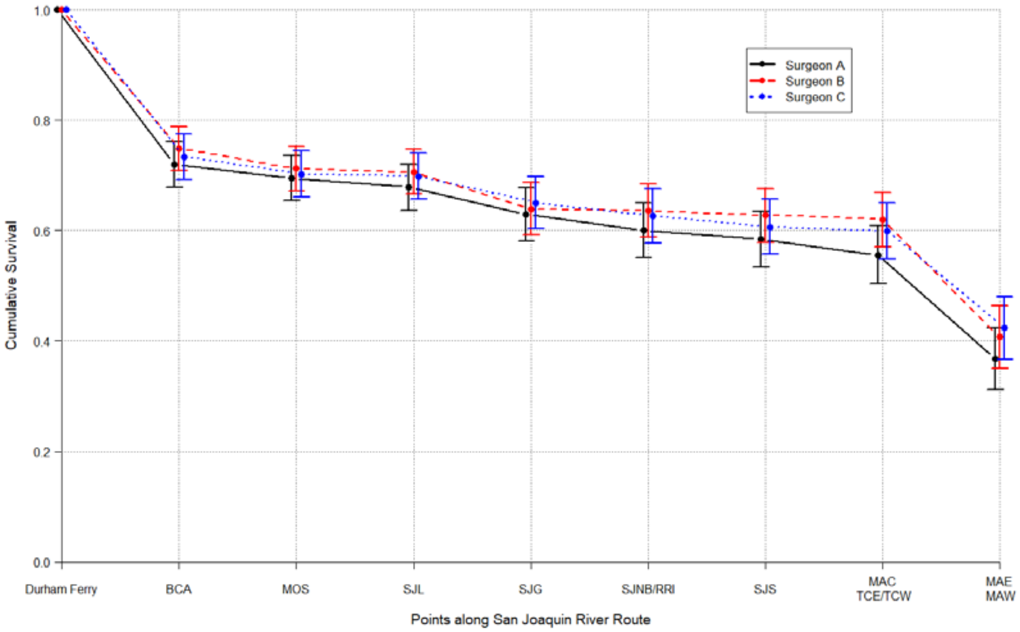

Figure 10. Cumulative survival from release at Durham Ferry to various points along the San Joaquin River route to Chipps Island, by surgeon. Error bars are 95% confidence intervals.

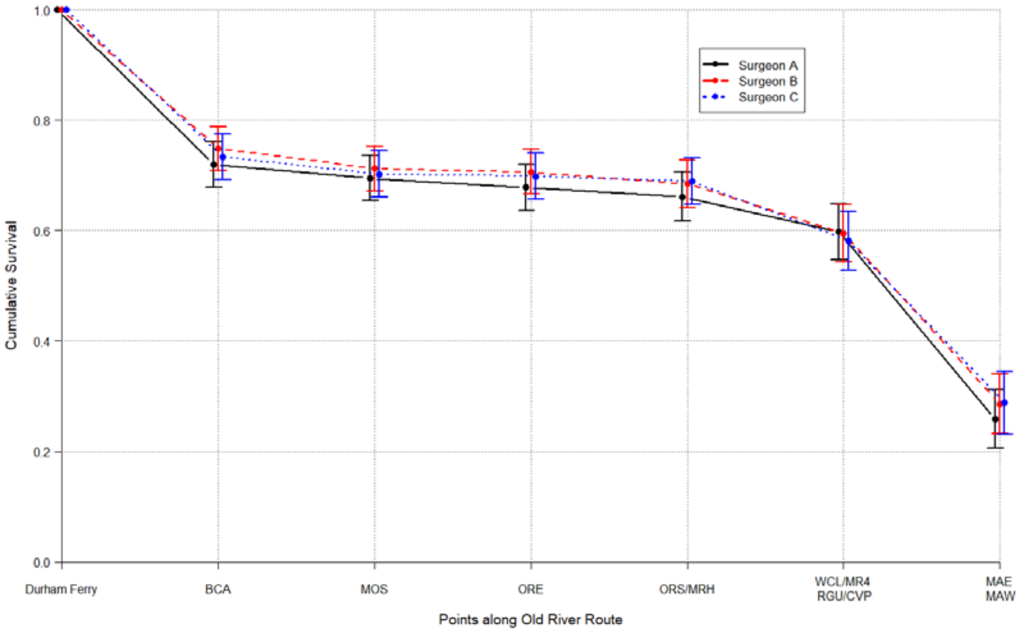

Figure 11. Cumulative survival from release at Durham Ferry to various points along the Old River route to Chipps Island, by surgeon. Error bars are 95% confidence intervals.

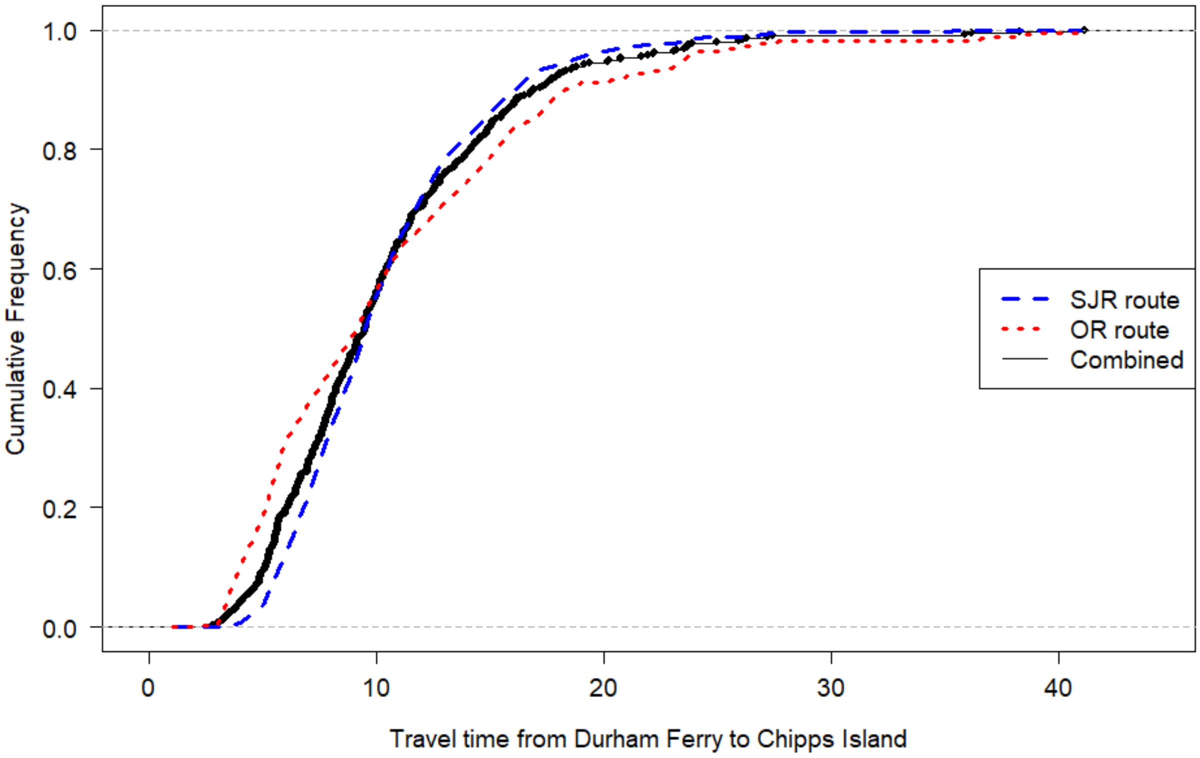

Figure 12. Empirical cumulative travel time distribution from Durham Ferry to Chipps Island for juvenile steelhead tagged and released at Durham Ferry in the 2016 Six-Year Study. Migration route (SJR = San Joaquin River, OR = Old River) was defined based on route selection at the head of Old River. Black points represent observed travel time for both routes combined. All release groups are represented.

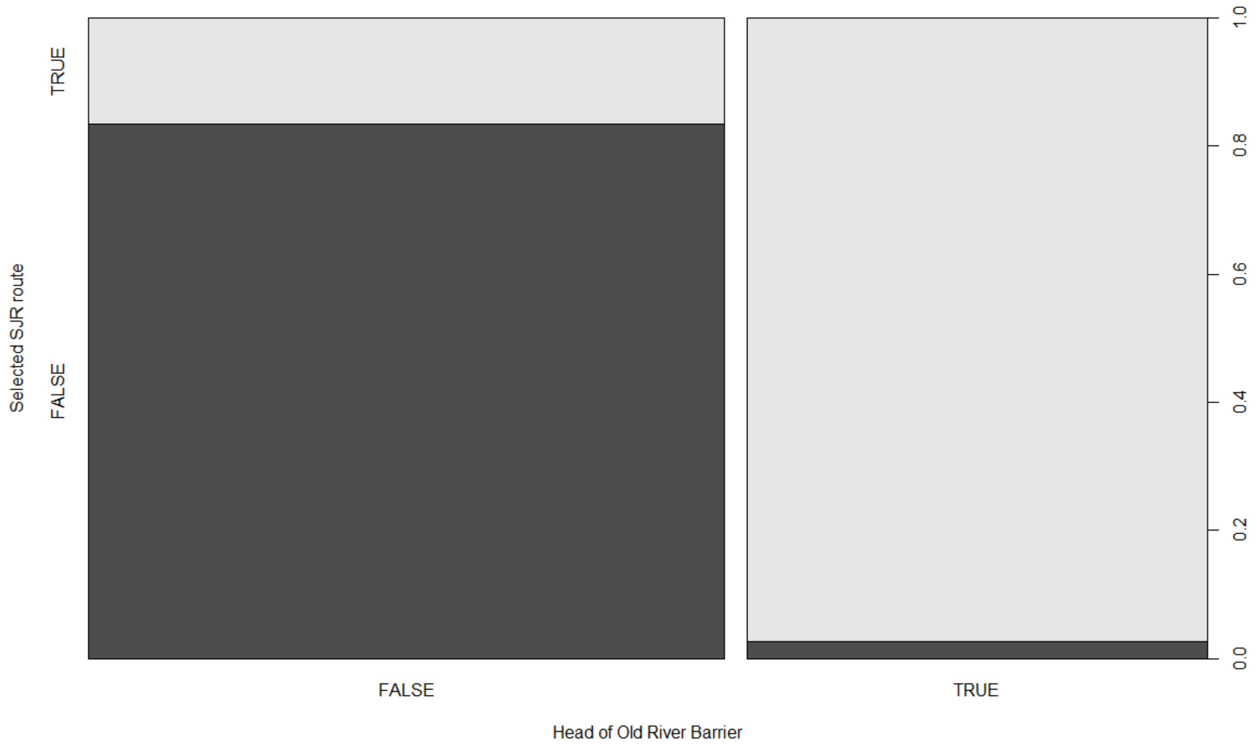

Figure 13. Relative proportions of 914 tags in the head of Old River route selection analysis observed selecting the San Joaquin River route (light shading) based on barrier status at time of arrival at the head of Old River in 2016. The short, dark region, denoting the "barrier" and "Old River route" combination, represented 10 tags. Tags observed at the junction after barrier opening and removal were omitted.

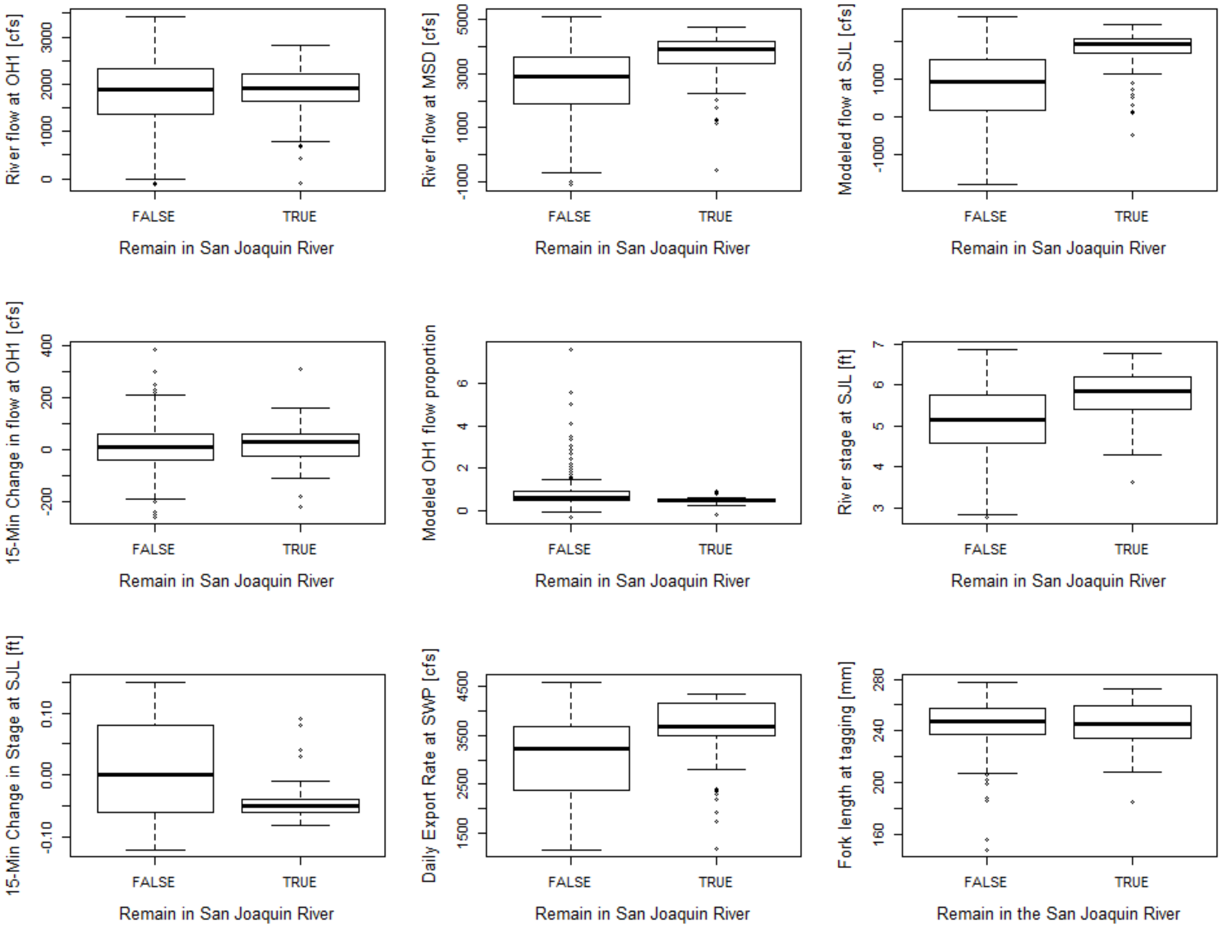

Figure 14. Conditions upon the estimated time of arrival at the head of Old River junction, daily export rates, and fork length at tagging, for steelhead detected at the SJL or ORE receivers and estimated to have arrived at the head of Old River junction before 1500 hours on 1 April 2016 (closure date for the head of Old River barrier). Data represent tags whose most recent detections were either upstream or in the other river branch, and did not linger in the vicinity of the river junction longer than 3 hours; predator-type detections were omitted. Bolded horizontal bar is median measure, upper and lower boundaries of box are the 25th and 75th quantiles (defining the interquartile range), and whiskers are the extremes or 1.5 × the interquartile range.

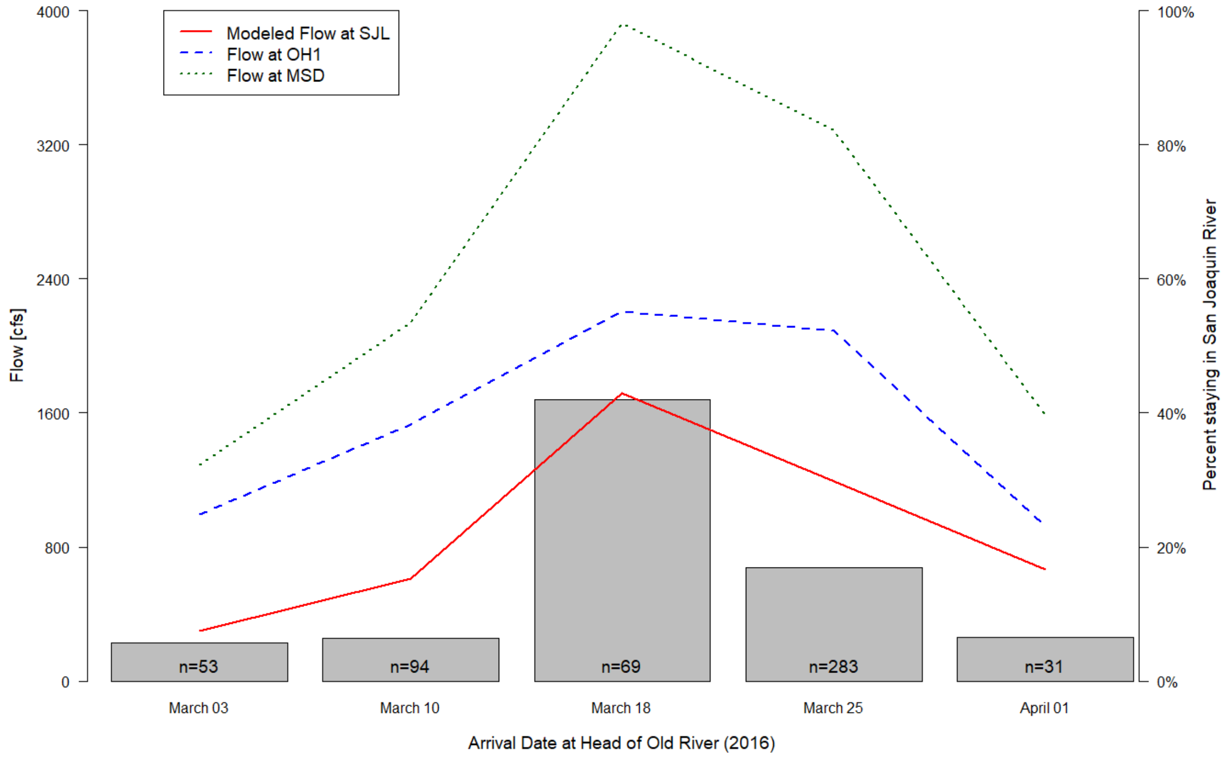

Figure 15. The observed proportion of tagged juvenile steelhead that remained in the San Joaquin River at the head of Old River during the 2016 tagging study (gray bars, representing weekly periods; n = weekly sample size), and the measured flow at the OH1 and MSD gaging stations and modeled flow at the SJL gaging station at the estimated time of fish arrival at the junction, averaged over fish, for steelhead estimated to have arrived at the junction before 1500 hours on 1 April 2016. Proportion of fish remaining in the San Joaquin River is shown only for time periods with at least 10 fish detected.

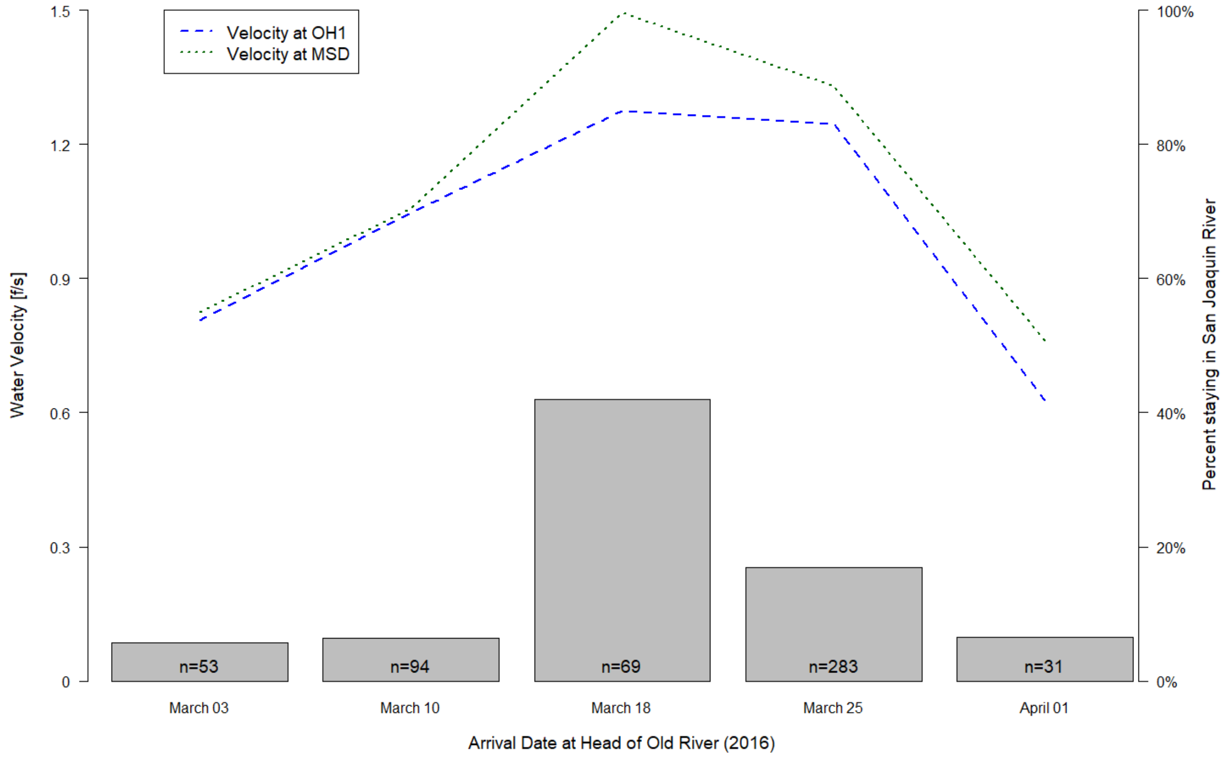

Figure 16. The observed proportion of tagged juvenile steelhead that remained in the San Joaquin River at the head of Old River during the 2016 tagging study (gray bars, representing weekly periods; n = weekly sample size), and the measured water velocity at the OH1 and MSD gaging stations at the estimated time of fish arrival at the junction, averaged over fish, for steelhead estimated to have arrived at the junction before 1500 hours on 1 April 2016. Proportion of fish remaining in the San Joaquin River is shown only for time periods with at least 10 fish detected.

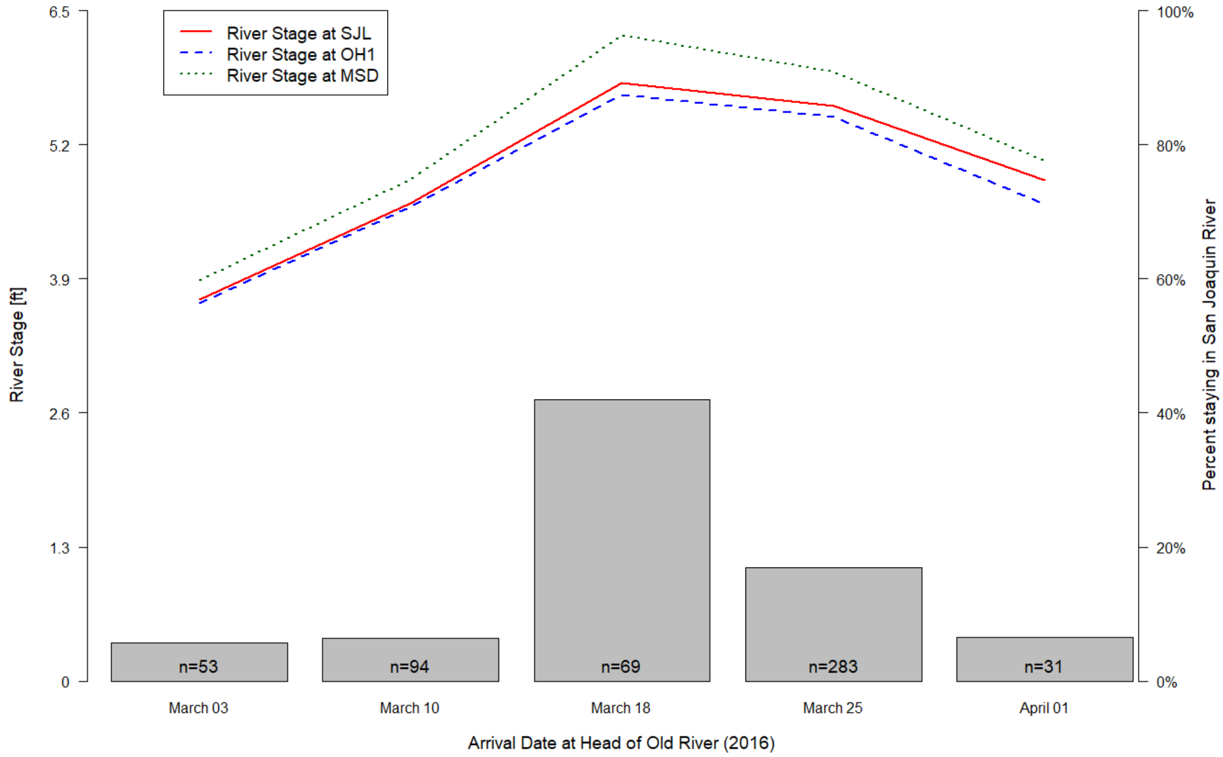

Figure 17. The observed proportion of tagged juvenile steelhead that remained in the San Joaquin River at the head of Old River during the 2016 tagging study (gray bars, representing weekly periods; n = weekly sample size), and the measured river stage at the SJL, OH1, and MSD gaging stations at the estimated time of fish arrival at the junction, averaged over fish, for steelhead estimated to have arrived at the junction before 1500 hours on 1 April 2016. Proportion of fish remaining in the San Joaquin River is shown only for time periods with at least 10 fish detected.

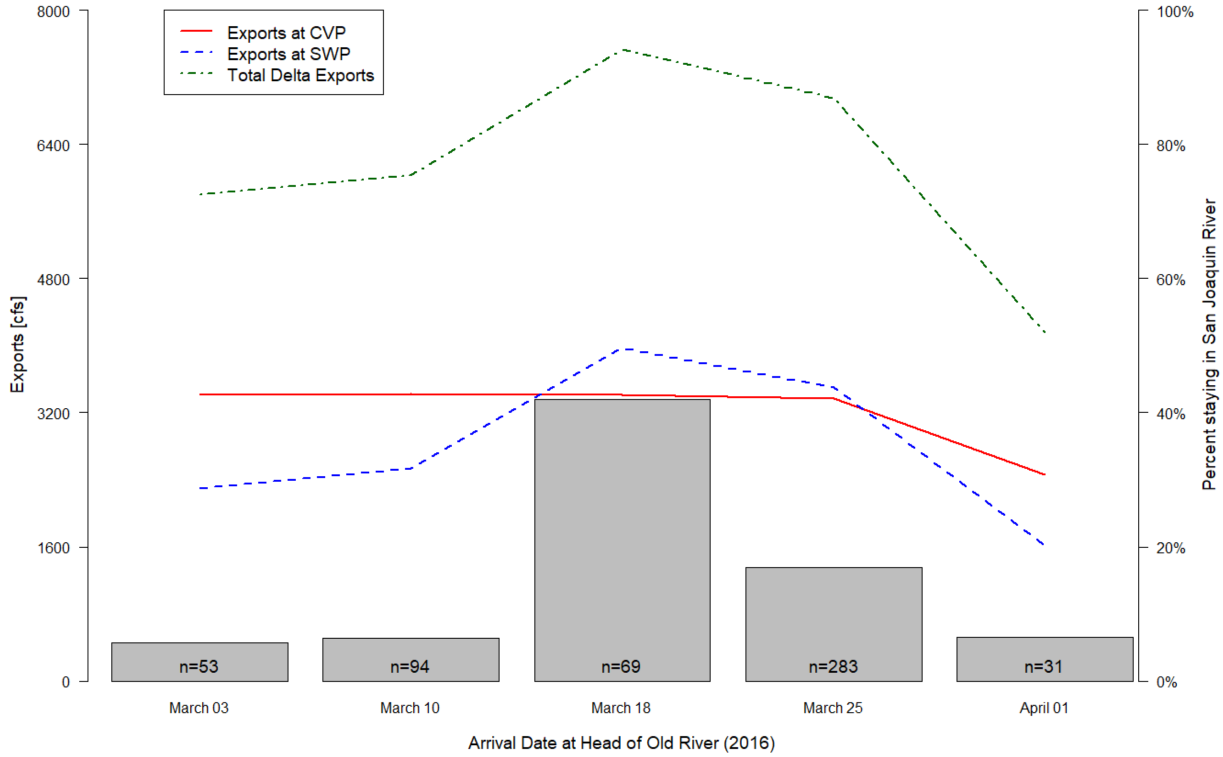

Figure 18. The observed proportion of tagged juvenile steelhead that remained in the San Joaquin River at the head of Old River during the 2016 tagging study (gray bars, representing weekly periods; n = weekly sample size), and the measured daily export rate at CVP, SWP, and total in the Delta on the estimated day of fish arrival at the junction, averaged over fish, for steelhead estimated to have arrived at the junction before 1500 hours on 1 April 2016. Proportion of fish remaining in the San Joaquin River is shown only for time periods with at least 10 fish detected.

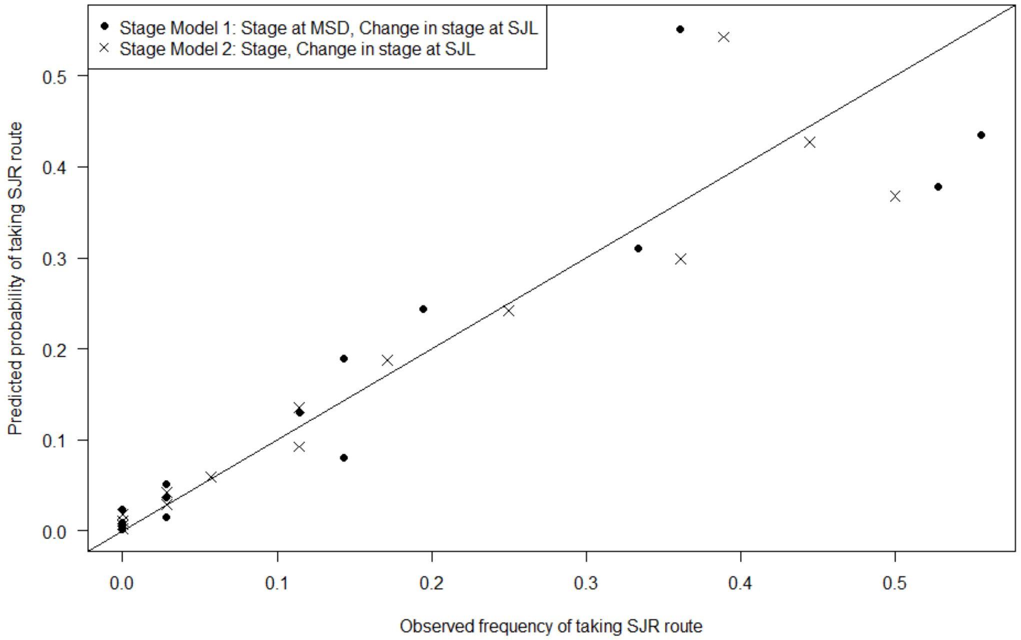

Figure 19. Predicted probability versus observed frequency of taking the San Joaquin River (SJR) route at the head of Old River, for two river stage models for route selection at the head of Old River. Dashed line is 1-1 line.

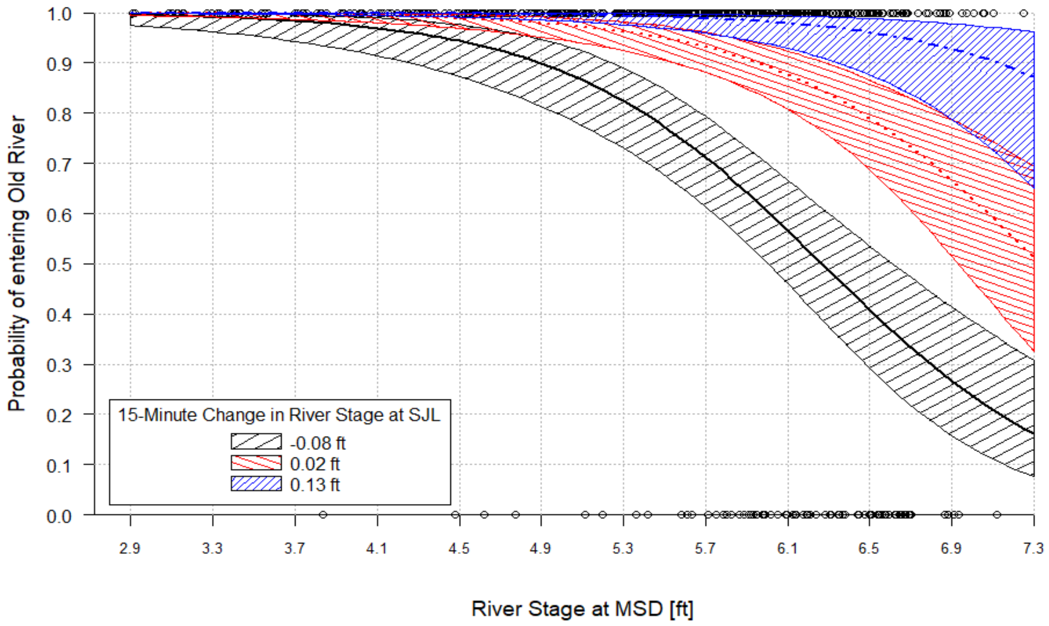

Figure 20. Fitted probability of entering Old River at its head versus river stage measured at the MSD gaging station in the San Joaquin River, for 15-minute change in river stage at SJL = -0.08, 0.02, and 0.13 ft, with 95% confidence bands, in 2016. Covariates were measured at the time of estimated tagged fish arrival at the head of Old River junction. Points indicate the observed route selection (0 = San Joaquin River, 1 = Old River) for each observed value of river stage.

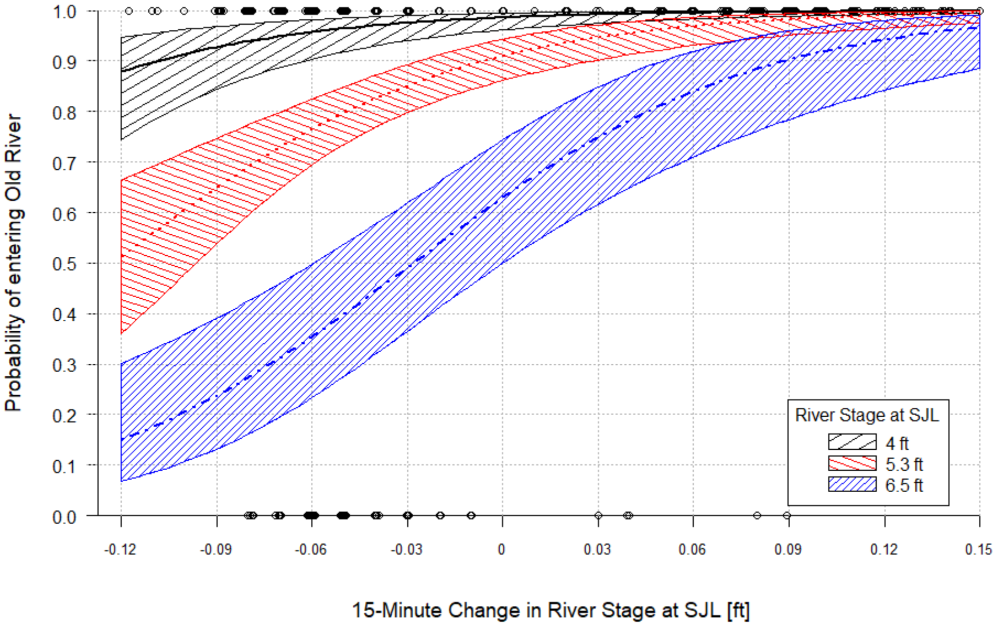

Figure 21. Fitted probability of entering Old River at its head versus the 15-minute change in river stage measured at the SJL gaging station in the San Joaquin River, for river stage at MSD = 4, 5.3, and 6.5 ft, with 95% confidence bands, in 2016. Covariates were measured at the time of estimated tagged fish arrival at the head of Old River junction. Points indicate the observed route selection (0 = San Joaquin River, 1 = Old River) for each observed value of 15-minute change in river stage; observed 15-minute change in river stage values have been offset slightly to avoid overlap in plotting.

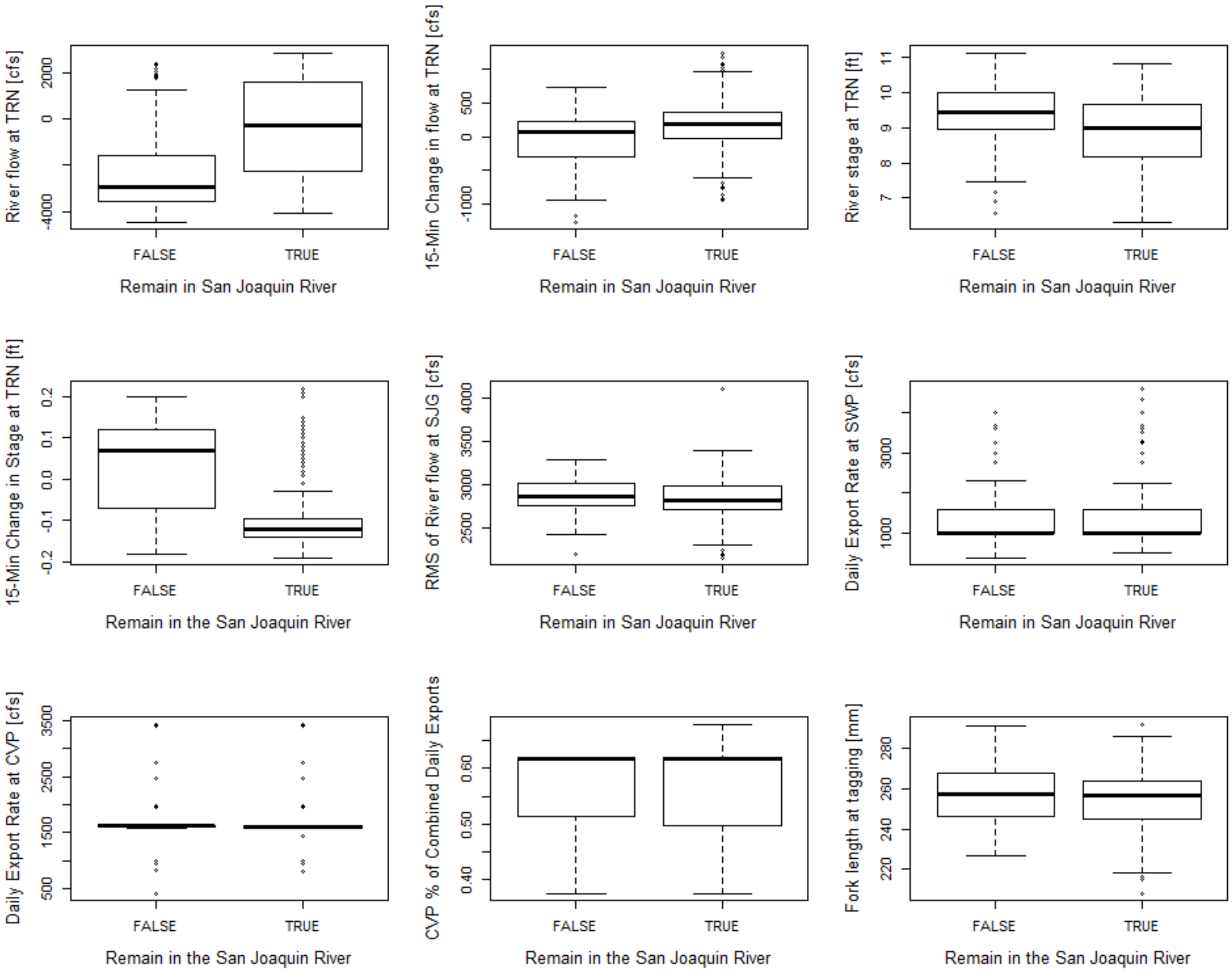

Figure 22. Hydrological conditions upon the estimated time of tag passage at the SJS receiver (0.39 km upstream of the Turner Cut junction), daily export rates, and fork length at tagging, for steelhead detected at the MAC or TCE/TCW receivers. Data represent tags that whose most recent detections were upstream and with travel time ≤8 hours from SJS to either MAC or TCE/TCW; predator-type detections were omitted. Bolded horizontal bar is median measure, upper and lower boundaries of box are the 25th and 75th quantiles (defining the interquartile range), and whiskers are the extremes or 1.5 × the interquartile range.

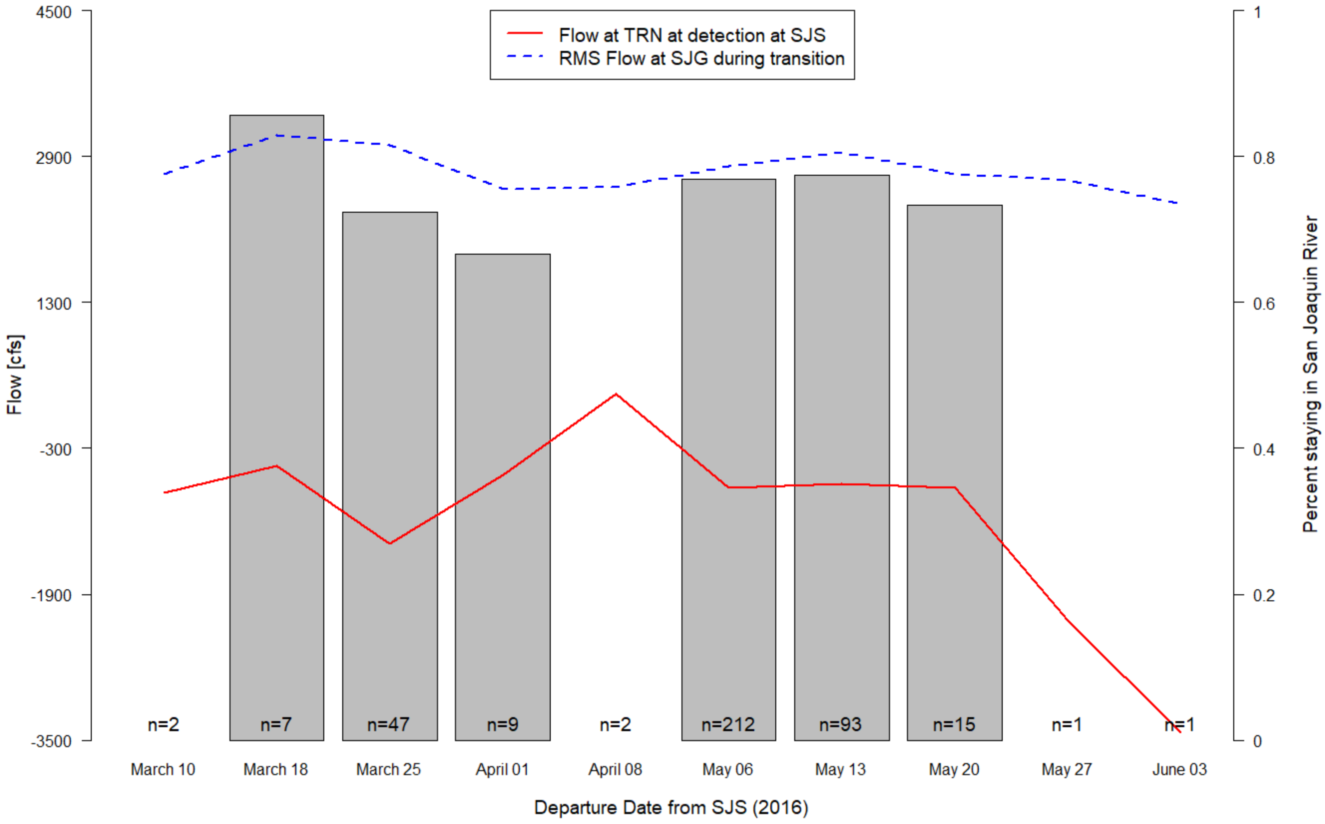

Figure 23. The observed proportion of tagged juvenile steelhead that remained in the San Joaquin River at the Turner Cut junction during the 2016 tagging study (gray bars, representing weekly periods; n = weekly sample size), the measured river discharge (flow) at the TRN gaging station in Turner Cut at the time of tag passage of the SJS receivers, averaged over fish (solid line), and the Root Mean Square (RMS) of river flow measured at the SJG gaging station during fish transition from the SJG telemetry receiver to the SJS receivers, averaged over fish (dashed line). Proportion of fish remaining in the San Joaquin River is shown only for time periods with at least 5 fish detected.

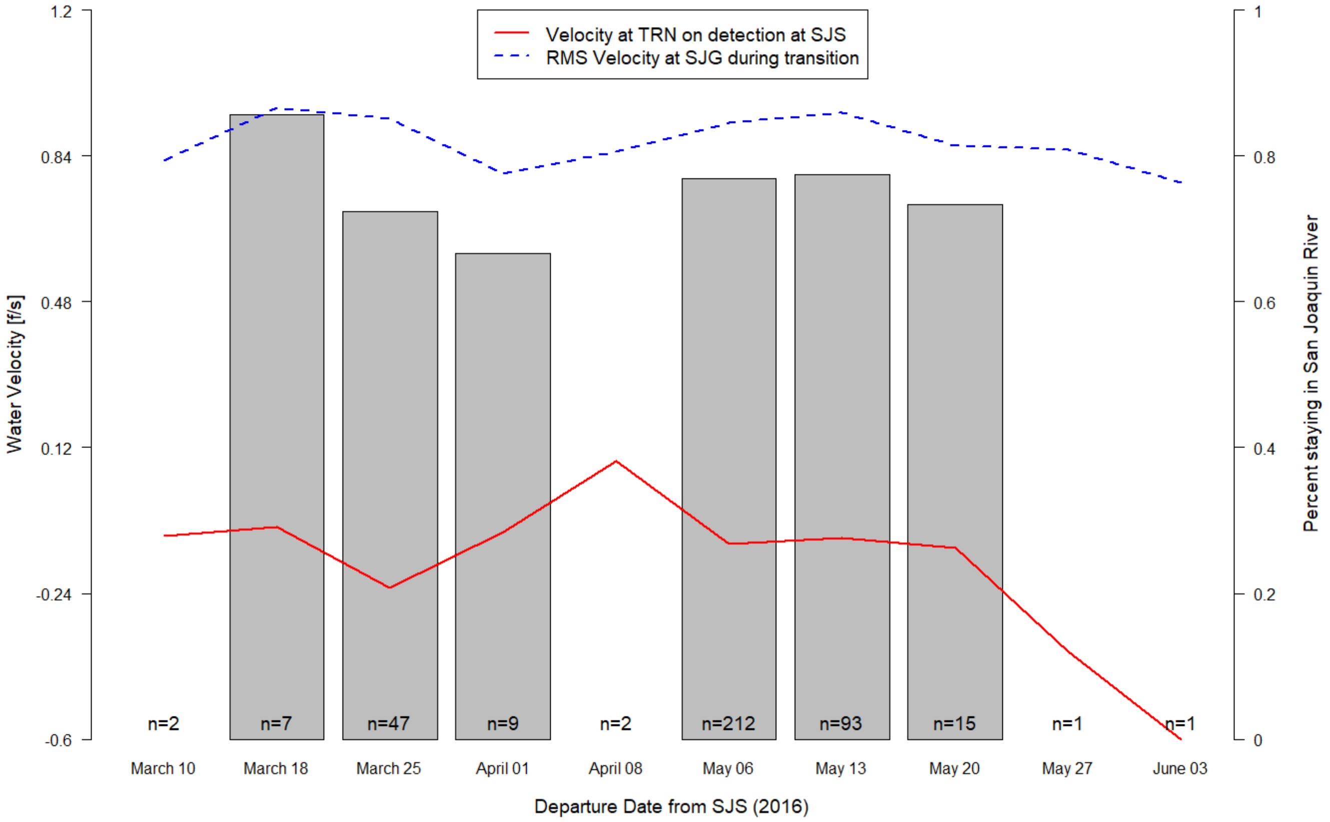

Figure 24. The observed proportion of tagged juvenile steelhead that remained in the San Joaquin River at the Turner Cut junction during the 2016 tagging study (gray bars, representing weekly periods; n = weekly sample size), the measured water velocity at the TRN gaging station in Turner Cut at the time of tag passage of the SJS receivers, averaged over fish (solid line), and the Root Mean Square (RMS) of water velocity measured at the SJG gaging station during fish transition from the SJG acoustic receiver to the SJS receivers, averaged over fish (dashed line). Proportion of fish remaining in the San Joaquin River is shown only for time periods with at least 5 fish detected.

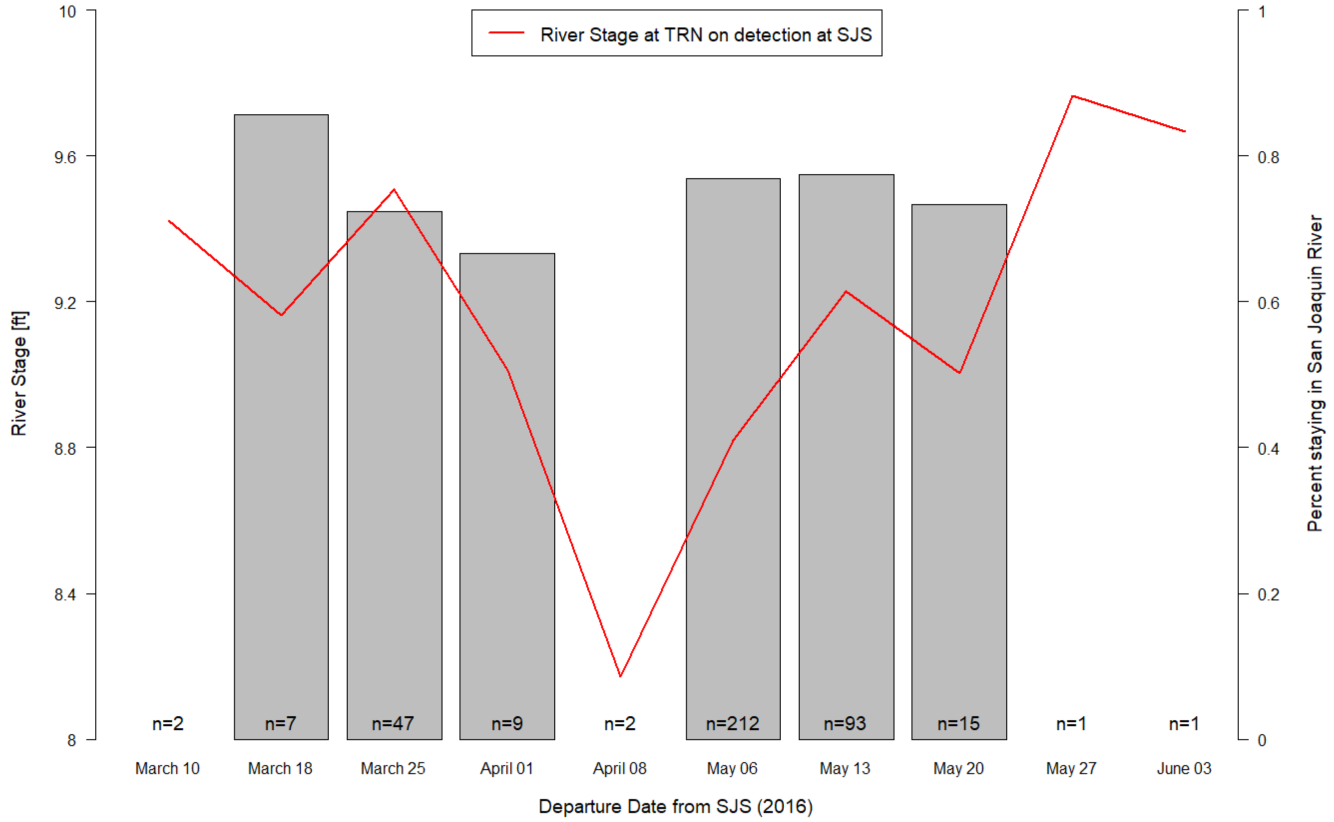

Figure 25. The observed proportion of tagged juvenile steelhead that remained in the San Joaquin River at the Turner Cut junction during the 2016 tagging study (gray bars, representing weekly periods; n = weekly sample size), and the measured river stage at the TRN gaging station in Turner Cut at the time of tag passage of the SJS receivers, averaged over fish. Proportion of fish remaining in the San Joaquin River is shown only for time periods with at least 5 fish detected.

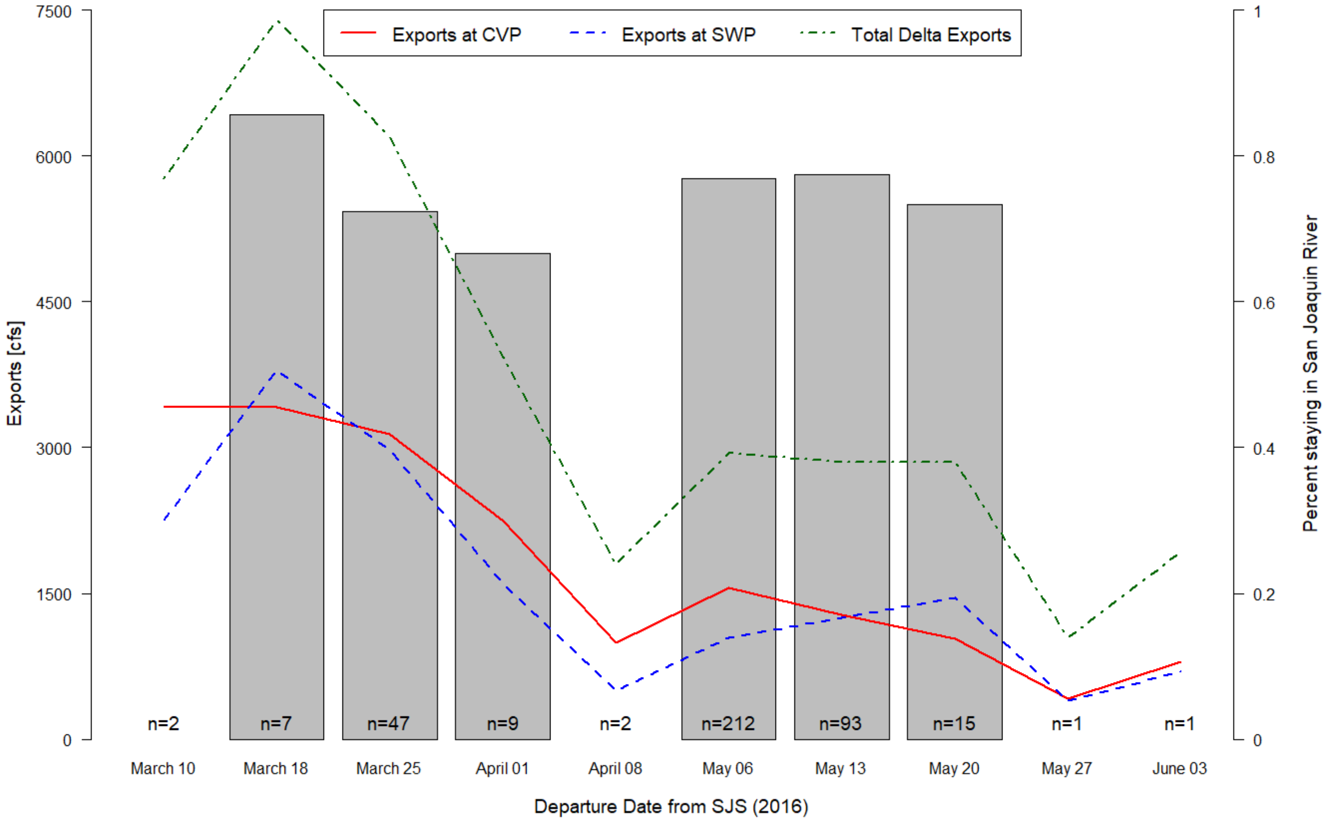

Figure 26. The observed proportion of tagged juvenile steelhead that remained in the San Joaquin River at the Turner Cut junction during the 2016 tagging study (gray bars, representing weekly periods; n = weekly sample size), and the measured daily export rate at CVP, SWP, and total in the Delta at the time of tag passage of the SJS receivers. Proportion of fish remaining in the San Joaquin River is shown only for time periods with at least 5 fish detected.

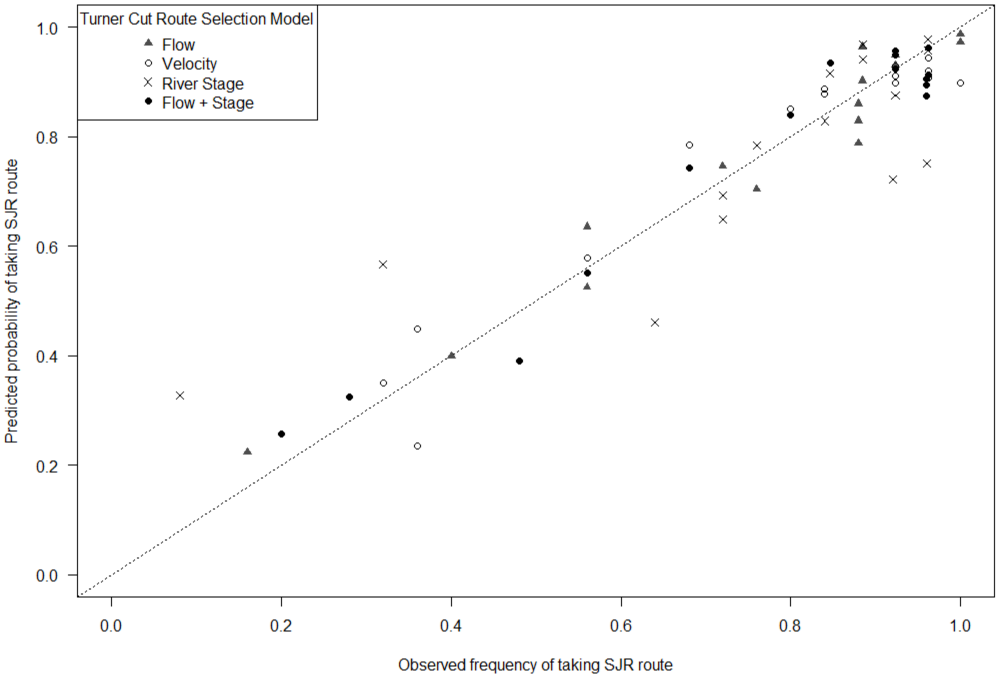

Figure 27. Predicted probability versus observed frequency of taking the San Joaquin River (SJR) route at the Turner Cut Junction, for the candidate models. Dashed line is 1-1 line.

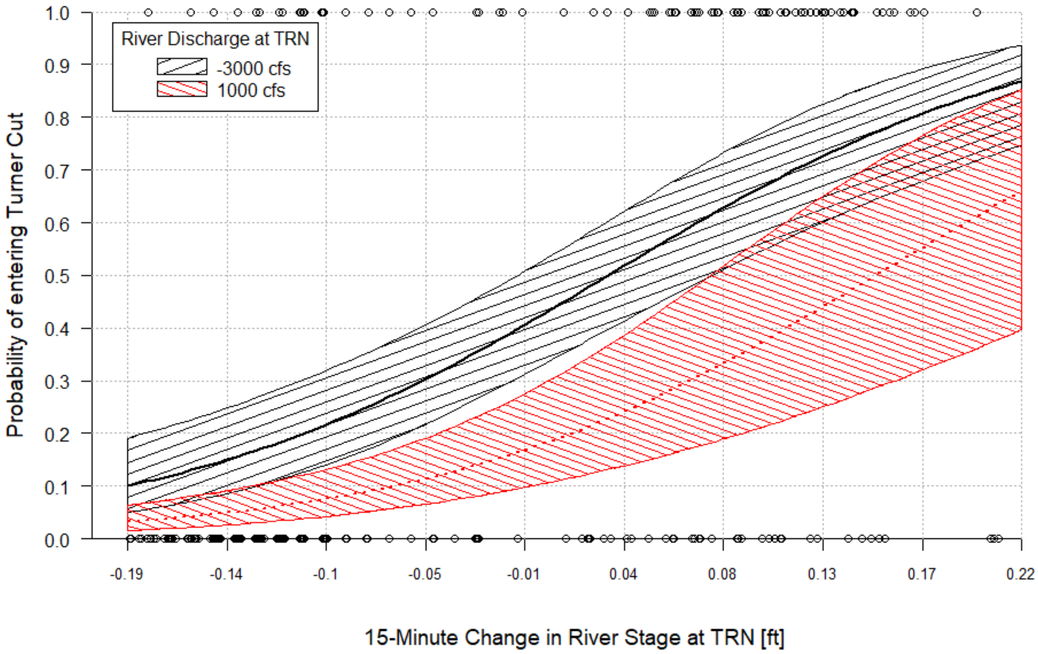

Figure 28. Fitted probability of entering Turner Cut versus 15-minute change in river stage measured at the TRN gaging station in Turner Cut, for river discharge (flow) at TRN = -3,000 cfs and 1,000 cfs, with 95% confidence bands, in 2016. Covariates were measured at the time of tag passage at the SJS receivers. Points indicate the observed route selection (0 = San Joaquin River, 1 = Turner Cut) for each observed value of 15-minute change in river stage; observed 15-minute change in river stage values have been offset slightly to avoid overlap in plotting.

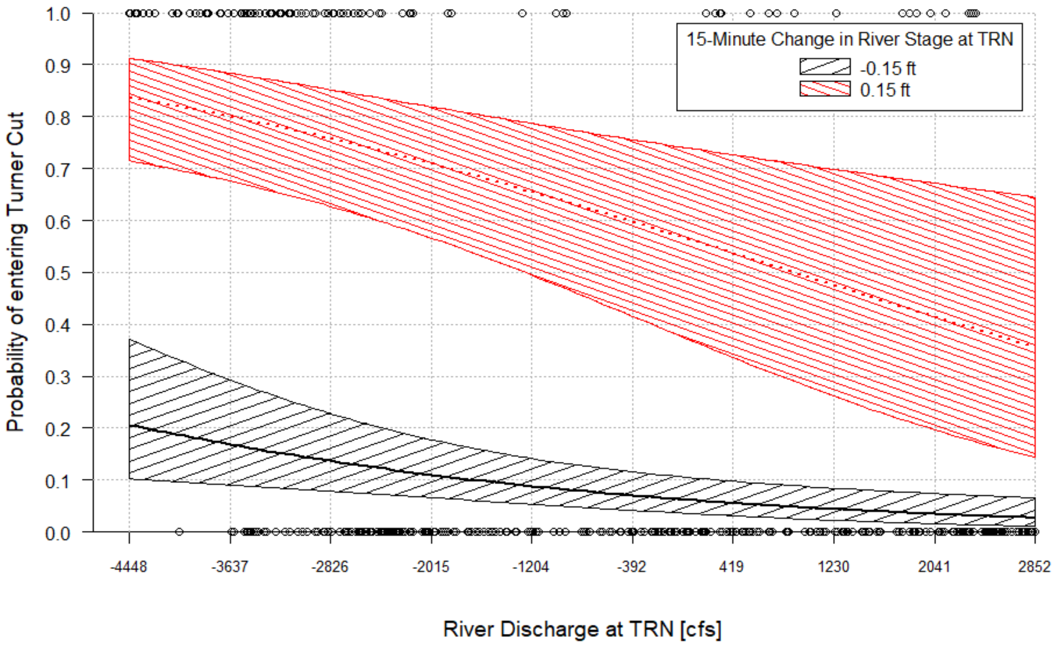

Figure 29. Fitted probability of entering Turner Cut versus river discharge (flow) measured at the TRN gaging station in Turner Cut, for 15-minute change in river stage at TRN = -0.15 ft and 0.15 ft, with 95% confidence bands, in 2016. Covariates were measured at the time of tag passage at the SJS receivers. Points indicate the observed route selection (0 = San Joaquin River, 1 = Turner Cut) for each observed value of river discharge.

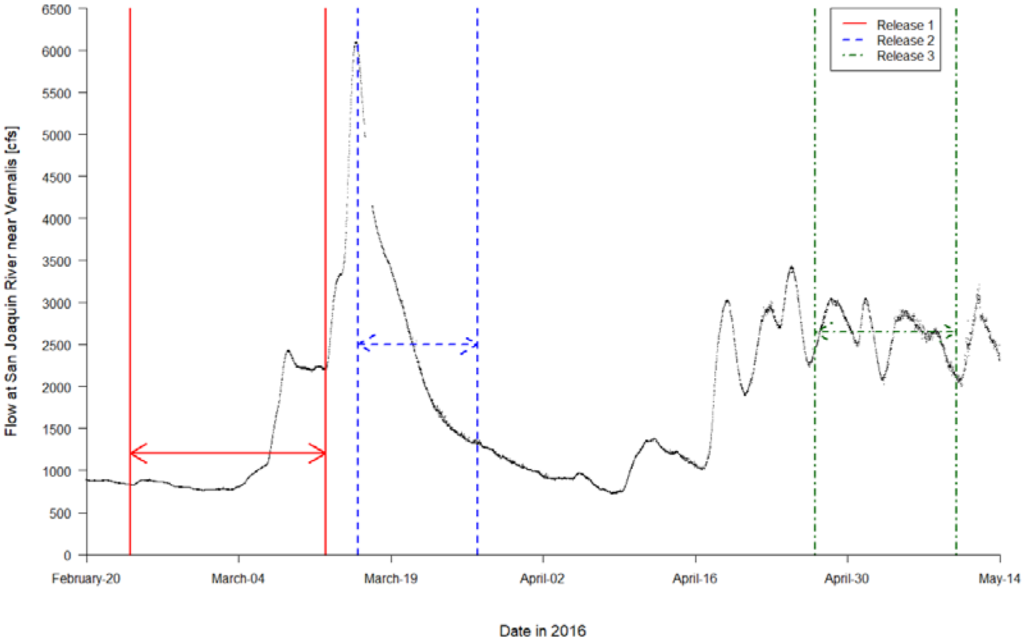

Figure 30. Delta inflow represented as river discharge (flow) measured at the San Joaquin River gaging station near Vernalis (VNS) during the 2016 study. Vertical lines represent the time period from the first day through the final day of release, plus the median observed travel time to Chipps Island for the release. Arrow height indicates mean discharge: 1,209 cfs, 2,508 cfs, and 2,649 cfs, respectively.

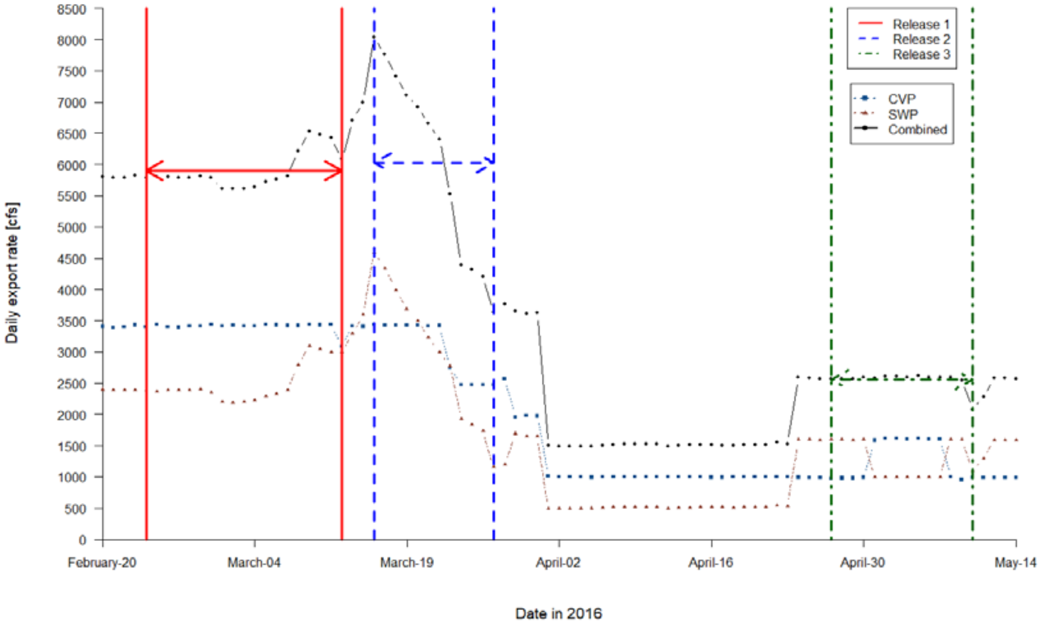

Figure 31. Daily export rate at CVP and SWP during the 2016 study. Vertical lines represent the time period from the first day through the final day of release, plus the median observed travel time to Chipps Island for the release. Arrow height indicates mean combined export rate: 5,899 cfs, 6,030 cfs, and 2,553 cfs, respectively.

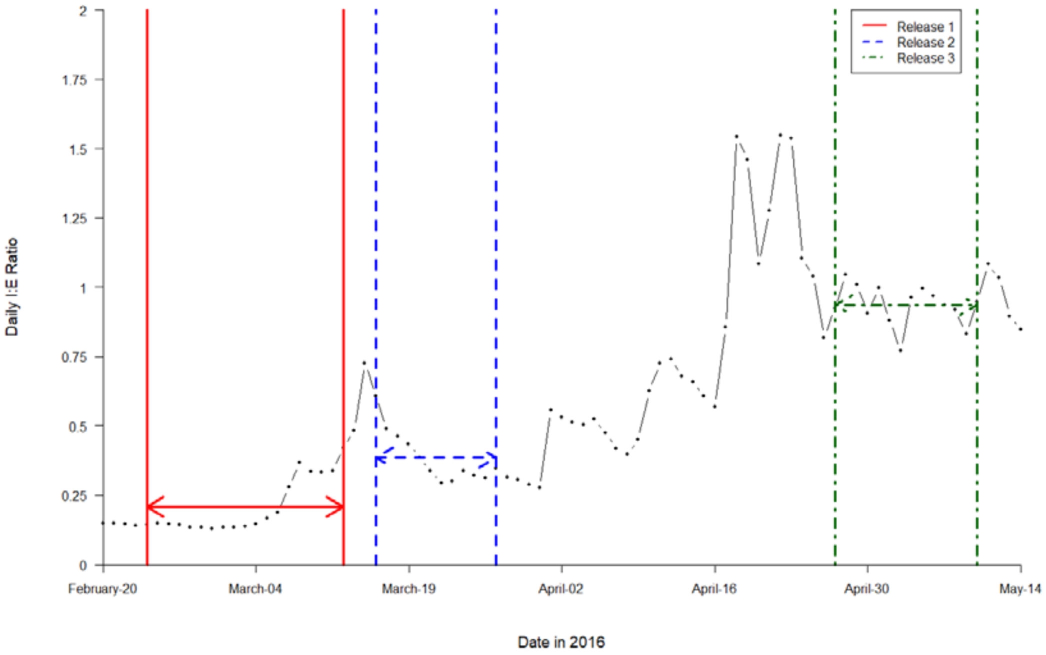

Figure 32. Daily Inflow : Export (I:E) ratio during the 2016 study, where I:E = VNS inflow : total Delta Export Rate; data from Dayflow. Vertical lines represent the time period from the first day through the final day of release, plus the median observed travel time to Chipps Island for the release. Arrow height indicates mean I:E ratio: 0.20, 0.39, and 0.93, respectively.

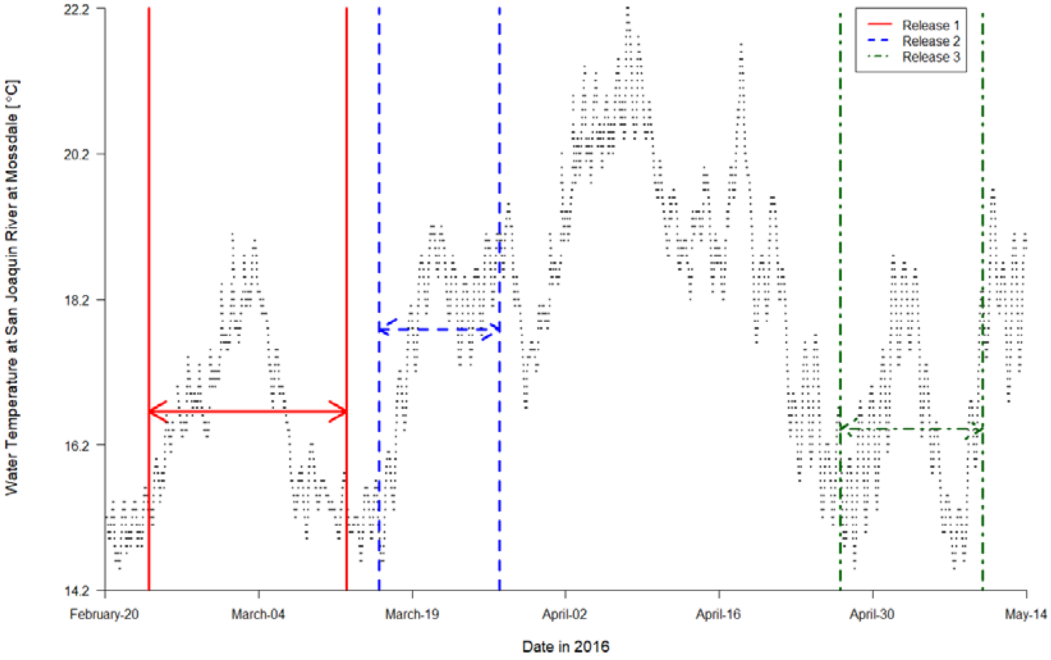

Figure 33. Water temperature at the San Joaquin River gaging station near Mossdale Bridge (MSD) during the 2016 study. Vertical lines represent the time period from the first day through the final day of release, plus the median observed travel time to Chipps Island for the release. Arrow height indicates mean temperature: 16.6°C, 17.8°C, and 16.4°C, respectively.

Tables

Table 1. Names and descriptions of receivers and hydrophones used in the 2016 Steelhead tagging study, with receiver codes used in Figure 1, the survival model (Figures 2 – 5), and in data processing by the United States Geological Survey (USGS). The release site was located at Durham Ferry. Average latitude and longitude are given for sites with multiple hydrophones. Receiver codes starting with "46" are high residency receivers (VEMCO HRR); all others are VEMCO VR2W or VR2C receivers.

Individual Receiver Name and Description	Hydrophone Location		Receiver Code	Survival Model Code	Data Processing Code
	Latitude (°N)	Longitude (°W)			
San Joaquin River near Durham Ferry upstream of the release site, upstream	37.68565	-121.2564	DFU1	A0a	300944
San Joaquin River near Durham Ferry upstream of the release site, downstream	37.68643	-121.2567	DFU2	A0b	300911
San Joaquin River near Durham Ferry; release site	37.68678	-121.2641	DF		
San Joaquin River near Durham Ferry downstream of the release site, upstream	37.68862	-121.2761	DFD1	A2a	300985 460084
San Joaquin River near Durham Ferry downstream of the release site, downstream	37.68875	-121.276	DFD2	A2b	460085
San Joaquin River below Durham Ferry, upstream	37.72132	-121.2622	BDF1	A3	460035
San Joaquin River below Durham Ferry, downstream	37.71787	-121.2783	BDF2	A4	460036
San Joaquin River near Banta Carbona, upstream	37.72778	-121.2987	BCAU	A5a	301503
San Joaquin River near Banta Carbona, downstream	37.72833	-121.2986	BCAD	A5b	460021
San Joaquin River near Mossdale Bridge, upstream	37.79173	-121.3070	MOSU	A6a	300928
San Joaquin River near Mossdale Bridge, downstream	37.79255	-121.3068	MOSD	A6b	300717
San Joaquin River near Lathrop, upstream	37.81103	-121.3196	SJLU	A7a	300721 300991
San Joaquin River near Lathrop, downstream	37.81162	-121.3187	SJLD	A7b	300957 301501
San Joaquin River near Garwood Bridge, upstream	37.93508	-121.3300	SJGU	A8a	300934 300892
San Joaquin River near Garwood Bridge, downstream	37.93529	-121.3305	SJGD	A8b	300903 300918
San Joaquin river near Navy Bridge, upstream[a]	37.94670	-121.3398	SJNBU	A9a	300723
San Joaquin river near Navy Bridge, downstream	37.94677	-121.3395	SJNBD	A9b	300888
San Joaquin River near Calaveras River, upstream	37.96895	-121.3718	SJCU	A10a	300952 300954
San Joaquin River near Calaveras River, downstream	37.96955	-121.3724	SJCD	A10b	300982 301153
San Joaquin River Shipping Channel	37.99562	-121.4404	SJS	A11	300729 300887 300724

a = no data reported

Table 1. (Continued)

Individual Receiver Name and Description	Hydrophone Location		Receiver Code	Survival Model Code	Data Processing Code
	Latitude (°N)	Longitude (°W)			
San Joaquin River near MacDonald Island, upstream	38.01763	-121.4620	MACU	A12a	300922 300883
San Joaquin River near MacDonald Island, downstream	38.02247	-121.4653	MACD	A12b	301163 300912
San Joaquin River near Medford Island, upstream (east)	38.05322	-121.5115	MFE	A13a	300920 300915
San Joaquin River near Medford Island, downstream (west)	38.05377	-121.5132	MFW	A13b	300712 300935
San Joaquin River near Disappointment Slough, upstream	38.09159	-121.5747	SJDU	A14a	300932 300956 300986
San Joaquin River near Disappointment Slough, downstream	38.09240	-121.5752	SJDD	A14b	300897 300899 300950
San Joaquin River upstream of Head of Old River, upstream[b]	37.80597	-121.3188	HORU	B0a	300866 300940
San Joaquin River upstream of Head of Old River, downstream[b]	37.80584	-121.3197	HORD	B0b	300905 300958
Old River East, near junction with San Joaquin, upstream	37.81186	-121.3356	OREU	B1a	300718 300930
Old River East, near junction with San Joaquin, downstream	37.81239	-121.3356	ORED	B1b	301452 300890
Old River South, upstream	37.82052	-121.3776	ORSU	B2a	300943
Old River South, downstream	37.82000	-121.3778	ORSD	B2b	300726
West Canal, upstream	37.84663	-121.5596	WCLU	B3a	300863
West Canal, downstream	37.84738	-121.5599	WCLD	B3b	300931
Old River near Highway 4, upstream	37.89294	-121.5673	OR4U	B4a	300902 300722
Old River near Highway 4, downstream	37.89380	-121.5671	OR4D	B4b	300713 301161
Old River at the San Joaquin River, upstream (closer to Old River mouth)	38.06233	-121.5811	OSJU	B5a	301512 301157 300885
Old River at the San Joaquin River, downstream (farther from Old River mouth)	38.06179	-121.5820	OSJD	B5b	300715 301510 301508
Middle River Head, upstream	37.82448	-121.3794	MRHU	C1a	300896
Middle River Head, downstream	37.82473	-121.3802	MRHD	C1b	300858
Middle River near Highway 4, upstream	37.89610	-121.4930	MR4U	C2a	300719 301165
Middle River near Highway 4, downstream	37.89680	-121.4933	MR4D	C2b	300948 300881
Middle River near Mildred Island, upstream[b]	38.00180	-121.5117	MIDU	C3a	300942 300913

b = not used in survival model

Table 1. (Continued)

Individual Receiver Name and Description	Hydrophone Location		Receiver Code	Survival Model Code	Data Processing Code
	Latitude (°N)	Longitude (°W)			
Middle River near Mildred Island, downstream[b]	38.00232	-121.5117	MIDD	C3b	300981 300714
Radial Gate at Clifton Court Forebay, upstream (in entrance channel to forebay), array 1 in dual array	37.83003	-121.5566	RGU1	D1a	300908
Radial Gate at Clifton Court Forebay, upstream (in entrance channel to forebay), array 2 in dual array	37.82960	-121.5570	RGU2	D1b	300910
Radial Gate at Clifton Court Forebay, downstream (inside forebay), array 1 in dual array	37.83019	-121.5575	RGD1	D2a	460009 300904
Radial Gate at Clifton Court Forebay, downstream (inside forebay), array 2 in dual array	37.83019	-121.5575	RGD2	D2b	460010 300980
Central Valley Project trashracks, upstream	37.81687	-121.5584	CVPU	E1a	460012 460023
Central Valley Project trashracks, downstream	37.81665	-121.5589	CVPD	E1b	300939
Central Valley Project holding tanks	37.81585	-121.5591	CVPT	E2	300891 300938 300876
Turner Cut, east	37.99167	-121.4549	TCE	F1a	450043 300868
Turner Cut, west	37.99133	-121.4555	TCW	F1b	300900 450024
Columbia Cut, upstream	38.02729	-121.5009	COLU	F2a	300898 300869
Columbia Cut, downstream	38.02697	-121.5017	COLD	F2b	300862 301502
San Joaquin River at Jersey Point, upstream (east)	38.05630	-121.6870	JPE	G1a	300889 300873 300867 300941 301511 300720 300895 301164
San Joaquin River at Jersey Point, downstream (west)	38.05556	-121.6884	JPW	G1b	301504 300877 301002 300994 301000 301001 301024 301156

b = not used in survival model

Table 1. (Continued)

Individual Receiver Name and Description	Hydrophone Location		Receiver Code	Survival Model Code	Data Processing Code
	Latitude (°N)	Longitude (°W)			
Chipps Island (aka Mallard Island), upstream (east)	38.04810	-121.9313	MAE	G2a	300936 300727 300906 301154 300865 300929 300886 301505 300880 301158 301509
Chipps Island (aka Mallard Island), downstream (west)	38.04926	-121.9328	MAW	G2b	300923 300731 300921 300728 300864 300990 300955 300909 300882 300989 301159
Benicia Bridge pier, upstream (east)	38.04275	-122.1215	BBE	G3a	301617 301615 300949 300946 300960 300961 300945 301616 301614
Benicia Bridge pier, downstream (west)	38.04066	-122.1235	BBW	G3b	301493 301492 301489 301490 301488 301487 301486 301491
False River, west (closer to San Joaquin)	38.05635	-121.6643	FRW	H1a	301507 300730
False River, east (farther from San Joaquin)	38.05635	-121.6637	FRE	H1b	301506 300984
Predator Removal Study Site 4[b]	37.81862	-121.3174	RS4	N1	300870 301166
Predator Removal Study Site 5[b]	37.83189	-121.3122	RS5	N2	300901 300872
Predator Removal Study Site 6[b]	37.85138	-121.3221	RS6	N3	300884 300924
Predator Removal Study Site 7[b]	37.86450	-121.3236	RS7	N4	300917 300879
Predator Removal Study Site 8[b]	37.88777	-121.3302	RS8	N5	300878 300861
Predator Removal Study Site 9[b]	37.90577	-121.3234	RS9	N6	300871 300937
Predator Removal Study Site 10[b]	37.91825	-121.3206	RS10	N7	300916 300914

b = not used in survival model

Table 1. (Continued)

Individual Receiver Name and Description	Hydrophone Location		Receiver Code	Survival Model Code	Data Processing Code
	Latitude (°N)	Longitude (°W)			
Burns Cutoff at Rough and Ready Island, upstream	37.94023	-121.3510	RRIU	R1a	300859
Burns Cutoff at Rough and Ready Island, downstream	37.94015	-121.3512	RRID	R1b	301155
Threemile Slough, south	38.10748	-121.6840	TMS	T1a	300875 301162
Threemile Slough, north	38.11111	-121.6832	TMN	T1b	300933 300732
Montezuma Slough, upstream[b]	38.07138	-121.8686	MTZU	T2a	301018
Montezuma Slough, downstream[b]	38.07148	-121.8697	MTZD	T2b	300860
Spoonbill Slough, upstream[b]	38.05525	-121.8953	SBSU	T3a	301014
Spoonbill Slough, downstream[b]	38.05542	-121.8955	SBSD	T3b	300999

b = not used in survival model

Table 2. Environmental monitoring sites used in predator decision rule and route entrainment analysis for 2016 Steelhead study. Database = CDEC (http://cdec.water.ca.gov/) or Water Library (http://www.water.ca.gov/waterdatalibrary/).

Environmental Monitoring Site			Detection Site	Data Available					Database
Site Name	Latitude (°N)	Longitude (°W)		River Flow	Water Velocity	River Stage	Pumping	Reservoir Inflow	
BDT	37.8650	121.3231	RS6, RS7, RS8	Yes	Yes	Yes	No	No	Water Library
CLC	37.8298	121.5574	RGU, RGD	No	No	No	No	Yes	CDEC
CSE	38.0740	121.8501	MTZ	No	No	Yes	No	No	CDEC
FAL	38.0554	121.6672	FRE/FRW	Yes	Yes	Yes	No	No	CDEC
GCT	37.8200	121.4498	ORS	No	No	Yes	No	No	Water Library
HLT	38.0030	121.5108	COL, MID	Yes	Yes	Yes	No	No	CDEC
MAL	38.0428	121.9201	MTZ, SBS, MAE/MAW	No	Yes	Yes[b]	No	No	CDEC
MDB	37.8908	121.4883	MR4	No	No	Yes	No	No	Water Library
MDM	37.9425	121.5340	MR4	Yes	Yes	No	No	No	CDEC
MRU	37.8339	121.3860	MRH	Yes	Yes	No	No	No	Water Library
MRZ	38.0276	122.1405	BBR	No	No	Yes	No	No	CDEC
MSD	37.7860	121.3060	HOR, MOS	Yes	Yes	Yes	No	No	Water Library
ODM	37.8101	121.5419	CVP/CVPtank	Yes	Yes	Yes	No	No	CDEC[a]
OH1	37.8080	121.3290	ORE	Yes	Yes	Yes	No	No	Water Library
OH4	37.8900	121.5697	OR4	Yes	Yes	Yes	No	No	CDEC
ORX	37.8110	121.3866	ORS	Yes	Yes	No	No	No	Water Library
OSJ	38.0711	121.5789	OSJ	Yes	Yes	Yes	No	No	CDEC
PRI	38.0593	121.5575	MAC, MFE/MFW, SJD	Yes	Yes	Yes	No	No	CDEC
RMID040	37.8350	121.3838	MRH	No	No	Yes	No	No	Water Library
ROLD040	37.8286	121.5531	RGU, RGD, WCL	No	No	Yes	No	No	Water Library
RRI	37.9360	121.3650	SJC, SJS	Yes	Yes	Yes	No	No	Water Library
SJD	37.8223	131.3177	RS4, RS5	Yes	Yes	No	No	No	Water Library
SJG	37.9351	121.3295	RS9, RS10, SJG, SJNB, RRI	Yes	Yes	Yes	No	No	CDEC
SJJ	38.0520	121.6891	JPE/JPW	Yes	Yes	Yes	No	No	CDEC

[a] = California Water Library was used for river stage.

[b] = Used for river stage for SBS and MAE/MAW.

Table 2. (Continued)

Environmental Monitoring Site			Detection Site	Data Available					Database
Site Name	Latitude (°N)	Longitude (°W)		River Flow	Water Velocity	River Stage	Pumping	Reservoir Inflow	
SJL	37.8100	121.3230	SJL	No	No	Yes	No	No	Water Library
TRN	37.9927	121.4541	TCE/TCW	Yes	Yes	Yes	No	No	CDEC
TRP	37.8165	121.5596	CVP/CVPtank	No	No	No	Yes	No	CDEC
TSJ	38.0900	121.6869	TMS/TMN	No	No	Yes	No	No	Water Library
TSL	38.1004	121.6866	TMS/TMN	Yes	Yes	No	No	No	CDEC
VNS	37.6670	121.2670	DFU, DFD, BDF1, BDF2, BCA	Yes	No	Yes	No	No	CDEC
WCI	37.8316	121.5541	RGU, RGD, WCL	Yes	Yes	No	No	No	Water Library

[a] = California Water Library was used for river stage.

[b] = Used for river stage for SBS and MAE/MAW.

Table 3a. Cutoff values used in predator filter in 2016. Observed values past cutoff or unmet conditions indicate a predator. Time durations are in hours unless otherwise specified. See Table 3b for Flow, Water Velocity, Extra Conditions, and Comment. Footnotes refer to both this table and Table 3b.

Detection Site	Previous Site	Residence Time[a] (hr)			Migration Rate[b, c] (km/hr)		Time since last visit (hr)	BLPS (Magnitude)	No. of Visits	No. of Cumulative Upstream Forays
		Near Field	Mid-field	Far-field						
		Maximum	Maximum	Maximum	Minimum	Maximum	Maximum	Maximum	Maximum	Maximum
DFU	DF	200	400	800	0	4			1	0
	DFU	200	800	1,000					2	2
	DFD, BDF1	200	400	800	0	4			2	2
	TCE/TCW	1	2	4	0.2	4			0	2
DFD	DF	300	600	1,000	0	4.5			1	0
	DFU, DFD	300	600 (1,000[f])	1,000	0	4.5 (NA[f])			10	2
	BDF1, BDF2, BCA	300	600	1,000		4			3	2
BDF1	DF	30	60	1,000	0	4.5			1	0
	DFD	30	60	1,000	0	4.5			10	0
	BDF1	60	440	1,000					10	1
	BDF2	30	60	1,000	0	4.5			3	2
	BCA	30	60	1,000	0.1	4.5			3	2
BDF2	DF, DFD, BDF1	30	60	1,000	0	4.5			10 (1[f])	0
	BDF2	60	440	1,000					10	1
	BCA	30	60	1,000	0.1	4.5			3	2
BCA	DF, DFU	30 (1000[f])	60 (1000[f])	1,000	0	4.5			1	0
	DFD, BDF1, BDF2	30 (1000[f])	60 (1000[f])	1,000	0	4.5			4	0
	BCA	60 (1000[f])	340 (1000[f])	1,000					5	1
	MOS	1	2	1,000	0.1	4			2	2
	MOS	30	300	1,100					5	5
	HOR, RS7	24	48	1,100		6	400	4.5	8	7

a = Near-field residence time includes up to 12 hours missing between detections, while mid-field residence time includes entire time lag between first and last detections without intervening detections elsewhere; far-field ("regional") residence time includes all time from entry in region to arrival at and departure from current site

b = Approximate migration rate calculated on most direct pathway

c = Missing values for transitions to and from same site: travel times must be 12 to 24 hours, unless otherwise specified under "Extra conditions"

f = See comments for alternate criteria

Table 3a. (Continued)

Detection Site	Previous Site	Residence Time[a] (hr)			Migration Rate[b, c] (km/hr)		Time since last visit (hr)	BLPS (Magnitude)	No. of Visits	No. of Cumulative Upstream Forays
		Near Field	Mid-field	Far-field						
		Maximum	Maximum	Maximum	Minimum	Maximum	Maximum	Maximum	Maximum	Maximum
MOS	DF, DFU, DFD, BDF1, BDF2, BCA	50 (100[f])	100 (200[f])	1,000		6		4.6	1	0
	MOS	30	250	1,000					4	4
	HOR	30	60	1,000		6		4.6	3	5
SJL	HOR	24	48	96	0.1	6	25	4.6	5	0
	SJL	5	164	385					4	2
	ORE	5 (1[f])	10 (2[f])	20 (4[f])	0.5	6	20 (15[f])	4.6	3 (0[f])	0
	RS4	10	20	483	0.1	4		4.6	5	5
RS4	SJL	24	48	448	0.1	6	25	4.6	5	0
	RS4	5	139	500					4	2
	RS5	12	24	500 (160[e])	0.1	4	168	4.6	5	7
	TCE/TCW	12	24	367 (160[e])	2.1	4	168	4.6	4	7
RS5	RS4	24	48	500	0.1	6	50	4.6	5	0
	RS5	5	139	500					4	3
	RS6	12	24	500 (140[e])	0.2	4	144	4.6	5	7
RS6	RS5	24	48	500	0.1	6	100	4.6	8	0
	RS6	5	139	500					8	4
	RS7	12	24	500 (130[e])	0.2	4	100	4.6	8	7
RS7	RS6	27	59	500	0.1	6	100	4.6	8	0
	RS7	5	82	500					9	5
	RS8	12	24	500 (130[e])	0.2	4	100	4.6	8	7
RS8	RS7	27	59	500	0.1	6	123	4.6	8	0

a = Near-field residence time includes up to 12 hours missing between detections, while mid-field residence time includes entire time lag between first and last detections without intervening detections elsewhere; far-field (“regional”) residence time includes all time from entry in region to arrival at and departure from current site

b = Approximate migration rate calculated on most direct pathway

c = Missing values for transitions to and from same site: travel times must be 12 to 24 hours, unless otherwise specified under "Extra conditions"

e = Condition at departure from previous site

f = See comments for alternate criteria

Table 3a. (Continued)

Detection Site	Previous Site	Residence Time[a] (hr)			Migration Rate[b, c] (km/hr)		Time since last visit (hr)	BLPS (Magnitude)	No. of Visits	No. of Cumulative Upstream Forays
		Near Field	Mid-field	Far-field						
		Maximum	Maximum	Maximum	Minimum	Maximum	Maximum	Maximum	Maximum	Maximum
RS8	RS8	5	82	500					6	3
	RS9	12	24	500 (200[e])	0.1	4	100	4.6	9	9
RS9	RS5, RS8	24	48	500	0.1	6	125	4.6	8	0
	RS9	5	79	500					3	3
	RS10	12	24	500 (200[e])	0.1	4	100	4.6	8	9
RS10	RS9	24	48	500	0.1	6	130	4.6	6	0
	RS10	5	79	500					3	3
	SJG, SJNB	12	24	500 (200[e])		4	130	4.6	6	6
SJG	RS6, RS10	30	60	500	0.1	6	140	4.6	5 (3[f])	0
	SJG	15	79	500					3	3
	SJNB, RRI	10	20	500		4	140	4.6	4	10
SJNB	SJG	30	60	500	0.1	6 (2[f])	140	4.6	5	0
	SJNB	15	90	500					3	4
	RRI	15	30	500	0.1	6	140		3	2
	SJC	15	30	500	0.1	4	140	4.6	5	10
RRI	SJG	20	40	500	0.1	6 (2[f])	25	4.6	2	0
	RRI	5	70	500					2	4
	SJNB	5	10	500	0.1	6	25		2	2
	SJC	2	4	500	0.2	4	25	4.6	2	6
SJC	SJG	55 (30[f])	110 (60[f])	500	0.1	6	75	4.6	1	0
	SJNB, RRI	55 (30[f])	110 (60[f])	500	0.1	6	75	4.6	3	0
	SJC	24	129	500					3	4

a = Near-field residence time includes up to 12 hours missing between detections, while mid-field residence time includes entire time lag between first and last detections without intervening detections elsewhere; far-field (“regional”) residence time includes all time from entry in region to arrival at and departure from current site

b = Approximate migration rate calculated on most direct pathway

c = Missing values for transitions to and from same site: travel times must be 12 to 24 hours, unless otherwise specified under "Extra conditions"

e = Condition at departure from previous site

f = See comments for alternate criteria

Table 3a. (Continued)

Detection Site	Previous Site	Residence Time[a] (hr)			Migration Rate[b, c] (km/hr)		Time since last visit (hr)	BLPS (Magnitude)	No. of Visits	No. of Cumulative Upstream Forays
		Near Field	Mid-field	Far-field						
		Maximum	Maximum	Maximum	Minimum	Maximum	Maximum	Maximum	Maximum	Maximum
SJC	SJS	24	48	180	0.6	4	75	4.6	4	10
	MFE/MFW	2	4	500	1.3	4	75	4.6	1	4
SJS	SJG, SJC	30	60	120	0.1	6	50	4.6	1 (4[f])	0
	SJS	24	104	264					3	6
	MAC, TCE/TCW	24	48	402 (500[f])	0.3 (0.1[f])	4	50	4.6 (5[f])	6	10
MAC	SJS	20	40	342 (317[f])	0.1 (0.3[f])	6	24	4.6	3	0
	MAC	15	69	435					2	4
	TCE/TCW	15	30	500	0.2	6	24		2	1
	MFE/MFW	15	30	500	0.4	4	36	4.6	3	10
	COL	15	30	500	0.3	4	24	4.6	2	4
MFE/MFW	SJC	20	40	500	0.1 (0.3[f])	6	36	4.6	1	0
	MAC	20	40	500 (496[f])	0.1 (0.3[f])	6	36	4.6	2	0
	MFE/MFW	10	100	500					2	4
	COL	12	24	500	0.1	6	24	4.6	2	1
	SJD	12	24	48	0.7	4	36	4.6	2	4
	MAE/MAW	1	2	4	0.1	4	36	4.6	0	4
	MID	20	40	80	0.1	4	36	4.6	2	4
SJD	MAC, MID	24	48	96	0.1 (0.3[f])	6	36	4.6	1	0
	MFE/MFW, COL	24	48	96	0.1 (0.3[f])	6	36	4.6	2	0
	SJD	15	109 (69[f])	265 (185[f])					2	4
	OSJ	15	30	192	0.2	4	36	4.6	2	2
	JPE/JPW, FRE/FRW, TMN/TMS	15	30	60		4	36	4.6	2	4

a = Near-field residence time includes up to 12 hours missing between detections, while mid-field residence time includes entire time lag between first and last detections without intervening detections elsewhere; far-field ("regional") residence time includes all time from entry in region to arrival at and departure from current site

b = Approximate migration rate calculated on most direct pathway

c = Missing values for transitions to and from same site: travel times must be 12 to 24 hours, unless otherwise specified under "Extra conditions"

f = See comments for alternate criteria

Table 3a. (Continued)

Detection Site	Previous Site	Residence Time[a] (hr)			Migration Rate[b, c] (km/hr)		Time since last visit (hr)	BLPS (Magnitude)	No. of Visits	No. of Cumulative Upstream Forays
		Near Field	Mid-field	Far-field						
		Maximum	Maximum	Maximum	Minimum	Maximum	Maximum	Maximum	Maximum	Maximum
HOR	MOS	25 (100[f])	50 (200[f])	1,000		6		4.6	3	0
	HOR	25	250	1,000					6	4
	SJL	15 (10[f])	30 (20[f])	1,000	0.2	6	192 (100[f])	4.6	10	10
	ORE	35 (1[f])	30 (2[f])	1,000	0.2 (0.6[f])	6	192 (5[f])	4.6	4 (0[f])	4
ORE	HOR	15	30	60	0.1	6	25	5	2 (1[f])	0
	ORE	5 (2[f])	90 (87[f])	210 (207[f])					2	1
	SJL	5 (2[f])	10 (4[f])	20 (8[f])	0.3	6	20 (15[f])	5	2 (1[f])	0
	ORS	3 (1[f])	6 (2[f])	324 (315[f])		4	25	5	2 (1[f])	2 (1[f])
ORS	ORE	24	48	308	0.1	6	40	4.6	1	0
	ORS	12	146	500					4	2
	MRH	12	24	380	0.2	6	40	4.6	2	2
	CVP	12	24	48	0.3	4	40	4.6	2	3
WCL	RGU/RGD	15	30	800	0.2	5	100	5	5	0
	CVP	15	30	800	0.1	4	100	4.6	5	0
	ORS	15	30	800	0.1	4	100	4.6	1	0
	WCL	2	82	800					5	4
	MR4	15	30	60	0.1	4	100	4.6	1	0
	OR4	15	30	800	0.1	4	100	4.6	5	7
OR4	WCL	20	40	800	0.1	4.5	100	4.6	3	0
	OR4	20	200	800					3	4
	JPE/JPW	20	40	80	0.1	4	100	4.6	1	4
	MR4	20	40	80	0.1	4	100	4.6	2	0
	MID, TCE/TCW	20	40	80	0.1	4	100	4.6	2 (1[f])	0

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b = Approximate migration rate calculated on most direct pathway

c = Missing values for transitions to and from same site: travel times must be 12 to 24 hours, unless otherwise specified under "Extra conditions"

f = See comments for alternate criteria

Table 3a. (Continued)

		Residence Time[a] (hr)			Migration Rate[b, c] (km/hr)		Time since last visit (hr)	BLPS (Magnitude)	No. of Visits	No. of Cumulative Upstream Forays
		Near Field	Mid-field	Far-field						
Detection Site	Previous Site	Maximum	Maximum	Maximum	Minimum	Maximum	Maximum	Maximum	Maximum	Maximum
OSJ	MFE/MFW	15	30	60	0.1	6	36	4.6	2	0
	TCE/TCW, MID	15	30	60	0.1	6	36	4.6	1	0
	COL	15	30	60	0.1	6	36	4.6	2	0
	OSJ	5	54	138					2	4
	SJD	10	20	325	0.1	4	36	4.6	2	2
	FRE/FRW	2	4	8	0.7	4	36	4.6	2	4
MRH	ORE	10	20	280	0.1	6	40	4.6	1	0
	MRH	3	47	351					0	2
	ORS	3	6	500	0.2	6	40	4.6	1	2
MR4	ORS	10	20	40	0.1	4.5		4.6	1	0
	MR4	10	80	170					2	2
	MID	10	20	217	0.1	4	100	4.6	2	2
	CVP, WCL	10	20	40	0.1	4	100	4.6	1	0
	TCE/TCW	10	20	40	0.1	4	100	4.6	1	0
MID	RS10	12	24	48	0.2	4	100	4.6	1	0
	MFE/MFW, SJD	12	24	48	0.1	4	100	4.6	1	0 (3[f])
	MID	12	134	282					3	2
	TCE/TCW	12	24	48	0.1	4	100	4.6	1	0
	COL	12	24	48		4	100	4.6	2	0
	OSJ	12	24	48	0.1	4	100	4.6	1	4
RGU/RGD	ORS	80 (336[h]; 800[i])	80 (336[h]; 800[i])	800	0.1	4.5	150	4.6	1	0

a = Near-field residence time includes up to 12 hours missing between detections, while mid-field residence time includes entire time lag between first and last detections without intervening detections elsewhere; far-field (“regional”) residence time includes all time from entry in region to arrival at and departure from current site

b = Approximate migration rate calculated on most direct pathway

c = Missing values for transitions to and from same site: travel times must be 12 to 24 hours, unless otherwise specified under "Extra conditions"

f = See comments for alternate criteria

h = If returned to Forebay entrance channel from Clifton Court Forebay and most detections were at RGU (not RGD)

i = If known presence at gates < 80 hours, or if present at RGU < 80% of total residence time and returned to Forebay entrance channel from RGD

Table 3a. (Continued)

Detection Site	Previous Site	Residence Time[a] (hr)			Migration Rate[b, c] (km/hr)		Time since last visit (hr)	BLPS (Magnitude)	No. of Visits	No. of Cumulative Upstream Forays
		Near Field	Mid-field	Far-field						
		Maximum	Maximum	Maximum	Minimum	Maximum	Maximum	Maximum	Maximum	Maximum
RGU/RGD	CVP	80 (336[h]; 800[i])	80 (336[h]; 800[i])	800	0.1	4.5	150	4.6	4	0
	WCL	80 (336[h]; 800[i])	80 (336[h]; 800[i])	800	0.1	5	150	4.6	5	4
	MR4	10 (336[h]; 100[j])	10 (336[h]; 100[j])	800	0.4	4.5	150	4.6	1	0
CVP	ORS	100	200	1,000	0.1	4.5	200	4	1	0
	CVP	25	236	1,000					4	3
	CVPtank	25	263	1,000		1			5	3
	RGU/RGD	80	160	1,000	0.1	4	200	4	4 (1[f])	4
	WCL	80	160	1,000	0.1	4	200	4	4 (1[f])	4
	MR4	80	160	1,000	0.1	4.5	200	4	4 (1[f])	0
CVPtank	CVP	30	90	1,000					2	4
TCE/TCW	SJS	24	48	328	0.1	6	24	4.6	3	0
	TCE/TCW	12	106	494					2	4
	MAC	12	24	483	0.2	6	24	4.6	2	1
	MR4	12	24	48	0.1	4	24	4.6	2	4
	MID	12	24	48	0.1	4	24	4.6	2	4
COL	MAC	24	48	500	0.1	6	36	4.6	2	0
	MFE/MFW	12	24	500	0.1	6	36	4.6	2	1

a = Near-field residence time includes up to 12 hours missing between detections, while mid-field residence time includes entire time lag between first and last detections without intervening detections elsewhere; far-field ("regional") residence time includes all time from entry in region to arrival at and departure from current site

b = Approximate migration rate calculated on most direct pathway

c = Missing values for transitions to and from same site: travel times must be 12 to 24 hours, unless otherwise specified under "Extra conditions"

f = See comments for alternate criteria

h = If returned to Forebay entrance channel from Clifton Court Forebay and most detections were at RGU (not RGD)

i = If known presence at gates < 80 hours, or if present at RGU < 80% of total residence time and returned to Forebay entrance channel from RGD

j = Maximum residence time is 100 hours if known presence at gates < 10 hours, or 800 hours if present at RGU < 80% of total residence time and returned to Forebay entrance channel from RGD

Table 3a. (Continued)

Detection Site	Previous Site	Residence Time[a] (hr)			Migration Rate[b, c] (km/hr)		Time since last visit (hr)	BLPS (Magnitude)	No. of Visits	No. of Cumulative Upstream Forays
		Near Field	Mid-field	Far-field						
		Maximum	Maximum	Maximum	Minimum	Maximum	Maximum	Maximum	Maximum	Maximum
JPE/JPW	MFE/MFW, TCE/TCW, OR4, MID, SJD, OSJ	40	80	160	0.2	4.5	30	4.6	1	0
	TMN/TMS	40	80	224	0.2	4.5	30	4.6	2	0
	RGU/RGD, CVPtank	40	80	160	0.1		30	4.6	1	3
	JPE/JPW	20	140	414					3	3
	FRE/FRW	20	140	414	0.2	7	30		3	3
	MAE/MAW	2	4	500	1	4	30	4.6	2	3
MAE/MAW	SJD, MFE/MFW, TCE/TCW, WCL, OSJ, TMN/TMS, JPE/JPW, FRE/FRW	40	200	500	0.2	4.5	50	4.6	1	0
	CVPtank	40	200	500		4	50	4.6	1	0
	RGU/RGD	40	200	500		5	50	4.6	1	0
	MTZ, SBS	40	200	500	0.2	4.5	50	4.6	2	0
	MAE/MAW	20	100	500					3	3
	BBR	10	50	500	0.2	4.5	50	4.6	3	4
BBR	TCE/TCW	40	200	500	0.2	6		4.6	1	0
	TMN/TMS, JPE/JPW, MTZ	40	200	500	0.2	6		4.6	1	0
	CVPtank	40	200	500	0.2	7		4.6	1	0
	RGU/RGD	40	200	500		8		4.6	1	0
	MAE/MAW	40	200	500	0.2	6		4.6	2	0
	BBR	10	50	500					3	0

a = Near-field residence time includes up to 12 hours missing between detections, while mid-field residence time includes entire time lag between first and last detections without intervening detections elsewhere; far-field (“regional”) residence time includes all time from entry in region to arrival at and departure from current site

b = Approximate migration rate calculated on most direct pathway

c = Missing values for transitions to and from same site: travel times must be 12 to 24 hours, unless otherwise specified under "Extra conditions"

Table 3a. (Continued)

Detection Site	Previous Site	Residence Time[a] (hr)			Migration Rate[b, c] (km/hr)		Time since last visit (hr)	BLPS (Magnitude)	No. of Visits	No. of Cumulative Upstream Forays
		Near Field	Mid-field	Far-field						
		Maximum	Maximum	Maximum	Minimum	Maximum	Maximum	Maximum	Maximum	Maximum
FRE/FRW	OR4, MR4, MID, TCE/TCW, SJD	20	40	80	0.2	4.5	15	4.6	1	0
	OSJ	20	40	80	0.2	4.5	15	4.6	2	0
	JPE/JPW	20	83	193	0.2	7	15		3	3
	FRE/FRW	3	83	193					3	3
TMN/TMS	SJD	10	20	40	0.2	4.5	15	4.6	1	0
	RGU/RGD, CVPtank	10	20	40	0.2 (0.1[f])	4.5	15	4.6	1	4
	TMN/TMS	3	47	111					2	3
	JPE/JPW	10	20	278	0.2	4.5	15	4.6	2	4
	FRE/FRW	10	20	137	0.2	4.5	15	4.6	2	4
	SBS, MAE/MAW	10	20	500	0.2	4.5	15	4.6	1	4
MTZ	RGU/RGD	5	10	20	0.1	4.5	15	4.6	1	0
	CVPtank	5	10	20	0.2	4.5	15	4.6	1	0
SBS	TMN/TMS, JPE/JPW	2	4	500	0.2	4.5	15	4.6	1	0
	SBS	1	37	500					2	3
	MAE/MAW	2	4	500	0.2	4.5	15	4.6	1	4

a = Near-field residence time includes up to 12 hours missing between detections, while mid-field residence time includes entire time lag between first and last detections without intervening detections elsewhere; far-field ("regional") residence time includes all time from entry in region to arrival at and departure from current site

b = Approximate migration rate calculated on most direct pathway

c = Missing values for transitions to and from same site: travel times must be 12 to 24 hours, unless otherwise specified under "Extra conditions"

f = See comments for alternate criteria

Table 3b. Cutoff values used in predator filter in 2016. Observed values past cutoff or unmet conditions indicate a predator. Time durations are in hours unless otherwise specified. Footnotes, Extra Conditions and Comment refer to both this table and Table 3a.

		Flow[d] (cfs)		Water Velocity[d] (ft/sec)			Extra Conditions	Comment
Detection Site	Previous Site	At arrival	At departure[e]	At arrival	At departure[e]	Average during transition		
DFU	DF						Travel time < 300	
	DFU						Travel time < 700	
	DFD, BDF1						Travel time < 300	
	TCE/TCW						Travel time < 300	Observed only among predator tags; not allowed
DFD	DF						Travel time < 300	
	DFU, DFD						Travel time < 300	Alternate value if coming from DFD
	BDF1, BDF2, BCA						Travel time < 50	
BDF1	DF						Travel time < 500	
	DFD						Travel time < 500	
	BDF1						Travel time < 300; known presence in detection range < 30	
	BDF2						Travel time < 100	
	BCA							
BDF2	DF, DFD, BDF1						Travel time < 500	Alternate value if coming from DF
	BDF2						Travel time < 300; known presence in detection range < 30	
	BCA							
BCA	DF, DFU						Travel time < 500	Alternate value if next transition is downstream
	DFD, BDF1, BDF2						Travel time < 500	Alternate value if next transition is downstream

d = Flow or velocity condition referred to in "Comment" is used to select criteria that prompts Comment. Otherwise, classified as predator if flow or velocity condition is violated

e = Condition at departure from previous site

Table 3b. (Continued)

		Flow[d] (cfs)		Water Velocity[d] (ft/sec)			Extra Conditions	Comment
Detection Site	Previous Site	At arrival	At departure[e]	At arrival	At departure[e]	Average during transition		
BCA	BCA						Maximum of 3 visits if arrival flow > 12000 cfs; Travel time < 200 (500[f])	Alternate value if next transition is downstream; otherwise, known presence in detection range < 30 hours.
	MOS		< 5000					
MOS	DF, DFU, DFD, BDF1, BDF2, BCA						Travel time < 200; allow 3 visits, travel time < 500 if arrival flow < 11,000 cfs	Alternate value if next transition is downstream
	MOS	<14000				<2.7	Travel time < 48	
	HOR	<14000				<3	Travel time < 60	
SJL	HOR							
	SJL						Travel time < 125	
	ORE						Regional residence time < 25 (15[f]) on departure from ORE	Alternate value if HOR barrier
	RS4							
RS4	SJL							
	RS4						Travel time < 100	
	RS5							
	TCE/TCW						Next transition must be downstream	Observed only among predator tags; not allowed
RS5	RS4							
	RS5						Travel time < 100	
	RS6							
RS6	RS5	>-500						
	RS6						Travel time < 100	

d = Flow or velocity condition referred to in "Comment" is used to select criteria that prompts Comment. Otherwise, classified as predator if flow or velocity condition is violated

e = Condition at departure from previous site

f = See comments for alternate criteria

Table 3b. (Continued)

		Flow[d] (cfs)		Water Velocity[d] (ft/sec)			Extra Conditions	Comment
Detection Site	Previous Site	At arrival	At departure[e]	At arrival	At departure[e]	Average during transition		
RS6	RS7	<1200						
RS7	RS6	>-500						
	RS7						Travel time < 40	
	RS8	<1200						
RS8	RS7	>-500						
	RS8						Travel time < 40	
	RS9	<1200						
RS9	RS5, RS8							
	RS9						Travel time < 40	
	RS10							
RS10	RS9							
	RS10						Travel time < 40	
	SJG, SJNB						Travel time < 15	
SJG	RS6, RS10							Alternate value if coming from RS6
	SJG	<2000 (>-2000)[g]	>-2000 (<2000)[g]	<0.5 (>-0.5)[g]	>-0.5 (<0.5)[g]	<0.8	Travel time < 24	
	SJNB, RRI	<3900	<3900	<1.4	<1.4	<1.4	Travel time < 15	
SJNB	SJG					>-0.15		Alternate value if water velocity condition is not met
	SJNB						Travel time < 35	
	RRI							
	SJC							

d = Flow or velocity condition referred to in "Comment" is used to select criteria that prompts Comment. Otherwise, classified as predator if flow or velocity condition is violated

e = Condition at departure from previous site

g = High flow/velocity on departure requires low values on arrival (and vice versa)

Table 3b. (Continued)

		Flow[d] (cfs)		Water Velocity[d] (ft/sec)			Extra Conditions	Comment
Detection Site	Previous Site	At arrival	At departure[e]	At arrival	At departure[e]	Average during transition		
RRI	SJG					>-0.15		Alternate value if water velocity condition is not met
	RRI						Travel time < 35	
	SJNB							
	SJC							
SJC	SJG					0.05 to 0.25		Alternate value if water velocity condition is not met
	SJNB, RRI					0.05 to 0.25		Alternate value if water velocity condition is not met
	SJC	<2000 (>-2000)[g]	>-2000 (<2000)[g]	<0.13 (>-0.13)[g]	>-0.13 (<0.13)[g]		Travel time < 40	
	SJS	<3500	<3900	<0.22	<0.22		Travel time < 12	
	MFE/MFW	<3500	<3900	<0.22	<0.22		Travel time < 12	
SJS	SJG, SJC							Alternate value if coming from SJC
	SJS	<3000 (>-3000)[g]	>-3000 (<3000)[g]	<0.18 (>-0.18)[g]	>-0.18 (<0.18)[g]		Travel time < 40	
	MAC, TCE/TCW	<4000	<40000 (NA[f])	<0.25	<0.75 (NA[f])		Travel time < 12	Alternate value if coming from TCE/TCW
MAC	SJS					-0.1 to 0.4		Alternate value if water velocity condition is not met
	MAC	<40000 (>-40000)[g]	>-40000 (<40000)[g]	<0.75 (>-0.75)[g]	>-0.75 (<0.75)[g]		Travel time < 24	
	TCE/TCW							

d = Flow or velocity condition referred to in "Comment" is used to select criteria that prompts Comment. Otherwise, classified as predator if flow or velocity condition is violated

e = Condition at departure from previous site

f = See comments for alternate criteria

g = High flow/velocity on departure requires low values on arrival (and vice versa)

Table 3b. (Continued)

		Flow[d] (cfs)		Water Velocity[d] (ft/sec)			Extra Conditions	Comment
Detection Site	Previous Site	At arrival	At departure[e]	At arrival	At departure[e]	Average during transition		
MAC	MFE/MFW			<0.5				
	COL			<0.5				
MFE/MFW	SJC					-0.1 to 0.4		Alternate value if water velocity condition is not met
	MAC					-0.1 to 0.4		Alternate value if water velocity condition is not met
	MFE/MFW	<40000 (>-40000)[g]	>-40000 (<40000)[g]	<0.75 (>-0.75)[g]	>-0.75 (<0.75)[g]		Travel time < 60	
	COL						Travel time < 24	
	SJD			<0.5		<0.1	Travel time < 12	
	MAE/MAW			<0.5		<0.1		Observed only among predator tags; not allowed
	MID		>-2000		>-0.1			
SJD	MAC, MID	>-27000		>-0.5		-0.1 to 0.4		Alternate value if condition for water velocity during transition is not met
	MFE/MFW, COL	>-27000		>-0.5		-0.1 to 0.4		Alternate value if condition for water velocity during transition is not met
	SJD	<40000 (>-40000)[g]	>-40000 (<40000)[g]	<0.75 (>-0.75)[g]	>-0.75 (<0.75)[g]	-0.1 to 0.4	Travel time < 60 (20[f])	Alternate value if condition for water velocity during transition is not met

d = Flow or velocity condition referred to in "Comment" is used to select criteria that prompts Comment. Otherwise, classified as predator if flow or velocity condition is violated

e = Condition at departure from previous site

f = See comments for alternate criteria

g = High flow/velocity on departure requires low values on arrival (and vice versa)

Table 3b. (Continued)

Detection Site	Previous Site	Flow[d] (cfs)		Water Velocity[d] (ft/sec)			Extra Conditions	Comment
		At arrival	At departure[e]	At arrival	At departure[e]	Average during transition		
SJD	OSJ				>-0.1		Travel time < 24	
	JPE/JPW, FRE/FRW, TMN/TMS	<27000		<0.5		<0.1 (NA[f])	Travel time < 12	Alternate value if coming from JPE/JPW or FRE/FRW
HOR	MOS						Travel time < 50; allow 4 visits, travel time < 100 if arrival flow < 11,000 cfs	Alternate value if next transition is downstream
	HOR	<14000				<2.7	Travel time < 48	
	SJL	<14000 (5000[f])				<3	Regional residence time < 180 (120[f]) at departure from SJL	Alternate value if HOR barrier
	ORE	<14000 (5000[f])				<3	Regional residence time < 50 (15[f]) at departure from ORE	Alternate value if HOR barrier
ORE	HOR							Alternate value if HOR barrier
	ORE						Travel time < 60	Alternate value if HOR barrier
	SJL	>-200 (>200[f])		>-0.1 (>0.2[f])			Regional residence time < 60 (30[f]) on departure from SJL; travel time < 6	Alternate value if HOR barrier
	ORS	<3000					Travel time < 10 (5[f])	Alternate value if HOR barrier
ORS	ORE						Travel time < 50	
	ORS	<1200 (>-1100)[g]	>-1100 (<1200)[g]	<0.5 (>-0.5)[g]	>-0.5 (<0.5)[g]		Travel time < 100	
	MRH						Travel time < 5	
	CVP					<1.5	Travel time < 70	
WCL	RGU/RGD	>-9000		>-1.5			Travel time < 12; CCFB inflow < 4000 cfs on departure[e]	

d = Flow or velocity condition referred to in "Comment" is used to select criteria that prompts Comment. Otherwise, classified as predator if flow or velocity condition is violated

e = Condition at departure from previous site

f = See comments for alternate criteria

g = High flow/velocity on departure requires low values on arrival (and vice versa)

Table 3b. (Continued)

		Flow[d] (cfs)		Water Velocity[d] (ft/sec)			Extra Conditions	Comment
Detection Site	Previous Site	At arrival	At departure[e]	At arrival	At departure[e]	Average during transition		
WCL	CVP	>-9000	>-2000	>-1.5	>-0.8		CVP pumping < 4000 cfs on departure[e]	
	ORS	>-9000		>-1.5				
	WCL						Travel time < 50	
	MR4							
	OR4	<150	<4500	<0	<0.6			
OR4	WCL	>-6000		>-0.8				
	OR4						Travel time < 150	
	JPE/JPW	<6000		<0.8				
	MR4						Travel time < 150	
	MID, TCE/TCW	<6000		<0.8	<0.1 (0.2[f])		Travel time < 150; known presence in detection range < 5	Alternate value if coming from TCE/TCW
OSJ	MFE/MFW			<0.1				
	TCE/TCW, MID							
	COL							
	OSJ	<4000 (>-4000)[g]	>-4000 (<4000)[g]	<0.2 (>-0.2)[g]	>-0.2 (<0.2)[g]		Travel time < 24	
	SJD			<0.1				
	FRE/FRW						Travel time < 12	
MRH	ORE						Travel time < 50	
	MRH						Travel time < 24	Not allowed
	ORS						Travel time < 5	
MR4	ORS						Travel time < 180	
	MR4	<6500 (>-6500)[g]	>-6500 (<6500)[g]	<0.5 (>-0.5)[g]	>-0.5 (<0.5)[g]		Travel time < 50	

d = Flow or velocity condition referred to in "Comment" is used to select criteria that prompts Comment. Otherwise, classified as predator if flow or velocity condition is violated

e = Condition at departure from previous site

f = See comments for alternate criteria

g = High flow/velocity on departure requires low values on arrival (and vice versa)

Table 3b. (Continued)

		Flow[d] (cfs)		Water Velocity[d] (ft/sec)			Extra Conditions	Comment
Detection Site	Previous Site	At arrival	At departure[e]	At arrival	At departure[e]	Average during transition		
MR4	MID			<0.5	<0.1	<0.1		
	CVP, WCL						CVP pumping < 4000 cfs on departure[e] from CVP	
	TCE/TCW			<0.5	<0.2			
MID	RS10						Travel time < 120	
	MFE/MFW, SJD	<2500		<0.1			Travel time < 120	Alternate value if coming from SJD
	MID	<2500 (>-2500)[g]	>-2500 (<2500)[g]	<0.1 (>-0.1)[g]	>-0.1 (<0.1)[g]		Travel time < 100	
	TCE/TCW	>-2500		>-0.1	<0.2		Travel time < 120	
	COL	<2500		<0.1			Travel time < 120	
	OSJ	<2500		<0.1			Travel time < 120	
RGU/RGD	ORS							
	CVP		>-2000		>-0.8		CVP pumping < 4000 cfs at departure[e]	
	WCL		<3500		<0.6		Travel time < 30	
	MR4						Travel time < 30	
CVP	ORS							
	CVP						Travel time < 100; CVP pumping > 800 cfs on arrival, and < 2500 cfs on departure from previous visit	
	CVPtank						Travel time < 3; CVP pumping < 1000 cfs on arrival	
	RGU/RGD	<2000		<0.8			CVP pumping > 800 cfs on arrival	Alternate value if came from lower SJR via Interior Delta

d = Flow or velocity condition referred to in "Comment" is used to select criteria that prompts Comment. Otherwise, classified as predator if flow or velocity condition is violated

e = Condition at departure from previous site

g = High flow/velocity on departure requires low values on arrival (and vice versa)

Table 3b. (Continued)

		Flow[d] (cfs)		Water Velocity[d] (ft/sec)			Extra Conditions	Comment
Detection Site	Previous Site	At arrival	At departure[e]	At arrival	At departure[e]	Average during transition		
CVP	WCL	<2000	<3500	<0.8	<0.6		CVP pumping > 800 cfs on arrival	Alternate value if came from lower SJR via Interior Delta
	MR4	<2000		<0.8				Alternate value if came from lower SJR via Interior Delta
CVPtank	CVP						Travel time < 20	
TCE/TCW	SJS			<0.1				
	TCE/TCW	<1500 (>-1500)[g]	>-1500 (<1500)[g]	<0.3 (>-0.3)[g]	>-0.3 (<0.3)[g]		Travel time < 60	
	MAC			<0.1		<0.1	Travel time < 24	
	MR4	>-500	>-6500	>-0.1	>-0.5	>-0.2		
	MID	>-500	<2000	>-0.1	<0.1	>-0.2		
COL	MAC							
	MFE/MFW							
JPE/JPW	MFE/MFW, TCE/TCW, OR4, MID, SJD, OSJ							
	TMN/TMS							
	RGU/RGD, CVPtank						Travel time 2 to 80 hours	
	JPE/JPW						Travel time < 50	
	FRE/FRW						No minimum travel time	
	MAE/MAW							

d = Flow or velocity condition referred to in "Comment" is used to select criteria that prompts Comment. Otherwise, classified as predator if flow or velocity condition is violated

e = Condition at departure from previous site

g = High flow/velocity on departure requires low values on arrival (and vice versa)

Table 3b. (Continued)

		Flow[d] (cfs)		Water Velocity[d] (ft/sec)			Extra Conditions	Comment
Detection Site	Previous Site	At arrival	At departure[e]	At arrival	At departure[e]	Average during transition		
MAE/MAW	SJD, MFE/MFW, TCE/TCW, WCL, OSJ, TMN/TMS, JPE/JPW, FRE/FRW			>-1				
	CVPtank			>-1			Travel time 5 to 100	
	RGU/RGD			>-1			Travel time 5 to 500	
	MTZ, SBS			>-1				
	MAE/MAW						Travel time < 36	
	BBR			<1				
BBR	TCE/TCW							
	TMN/TMS, JPE/JPW, MTZ							
	CVPtank						Travel time 5 to 180	
	RGU/RGD						Travel time 5 to 600	
	MAE/MAW							
	BBR						Travel time < 36	
FRE/FRW	OR4, MR4, MID, TCE/TCW, SJD							
	OSJ							
	JPE/JPW						No minimum travel time	
	FRE/FRW						Travel time < 30	
TMN/TMS	SJD		>-27000		>-0.5			
	RGU/RGD, CVPtank							Alternate value if coming from RGU/RGD
	TMN/TMS	<0 (>0)[g]	>0 (<0)[g]	<0 (>0)[g]	>0 (<0)[g]		Travel time < 24	

d = Flow or velocity condition referred to in "Comment" is used to select criteria that prompts Comment. Otherwise, classified as predator if flow or velocity condition is violated

e = Condition at departure from previous site

g = High flow/velocity on departure requires low values on arrival (and vice versa)

Table 3b. (Continued)

		Flow[d] (cfs)		Water Velocity[d] (ft/sec)			Extra Conditions	Comment
Detection Site	Previous Site	At arrival	At departure[e]	At arrival	At departure[e]	Average during transition		
TMN/TMS	JPE/JPW							
	FRE/FRW							
	SBS, MAE/MAW							
MTZ	RGU/RGD							
	CVPtank							
SBS	TMN/TMS, JPE/JPW							
	SBS						Travel time < 24	
	MAE/MAW							

d = Flow or velocity condition referred to in "Comment" is used to select criteria that prompts Comment. Otherwise, classified as predator if flow or velocity condition is violated

e = Condition at departure from previous site

Table 4. Regions used in the far-field residence time components of the predator filter in 2016.

Region	Detection Sites
I	DFU, DFD, BDF1, BDF2, BCA, MOS, HOR
IIA	SJL, RS4–RS10, SJG, SJNB, RRI, SJC
IIB	ORE, ORS, MRH
IIIA	SJS, MAC, MFE/MFW, TCE/TCW, COL
IIIB	WCL, OR4, RGU, RGD, CVP, CVPtank
IIIC	MR4, MID
IV	JPE/JPW, MAE/MAW, FRE/FRW, TMN/TMS, MTZ, SBS, BBE/BBW
IVB	SJD, OSJ

Table 5. Number of tags from each release group that were detected after release in 2016, including predator-type detections and detections omitted from the survival analysis. Releases are: 1 = February, 2 = March, 3 = April.

Release Group	1	2	3	Total
Number Released	480	480	480	1,440
Number Detected	399	461	471	1,331
Number Detected Downstream	379	458	463	1,300
Number Detected Upstream of Study Area	399	444	467	1,310
Number Detected in Study Area	217	376	427	1,020
Number Detected in San Joaquin River Route	72	143	415	630
Number Detected in Old River Route	182	290	19	491
Number Assigned to San Joaquin River Route	27	85	409	521
Number Assigned to Old River Route	180	288	15	483

Table 6. Number of tags observed from each release group at each detection site in 2016, including predator-type detections. Routes (SJR = San Joaquin River, OR = Old River) represent route assignment at the head of Old River. Pooled counts are summed over all receivers in array and all routes. Route could not be identified for some tags. Releases are: 1 = February, 2 = March, 3 = April.

Detection Site	Site Code	Survival Model Code	Release Group 1	Release Group 2	Release Group 3	Total
Release site at Durham Ferry			480	480	480	1,440
Durham Ferry Upstream, Upstream	DFU1	A0a	79	16	33	128
Durham Ferry Upstream, Downstream	DFU2	A0b	69	11	19	99
Durham Ferry Upstream (Pooled)	DFU	A0	80	16	34	130
Durham Ferry Downstream, Upstream	DFD1	A2a	378	370	419	1,167
Durham Ferry Downstream, Downstream	DFD2	A2b	378	288	358	1,024
Durham Ferry Downstream (Pooled)	DFD	A2	378	396	434	1,208
Below Durham Ferry 1	BDF1	A3	234	136	203	573
Below Durham Ferry 2	BDF2	A4	236	170	213	619
Banta Carbona, Upstream	BCAU	A5a	220	150	337	707
Banta Carbona, Downstream	BCAD	A5b	223	164	310	697
Banta Carbona (Pooled)	BCA	A5	231	208	384	823
Mossdale, Upstream	MOSU	A6a	217	374	427	1,018
Mossdale, Downstream	MOSD	A6b	217	376	427	1,020
Mossdale (Pooled)	MOS	A6	217	376	427[a]	1,020
Head of Old River (Pooled)	HOR	B0	214	374	427	1,015
Lathrop, Upstream	SJLU	A7a	72	142	410	624
Lathrop, Downstream	SJLD	A7b	71	141	415	627
Lathrop (Pooled)	SJL	A7	72	142	415	629
Predator Removal Study 4	RS4	N1	49	112	411	572
Predator Removal Study 5	RS5	N2	41	97	408	546
Predator Removal Study 6	RS6	N3	31	87	406	524
Predator Removal Study 7	RS7	N4	27	83	406	516
Predator Removal Study 8	RS8	N5	25	81	405	511
Predator Removal Study 9	RS9	N6	24	79	404	507
Predator Removal Study 10	RS10	N7	24	77	404	505
Garwood Bridge, Upstream	SJGU	A8a	22	72	402	496
Garwood Bridge, Downstream	SJGD	A8b	22	72	402	496
Garwood Bridge (Pooled)	SJG	A8	22	72	402	496
Navy Drive Bridge	SJNB	A9	21	69	396	486
Rough and Ready Island, Upstream	RRIU	R1a	1	4	41	46
Rough and Ready Island, Downstream	RRID	R1b	1	4	41	46
Rough and Ready Island (Pooled)	RRI	R1	1	4	41	46
Calaveras River, Upstream	SJCU	A10a	20	67	392	479
Calaveras River, Downstream	SJCD	A10b	20	67	394	481
Calaveras River (Pooled)	SJC	A10	20	67	394	481
San Joaquin River Shipping Channel	SJS	A11	19	67	386	472
MacDonald Island Upstream	MACU	A12a	13	58	318	389

a = One tagged steelhead was recaptured after detection at MOS and then returned to the river

Table 6. (Continued)

Detection Site	Site Code	Survival Model Code	Release Group 1	Release Group 2	Release Group 3	Total
MacDonald Island Downstream	MACD	A12b	12	55	307	374
MacDonald Island (Pooled)	MAC	A12	13	58	319	390
Turner Cut, Upstream	TCE	F1a	8	22	114	144
Turner Cut, Downstream	TCW	F1b	8	22	114	144
Turner Cut (Pooled)	TCE/TCW	F1	8	22	114	144
Medford Island East	MFE	A13a	5	42	229	276
Medford Island West	MFW	A13b	5	42	230	277
Medford Island (Pooled)	MFE/MFW	A13	5	42	230	277
Columbia Cut, Upstream	COLU	F2a	2	5	62	69
Columbia Cut, Downstream	COLD	F2b	2	5	64	71
Columbia Cut (Pooled)	COL	F2	2	5	64	71
Disappointment Slough, Upstream	SJDU	A14a	6	41	223	270
Disappointment Slough, Downstream	SJDD	A14b	6	40	218	264
Disappointment Slough (Pooled)	SJD	A14	6	41	223	270
Old River at the San Joaquin, Upstream	OSJU	B5a	3	10	34	47
Old River at the San Joaquin, Downstream	OSJD	B5b	3	10	35	48
Old River at the San Joaquin (Pooled)	OSJ	B5	3	10	35	48
Old River East, Upstream	OREU	B1a	182	290	19	491
Old River East, Downstream	ORED	B1b	182	290	19	491
Old River East (Pooled)	ORE	B1	182	290	19	491
Old River South, Upstream	ORSU	B2a	179	283	17	479
Old River South, Downstream	ORSD	B2b	179	282	17	478
Old River South (Pooled)	ORS	B2	179	283	17	479
West Canal, Upstream	WCLU	B3a	42	83	42	167
West Canal, Downstream	WCLD	B3b	39	81	42	162
West Canal: SJR Route	WCL	B3	4	5	40	49
West Canal: OR Route	WCL	B3	38	78	2	118
West Canal (Pooled)	WCL	B3	42	83	42	167
Old River at Highway 4, Upstream	OR4U	B4a	7	19	31	57
Old River at Highway 4, Downstream	OR4D	B4b	7	19	30	56
Old River at Highway 4, SJR Route	OR4	B4	4	5	30	39
Old River at Highway 4, OR Route	OR4	B4	3	14	1	18
Old River at Highway 4 (Pooled)	OR4	B4	7	19	31	57
Middle River Head, Upstream	MRHU	C1a	4	1	2	7
Middle River Head, Downstream	MRHD	C1b	4	1	2	7
Middle River Head (Pooled)	MRH	C1	4	1	2	7
Middle River at Highway 4, Upstream	MR4U	C2a	1	5	29	35
Middle River at Highway 4, Downstream	MR4D	C2b	1	5	29	35
Middle River at Highway 4, SJR Route	MR4	C2	1	1	29	31
Middle River at Highway 4, OR Route	MR4	C2	0	4	0	4
Middle River at Highway 4 (Pooled)	MR4	C2	1	5	29	35

Table 6. (Continued)

Detection Site	Site Code	Survival Model Code	Release Group			Total
			1	2	3	
Middle River near Mildred Island	MID	C3	1	5	51	57
Radial Gates Upstream #1	RGU1	D1a	84	137	38	259
Radial Gates Upstream #2	RGU2	D1b	85	138	37	260
Radial Gates Upstream: SJR Route	RGU	D1	2	4	34	40
Radial Gates Upstream: OR Route	RGU	D1	84	138	6	228
Radial Gates Upstream (Pooled)	RGU	D1	86	142	40	268
Radial Gates Downstream #1	RGD1	D2a	30	65	16	111
Radial Gates Downstream #2	RGD2	D2b	34	68	17	119
Radial Gates Downstream: SJR Route	RGD	D2	0	2	12	14
Radial Gates Downstream: OR Route	RGD	D2	34	66	5	105
Radial Gates Downstream (Pooled)	RGD	D2	34	68	17	119
Central Valley Project Trashrack, Upstream	CVPU	E1a	127	187	37	351
Central Valley Project Trashrack, Downstream	CVPD	E1b	122	177	36	335
CVP Trashrack: SJR Route	CVP	E1	4	2	31	37
CVP Trashrack: OR Route	CVP	E1	123	185	6	314
CVP Trashrack (Pooled)	CVP	E1	127	187	37	351
CVP Holding Tank: SJR Route	CVPtank	E2	2	0	13	15
CVP Holding Tank: OR Route	CVPtank	E2	70	85	2	157
CVP Holding Tank	CVPtank	E2	72[b]	85[c]	15	172
Threemile Slough, Upstream	TMS	T1a	1	9	38	48
Threemile Slough, Downstream	TMN	T1b	1	8	36	45
Threemile Slough: SJR Route	TMS/TMN	T1	0	6	38	44
Threemile Slough: OR Route	TMS/TMN	T1	1	3	0	4
Threemile Slough (Pooled)	TMS/TMN	T1	1	9	38	48
Jersey Point East	JPE	G1a	20	61	241	322
Jersey Point West	JPW	G1b	20	60	242	322
Jersey Point: SJR Route	JPE/JPW	G1	5	47	242	294
Jersey Point: OR Route	JPE/JPW	G1	15	15	0	30
Jersey Point (Pooled)	JPE/JPW	G1	20	62	242	324
False River West	FRW	H1a	4	18	31	53
False River East	FRE	H1b	8	19	45	72
False River: SJR Route	FRE/FRW	H1	4	15	46	65
False River: OR Route	FRE/FRW	H1	4	6	0	10
False River (Pooled)	FRE/FRW	H1	8	21	46	75
Montezuma Slough, Upstream	MTZU	T2a	0	2	0	2
Montezuma Slough, Downstream	MTZD	T2b	0	1	0	1
Montezuma Slough (Pooled)	MTZ	T2	0	2	0	2
Spoonbill Slough, Upstream	SBSU	T3a	2	0	2	4

[b] = Ten tagged steelhead were recaptured in the CVP holding tank after detection, and then returned to the river

[c] = Six tagged steelhead were recaptured in the CVP holding tank after detection, and then returned to the river

Table 6. (Continued)

Detection Site	Site Code	Survival Model Code	Release Group 1	2	3	Total
Spoonbill Slough, Downstream	SBSD	T3b	3	4	2	9
Spoonbill Slough (Pooled)	SBS	T3	3	4	2	9
Chipps Island East	MAE	G2a	78	135	246	459
Chipps Island West	MAW	G2b	77	135	243	455
Chipps Island: SJR Route	MAE/MAW	G2	6	38	247	291
Chipps Island: OR Route	MAE/MAW	G2	73	107	4	184
Chipps Island (Pooled)	MAE/MAW	G2	79	145	251	475
Benicia Bridge, East	BBE	G3a	73	151	253	477
Benicia Bridge, West	BBW	G3b	72	150	265	487
Benicia Bridge: SJR Route	BBE/BBW	G3	6	43	263	312
Benicia Bridge: OR Route	BBE/BBW	G3	68	109	4	181
Benicia Bridge (Pooled)	BBE/BBW	G3	74	152	267	493

Table 7. Number of tags observed from each release group at each detection site in 2016 and used in the survival analysis, including predator-type detections. Numbers in parentheses are counts of tags whose detection histories were right-censored at that site. Pooled counts are summed over all receivers in array. Route could not be identified for some tags. Releases are: 1 = February, 2 = March, 3 = April.

			Release Group			
Detection Site	Site Code	Survival Model Code	1	2	3	Total
Release site at Durham Ferry			480	480	480	1,440
Durham Ferry Upstream, Upstream	DFU1	A0a	38	10	22	70
Durham Ferry Upstream, Downstream	DFU2	A0b	26	6	13	45
Durham Ferry Upstream (Pooled)	DFU	A0	38	10	23	71
Durham Ferry Downstream	DFD	A2	360	389	419	1,168
Below Durham Ferry 1	BDF1	A3	226	126	192	544
Below Durham Ferry 2	BDF2	A4	221	165	199	585
Banta Carbona	BCA	A5	224	203	377	804
Mossdale	MOS	A6	214	376	426 (1)	1,016
Lathrop, Upstream	SJLU	A7a	27	83	402	512
Lathrop, Downstream	SJLD	A7b	27	85	409	521
Lathrop (Pooled)	SJL	A7	27	85	409	521
Garwood Bridge	SJG	A8	21	69	399	489
Navy Drive Bridge	SJNB	A9	20	67	387	474
Rough and Ready Island, Upstream	RRIU	R1a	0	0	7	7
Rough and Ready Island, Downstream	RRID	R1b	0	0	7	7
Rough and Ready Island (Pooled)	RRI	R1	0	0	7	7
San Joaquin River near Calaveras	SJC	A10	20	66	389	475
San Joaquin River Shipping Channel	SJS	A11	19	66	384	469
MacDonald Island Upstream	MACU	A12a	10	46	274	330
MacDonald Island Downstream	MACD	A12b	9	46	277	332
MacDonald Island (Pooled)	MAC	A12	10	46	280	336
Turner Cut, Upstream	TCE	F1a	8	20	99	127
Turner Cut, Downstream	TCW	F1b	8	20	99	127
Turner Cut (Pooled)	TCE/TCW	F1	8	20	99	127
Medford Island East	MFE	A13a	5	40	209	254
Medford Island West	MFW	A13b	5	40	211	256
Medford Island (Pooled)	MFE/MFW	A13	5	40	212	257
Columbia Cut, Upstream	COLU	F2a	2[a]	5	56	63
Columbia Cut, Downstream	COLD	F2b	2[a]	5	56	63
Columbia Cut (Pooled)	COL	F2	2[a]	5	56	63
Disappointment Slough, Upstream	SJDU	A14a	3[a]	32	203	238
Disappointment Slough, Downstream	SJDD	A14b	3[a]	32	197	232
Disappointment Slough (Pooled)	SJD	A14	3[a]	32	203	238
Old River at the San Joaquin, Upstream	OSJU	B5a	2[a]	8	29	39
Old River at the San Joaquin, Downstream	OSJD	B5b	2[a]	8	29	39

a = detections were not used in the survival model

Table 7. (Continued)

Detection Site	Site Code	Survival Model Code	Release Group			Total
			1	2	3	
Old River at the San Joaquin (Pooled)	OSJ	B5	2[a]	8	29	39
Old River East, Upstream	OREU	B1a	180	288	15	483
Old River East, Downstream	ORED	B1b	180	288	15	483
Old River East (Pooled)	ORE	B1	180	288	15	483
Old River South, Upstream	ORSU	B2a	175	281	14	470
Old River South, Downstream	ORSD	B2b	177	281	15	473
Old River South (Pooled)	ORS	B2	177	282	15	474
West Canal, Upstream	WCLU	B3a	1[a]	16	0[a]	17
West Canal, Downstream	WCLD	B3b	1[a]	16	0[a]	17
West Canal: OR Route (Pooled)	WCL	B3	1[a]	16	0[a]	17
Old River at Highway 4, Upstream	OR4U	B4a	5	15	29	49
Old River at Highway 4, Downstream	OR4D	B4b	5	15	29	49
Old River at Highway 4, SJR Route	OR4	B4	4[a]	5[a]	29	38
Old River at Highway 4, OR Route	OR4	B4	1 (1)	10	0	11
Old River at Highway 4 (Pooled)	OR4	B4	5 (1)	15	29	49
Middle River Head, Upstream	MRHU	C1a	1	0	0	1
Middle River Head, Downstream	MRHD	C1b	1	0	0	1
Middle River Head (Pooled)	MRH	C1	1 (1)	0	0	1
Middle River at Highway 4, Upstream	MR4U	C2a	1	4	20	25
Middle River at Highway 4, Downstream	MR4D	C2b	1	4	20	25
Middle River at Highway 4, SJR Route	MR4	C2	1[a]	0[a]	20	21
Middle River at Highway 4, OR Route	MR4	C2	0	4	0	4
Middle River at Highway 4 (Pooled)	MR4	C2	1	4	20	25
Radial Gates Upstream: SJR Route	RGU	D1	0[a]	2[a]	14	16
Radial Gates Upstream: OR Route	RGU	D1	38	65	4	107
Radial Gates Upstream (Pooled)	RGU	D1	38	67	18	123
Radial Gates Downstream: SJR Route	RGD	D2	0[a]	2[a]	11	13
Radial Gates Downstream: OR Route	RGD	D2	34	66	5	105
Radial Gates Downstream (Pooled)	RGD	D2	34	68	16	118
CVP Trashrack: SJR Route	CVP	E1	4[a]	2[a]	24	30
CVP Trashrack: OR Route	CVP	E1	120	160	5	285
CVP Trashrack (Pooled)	CVP	E1	124	162	29	315
CVP Holding Tank: SJR Route	CVPtank	E2	2[a]	0[a]	13	15
CVP Holding Tank: OR Route	CVPtank	E2	70 (10)	84 (6)	2	156
CVP Holding Tank (Pooled)	CVPtank	E2	72 (10)	84 (6)	15	171
Threemile Slough, Upstream	TMS	T1a	0[a]	1	23	24
Threemile Slough, Downstream	TMN	T1b	0[a]	1	23	24
Threemile Slough: SJR Route (Pooled)	TMS/TMN	T1	0[a]	1	23	24

a = detections were not used in the survival model

Table 7. (Continued)

Detection Site	Site Code	Survival Model Code	Release Group 1	Release Group 2	Release Group 3	Total
Jersey Point East	JPE	G1a	4[a]	50	226	280
Jersey Point West	JPW	G1b	4[a]	48	227	279
Jersey Point: SJR Route	JPE/JPW	G1	4[a]	47	227	278
Jersey Point: OR Route	JPE/JPW	G1	0[a]	3	0	3
Jersey Point (Pooled)	JPE/JPW	G1	4[a]	50	227	281
False River West	FRW	H1a	0[a]	0[a]	0[a]	0
False River East	FRE	H1b	1[a]	0[a]	0[a]	1
False River: SJR Route	FRE/FRW	H1	1[a]	0[a]	0[a]	1
False River: OR Route	FRE/FRW	H1	0[a]	0[a]	0[a]	0
False River (Pooled)	FRE/FRW	H1	1[a]	0[a]	0[a]	0
Chipps Island: SJR Route	MAE/MAW	G2	6	38	245	289
Chipps Island: OR Route	MAE/MAW	G2	65	103	4	172
Chipps Island (Pooled)	MAE/MAW	G2	71	141	249	461
Benicia Bridge, East	BBE	G3a	63	143	247	453
Benicia Bridge, West	BBW	G3b	62	144	261	467
Benicia Bridge: SJR Route	BBE/BBW	G3	6	43	260	309
Benicia Bridge: OR Route	BBE/BBW	G3	58	103	3	164
Benicia Bridge (Pooled)	BBE/BBW	G3	64	146	263	473

a = detections were not used in the survival model

Table 8. Number of tags from each release group in 2016 first classified as in a predator at each detection site, based on the predator filter.

			Durham Ferry Release Groups							
Detection Site and Code			Classified as Predator on Arrival at Site				Classified as Predator on Departure from Site			
Detection Site	Site Code	Survival Model Code	1	2	3	Total	1	2	3	Total
Durham Ferry Upstream	DFU	A0	6	0	7	13	1	0	0	1
Durham Ferry Downstream	DFD	A2	2	1	0	3	0	0	0	0
Below Durham Ferry 1	BDF1	A3	0	0	1	1	0	1	0	1
Below Durham Ferry 2	BDF2	A4	2	1	0	3	3	0	0	3
Banta Carbona	BCA	A5	3	0	2	5	0	0	0	0
Mossdale	MOS	A6	0	0	1	1	0	0	0	0
Head of Old River	HOR	B0	0	2	0	2	1	0	1	2
Lathrop	SJL	A7	0	0	0	0	1	0	1	2
Predator Removal Study 4	RS4	N1	0	0	0	0	0	2	1	3
Predator Removal Study 5	RS5	N2	0	0	1	1	1	0	1	2
Predator Removal Study 6	RS6	N3	0	1	3	4	0	0	3	3
Predator Removal Study 7	RS7	N4	1	1	2	4	0	0	1	1
Predator Removal Study 8	RS8	N5	1	0	1	2	0	1	0	1
Predator Removal Study 9	RS9	N6	0	0	0	0	0	1	2	3
Predator Removal Study 10	RS10	N7	0	0	2	2	0	0	0	0
Garwood Bridge	SJG	A8	0	0	0	0	0	1	2	3
Navy Drive Bridge	SJNB	A9	0	0	0	0	0	0	0	0
Rough and Ready Island	RRI	R1	0	0	0	0	0	0	1	1
San Joaquin River at Calaveras River	SJC	A10	0	0	2	2	0	0	2	2
San Joaquin River Shipping Channel	SJS	A11	0	1	1	2	0	0	1	1
MacDonald Island	MAC	A12	0	0	2	2	1	1	1	3
Medford Island	MFE/MFW	A13	0	0	1	1	0	0	2	2
San Joaquin River at Disappointment Slough	SJD	A14	0	0	1	1	0	1	1	2
Old River East	ORE	B1	1	0	1	2	0	2	0	2
Old River South	ORS	B2	0	0	1	1	1	0	0	1
West Canal	WCL	B3	0	0	2	2	0	0	0	0
Old River at Highway 4	OR4	B4	0	1	2	3	1	0	1	2
Old River at the San Joaquin Mouth	OSJ	B5	0	0	0	0	0	0	2	2
Middle River Head	MRH	C1	0	0	1	1	1	0	1	2
Middle River at Highway 4	MR4	C2	0	0	0	0	0	0	1	1
Middle River near Mildred Island	MID	C3	0	0	0	0	0	0	0	0
Radial Gates Upstream	RGU	D1	1	1	0	2	6	2	1	9
Radial Gates Downstream	RGD	D2	0	0	0	0	0	1	0	1
Central Valley Project Trashrack	CVP	E1	1	8	1	10	4	14	5	23
Central Valley Project Holding Tank	CVPtank	E2	0	0	0	0	0	0	0	0
Turner Cut	TCE/TCW	F1	0	0	3	3	0	0	0	0

Table 8. (Continued)

Detection Site and Code			Durham Ferry Release Groups							
			Classified as Predator on Arrival at Site				Classified as Predator on Departure from Site			
Detection Site	Site Code	Survival Model Code	1	2	3	Total	1	2	3	Total
Columbia Cut	COL	F2	0	0	0	0	0	0	0	0
Jersey Point	JPE/JPW	G1	0	1	1	2	0	0	0	0
Chipps Island	MAE/MAW	G2	0	0	1	1	2	0	0	2
Benicia Bridge	BBR	G3	1	1	0	2	0	1	0	1
False River	FRE/FRW	H1	0	0	0	0	0	0	0	0
Threemile Slough	TMS/TMN	T1	0	1	0	1	0	0	0	0
Montezuma Slough	MTZ	T2	0	0	0	0	0	0	0	0
Spoonbill Slough	SBS	T3	0	0	0	0	0	0	0	0
Total Tags			19	20	40	79	23	28	31	82

Table 9. Number of tags from each release group that were detected after release in 2016, excluding predator-type detections and detections omitted from the survival analysis. Releases are: 1 = February, 2 = March, 3 = April.

Release Group	1	2	3	Total
Number Released	480	480	480	1,440
Number Detected	399	461	469	1,329
Number Detected Downstream	378	458	461	1,297
Number Detected Upstream of Study Area	399	444	465	1,308
Number Detected in Study Area	212	374	426	1,012
Number Detected in San Joaquin River Route	67	141	413	621
Number Detected in Old River Route	181	286	16	483
Number Assigned to San Joaquin River Route	25	85	408	518
Number Assigned to Old River Route	178	286	15	479

Table 10. Number of tags observed from each release group at each detection site in 2016, excluding predator-type detections. Routes (SJR = San Joaquin River, OR = Old River) represent route assignment at the head of Old River. Pooled counts are summed over all receivers in array and all routes. Route could not be identified for some tags. Releases are: 1 = February, 2 = March, 3 = April.

Detection Site	Site Code	Survival Model Code	Release Group			Total
			1	2	3	
Release site at Durham Ferry			480	480	480	1,440
Durham Ferry Upstream, Upstream	DFU1	A0a	77	16	27	120
Durham Ferry Upstream, Downstream	DFU2	A0b	67	11	12	90
Durham Ferry Upstream (Pooled)	DFU	A0	78	16	28	122
Durham Ferry Downstream, Upstream	DFD1	A2a	377	370	417	1,164
Durham Ferry Downstream, Downstream	DFD2	A2b	377	288	355	1,020
Durham Ferry Downstream (Pooled)	DFD	A2	377	396	432	1,205
Below Durham Ferry 1	BDF1	A3	231	136	198	565
Below Durham Ferry 2	BDF2	A4	233	170	209	612
Banta Carbona, Upstream	BCAU	A5a	214	149	336	699
Banta Carbona, Downstream	BCAD	A5b	217	163	309	689
Banta Carbona (Pooled)	BCA	A5	225	207	383	815
Mossdale, Upstream	MOSU	A6a	212	372	426	1,010
Mossdale, Downstream	MOSD	A6b	212	374	426	1,012
Mossdale (Pooled)	MOS	A6	212	374	426[a]	1,012
Head of Old River (Pooled)	HOR	B0	209	372	425	1,006
Lathrop, Upstream	SJLU	A7a	67	140	408	615
Lathrop, Downstream	SJLD	A7b	66	139	413	618
Lathrop (Pooled)	SJL	A7	67	140	413	620
Predator Removal Study 4	RS4	N1	44	109	409	562
Predator Removal Study 5	RS5	N2	37	94	405	536
Predator Removal Study 6	RS6	N3	27	85	402	514
Predator Removal Study 7	RS7	N4	23	81	400	504
Predator Removal Study 8	RS8	N5	21	79	396	496
Predator Removal Study 9	RS9	N6	20	77	395	492
Predator Removal Study 10	RS10	N7	20	75	393	488
Garwood Bridge, Upstream	SJGU	A8a	18	70	391	479
Garwood Bridge, Downstream	SJGD	A8b	18	70	391	479
Garwood Bridge (Pooled)	SJG	A8	18	70	391	479
Navy Drive Bridge	SJNB	A9	18	67	383	468
Rough and Ready Island, Upstream	RRIU	R1a	0	3	36	39
Rough and Ready Island, Downstream	RRID	R1b	0	3	36	39
Rough and Ready Island (Pooled)	RRI	R1	0	3	36	39
San Joaquin River near Calaveras, Upstream	SJCU	A10a	17	63	382	462
San Joaquin River near Calaveras, Downstream	SJCD	A10b	17	63	384	464
San Joaquin River near Calaveras (Pooled)	SJC	A10	17	63	384	464
San Joaquin River Shipping Channel	SJS	A11	16	63	375	454

[a] = One tagged steelhead was recaptured after detection at MOS and then returned to the river

Table 10. (Continued)

Detection Site	Site Code	Survival Model Code	Release Group			Total
			1	2	3	
MacDonald Island Upstream	MACU	A12a	12	56	310	378
MacDonald Island Downstream	MACD	A12b	11	54	298	363
MacDonald Island (Pooled)	MAC	A12	12	56	311	379
Turner Cut, Upstream	TCE	F1a	6	20	106	132
Turner Cut, Downstream	TCW	F1b	6	20	106	132
Turner Cut (Pooled)	TCE/TCW	F1	6	20	106	132
Medford Island East	MFE	A13a	4	41	219	264
Medford Island West	MFW	A13b	4	41	220	265
Medford Island (Pooled)	MFE/MFW	A13	4	41	220	265
Columbia Cut, Upstream	COLU	F2a	2	5	59	66
Columbia Cut, Downstream	COLD	F2b	2	5	61	68
Columbia Cut (Pooled)	COL	F2	2	5	61	68
Disappointment Slough, Upstream	SJDU	A14a	5	40	212	257
Disappointment Slough, Downstream	SJDD	A14b	5	39	207	251
Disappointment Slough (Pooled)	SJD	A14	5	40	212	257
Old River at the San Joaquin, Upstream	OSJU	B5a	3	10	32	45
Old River at the San Joaquin, Downstream	OSJD	B5b	3	10	33	46
Old River at the San Joaquin (Pooled)	OSJ	B5	3	10	33	46
Old River East, Upstream	OREU	B1a	181	286	16	483
Old River East, Downstream	ORED	B1b	181	286	16	483
Old River East (Pooled)	ORE	B1	181	286	16	483
Old River South, Upstream	ORSU	B2a	177	279	15	471
Old River South, Downstream	ORSD	B2b	177	278	15	470
Old River South (Pooled)	ORS	B2	177	279	15	471
West Canal, Upstream	WCLU	B3a	38	80	39	157
West Canal, Downstream	WCLD	B3b	35	78	39	152
West Canal: SJR Route	WCL	B3	2	4	37	43
West Canal: OR Route	WCL	B3	36	76	2	114
West Canal (Pooled)	WCL	B3	38	80	39	157
Old River at Highway 4, Upstream	OR4U	B4a	5	16	27	48
Old River at Highway 4, Downstream	OR4D	B4b	5	16	26	47
Old River at Highway 4, SJR Route	OR4	B4	2	4	26	32
Old River at Highway 4, OR Route	OR4	B4	3	12	1	16
Old River at Highway 4 (Pooled)	OR4	B4	5	16	27	48
Middle River Head, Upstream	MRHU	C1a	3	1	2	6
Middle River Head, Downstream	MRHD	C1b	3	1	2	6
Middle River Head (Pooled)	MRH	C1	3	1	2	6
Middle River at Highway 4, Upstream	MR4U	C2a	1	5	26	32
Middle River at Highway 4, Downstream	MR4D	C2b	1	5	26	32
Middle River at Highway 4, SJR Route	MR4	C2	1	1	26	28
Middle River at Highway 4, OR Route	MR4	C2	0	4	0	4

Table 10. (Continued)

Detection Site	Site Code	Survival Model Code	Release Group 1	2	3	Total
Middle River at Highway 4 (Pooled)	MR4	C2	1	5	26	32
Middle River near Mildred Island, Upstream	MIDU	C3a	1	5	49	55
Middle River near Mildred Island, Downstream	MIDD	C3b	1	5	49	55
Middle River near Mildred Island (Pooled)	MID	C3	1	5	49	55
Radial Gates Upstream #1	RGU1	D1a	78	133	36	247
Radial Gates Upstream #2	RGU2	D1b	79	134	35	248
Radial Gates Upstream: SJR Route	RGU	D1	0	3	32	35
Radial Gates Upstream: OR Route	RGU	D1	80	135	6	221
Radial Gates Upstream (Pooled)	RGU	D1	80	138	38	256
Radial Gates Downstream #1	RGD1	D2a	29	63	15	107
Radial Gates Downstream #2	RGD2	D2b	33	66	16	115
Radial Gates Downstream: SJR Route	RGD	D2	0	1	11	12
Radial Gates Downstream: OR Route	RGD	D2	33	65	5	103
Radial Gates Downstream (Pooled)	RGD	D2	33	66	16	115
Central Valley Project Trashrack, Upstream	CVPU	E1a	122	182	32	336
Central Valley Project Trashrack, Downstream	CVPD	E1b	118	171	31	320
CVP Trashrack: SJR Route	CVP	E1	2	2	28	32
CVP Trashrack: OR Route	CVP	E1	120	180	4	304
CVP Trashrack (Pooled)	CVP	E1	122	182	32	336
CVP Holding Tank: SJR Route	CVPtank	E2	2	0	11	13
CVP Holding Tank: OR Route	CVPtank	E2	69	85	1	155
CVP Holding Tank (Pooled)	CVPtank	E2	71[b]	85[c]	12	168
Threemile Slough, Upstream	TMS	T1a	1	8	33	42
Threemile Slough, Downstream	TMN	T1b	1	7	32	40
Threemile Slough: SJR Route	TMS/TMN	T1	0	6	33	39
Threemile Slough: OR Route	TMS/TMN	T1	1	2	0	3
Threemile Slough (Pooled)	TMS/TMN	T1	1	8	33	42
Jersey Point East	JPE	G1a	19	61	225	305
Jersey Point West	JPW	G1b	19	60	226	305
Jersey Point: SJR Route	JPE/JPW	G1	4	47	226	277
Jersey Point: OR Route	JPE/JPW	G1	15	15	0	30
Jersey Point (Pooled)	JPE/JPW	G1	19	62	226	307
False River West	FRW	H1a	4	18	28	50
False River East	FRE	H1b	7	19	40	66
False River: SJR Route	FRE/FRW	H1	3	15	42	60
False River: OR Route	FRE/FRW	H1	4	6	0	10
False River (Pooled)	FRE/FRW	H1	7	21	42	70

[b] = Ten tagged steelhead were recaptured in the CVP holding tank after detection, and then returned to the river

[c] = Six tagged steelhead were recaptured in the CVP holding tank after detection, and then returned to the river

Table 10. (Continued)

Detection Site	Site Code	Survival Model Code	Release Group 1	2	3	Total
Montezuma Slough, Upstream	MTZU	T2a	0	2	0	2
Montezuma Slough, Downstream	MTZD	T2b	0	1	0	1
Montezuma Slough (Pooled)	MTZ	T2	0	2	0	2
Spoonbill Slough, Upstream	SBSU	T3a	1	0	2	3
Spoonbill Slough, Downstream	SBSD	T3b	2	4	2	8
Spoonbill Slough (Pooled)	SBS	T3	2	4	2	8
Chipps Island East	MAE	G2a	77	135	231	443
Chipps Island West	MAW	G2b	76	135	227	438
Chipps Island: SJR Route	MAE/MAW	G2	6	38	232	276
Chipps Island: OR Route	MAE/MAW	G2	72	107	3	182
Chipps Island (Pooled)	MAE/MAW	G2	78	145	235	458
Benicia Bridge, East	BBE	G3a	72	151	239	462
Benicia Bridge, West	BBW	G3b	71	150	249	470
Benicia Bridge: SJR Route	BBE/BBW	G3	6	43	248	297
Benicia Bridge: OR Route	BBE/BBW	G3	67	109	3	179
Benicia Bridge (Pooled)	BBE/BBW	G3	73	152	251	476

Table 11. Number of tags observed from each release group at each detection site in 2016 and used in the survival analysis, excluding predator-type detections. Numbers in parentheses are counts of tags whose detection histories were right-censored at that site. Pooled counts are summed over all receivers in array. Route could not be identified for some tags. Releases are: 1 = February, 2 = March, 3 = April.

			Release Group			Total
Detection Site	Site Code	Survival Model Code	1	2	3	
Release site at Durham Ferry			480	480	480	1,440
Durham Ferry Upstream, Upstream	DFU1	A0a	37	10	18	65
Durham Ferry Upstream, Downstream	DFU2	A0b	25	6	8	39
Durham Ferry Upstream (Pooled)	DFU	A0	37	10	19	66
Durham Ferry Downstream	DFD	A2	361	389	421	1171
Below Durham Ferry 1	BDF1	A3	227	126	190	543
Below Durham Ferry 2	BDF2	A4	222	164	198	584
Banta Carbona	BCA	A5	221	201	379	801
Mossdale	MOS	A6	211	374	426 (1)	1011
Lathrop, Upstream	SJLU	A7a	25	83	402	510
Lathrop, Downstream	SJLD	A7b	25	85	408	518
Lathrop (Pooled)	SJL	A7	25	85	408	518
Garwood Bridge	SJG	A8	18	69	390	477
Navy Drive Bridge	SJNB	A9	17	64	374	455
Rough and Ready Island, Upstream	RRIU	R1a	0	0	6	6
Rough and Ready Island, Downstream	RRID	R1b	0	0	6	6
Rough and Ready Island (Pooled)	RRI	R1	0	0	6	6
San Joaquin River near Calaveras	SJC	A10	17	63	380	460
San Joaquin River Shipping Channel	SJS	A11	16	63	372	451
Lathrop, Upstream	SJLU	A7a	25	83	402	510
MacDonald Island Upstream	MACU	A12a	9	45	265	319
MacDonald Island Downstream	MACD	A12b	8	45	268	321
MacDonald Island (Pooled)	MAC	A12	9	45	271	325
Turner Cut, Upstream	TCE	F1a	6	18	91	115
Turner Cut, Downstream	TCW	F1b	6	18	91	115
Turner Cut (Pooled)	TCE/TCW	F1	6	18	91	115
Medford Island East	MFE	A13a	4	39	202	245
Medford Island West	MFW	A13b	4	39	205	248
Medford Island (Pooled)	MFE/MFW	A13	4	39	205	248
Columbia Cut, Upstream	COLU	F2a	2[a]	5	54	61
Columbia Cut, Downstream	COLD	F2b	2[a]	5	54	61
Columbia Cut (Pooled)	COL	F2	2[a]	5	54	61
Disappointment Slough, Upstream	SJDU	A14a	2[a]	31	192	225
Disappointment Slough, Downstream	SJDD	A14b	2[a]	31	186	219
Disappointment Slough (Pooled)	SJD	A14	2[a]	31	192	225
Old River at the San Joaquin, Upstream	OSJU	B5a	2[a]	8	28	38

a = detections were not used in the survival model

Table 11. (Continued)

Detection Site	Site Code	Survival Model Code	Release Group 1	2	3	Total
Old River at the San Joaquin, Downstream	OSJD	B5b	2[a]	8	28	38
Old River at the San Joaquin (Pooled)	OSJ	B5	2[a]	8	28	38
Old River East, Upstream	OREU	B1a	178	286	15	479
Old River East, Downstream	ORED	B1b	178	286	15	479
Old River East (Pooled)	ORE	B1	178	286	15	479
Old River South, Upstream	ORSU	B2a	173	276	12	461
Old River South, Downstream	ORSD	B2b	175	276	13	464
Old River South (Pooled)	ORS	B2	175	277	13	465
West Canal, Upstream	WCLU	B3a	2[a]	16	0[a]	18
West Canal, Downstream	WCLD	B3b	2[a]	16	0[a]	18
West Canal: OR Route (Pooled)	WCL	B3	2[a]	16	0[a]	18
Old River at Highway 4, Upstream	OR4U	B4a	4	12	25	41
Old River at Highway 4, Downstream	OR4D	B4b	4	12	25	41
Old River at Highway 4, SJR Route	OR4	B4	2[a]	4[a]	25	31
Old River at Highway 4, OR Route	OR4	B4	2 (2)	8	0	10
Old River at Highway 4 (Pooled)	OR4	B4	4 (2)	12	25	41
Middle River Head, Upstream	MRHU	C1a	1	0	2	3
Middle River Head, Downstream	MRHD	C1b	1	0	2	3
Middle River Head (Pooled)	MRH	C1	1 (1)	0	2 (2)	3
Middle River at Highway 4, Upstream	MR4U	C2a	1	4	20	25
Middle River at Highway 4, Downstream	MR4D	C2b	1	4	20	25
Middle River at Highway 4, SJR Route	MR4	C2	1[a]	0[a]	20	21
Middle River at Highway 4, OR Route	MR4	C2	0	4	0	4
Middle River at Highway 4 (Pooled)	MR4	C2	1	4	20	25
Radial Gates Upstream: SJR Route	RGU	D1	0[a]	1[a]	13	14
Radial Gates Upstream: OR Route	RGU	D1	36	63	4	103
Radial Gates Upstream (Pooled)	RGU	D1	36	64	17	117
Radial Gates Downstream: SJR Route	RGD	D2	0[a]	1[a]	10	11
Radial Gates Downstream: OR Route	RGD	D2	33	65	5	103
Radial Gates Downstream (Pooled)	RGD	D2	33	66	15	114
CVP Trashrack: SJR Route	CVP	E1	2[a]	2[a]	24	28
CVP Trashrack: OR Route	CVP	E1	117	157	3	277
CVP Trashrack (Pooled)	CVP	E1	119	159	27	305
CVP Holding Tank: SJR Route	CVPtank	E2	2[a]	0[a]	11	13
CVP Holding Tank: OR Route	CVPtank	E2	69 (10)	85 (6)	1	155
CVP Holding Tank (Pooled)	CVPtank	E2	71 (10)	85 (6)	12	168
Threemile Slough, Upstream	TMS	T1a	0[a]	1	21	22
Threemile Slough, Downstream	TMN	T1b	0[a]	1	21	22

a = detections were not used in the survival model

Table 11. (Continued)

Detection Site	Site Code	Survival Model Code	Release Group			Total
			1	2	3	
Threemile Slough: SJR Route (Pooled)	TMS/TMN	T1	0[a]	1	21	22
Jersey Point East	JPE	G1a	4[a]	50	212	266
Jersey Point West	JPW	G1b	4[a]	48	213	265
Jersey Point: SJR Route	JPE/JPW	G1	4[a]	47	213	264
Jersey Point: OR Route	JPE/JPW	G1	0[a]	3	0	3
Jersey Point (Pooled)	JPE/JPW	G1	4[a]	50	213	267
False River West	FRW	H1a	0[a]	0[a]	0[a]	0
False River East	FRE	H1b	0[a]	0[a]	0[a]	0
False River: SJR Route	FRE/FRW	H1	0[a]	0[a]	0[a]	0
False River: OR Route	FRE/FRW	H1	0[a]	0[a]	0[a]	0
False River (Pooled)	FRE/FRW	H1	0[a]	0[a]	0[a]	0
Chipps Island: SJR Route	MAE/MAW	G2	6	38	230	274
Chipps Island: OR Route	MAE/MAW	G2	64	103	3	170
Chipps Island (Pooled)	MAE/MAW	G2	70	141	233	444
Benicia Bridge, East	BBE	G3a	62	145	234	441
Benicia Bridge, West	BBW	G3b	61	144	246	451
Benicia Bridge: SJR Route	BBE/BBW	G3	6	43	246	295
Benicia Bridge: OR Route	BBE/BBW	G3	57	103	2	162
Benicia Bridge (Pooled)	BBE/BBW	G3	63	146	248	457

a = detections were not used in the survival model

Table 12. Number of juvenile Steelhead tagged by each surgeon in each release group during the 2016 tagging study. Releases are: 1 = February, 2 = March, 3 = April.

	Release Group			
Surgeon	1	2	3	Total Tags
A	160	160	160	480
B	160	160	168	488
C	160	160	152	472
Total Tags	480	480	480	1,440

Table 13. Release size and counts of juvenile Steelhead tag detections at key detection sites by surgeon in 2016, excluding predator-type detections. * = omitted from chi-square test of independence because of low counts.

Detection Site	Surgeon A	Surgeon B	Surgeon C
Release at Durham Ferry	480	488	472
Below Durham Ferry 1 (BDF1)	181	200	162
Below Durham Ferry 2 (BDF2)	184	215	185
Banta Carbona (BCA)	259	286	256
Mossdale (MOS)	333	347	331
Lathrop (SJL)	165	179	174
Garwood Bridge (SJG)	153	162	162
Navy Bridge (SJNB)	144	159	152
Rough and Ready Island (RRI)*	2	1	3
Calaveras River (SJC)	145	160	155
Shipping Channel (SJS)	142	159	150
MacDonald Island (MAC)	99	121	105
Turner Cut (TCE/TCW)	36	36	43
Medford Island (MFE/MFW)	75	91	82
Columbia Cut (COL)	17	23	21
Disappointment Slough	71	77	77
Old River Mouth (OSJ)	8	17	13
Old River East (ORE)	159	165	155
Old River South (ORS)	155	159	151
West Canal (WCL)*	8	7	3
Old River at Highway 4 (OR4)	15	12	14
Middle River Head (MRH)*	0	1	2
Middle River at Highway 4 (MR4)	8	6	11
Clifton Court Forebay Exterior (RGU)	38	39	40
Clifton Court Forebay Interior (RGD)	37	36	41
Central Valley Project Trash Rack (CVP)	104	104	97
Central Valley Project Holding Tank (CVPtank)	57	59	52
Threemile Slough (TMN/TMS)	8	6	8
Jersey Point (JPT/JPE/JPW)	82	95	90
Chipps Island (MAT/MAE/MAW)	131	157	156
Benicia Bridge (BBR)	138	159	160

Table 14. Performance metric estimates (standard errors or 95% bound [UB = upper bound, LB = lower bound] in parentheses) for tagged juvenile Steelhead released in the 2016 tagging study, excluding predator-type detections. South Delta ("SD") survival extended to MacDonald Island and Turner Cut in Route A, and the Central Valley Project trash rack, exterior radial gate receiver at Clifton Court Forebay, and Old River and Middle River receivers at Highway 4 in Route B. Population-level estimates were weighted averages over the available release-specific estimates, using weights proportional to release size. Releases are: 1 = February, 2 = March, 3 = April.

Parameter	Release 1[ab]	Release 2	Release 3[b]	Population Estimate
ψ_{AA}	0.07 (0.02)	0.16 (0.02)	0.72 (0.02)	0.32 (0.01)
ψ_{AF}	0.05 (0.02)	0.07 (0.01)	0.24 (0.02)	0.12 (0.01)
ψ_{BB}	0.87 (0.02)	0.77 (0.02)	0.03 (0.01)	0.56 (0.01)
ψ_{BC}	0.00 (<0.01)	0	0.00 (<0.01)	0.00 (<0.01)
S_{AA}	0.19 (0.10)	0.61 (0.06)	0.72 (0.02)	0.51 (0.04)
S_{AF}	0.29 (0.13)	0.25 (0.08)	0.27 (0.04)	0.27 (0.05)
S_{BB}	0.41 (0.04)	0.40 (0.03)	0.20 (0.06)	0.34 (0.03)
S_{BC}[c]	NA	NA	NA	NA
ψ_{A}	0.12[d] (0.02)	0.23[d] (0.02)	0.96[e] (0.01)	0.44[d] (0.01)
ψ_{B}	0.88[d] (0.02)	0.77[d] (0.02)	0.04[e] (0.01)	0.56[d] (0.01)
S_{A}	0.23 (0.08)	0.50[f] (0.05)	0.61[g] (0.02)	0.45[g] (0.03)
S_{B}	0.41 (0.04)	0.40[f] (0.03)	0.17[g] (0.06)	0.33[g] (0.03)
S_{Total}	0.39 (0.03)	0.42 (0.03)	0.59 (0.02)	0.47 (0.02)
$S_{A(MD)}$[h]	NA	0.58[g] (0.05)	0.55[g] (0.02)	0.56[gi] (0.03)
$S_{B(MD)}$[h]	NA	0.01[g] (0.01)	0[g] (95% UB: 0.19)	0.01[gi] (<0.01)
$S_{Total(MD)}$[h]	NA	0.14 (0.02)	0.53 (0.02)	0.34[i] (0.02)
$S_{A(SD)}$	0.58 (0.09)	0.74 (0.05)	0.89 (0.02)	0.73 (0.04)
$S_{B(SD)}$	NA	0.83 (0.02)	NA	NA
$S_{Total(SD)}$	NA	0.81 (0.02)	NA	NA
ϕ_{A1A6}	0.44 (0.02)	0.78 (0.02)	0.89 (0.01)	0.70 (0.01)

a = there were too few tags detected at Jersey Point to estimate survival through the Mid-Delta region

b = there were too few tags detected at Highway 4 to estimate survival in the South Delta region

c = there were too few tags detected in the Middle River route to estimate route-specific survival

d = significant preference for route B (Old River Route) (α=0.05)

e = significant preference for route A (San Joaquin River Route) (α=0.05)
f = estimated survival is significantly higher in route A (San Joaquin River Route) than in route B (Old River Route) (α=0.10) (tested only for Delta and Mid-Delta survival)
g = estimated survival is significantly higher in route A (San Joaquin River Route) than in route B (Old River Route) (α=0.05) (tested only for Delta and Mid-Delta survival)
h = estimates are the joint probability of surviving to the Jersey Point/False River junction, and moving downstream from that junction toward Jersey Point
i = population estimate is based on only two release groups

Table 15. Performance metric estimates (standard error or 95% bound [UB = upper bound, LB = lower bound] in parentheses) for tagged juvenile Steelhead released in the 2016 tagging study, including predator-type detections. South Delta ("SD") survival extended to MacDonald Island and Turner Cut in Route A, and the Central Valley Project trash rack, exterior radial gate receiver at Clifton Court Forebay, and Old River and Middle River receivers at Highway 4 in Route B. Population-level estimates were weighted averages over the available release-specific estimates, using weights proportional to release size. Releases are: 1 = February, 2 = March, 3 = April.

Parameter	Release 1[ab]	Release 2	Release 3	Population Estimate
ψ_{AA}	0.07 (0.02)	0.16 (0.02)	0.71 (0.02)	0.31 (0.01)
ψ_{AF}	0.06 (0.02)	0.07 (0.01)	0.25 (0.02)	0.13 (0.01)
ψ_{BB}	0.86 (0.02)	0.77 (0.02)	0.04 (0.01)	0.56 (0.01)
ψ_{BC}	0.00 (<0.01)	0	0	0.00 (<0.01)
S_{AA}	0.20 (0.10)	0.62 (0.06)	0.77 (0.02)	0.53 (0.04)
S_{AF}	0.24 (0.12)	0.23 (0.08)	0.29 (0.04)	0.26 (0.05)
S_{BB}	0.42 (0.04)	0.39 (0.03)	0.25 (0.07)	0.35 (0.03)
S_{BC}[c]	NA	NA	NA	NA
ψ_{A}	0.13[d] (0.02)	0.23[d] (0.02)	0.96[e] (0.01)	0.44[d] (0.01)
ψ_{B}	0.87[d] (0.02)	0.77[d] (0.02)	0.04[e] (0.01)	0.56[d] (0.01)
S_{A}	0.22[f] (0.08)	0.50[g] (0.05)	0.65[h] (0.02)	0.46[h] (0.03)
S_{B}	0.41[f] (0.04)	0.39[g] (0.03)	0.25[h] (0.07)	0.35[h] (0.03)
S_{Total}	0.39 (0.03)	0.42 (0.03)	0.63 (0.02)	0.48 (0.02)
$S_{A(MD)}$[i]	NA	0.58[h] (0.05)	0.58[h] (0.02)	0.58[hj] (0.03)
$S_{B(MD)}$[i]	NA	0.01[h] (0.01)	0[h] (95% UB: 0.19)	0.01[hj] (<0.01)
$S_{Total(MD)}$[i]	NA	0.14 (0.02)	0.56 (0.02)	0.35[j] (0.02)
$S_{A(SD)}$	0.65 (0.09)	0.77 (0.05)	0.93 (0.01)	0.78 (0.03)
$S_{B(SD)}$	NA	0.86 (0.02)	0.67 (0.12)	0.76[j] (0.06)
$S_{Total(SD)}$	NA	0.84 (0.02)	0.92 (0.01)	0.88[j] (0.01)
ϕ_{A1A6}	0.45 (0.02)	0.78 (0.02)	0.89 (0.01)	0.71 (0.01)

a = there were too few tags detected at Jersey Point to estimate survival through the Mid-Delta region

b = there were too few tags detected at Highway 4 to estimate survival in the South Delta region

c = there were too few tags detected in the Middle River route to estimate route-specific survival

d = significant preference for route B (Old River Route) (α=0.05)

e = significant preference for route A (San Joaquin River Route) (α=0.05)

f = estimated survival is significantly higher in route B (Old River Route) than in route A (San Joaquin River Route) (α=0.10) (tested only for Delta and Mid-Delta survival)

g = estimated survival is significantly higher in route A (San Joaquin River Route) than in route B (Old River Route) (α=0.10) (tested only for Delta and Mid-Delta survival)

h = estimated survival is significantly higher in route A (San Joaquin River Route) than in route B (Old River Route) (α=0.05) (tested only for Delta and Mid-Delta survival)

i = estimates are the joint probability of surviving to the Jersey Point/False River junction, and moving downstream from that junction toward Jersey Point

j = population estimate is based on only two release groups

Table 16a. Average travel time in days (harmonic mean) of acoustic-tagged juvenile Steelhead from release at Durham Ferry during the 2016 tagging study, without predator-type detections. Standard errors are in parentheses. NA entries for N (sample size) correspond to detection sites or routes that were removed from the survival model because of sparse data. See Table 16b for travel time from release with predator-type detections. Releases are: 1 = February, 2 = March, 3 = April.

	Without Predator-Type Detections							
	All releases		Release 1		Release 2		Release 3	
Detection Site and Route	N	Travel Time	N	Travel Time	N	Travel Time	N	Travel Time
Durham Ferry Upstream (DFU)	66	0.56 (0.16)	37	0.48 (0.16)	10	0.45 (0.37)	19	1.11 (0.45)
Durham Ferry Downstream (DFD)	1170	0.04 (<0.01)	360	0.10 (0.01)	389	0.03 (<0.01)	421	0.04 (<0.01)
Below Durham Ferry 1 (BDF1)	543	0.32 (0.02)	227	0.78 (0.09)	126	0.19 (0.01)	190	0.26 (0.02)
Below Durham Ferry 2 (BDF2)	584	0.42 (0.02)	222	1.32 (0.16)	164	0.26 (0.02)	198	0.33 (0.02)
Banta Carbona (BCA)	800	0.67 (0.03)	220	2.53 (0.30)	201	0.50 (0.03)	379	0.54 (0.03)
Mossdale (MOS)	1010	1.44 (0.05)	210	6.18 (0.46)	374	0.95 (0.04)	426	1.56 (0.07)
Lathrop (SJL)	517	1.82 (0.07)	24	8.48 (2.55)	85	1.02 (0.07)	408	2.07 (0.08)
Garwood Bridge (SJG)	476	3.35 (0.10)	17	16.07 (1.28)	69	2.59 (0.17)	390	3.41 (0.11)
Navy Drive Bridge (SJNB)	454	3.54 (0.11)	16	15.95 (1.13)	64	2.75 (0.18)	374	3.60 (0.12)
Rough and Ready Island (RRI)	6	4.74 (1.18)	0	NA	0	NA	6	4.74 (1.18)
San Joaquin River near Calaveras (SJC)	459	4.29 (0.12)	16	16.46 (1.21)	63	3.66 (0.21)	380	4.27 (0.12)
San Joaquin Shipping Channel (SJS)	450	4.99 (0.12)	15	17.53 (1.40)	63	4.76 (0.23)	372	4.88 (0.13)
MacDonald Island (MAC)	324	5.13 (0.14)	8	17.59 (2.06)	45	5.20 (0.28)	271	5.01 (0.15)
Turner Cut (TCE/TCW)	115	5.71 (0.24)	6	17.74 (2.41)	18	5.05 (0.45)	91	5.60 (0.25)
Turner Cut Junction (MAC or TCE/TCW)	439	5.27 (0.12)	14	17.65 (1.50)	63	5.16 (0.24)	362	5.15 (0.13)
Medford Island (MFE/MFW)	247	5.54 (0.16)	3	15.94 (4.28)	39	5.64 (0.29)	205	5.47 (0.18)
Columbia Cut (COL)	61	5.54 (0.37)	NA	NA	5	6.56 (1.64)	54	5.33 (0.36)
Disappointment Slough (SJD)	225	6.18 (0.18)	NA	NA	31	6.82 (0.40)	192	6.05 (0.20)
Old River at the San Joaquin (OSJ)	37	5.99 (0.41)	NA	NA	8	5.49 (0.39)	28	5.98 (0.50)
Old River East (ORE)	479	2.10 (0.10)	178	7.10 (0.47)	286	1.44 (0.06)	15	3.71 (0.88)
Old River South (ORS)	465	2.68 (0.12)	175	7.90 (0.45)	277	1.86 (0.08)	13	5.36 (1.19)
West Canal (WCL)	18	5.61 (1.20)	NA	NA	16	5.16 (1.10)	0	NA
Old River at Highway 4 (OR4), SJR Route	31	10.13 (0.69)	NA	NA	NA	NA	25	9.82 (0.74)
Old River at Highway 4 (OR4), OR Route	10	10.74 (1.90)	2	19.89 (8.88)	8	9.63 (1.70)	0	NA
Old River at Highway 4 (OR4)	41	10.27 (0.68)	2	19.89 (8.88)	8	9.63 (1.70)	25	9.82 (0.74)
Middle River Head (MRH)	3	6.69 (2.59)	1	9.36 (NA)	0	NA	2	5.86 (3.20)

Table 16a. (Continued)

	Without Predator-Type Detections							
	All releases		Release 1		Release 2		Release 3	
Detection Site and Route	N	Travel Time	N	Travel Time	N	Travel Time	N	Travel Time
Middle River at Highway 4 (MR4), SJR Route	21	8.73 (0.82)	NA	NA	NA	NA	20	8.46 (0.77)
Middle River at Highway 4 (MR4), OR Route	4	6.48 (1.65)	0	NA	4	6.48 (1.65)	0	NA
Middle River at Highway 4 (MR4)	25	8.27 (0.75)	0	NA	4	6.48 (1.65)	20	8.46 (0.77)
Radial Gates Upstream (DFU), SJR Route	14	10.91 (0.69)	NA	NA	NA	NA	13	10.85 (0.73)
Radial Gates Upstream (DFU), OR Route	103	4.50 (0.32)	36	10.81 (1.28)	63	3.31 (0.21)	4	7.30 (2.13)
Radial Gates Upstream (DFU)	117	4.84 (0.34)	36	10.81 (1.28)	63	3.31 (0.21)	17	9.73 (1.02)
Radial Gates Downstream (DFD), SJR Route	11	11.33 (0.83)	NA	NA	NA	NA	10	11.28 (0.91)
Radial Gates Downstream (DFD), OR Route	103	4.61 (0.33)	33	10.90 (1.35)	65	3.47 (0.23)	5	8.08 (2.16)
Radial Gates Downstream (DFD)	114	4.89 (0.35)	33	10.90 (1.35)	65	3.47 (0.23)	15	9.96 (1.20)
Central Valley Project Trashrack (CVP), SJR Route	28	10.36 (0.77)	NA	NA	NA	NA	24	10.15 (0.81)
Central Valley Project Trashrack (CVP), OR Route	277	5.36 (0.24)	117	10.02 (0.53)	157	3.99 (0.19)	3	4.47 (0.54)
Central Valley Project Trashrack (CVP)	305	5.61 (0.24)	117	10.02 (0.53)	157	3.99 (0.19)	27	8.89 (0.85)
Central Valley Project Holding Tank (CVPtank), SJR Route	13	10.26 (1.27)	NA	NA	NA	NA	11	9.47 (1.14)
Central Valley Project Holding Tank (CVPtank), OR Route	155	5.44 (0.31)	69	9.98 (0.71)	85	3.99 (0.23)	1	3.71 (NA)
Central Valley Project Holding Tank (CVPtank)	168	5.65 (0.31)	69	9.98 (0.71)	85	3.99 (0.23)	12	8.39 (1.26)
Threemile Slough (TMN/TMS)	22	7.71 (0.69)	NA	NA	1	8.18 (NA)	21	7.69 (0.72)
Jersey Point (JPE/JPW), SJR Route	264	7.31 (0.19)	NA	NA	47	7.59 (0.33)	213	7.15 (0.20)
Jersey Point (JPE/JPW), OR Route	3	14.35 (3.31)	NA	NA	3	14.35 (3.31)	0	NA
Jersey Point (JPE/JPW)	267	7.35 (0.19)	NA	NA	50	7.81 (0.36)	213	7.15 (0.20)
Chipps Island (MAE/MAW), SJR Route	273	8.92 (0.21)	5	22.47 (1.75)	38	9.11 (0.41)	230	8.78 (0.22)
Chipps Island (MAE/MAW), OR Route	170	7.52 (0.33)	64	12.76 (0.88)	103	5.99 (0.26)	3	7.52 (2.80)
Chipps Island (MAE/MAW)	443	8.32 (0.19)	69	13.17 (0.89)	141	6.60 (0.25)	233	8.76 (0.22)
Benicia Bridge (BBR)	456	9.31 (0.19)	62	14.85 (0.95)	146	7.53 (0.23)	248	9.75 (0.22)

Table 16b. Average travel time in days (harmonic mean) of acoustic-tagged juvenile Steelhead from release at Durham Ferry during the 2016 tagging study, with predator-type detections. Standard errors are in parentheses. NA entries for N (sample size) correspond to detection sites or routes that were removed from the survival model because of sparse data. See Table 16a for travel time from release without predator-type detections. Releases are: 1 = February, 2 = March, 3 = April.

	With Predator-Type Detections							
	All releases		Release 1		Release 2		Release 3	
Detection Site and Route	N	Travel Time	N	Travel Time	N	Travel Time	N	Travel Time
Durham Ferry Upstream (DFU)	71	0.66 (0.20)	38	0.54 (0.20)	10	0.45 (0.37)	23	1.46 (0.66)
Durham Ferry Downstream (DFD)	1167	0.04 (<0.01)	359	0.10 (0.01)	389	0.03 (<0.01)	419	0.04 (<0.01)
Below Durham Ferry 1 (BDF1)	544	0.32 (0.02)	226	0.78 (0.09)	126	0.19 (0.01)	192	0.26 (0.02)
Below Durham Ferry 2 (BDF2)	585	0.43 (0.02)	221	1.38 (0.18)	165	0.27 (0.02)	199	0.34 (0.03)
Banta Carbona (BCA)	803	0.67 (0.03)	223	2.57 (0.31)	203	0.50 (0.03)	377	0.53 (0.03)
Mossdale (MOS)	1015	1.45 (0.05)	213	6.25 (0.46)	376	0.96 (0.04)	426	1.56 (0.07)
Lathrop (SJL)	520	1.85 (0.07)	26	9.03 (2.69)	85	1.04 (0.08)	409	2.08 (0.08)
Garwood Bridge (SJG)	488	3.43 (0.11)	20	17.78 (1.68)	69	2.61 (0.17)	399	3.47 (0.11)
Navy Drive Bridge (SJNB)	473	3.66 (0.11)	19	17.75 (1.61)	67	2.87 (0.20)	387	3.69 (0.12)
Rough and Ready Island (RRI)	7	5.33 (1.43)	0	NA	0	NA	7	5.33 (1.43)
San Joaquin River near Calaveras (SJC)	474	4.40 (0.12)	19	18.34 (1.70)	66	3.82 (0.24)	389	4.35 (0.13)
San Joaquin Shipping Channel (SJS)	468	5.13 (0.13)	18	19.59 (1.91)	66	4.96 (0.26)	384	4.99 (0.14)
MacDonald Island (MAC)	335	5.25 (0.15)	9	19.02 (2.62)	46	5.30 (0.31)	280	5.12 (0.16)
Turner Cut (TCE/TCW)	127	6.01 (0.26)	8	20.89 (3.45)	20	5.54 (0.60)	99	5.78 (0.26)
Turner Cut Junction (MAC or TCE/TCW)	462	5.44 (0.13)	17	19.86 (2.05)	66	5.37 (0.28)	379	5.28 (0.14)
Medford Island (MFE/MFW)	256	5.71 (0.17)	4	19.36 (6.10)	40	5.77 (0.32)	212	5.62 (0.19)
Columbia Cut (COL)	63	5.65 (0.38)	NA	NA	5	6.56 (1.64)	56	5.45 (0.37)
Disappointment Slough (SJD)	238	6.36 (0.19)	NA	NA	32	7.00 (0.45)	203	6.21 (0.20)
Old River at the San Joaquin (OSJ)	38	6.13 (0.44)	NA	NA	8	5.49 (0.39)	29	6.16 (0.54)
Old River East (ORE)	483	2.12 (0.10)	180	7.14 (0.47)	288	1.45 (0.07)	15	3.71 (0.88)
Old River South (ORS)	474	2.72 (0.12)	177	7.93 (0.45)	282	1.89 (0.08)	15	5.73 (1.23)
West Canal (WCL)	17	5.36 (1.13)	NA	NA	16	5.16 (1.10)	0	NA
Old River at Highway 4 (OR4), SJR Route	38	11.26 (0.85)	NA	NA	NA	NA	29	10.36 (0.76)
Old River at Highway 4 (OR4), OR Route	11	7.09 (2.46)	1	13.75 (NA)	10	6.76 (2.45)	0	NA
Old River at Highway 4 (OR4)	49	9.95 (1.21)	1	13.75 (NA)	10	6.76 (2.45)	29	10.36 (0.76)
Middle River Head (MRH)	1	13.43 (NA)	1	13.43 (NA)	0	NA	0	NA

Table 16b. (Continued)

	With Predator-Type Detections							
	All releases		Release 1		Release 2		Release 3	
Detection Site and Route	N	Travel Time	N	Travel Time	N	Travel Time	N	Travel Time
Middle River at Highway 4 (MR4), SJR Route	21	8.99 (0.94)	NA	NA	NA	NA	20	8.71 (0.88)
Middle River at Highway 4 (MR4), OR Route	4	6.48 (1.65)	0	NA	4	6.48 (1.65)	0	NA
Middle River at Highway 4 (MR4)	25	8.46 (0.84)	0	NA	4	6.48 (1.65)	20	8.71 (0.88)
Radial Gates Upstream (DFU), SJR Route	16	12.10 (1.10)	NA	NA	NA	NA	14	11.48 (0.94)
Radial Gates Upstream (DFU), OR Route	107	4.62 (0.34)	38	11.03 (1.28)	65	3.40 (0.23)	4	7.30 (2.13)
Radial Gates Upstream (DFU)	123	5.03 (0.36)	38	11.03 (1.28)	65	3.40 (0.23)	18	10.19 (1.13)
Radial Gates Downstream (DFD), SJR Route	13	12.48 (1.24)	NA	NA	NA	NA	11	11.72 (0.99)
Radial Gates Downstream (DFD), OR Route	105	4.67 (0.34)	34	10.92 (1.32)	66	3.52 (0.24)	5	8.08 (2.16)
Radial Gates Downstream (DFD)	118	5.01 (0.36)	34	10.92 (1.32)	66	3.52 (0.24)	16	10.27 (1.23)
Central Valley Project Trashrack (CVP), SJR Route	30	11.57 (1.08)	NA	NA	NA	NA	24	10.44 (0.90)
Central Valley Project Trashrack (CVP), OR Route	285	5.65 (0.26)	120	10.21 (0.55)	160	4.22 (0.22)	5	6.10 (1.47)
Central Valley Project Trashrack (CVP)	315	5.94 (0.27)	120	10.21 (0.55)	160	4.22 (0.22)	29	9.30 (0.90)
Central Valley Project Holding Tank (CVPtank), SJR Route	15	11.17 (1.46)	NA	NA	NA	NA	13	10.51 (1.42)
Central Valley Project Holding Tank (CVPtank), OR Route	156	5.48 (0.31)	70	10.10 (0.73)	84	3.97 (0.23)	2	5.94 (3.58)
Central Valley Project Holding Tank (CVPtank)	171	5.74 (0.32)	70	10.10 (0.73)	84	3.97 (0.23)	15	9.53 (1.48)
Threemile Slough (TMN/TMS)	24	7.83 (0.66)	NA	NA	1	8.18 (NA)	23	7.82 (0.69)
Jersey Point (JPE/JPW), SJR Route	278	7.46 (0.19)	NA	NA	47	7.62 (0.35)	227	7.33 (0.21)
Jersey Point (JPE/JPW), OR Route	3	14.35 (3.31)	NA	NA	3	14.35 (3.31)	0	NA
Jersey Point (JPE/JPW)	281	7.50 (0.19)	NA	NA	50	7.84 (0.37)	227	7.33 (0.21)
Chipps Island (MAE/MAW), SJR Route	288	9.14 (0.22)	5	22.47 (1.75)	38	9.11 (0.41)	245	9.03 (0.24)
Chipps Island (MAE/MAW), OR Route	172	7.59 (0.34)	65	12.98 (0.91)	103	5.99 (0.26)	4	8.70 (2.99)
Chipps Island (MAE/MAW)	460	8.49 (0.20)	70	13.39 (0.92)	141	6.60 (0.25)	249	9.03 (0.24)
Benicia Bridge (BBR)	472	9.46 (0.19)	63	15.02 (0.97)	146	7.56 (0.24)	263	9.98 (0.23)

Table 17a. Average travel time in days (harmonic mean) of acoustic-tagged juvenile Steelhead through the San Joaquin River Delta river reaches during the 2016 tagging study, without predator-type detections. Standard errors are in parentheses. NA entries for N (sample size) correspond to detection sites or routes that were removed from the survival model because of sparse data. * = all routes combined between upstream and downstream boundaries. Reaches that were not modeled for individual release groups were excluded. Releases are: 1 = February, 2 = March, 3 = April. See Table 17b for travel time through reaches with predator-type detections.

Upstream Reach Boundary	Downstream Reach Boundary	All Releases: N	All Releases: Travel Time	Release 1: N	Release 1: Travel Time	Release 2: N	Release 2: Travel Time	Release 3: N	Release 3: Travel Time
Durham Ferry (Release)	DFU	66	0.56 (0.16)	37	0.48 (0.16)	10	0.45 (0.37)	19	1.11 (0.45)
	DFD	1170	0.04 (<0.01)	360	0.10 (0.01)	389	0.03 (<0.01)	421	0.04 (<0.01)
DFD	BDF1	512	0.22 (0.01)	227	0.44 (0.04)	104	0.14 (0.01)	181	0.16 (0.01)
BDF1	BDF2	359	0.06 (<0.01)	198	0.07 (<0.01)	58	0.06 (0.01)	103	0.04 (<0.01)
BDF2	BCA	465	0.15 (0.01)	197	0.17 (0.01)	97	0.16 (0.01)	171	0.13 (0.01)
BCA	MOS	766	0.51 (0.01)	201	0.65 (0.03)	189	0.47 (0.03)	376	0.47 (0.02)
MOS	SJL	517	0.24 (0.01)	24	0.43 (0.08)	85	0.22 (0.01)	408	0.24 (0.01)
	ORE	479	0.23 (0.01)	178	0.27 (0.01)	286	0.21 (0.01)	15	0.42 (0.11)
SJL	SJG	476	1.01 (0.03)	17	1.68 (0.30)	69	1.53 (0.09)	390	0.93 (0.03)
SJG	SJNB	454	0.09 (<0.01)	16	0.11 (0.02)	64	0.09 (0.01)	374	0.09 (<0.01)
	RRI	6	0.28 (0.03)	0	NA	0	NA	6	0.28 (0.03)
SJNB	SJC	452	0.33 (0.01)	16	0.32 (0.07)	63	0.48 (0.06)	373	0.31 (0.01)
RRI		5	0.62 (0.14)	0	NA	0	NA	5	0.62 (0.14)
SJC	SJS	450	0.34 (0.01)	15	0.54 (0.12)	63	0.52 (0.06)	372	0.31 (0.01)
SJS	MAC	324	0.11 (<0.01)	8	0.12 (0.03)	45	0.15 (0.02)	271	0.11 (<0.01)
	TCE/TCW	115	0.12 (0.01)	6	0.26 (0.09)	18	0.18 (0.05)	91	0.11 (0.01)
MAC	MFE/MFW	246	0.20 (0.01)	3	0.30 (0.15)	39	0.35 (0.04)	204	0.18 (0.01)
	COL*	61	0.22 (0.11)	NA	NA	5	0.18 (0.06)	54	0.23 (0.13)
	SJD*	224	0.71 (0.03)	NA	NA	31	0.93 (0.10)	191	0.68 (0.03)
	OSJ*	37	0.72 (0.08)	NA	NA	8	0.85 (0.11)	28	0.67 (0.09)
	JPE/JPW*	197	1.62 (0.05)	NA	NA	29	2.09 (0.10)	167	1.57 (0.05)
	OR4/MR4*	15	2.75 (0.23)	NA	NA	NA	NA	15	2.75 (0.23)
MFE/MFW	SJD	194	0.28 (0.02)	NA	NA	28	0.35 (0.07)	165	0.27 (0.02)
	OSJ	29	0.43 (0.06)	NA	NA	8	0.42 (0.07)	20	0.42 (0.07)
	JPE/JPW*	172	1.19 (0.05)	NA	NA	27	1.65 (0.10)	145	1.13 (0.05)
	OR4/MR4*	7	2.18 (0.11)	NA	NA	NA	NA	7	2.18 (0.11)

Table 17a. (Without predators: continued)

Upstream Reach Boundary	Downstream Reach Boundary	All Releases: N	All Releases: Travel Time	Release 1: N	Release 1: Travel Time	Release 2: N	Release 2: Travel Time	Release 3: N	Release 3: Travel Time
SJD	JPE/JPW	192	0.65 (0.04)	NA	NA	28	0.92 (0.07)	163	0.63 (0.04)
	TMN/TMS	22	0.72 (0.12)	NA	NA	1	1.95 (NA)	21	0.69 (0.12)
TCE/TCW	JPE/JPW	23	3.01 (0.31)	NA	NA	9	3.05 (0.59)	14	2.99 (0.35)
	OR4/MR4	37	2.04 (0.22)	NA	NA	NA	NA	30	1.94 (0.23)
COL	SJD	31	0.58 (0.09)	NA	NA	3	0.79 (0.29)	27	0.56 (0.09)
	OSJ	7	0.71 (0.14)	NA	NA	0	NA	7	0.71 (0.14)
	JPE/JPW*	26	1.52 (0.15)	NA	NA	2	1.30 (0.13)	23	1.57 (0.18)
	OR4/MR4*	8	2.46 (0.33)	NA	NA	NA	NA	8	2.46 (0.33)
OSJ	JPE/JPW	32	0.43 (0.05)	NA	NA	8	0.44 (0.09)	23	0.43 (0.06)
	OR4/MR4	0	NA	NA	NA	NA	NA	0	NA
ORE	ORS	465	0.28 (0.01)	175	0.30 (0.01)	277	0.26 (0.01)	13	0.48 (0.15)
	MRH	3	0.94 (0.42)	1	0.62 (NA)	0	NA	2	1.27 (1.07)
ORS	WCL	18	1.21 (0.38)	NA	NA	16	1.22 (0.43)	NA	NA
	OR4*	10	1.71 (0.91)	2	1.69 (1.25)	8	1.72 (1.14)	0	NA
	MR4	4	2.11 (0.93)	0	NA	4	2.11 (0.93)	0	NA
	RGU	103	1.37 (0.07)	36	1.52 (0.12)	63	1.30 (0.08)	4	1.32 (0.42)
	CVP	277	1.39 (0.05)	117	1.42 (0.07)	157	1.40 (0.06)	3	0.74 (0.35)
WCL	OR4	10	0.21 (0.08)	NA	NA	8	0.22 (0.09)	NA	NA
OR4 via OR	JPE/JPW	3	1.13 (0.62)	NA	NA	3	1.13 (0.62)	0	NA
OR4 via SJR	JPE/JPW	1	1.90 (NA)	NA	NA	NA	NA	1	1.90 (NA)
	RGU	6	0.36 (0.14)	NA	NA	NA	NA	5	0.32 (0.12)
	CVP	19	0.45 (0.09)	NA	NA	NA	NA	15	0.60 (0.09)
MRH	WCL	0	NA	NA	NA	0	NA	NA	NA
	OR4	0	NA	NA	NA	0	NA	NA	NA
	MR4	0	NA	NA	NA	0	NA	NA	NA
	RGU	0	NA	NA	NA	0	NA	NA	NA
	CVP	0	NA	NA	NA	0	NA	NA	NA
MR4 via OR	JPE/JPW	0	NA	NA	NA	0	NA	0	NA
MR4 via SJR	JPE/JPW	1	1.82 (NA)	NA	NA	NA	NA	0	NA

Table 17a. (Without predators: continued)

Upstream Reach Boundary	Downstream Reach Boundary	All Releases: N	All Releases: Travel Time	Release 1: N	Release 1: Travel Time	Release 2: N	Release 2: Travel Time	Release 3: N	Release 3: Travel Time
MR4 via SJR	RGU	8	0.73 (0.29)	NA	NA	NA	NA	8	0.73 (0.29)
	CVP	9	1.18 (0.22)	NA	NA	NA	NA	9	1.18 (0.22)
RGU via OR	RGD	97	0.01 (<0.01)	32	0.01 (<0.01)	61	0.01 (<0.01)	4	0.01 (0.01)
RGU via SJR	RGD	11	0.01 (<0.01)	NA	NA	NA	NA	10	0.01 (<0.01)
CVP via OR	CVPtank	155	0.06 (0.01)	69	0.06 (0.01)	85	0.06 (0.01)	1	0.02 (NA)
CVP via SJR	CVPtank	13	0.07 (0.04)	NA	NA	NA	NA	11	0.16 (0.06)
JPE/JPW	MAE/MAW* (Chipps Island)	233	1.04 (0.03)	NA	NA	38	1.00 (0.06)	192	1.04 (0.03)
TMN/TMS		19	1.03 (0.08)	NA	NA	0	NA	19	1.03 (0.08)
MAC		237	2.85 (0.06)	2	2.95 (0.60)	32	3.09 (0.13)	203	2.81 (0.07)
MFE/MFW		200	2.43 (0.06)	1	3.54 (NA)	31	2.66 (0.12)	168	2.39 (0.06)
SJD		193	1.89 (0.05)	NA	NA	25	1.96 (0.12)	167	1.88 (0.05)
TCE/TCW		35	4.48 (0.30)	3	4.91 (1.40)	6	5.30 (0.84)	26	4.29 (0.33)
COL		37	2.78 (0.18)	NA	NA	1	1.80 (NA)	35	2.84 (0.19)
OSJ		26	1.83 (0.12)	NA	NA	5	1.99 (0.14)	20	1.84 (0.16)
OR4		3	3.41 (0.79)	0	NA	2	3.63 (1.49)	1	3.03 (NA)
MR4		1	2.83 (NA)	1	2.83 (NA)	0	NA	0	NA
RGD		54	2.93 (0.16)	14	3.10 (0.46)	35	2.87 (0.16)	5	2.90 (0.55)
CVPtank		123	1.11 (0.05)	50	1.28 (0.09)	64	1.01 (0.07)	9	1.16 (0.18)
MAE/MAW	BBR	425	0.70 (0.02)	59	0.88 (0.07)	136	0.72 (0.04)	230	0.66 (0.03)

Table 17b. Average travel time in days (harmonic mean) of acoustic-tagged juvenile Steelhead through the San Joaquin River Delta river reaches during the 2016 tagging study, with predator-type detections. Standard errors are in parentheses. NA entries for N (sample size) correspond to detection sites or routes that were removed from the survival model because of sparse data. * = all routes combined between upstream and downstream boundaries. Reaches that were not modeled for individual release groups were excluded. Releases are: 1 = February, 2 = March, 3 = April. See Table 17a for travel time through reaches without predator-type detections.

Upstream Reach Boundary	Downstream Reach Boundary	All Releases: N	All Releases: Travel Time	Release 1: N	Release 1: Travel Time	Release 2: N	Release 2: Travel Time	Release 3: N	Release 3: Travel Time
Durham Ferry (Release)	DFU	71	0.66 (0.20)	38	0.54 (0.20)	10	0.45 (0.37)	23	1.46 (0.66)
	DFD	1167	0.04 (<0.01)	359	0.10 (0.01)	389	0.03 (<0.01)	419	0.04 (<0.01)
DFD	BDF1	513	0.22 (0.01)	226	0.43 (0.04)	104	0.14 (0.01)	183	0.16 (0.01)
BDF1	BDF2	360	0.06 (<0.01)	197	0.07 (<0.01)	58	0.06 (0.01)	105	0.04 (<0.01)
BDF2	BCA	468	0.15 (0.01)	199	0.17 (0.01)	98	0.16 (0.01)	171	0.13 (0.01)
BCA	MOS	771	0.51 (0.01)	204	0.65 (0.03)	191	0.47 (0.02)	376	0.48 (0.02)
MOS	SJL	520	0.24 (0.01)	26	0.43 (0.08)	85	0.22 (0.01)	409	0.24 (0.01)
	ORE	483	0.23 (0.01)	180	0.27 (0.01)	288	0.21 (0.01)	15	0.42 (0.11)
SJL	SJG	488	1.02 (0.03)	20	1.80 (0.30)	69	1.50 (0.09)	399	0.95 (0.03)
SJG	SJNB	473	0.09 (<0.01)	19	0.11 (0.02)	67	0.09 (0.01)	387	0.09 (<0.01)
	RRI	7	0.33 (0.06)	0	NA	0	NA	7	0.33 (0.06)
SJNB	SJC	465	0.33 (0.01)	19	0.35 (0.08)	66	0.49 (0.05)	380	0.31 (0.01)
RRI		7	0.67 (0.15)	0	NA	0	NA	7	0.67 (0.15)
SJC	SJS	468	0.34 (0.01)	18	0.47 (0.09)	66	0.52 (0.06)	384	0.32 (0.01)
SJS	MAC	335	0.11 (<0.01)	9	0.12 (0.02)	46	0.15 (0.02)	280	0.11 (<0.01)
	TCE/TCW	127	0.12 (0.01)	8	0.23 (0.06)	20	0.18 (0.05)	99	0.11 (0.01)
MAC	MFE/MFW	255	0.20 (0.01)	4	0.31 (0.12)	40	0.33 (0.04)	211	0.19 (0.01)
	COL*	63	0.22 (0.11)	NA	NA	5	0.18 (0.06)	56	0.23 (0.13)
	SJD*	237	0.72 (0.03)	NA	NA	32	0.84 (0.11)	202	0.70 (0.03)
	OSJ*	38	0.72 (0.08)	NA	NA	8	0.85 (0.11)	29	0.67 (0.09)
	JPE/JPW*	207	1.64 (0.05)	NA	NA	29	2.09 (0.10)	177	1.59 (0.05)
	OR4/MR4*	16	2.94 (0.31)	NA	NA	NA	NA	16	2.94 (0.31)
MFE/MFW	SJD	205	0.28 (0.02)	NA	NA	29	0.33 (0.06)	174	0.27 (0.02)
	OSJ	30	0.43 (0.05)	NA	NA	8	0.42 (0.07)	21	0.42 (0.07)
	JPE/JPW*	181	1.19 (0.05)	NA	NA	27	1.65 (0.10)	154	1.14 (0.05)
	OR4/MR4*	7	2.18 (0.11)	NA	NA	NA	NA	7	2.18 (0.11)

Table 17b. (With predators: continued)

Upstream Reach Boundary	Downstream Reach Boundary	All Releases: N	All Releases: Travel Time	Release 1: N	Release 1: Travel Time	Release 2: N	Release 2: Travel Time	Release 3: N	Release 3: Travel Time
SJD	JPE/JPW	202	0.64 (0.04)	NA	NA	28	0.92 (0.07)	173	0.61 (0.04)
	TMN/TMS	24	0.74 (0.12)	NA	NA	1	1.95 (NA)	23	0.72 (0.12)
TCE/TCW	JPE/JPW	24	3.05 (0.31)	NA	NA	9	3.09 (0.63)	15	3.03 (0.34)
	OR4/MR4	43	2.16 (0.22)	NA	NA	NA	NA	33	2.06 (0.24)
COL	SJD	33	0.61 (0.09)	NA	NA	3	0.79 (0.29)	29	0.59 (0.10)
	OSJ	7	0.65 (0.09)	NA	NA	0	NA	7	0.65 (0.09)
	JPE/JPW*	27	1.53 (0.15)	NA	NA	2	1.30 (0.13)	24	1.59 (0.18)
	OR4/MR4*	9	2.76 (0.50)	NA	NA	NA	NA	9	2.76 (0.50)
OSJ	JPE/JPW	34	0.42 (0.04)	NA	NA	8	0.44 (0.09)	25	0.42 (0.05)
	OR4/MR4	1	2.99 (NA)	NA	NA	NA	NA	1	2.99 (NA)
ORE	ORS	474	0.28 (0.01)	177	0.30 (0.01)	282	0.26 (0.01)	15	0.54 (0.17)
	MRH	1	4.29 (NA)	1	4.29 (NA)	0	NA	0	NA
ORS	WCL	17	1.20 (0.39)	NA	NA	16	1.22 (0.43)	NA	NA
	OR4*	11	1.30 (0.58)	1	0.97 (NA)	10	1.35 (0.68)	0	NA
	MR4	4	2.11 (0.93)	0	NA	4	2.11 (0.93)	0	NA
	RGU	107	1.40 (0.07)	38	1.54 (0.12)	65	1.33 (0.09)	4	1.32 (0.42)
	CVP	285	1.43 (0.05)	120	1.45 (0.07)	160	1.45 (0.07)	5	0.98 (0.40)
WCL	OR4	11	0.16 (0.04)	NA	NA	10	0.17 (0.05)	NA	NA
OR4 via OR	JPE/JPW	3	1.13 (0.62)	NA	NA	3	1.13 (0.62)	0	NA
OR4 via SJR	JPE/JPW	2	2.02 (0.13)	NA	NA	NA	NA	2	2.02 (0.13)
	RGU	9	0.50 (0.19)	NA	NA	NA	NA	7	0.43 (0.18)
	CVP	21	0.52 (0.12)	NA	NA	NA	NA	15	0.63 (0.10)
MRH	WCL	0	NA	NA	NA	0	NA	0	NA
	OR4	0	NA	NA	NA	0	NA	0	NA
	MR4	0	NA	NA	NA	0	NA	0	NA
	RGU	0	NA	NA	NA	0	NA	0	NA
	CVP	0	NA	NA	NA	0	NA	0	NA
MR4 via OR	JPE/JPW	0	NA	NA	NA	0	NA	0	NA
MR4 via SJR	JPE/JPW	1	1.82 (NA)	NA	NA	NA	NA	0	NA

Table 17b. (With predators: continued)

Upstream Reach Boundary	Downstream Reach Boundary	All Releases: N	All Releases: Travel Time	Release 1: N	Release 1: Travel Time	Release 2: N	Release 2: Travel Time	Release 3: N	Release 3: Travel Time
MR4 via SJR	RGU	7	0.76 (0.36)	NA	NA	NA	NA	7	0.76 (0.36)
	CVP	9	1.32 (0.31)	NA	NA	NA	NA	9	1.32 (0.31)
RGU via OR	RGD	99	0.01 (<0.01)	33	0.01 (<0.01)	62	0.01 (<0.01)	4	0.01 (0.01)
RGU via SJR	RGD	13	0.01 (<0.01)	NA	NA	NA	NA	11	0.01 (<0.01)
CVP via OR	CVPtank	156	0.06 (0.01)	70	0.06 (0.01)	84	0.06 (0.01)	2	0.04 (0.03)
CVP via SJR	CVPtank	15	0.08 (0.05)	NA	NA	NA	NA	13	0.18 (0.08)
JPE/JPW	MAE/MAW* (Chipps Island)	243	1.04 (0.03)	NA	NA	38	1.00 (0.06)	202	1.05 (0.03)
TMN/TMS		21	1.07 (0.09)	NA	NA	0	NA	21	1.07 (0.09)
MAC		249	2.91 (0.06)	2	2.95 (0.60)	32	3.09 (0.13)	215	2.88 (0.07)
MFE/MFW		209	2.46 (0.06)	1	3.54 (NA)	31	2.66 (0.12)	177	2.43 (0.07)
SJD		202	1.91 (0.05)	NA	NA	25	1.96 (0.12)	176	1.90 (0.05)
TCE/TCW		38	4.64 (0.31)	3	4.91 (1.40)	6	5.30 (0.84)	29	4.50 (0.35)
COL		40	2.90 (0.20)	NA	NA	1	1.80 (NA)	38	2.97 (0.21)
OSJ		29	1.96 (0.16)	NA	NA	5	1.99 (0.14)	23	1.99 (0.20)
OR4		4	3.34 (0.54)	0	NA	2	3.63 (1.49)	2	3.09 (0.07)
MR4		1	2.83 (NA)	1	2.83 (NA)	0	NA	0	NA
RGD		54	2.93 (0.16)	14	3.10 (0.46)	35	2.87 (0.16)	5	2.90 (0.55)
CVPtank		127	1.13 (0.06)	51	1.31 (0.09)	64	1.01 (0.07)	12	1.27 (0.18)
MAE/MAW	BBR	440	0.70 (0.02)	60	0.88 (0.07)	136	0.72 (0.04)	244	0.66 (0.03)

Table 18. Results of single-variate analyses of 2016 route selection at the Head of Old River, for tags estimated to have arrived at the river junction before 1500 on April 1, 2016 (date of barrier closure). The values df1 and df2 are the degrees of freedom for the F-test. Covariates are ordered by P-value and F statistic.

Covariate	*F*	df1	df2	*P*	Sign
Modeled flow at SJL[a]	26.2586	1	86	<0.0001	+
Stage at MSD[a]	15.9108	1	86	0.0001	+
Flow at MSD[a]	12.8721	1	86	0.0006	+
Stage at OH1[a]	11.8732	1	86	0.0009	+
OH1:MSD flow ratio flow[a]	10.7756	1	86	0.0015	-
Stage at SJL[a]	10.4644	1	86	0.0017	+
Change in stage at SJL	9.9023	1	86	0.0023	-
Exports at SWP	9.5779	1	86	0.0027	+
Total Exports in Delta	9.0747	1	86	0.0034	+
Change in stage at OH1	8.9801	1	86	0.0036	-
CVP Proportion of Exports	8.7290	1	86	0.0040	-
Change in stage at MSD	5.8212	1	86	0.0180	-
Change in velocity at MSD	4.8349	1	86	0.0306	+
Velocity at MSD	4.7283	1	86	0.0324	+
Change in flow at MSD	2.8893	1	86	0.0928	+
Release Group	2.5835	1	86	0.1117	+
Velocity at OH1	1.0762	1	86	0.3025	-
Exports at CVP	1.0714	1	96	0.3035	+
Change in velocity at OH1	0.3194	1	86	0.5734	+
Arrive at junction during day	0.2218	1	86	0.6389	-
Change in flow at OH1	0.0410	1	86	0.8401	+
Time of day of arrival	0.1212	3	84	0.9474	-[b]
Flow at OH1	0.0017	1	86	0.9673	-
Fork Length	0.0001	1	86	0.9932	+

a = Significant at experimentwise 5% level

b = Regression coefficients for day, dusk, and night relative to dawn

Table 19. Results of multivariate analyses of route selection at the head of Old River in 2016. Modeled response is the probability of selecting the San Joaquin River route. The columns labeled *t*, df, and P refer to the *t*-tests.

Model Type	Covariate[a]	Estimate	S.E.	*t*	df	*P*
Flow: Q_{MSD} and Q_{OH1}	Intercept	-2.5287	0.2324	-10.8823	85	<0.0001
	Q_{MSD}	2.4960	0.3217	7.7585	85	<0.0001
	Q_{OH1}	-1.6322	0.2685	-6.0799	85	<0.0001
	Goodness-of-fit: χ^2= 16.7583, df=13, P=0.2106; AIC = 368.55					
Flow: qQ_{SJL}	Intercept	-2.4853	0.2254	-11.0272	86	<0.0001
	qQ_{SJL}	1.8587	0.2382	7.8040	86	<0.0001
	Goodness-of-fit: χ^2= 26.6220, df=13, P=0.0140; AIC = 369.06					
Flow Ratio	Intercept	-2.8211	0.2581	-10.9303	85	<0.0001
	r_Q	-3.1826	0.4855	-6.5548	85	<0.0001
	SWP	1.0639	0.1651	6.4432	85	<0.0001
	Goodness-of-fit: χ^2= 8.2192, df=13, P=0.8290; AIC = 375.22					
Velocity	Intercept	-2.1791	0.1750	-12.4521	85	<0.0001
	V_{OH1}	-1.2177	0.1681	-7.2440	85	<0.0001
	SWP	1.6839	0.1987	8.4752	85	<0.0001
	Goodness-of-fit: χ^2= 19.7497, df=13, P=0.1016; AIC = 375.40					
Stage	Intercept	-2.6012	0.2433	-10.6920	85	<0.0001
	C_{MSD}	1.4480	0.2116	6.8441	85	<0.0001
	ΔC_{SJL}	-1.2317	0.2244	-5.4880	85	<0.0001
	Goodness-of-fit: χ^2= 10.4716, df=13, P=0.6550; AIC = 360.89					
Flow + Stage	Intercept	-2.578	0.2308	-11.1696	84	<0.0001
	Q_{OH1}	-1.1397	0.2036	-5.5980	84	<0.0001
	C_{OH1}	-5.0271	0.9141	-5.4996	84	<0.0001
	C_{MSD}	7.1223	1.0642	6.6930	84	<0.0001
	Goodness-of-fit: χ^2= 9.1204, df=13, P=0.7638; AIC = 360.10					

a = continuous covariates (Q_{MSD}, Q_{OH1}, qQ_{SJL}, r_Q, SWP, V_{OH1}, C_{MSD}, ΔC_{SJL}, C_{OH1}) are standardized. Intercept and slope estimates for the unstandardized covariates are -11.3675 (SE=1.4558), 1.5972 (SE=0.2334; C_{MSD}), and -16.9854 (SE=3.0950; ΔC_{SJL}) for the stage model.

Table 20. Results of single-variate analyses of 2016 route selection at the Turner Cut junction. The values df1 and df2 are the degrees of freedom for the F-test. Covariates are ordered by P-value and F statistic.

Covariate	*F*	df1	df2	*P*	Sign
Change in stage at TRN[a]	28.5919	1	88	0.0000	-
Flow at TRN[a]	14.1468	1	91	0.0003	+
Velocity at TRN[a]	13.7104	1	91	0.0003	+
Change in flow at TRN	6.9271	1	88	0.0100	+
Change in velocity at TRN	6.5850	1	88	0.0120	+
Negative flow at TRN	4.3586	1	91	0.0396	-
Stage at TRN	3.5000	1	91	0.0646	-
Velocity during transition from SJG	1.1272	1	91	0.2912	-
Flow during transition from SJG	0.6115	1	91	0.4362	-
Leave SJS during day	0.3303	1	91	0.5669	+
Fork Length	0.3086	1	91	0.5799	-
Time of Day of Departure from SJS	0.1857	3	89	0.9059	-[b]
Exports at CVP	0.0539	1	91	0.8170	-
Release Group	0.0530	2	90	0.9484	+[c]
Total Exports in Delta	0.0394	1	91	0.8430	-
Exports at SWP	0.0368	1	91	0.8483	-
CVP Proportion of Exports	0.0002	1	91	0.9891	+

a = Significant at experimentwise 5% level

b = Regression coefficients for day, dusk, and night relative to dawn

c = Regression coefficients for Release Groups 2 and 3 relative to Group 1

Table 21. Results of multivariate analyses of route selection at the Turner Cut junction in 2016. Modeled response is the probability of selecting the San Joaquin River route. The columns labeled *t*, df, and P refer to the *t*-tests.

Model Type	Covariate[a]	Estimate	S.E.	*t*	df	*P*
Flow	Intercept	-0.3727	0.4182	-0.8912	86	0.3753
	Q_{TRN}	2.4583	0.3774	6.5133	86	<0.0001
	ΔQ_{TRN}	0.6901	0.1510	4.5685	86	0.0002
	U_{QTRN}: $Q_{TRN} < 0$	3.3722	0.7423	4.5430	86	0.0002
	Goodness-of-fit: χ^2=1.4554, df=13, P=1.0000; AIC =320.84					
Velocity	Intercept	-0.2701	0.3869	-0.6982	87	0.4869
	V_{TRN}	2.4159	0.3621	6.6716	87	<0.0001
	U_{VTRN}: $V_{TRN} < 0$	3.0464	0.3776	4.4978	87	<0.0001
	Goodness-of-fit: χ^2=1.4554, df=13, P=0.4758; AIC = 344.01					
Stage	Intercept	1.4933	0.1552	9.6196	88	<0.0001
	ΔC_{TRN}	-1.2375	0.1365	-9.0646	88	<0.0001
	Goodness-of-fit: χ^2=3.2045, df=13, P=0.9971; AIC = 318.42					
Flow + Stage	Intercept	1.6133	0.1705	9.4621	87	<0.0001
	Q_{TRN}	0.6600	0.1755	3.7597	87	0.0003
	ΔC_{TRN}	-1.0096	0.1394	-7.2432	87	<0.0001
	Goodness-of-fit: χ^2=1.9068, df=13, P=0.9998; AIC = 304.89					

a = continuous covariates (Q_{TRN}, ΔQ_{TRN}, V_{TRN}, ΔC_{TRN}) are standardized. Intercept and slope estimates for the unstandardized covariates are -1.2132 (SE=0.2098), -9.9211 (SE=1.3697; ΔC_{TRN}), and 0.0003 (SE=0.0001; Q_{TRN}) for the flow + stage model.

Table 22. Estimates of survival from downstream receivers at water export facilities (CVP holding tank or interior of Clifton Court Forebay at radial gates) through salvage to receivers* after release from truck in 2016, excluding predator-type detections (95% profile likelihood interval or 95% lower bound [LB] in parentheses). Population estimate is based on data pooled from all releases. * = receiver sites indicating survival were G1, G2, G3, H1, T1, T2, and T3. Estimates are based on assumption of 100% detection probability at T2 and T3.

Facility	Upstream Site Code	Release 1	Release 2	Release 3	Population Estimate
CVP	E2	0.86 (0.75, 0.93)	0.88 (0.79, 0.94)	1 (95% LB: 0.78)	0.88 (0.82, 0.92)
SWP	D2	0.43 (0.27, 0.60)	0.56 (0.44, 0.68)	0.33 (0.13, 0.58)	0.49 (0.40, 0.58)

Table 23. Estimates (standard errors in parentheses) of linear contrasts comparing estimates of survival from release group in question to average estimates from the other two release groups. Estimates were based on data that excluded predator-type detections. * = significant difference from 0 for experimentwise α=0.10 (testwise α=0.0083). Releases are: 1 =February, 2 = March, 3 = April.

Parameter	Release 1	Release 2	Release 3
ϕ_{A1A6}	-0.39* (0.02)	0.11* (0.02)	0.28* (0.02)
S_A	-0.32* (0.09)	0.08 (0.07)	0.24* (0.06)
S_B	0.13 (0.05)	0.10 (0.04)	-0.23* (0.06)
S_{Total}	-0.12* (0.04)	-0.07 (0.03)	0.19* (0.03)

* = significant difference from 0 for experimentwise α=0.10

Appendix A. Survival Model Parameters

Table A1. Definitions of parameters used in the release-recapture survival model in the 2016 tagging study. Parameters used only in particular submodels are noted. * = estimated directly or derived from model.

Parameter	Definition
S_{A2}	Probability of survival from Durham Ferry Downstream (DFD) to Below Durham Ferry 1 (BDF1)
S_{A3}	Probability of survival from Below Durham Ferry 1 (BDF1) to Below Durham Ferry 2 (BDF2)
S_{A4}	Probability of survival from Below Durham Ferry 2 (BDF2) to Banta Carbona (BCA)
S_{A5}	Probability of survival from Banta Carbona (BCA) to Mossdale (MOS)
S_{A6}	Probability of survival from Mossdale (MOS) to Lathrop (SJL) or Old River East (ORE)
S_{A7}	Probability of survival from Lathrop (SJL) to Garwood Bridge (SJG)
S_{A8}	Probability of survival from Garwood Bridge (SJG) to Navy Drive Bridge (SJNB) or Rough and Ready Island (RRI)
$S_{A8,G2}$	Overall survival from Garwood Bridge (SJG) to Chipps Island (MAE/MAW) (derived from Submodel I)
S_{A9}	Probability of survival from Navy Drive Bridge (SJNB) to San Joaquin River near Calaveras River (SJC)
$S_{A9,G2}$	Overall survival from Navy Drive Bridge (SJNB) to Chipps Island (MAE/MAW) (derived from Submodel I)
S_{A10}	Probability of survival from San Joaquin River near Calaveras River (SJC) to San Joaquin River Shipping Channel (SJS)
$S_{A10,G2}$	Overall survival from San Joaquin River near Calaveras River (SJC) to Chipps Island (MAE/MAW) (derived from Submodel I)
S_{A11}	Probability of survival from San Joaquin River Shipping Channel (SJS) to MacDonald Island (MAC) or Turner Cut (TCE/TCW)
$S_{A11,G2}$	Overall survival from San Joaquin River Shipping Channel (SJS) to Chipps Island (MAE/MAW) (derived from Submodel I)
$S_{A12,G2}$	Overall survival from MacDonald Island (MAC) to Chipps Island (MAE/MAW) (Submodel I)
$S_{A13,G2}$	Overall survival from Medford Island (MFE/MFW) to Chipps Island (MAE/MAW) (derived from Submodel II)
S_{B1}	Probability of survival from Old River East (ORE) to Old River South (ORS) or Middle River Head (MRH) (Submodel I)
$S_{B2,G2}$	Overall survival from Old River South (ORS) to Chipps Island (MAE/MAW) (derived from Submodel I)
$S_{B2(SD)}$	Overall survival from Old River South (ORS) to the exit points of the Route B South Delta Region: OR4, MR4, RGU, CVP (derived from Submodel I)
$S_{C1,G2}$	Overall survival from head of Middle River (MRH) to Chipps Island (MAE/MAW) (derived from Submodel I)
$S_{C1(SD)}$	Overall survival from head of Middle River (MRH) to the exit points of the Route B South Delta Region: OR4, MR4, RGU, CVP (derived from Submodel I)
$S_{F1,G2}$	Overall survival from Turner Cut (TCE/TCW) to Chipps Island (MAE/MAW) (Submodel I)
S_{R1}	Probability of survival from Rough and Ready Island (RRI) to San Joaquin River near Calaveras River (SJC)
$\phi_{A1,A0}$	Joint probability of moving from Durham Ferry release site upstream toward DFU, and surviving to DFU
$\phi_{A1,A2}$	Joint probability of moving from Durham Ferry release site downstream toward DFD, and surviving to DFD
$\phi_{A1,A5}$	Joint probability of moving from Durham Ferry release site downstream toward BCA, and surviving to BCA; = $\phi_{A1,A2} S_{A2} S_{A3} S_{A4}$
$\phi_{A1,A6}$	Joint probability of moving from Durham Ferry release site downstream toward MOS, and surviving to MOS; = $\phi_{A1,A2} S_{A2} S_{A3} S_{A4} S_{A5}$
$\phi_{A12,A13}$	Joint probability of moving from MAC toward MFE/MFW, and surviving from MAC to MFE/MFW (Submodel II)
$\phi_{A12,F2}$	Joint probability of moving from MAC toward COL, and surviving from MAC to COL (Submodel II)
$\phi_{A12,G2}$	Joint probability of moving from MAC toward MAE/MAW without passing MFE/MFW, and surviving from MAC to MAE/MAW (Submodel II*)
$\phi_{A13,A14}$	Joint probability of moving from MFE/MFW toward SJD, and surviving from MFE/MFW to SJD (Submodel II)
$\phi_{A13,B4}$	Joint probability of moving from MFE/MFW directly toward OR4, and surviving from MFE/MFW to OR4 (Submodel II)
$\phi_{A13,B5}$	Joint probability of moving from MFE/MFW directly toward OSJ, and surviving from MFE/MFW to OSJ (Submodel II)
$\phi_{A13,C2}$	Joint probability of moving from MFE/MFW directly toward MR4, and surviving from MFE/MFW to MR4 (Submodel II)

Table A1. (Continued)

Parameter	Definition
$\phi_{A13,GH}$	Joint probability of moving from MFE/MFW directly toward Jersey Point (JPE/JPW) or False River (FRE/FRW), and surviving to JPE/JPW or FRE/FRW (Submodel II*)
$\phi_{A13,G1}$	Joint probability of moving from MFE/MFW directly toward Jersey Point (JPE/JPW) and surviving to JPE/JPW (Submodel II*); = $\phi_{A13,GH(A)}\psi_{G1}$
$\phi_{A13,G2}$	Joint probability of moving from MFE/MFW toward MAE/MAW, and surviving from MFE/MFW to MAE/MAW (Submodel II*)
$\phi_{A14,GH}$	Joint probability of moving from SJD toward Jersey Point (JPE/JPW) or False River (FRE/FRW), and surviving to JPE/JPW or FRE/FRW (Submodel II)
$\phi_{A14,G1}$	Joint probability of moving from SJD toward Jersey Point (JPE/JPW) and surviving to JPE/JPW (Submodel II); = $\phi_{A14,GH(A)}\psi_{G1}$
$\phi_{A14,T1}$	Joint probability of moving from SJD toward TMS/TMN and surviving to TMS/TMN (Submodel II)
$\phi_{B2,B3}$	Joint probability of moving from ORS toward WCL, and surviving from ORS to WCL (Submodel I)
$\phi_{B2,B4}$	Joint probability of moving from ORS toward OR4, and surviving from ORS to OR4 (Submodel I*); = $\phi_{B2,B3}\phi_{B3,B4}$
$\phi_{B2,C2}$	Joint probability of moving from ORS toward MR4, and surviving from ORS to MR4 (Submodel I)
$\phi_{B2,D1O}$	Joint probability of moving from ORS toward RGU, surviving to RGU, and arriving when the radial gates are open (Submodel I)
$\phi_{B2,D1C}$	Joint probability of moving from ORS toward RGU, surviving to RGU, and arriving when the radial gates are closed (Submodel I)
$\phi_{B2,D1}$	Joint probability of moving from ORS toward RGU, and surviving from ORS to RGU (Submodel I)
$\phi_{B2,E1}$	Joint probability of moving from ORS toward CVP, and surviving from ORS to CVP (Submodel I)
$\phi_{B3,B4}$	Joint probability of moving from WCL toward OR4, and surviving from WCL to OR4 (Submodel I)
$\phi_{B4,D1O}$	Joint probability of moving from OR4 toward RGU, surviving to RGU, and arriving when the radial gates are open (Submodel II)
$\phi_{B4,D1C}$	Joint probability of moving from OR4 toward RGU, surviving to RGU, and arriving when the radial gates are closed (Submodel II)
$\phi_{B4,D1}$	Joint probability of moving from OR4 toward RGU and surviving to RGU (Submodel II)
$\phi_{B4,E1}$	Joint probability of moving from OR4 toward CVP and surviving to CVP (Submodel II)
$\phi_{B4,GH(A)}$	Joint probability of moving from OR4 toward Jersey Point (JPE/JPW) or False River (FRE/FRW), and surviving from OR4 to JPE/JPW or FRE/FRW (Submodel II)
$\phi_{B4,GH(B)}$	Joint probability of moving from OR4 toward Jersey Point (JPE/JPW) or False River (FRE/FRW), and surviving from OR4 to JPE/JPW or FRE/FRW (Submodel I)
$\phi_{B4,G1(A)}$	Joint probability of moving from OR4 toward Jersey Point (JPE/JPW) and surviving from OR4 to JPE/JPW (Submodel II); = $\phi_{B4,GH(A)}\psi_{G1}$
$\phi_{B4,G1(B)}$	Joint probability of moving from OR4 toward Jersey Point (JPE/JPW) and surviving from OR4 to JPE/JPW (Submodel I); = $\phi_{B4,GH(B)}\psi_{G1}$
$\phi_{B5,B4}$	Joint probability of moving from OSJ directly toward OR4, and surviving from OSJ to OR4 (Submodel II)
$\phi_{B5,C2}$	Joint probability of moving from OSJ directly toward MR4, and surviving from OSJ to MR4 (Submodel II)
$\phi_{B5,GH}$	Joint probability of moving from OSJ directly toward Jersey Point (JPE/JPW) or False River (FRE/FRW), and surviving to JPE/JPW or FRE/FRW (Submodel II*)
$\phi_{B5,G1}$	Joint probability of moving from OSJ directly toward Jersey Point (JPE/JPW) and surviving to JPE/JPW (Submodel II*); = $\phi_{B5,GH(A)}\psi_{G1}$
$\phi_{C1,B3}$	Joint probability of moving from MRH toward WCL, and surviving from MRH to WCL (Submodel I)
$\phi_{C1,B4}$	Joint probability of moving from MRH toward OR4, and surviving from MRH to OR4 (Submodel I*); = $\phi_{C1,B3}\phi_{B3,B4}$
$\phi_{C1,C2}$	Joint probability of moving from MRH toward MR4, and surviving from MRH to MR4 (Submodel I)
$\phi_{C1,D1O}$	Joint probability of moving from MRH toward RGU, surviving to RGU, and arriving when the radial gates are open (Submodel I)
$\phi_{C1,D1C}$	Joint probability of moving from MRH toward RGU, surviving to RGU, and arriving when the radial gates are closed (Submodel I)
$\phi_{C1,D1}$	Joint probability of moving from MRH toward RGU, and surviving from MRH to RGU (Submodel I)
$\phi_{C1,E1}$	Joint probability of moving from MRH toward CVP, and surviving from MRH to CVP (Submodel I)

Table A1. (Continued)

Parameter	Definition
$\phi_{C2,D1O}$	Joint probability of moving from MR4 toward RGU, surviving to RGU, and arriving when the radial gates are open (Submodel II)
$\phi_{C2,D1C}$	Joint probability of moving from MR4 toward RGU, surviving to RGU, and arriving when the radial gates are closed (Submodel II)
$\phi_{C2,D1}$	Joint probability of moving from MR4 toward RGU and surviving to RGU (Submodel II)
$\phi_{C2,E1}$	Joint probability of moving from MR4 toward CVP and surviving to CVP (Submodel II)
$\phi_{C2,GH(A)}$	Joint probability of moving from MR4 toward Jersey Point (JPE/JPW) or False River (FRE/FRW), and surviving from MR4 to JPE/JPW or FRE/FRW (Submodel II)
$\phi_{C2,GH(B)}$	Joint probability of moving from MR4 toward Jersey Point (JPE/JPW) or False River (FRE/FRW), and surviving from MR4 to JPE/JPW or FRE/FRW (Submodel I)
$\phi_{C2,G1(A)}$	Joint probability of moving from MR4 toward Jersey Point (JPE/JPW) and surviving from MR4 to JPE/JPW (Submodel II); = $\phi_{C2,GH(A)}\psi_{G1}$
$\phi_{C2,G1(B)}$	Joint probability of moving from MR4 toward Jersey Point (JPE/JPW) and surviving from MR4 to JPE/JPW (Submodel I); = $\phi_{C2,GH(B)}\psi_{G1}$
$\phi_{D1O,D2(A)}$	Joint probability of moving from RGU toward RGD, and surviving from RGU to RGD, conditional on arrival at RGU when the radial gates are open (Submodel II)
$\phi_{D1O,D2(B)}$	Joint probability of moving from RGU toward RGD, and surviving from RGU to RGD, conditional on arrival at RGU when the radial gates are open (Submodel I)
$\phi_{D1C,D2(A)}$	Joint probability of moving from RGU toward RGD, and surviving from RGU to RGD, conditional on arrival at RGU when the radial gates are closed (Submodel II)
$\phi_{D1C,D2(B)}$	Joint probability of moving from RGU toward RGD, and surviving from RGU to RGD, conditional on arrival at RGU when the radial gates are closed (Submodel I)
$\phi_{D1,D2(A)}$	Joint probability of moving from RGU toward RGD, and surviving from RGU to RGD (Submodel II)
$\phi_{D1,D2(B)}$	Joint probability of moving from RGU toward RGD, and surviving from RGU to RGD (Submodel I)
$\phi_{D2,G2(A)}$	Joint probability of moving from RGD toward Chipps Island (MAE/MAW) and surviving from RGD to MAE/MAW (Submodel II)
$\phi_{E1,E2(A)}$	Joint probability of moving from CVP toward CVPtank and surviving from CVP to CVPtank (Submodel II)
$\phi_{E1,E2(B)}$	Joint probability of moving from CVP toward CVPtank and surviving from CVP to CVPtank (Submodel I)
$\phi_{E2,G2(A)}$	Joint probability of moving from CVPtank toward Chipps Island (MAE/MAW) and surviving from CVPtank to MAE/MAW (Submodel II)
$\phi_{E2,G2(B)}$	Joint probability of moving from CVPtank toward Chipps Island (MAE/MAW) and surviving from CVPtank to MAE/MAW (Submodel I)
$\phi_{F1,B4}$	Joint probability of moving from TCE/TCW directly toward OR4, and surviving from TCE/TCW to OR4 (Submodel II)
$\phi_{F1,C2}$	Joint probability of moving from TCE/TCW directly toward MR4, and surviving from TCE/TCW to MR4 (Submodel II)
$\phi_{F1,GH}$	Joint probability of moving from TCE/TCW directly toward Jersey Point (JPE/JPW) or False River (FRE/FRW), and surviving to JPE/JPW or FRE/FRW (Submodel II*)
$\phi_{F1,G1}$	Joint probability of moving from TCE/TCW directly toward Jersey Point (JPE/JPW) and surviving to JPE/JPW (Submodel II*); = $\phi_{F1,GH(A)}\psi_{G1}$
$\phi_{F1,G2}$	Joint probability of moving from TCE/TCW toward MAE/MAW, and surviving from TCE/TCW to MAE/MAW (Submodel II*)
$\phi_{F2,A14}$	Joint probability of moving from COL toward SJD, and surviving from COL to SJD (Submodel II)
$\phi_{F2,B4}$	Joint probability of moving from COL directly toward OR4, and surviving from COL to OR4 (Submodel II)
$\phi_{F2,B5}$	Joint probability of moving from COL directly toward OSJ, and surviving from COL to OSJ (Submodel II)
$\phi_{F2,C2}$	Joint probability of moving from COL directly toward MR4, and surviving from COL to MR4 (Submodel II)
$\phi_{F2,GH}$	Joint probability of moving from COL directly toward Jersey Point (JPE/JPW) or False River (FRE/FRW), and surviving to JPE/JPW or FRE/FRW (Submodel II*)
$\phi_{F2,G1}$	Joint probability of moving from COL directly toward Jersey Point (JPE/JPW) and surviving to JPE/JPW (Submodel II*); = $\phi_{F2,GH(A)}\psi_{G1}$
$\phi_{G1,G2(A)}$	Joint probability of moving from JPE/JPW toward Chipps Island (MAE/MAW), and surviving to MAE/MAW (Submodel II)

Table A1. (Continued)

Parameter	Definition
$\phi_{G1,G2(B)}$	Joint probability of moving from JPE/JPW toward Chipps Island (MAE/MAW), and surviving to MAE/MAW (Submodel I)
$\phi_{G2,G3}$	Joint probability of moving from Chipps Island (MAE/MAW) toward Benicia Bridge (BBR), and surviving from MAE/MAW to BRR
$\phi_{T1,G2}$	Joint probability of moving from TMS/TMN toward Chipps Island (MAE/MAW), and surviving to MAE/MAW (Submodel II)
ψ_{A1}	Probability of remaining in the San Joaquin River at the head of Old River; = 1 - ψ_{B1}
ψ_{A2}	Probability of remaining in the San Joaquin River at its upstream junction with Burns Cutoff; = 1 - ψ_{R2}
ψ_{A3}	Probability of remaining in the San Joaquin River at the junction with Turner Cut; = 1 - ψ_{F3}
ψ_{B1}	Probability of entering Old River at the head of Old River; = 1 - ψ_{A1}
ψ_{B2}	Probability of remaining in Old River at the head of Middle River; = 1 - ψ_{C2}
ψ_{C2}	Probability of entering Middle River at the head of Middle River; = 1 - ψ_{B2}
ψ_{F3}	Probability of entering Turner Cut at the junction with the San Joaquin River; = 1 - ψ_{A3}
ψ_{G1}	Probability of moving downriver in the San Joaquin River at the Jersey Point/False River junction (equated between submodels); = 1 - ψ_{H1}
ψ_{H1}	Probability of entering False River at the Jersey Point/False River junction (equated between submodels); = 1 - ψ_{G1}
ψ_{R2}	Probability of entering Burns Cutoff at its upstream junction with the San Joaquin River; = 1 - ψ_{R2}
P_{A0a}	Conditional probability of detection at DFU1
P_{A0b}	Conditional probability of detection at DFU2
P_{A0}	Conditional probability of detection at DFU (either DFU1 or DFU2)
P_{A2}	Conditional probability of detection at DFD
P_{A3}	Conditional probability of detection at BDF1
P_{A4}	Conditional probability of detection at BDF2
P_{A5}	Conditional probability of detection at BCA
P_{A6}	Conditional probability of detection at MOS
P_{A7a}	Conditional probability of detection at SJLU
P_{A7b}	Conditional probability of detection at SJLD
P_{A7}	Conditional probability of detection at SJL (either SJLU or SJLD)
P_{A8}	Conditional probability of detection at SJG
P_{A9}	Conditional probability of detection at SJNB
P_{A10}	Conditional probability of detection at SJC
P_{A11}	Conditional probability of detection at SJS
P_{A12a}	Conditional probability of detection at MACU
P_{A12b}	Conditional probability of detection at MACD
P_{A12}	Conditional probability of detection at MAC (either MACU or MACD)
P_{A13a}	Conditional probability of detection at MFE
P_{A13b}	Conditional probability of detection at MFW
P_{A13}	Conditional probability of detection at MFE/MFW (either MFE or MFW)
P_{A14a}	Conditional probability of detection at SJDU
P_{A14b}	Conditional probability of detection at SJDD
P_{A14}	Conditional probability of detection at SJD (either SJDU or SJDD)
P_{B1a}	Conditional probability of detection at OREU
P_{B1b}	Conditional probability of detection at ORED

Table A1. (Continued)

Parameter	Definition
P_{B1}	Conditional probability of detection at ORE (either OREU or ORED)
P_{B2a}	Conditional probability of detection at ORSU
P_{B2b}	Conditional probability of detection at ORSD
P_{B2}	Conditional probability of detection at ORS (either ORSU or ORSD)
P_{B3a}	Conditional probability of detection at WCLU
P_{B3b}	Conditional probability of detection at WCLD
P_{B3}	Conditional probability of detection at WCL (either WCLU or WCLD)
P_{B4a}	Conditional probability of detection at OR4U
P_{B4b}	Conditional probability of detection at OR4D
P_{B4}	Conditional probability of detection at OR4 (either OR4U or OR4D)
P_{B5a}	Conditional probability of detection at OSJU
P_{B5b}	Conditional probability of detection at OSJD
P_{B5}	Conditional probability of detection at OSJ (either OSJU or OSJD)
P_{C1a}	Conditional probability of detection at MRHU
P_{C1b}	Conditional probability of detection at MRHD
P_{C1}	Conditional probability of detection at MRH (either MRHU or MRHD)
P_{C2a}	Conditional probability of detection at MR4U
P_{C2b}	Conditional probability of detection at MR4D
P_{C2}	Conditional probability of detection at MR4 (either MR4U or MR4D)
P_{D1}	Conditional probability of detection at RGU
P_{D2}	Conditional probability of detection at RGD
P_{E1}	Conditional probability of detection at CVP
P_{E2}	Conditional probability of detection at CVPtank
P_{F1a}	Conditional probability of detection at TCE
P_{F1b}	Conditional probability of detection at TCW
P_{F1}	Conditional probability of detection at TCE/TCW (either TCE or TCW)
P_{F2a}	Conditional probability of detection at COLU
P_{F2b}	Conditional probability of detection at COLD
P_{F2}	Conditional probability of detection at COL (either COLU or COLD)
P_{G1a}	Conditional probability of detection at JPE
P_{G1b}	Conditional probability of detection at JPW
P_{G1}	Conditional probability of detection at JPE/JPW (either JPE or JPW)
P_{G2}	Conditional probability of detection at MAE/MAW
P_{G3a}	Conditional probability of detection at BBE
P_{G3b}	Conditional probability of detection at BBW
P_{G3}	Conditional probability of detection at BBR (either BBE or BBW)
P_{H1a}	Conditional probability of detection at FRW
P_{H1b}	Conditional probability of detection at FRE
P_{H1}	Conditional probability of detection at FRE/FRW (either FRE or FRW)
P_{R1a}	Conditional probability of detection at RRIU
P_{R1b}	Conditional probability of detection at RRID

Table A1. (Continued)

Parameter	Definition
P_{R1}	Conditional probability of detection at RRI (either RRIU or RRID)
P_{T1a}	Conditional probability of detection at TMS
P_{T1b}	Conditional probability of detection at TMN
P_{T1}	Conditional probability of detection at TMS/TMN (either TMS or TMN)

Table A2. Parameter estimates (standard errors or 95% bound [UB = upper bound, LB = lower bound] in parentheses) for tagged juvenile Steelhead released in 2016, excluding predator-type detections. Parameters without standard errors were estimated at fixed values in the model. Population-level estimates are weighted averages of the available release-specific estimates. Some parameters were not estimable because of sparse data.

Parameter	Release 1	Release 2	Release 3	Population Estimate
S_{A2}	0.74 (0.02)	0.93 (0.02)	0.98 (0.01)	0.88 (0.01)
S_{A3}	0.95 (0.02)	0.98 (0.03)	1.00 (0.01)	0.97 (0.01)
S_{A4}	0.91 (0.02)	0.95 (0.02)	0.98 (0.01)	0.95 (0.01)
S_{A5}	0.91 (0.02)	0.94 (0.02)	0.99 (<0.01)	0.95 (0.01)
S_{A6}	0.96 (0.01)	0.99 (<0.01)	1.00 (<0.01)	0.98 (<0.01)
S_{A7}	0.72 (0.09)	0.81 (0.04)	0.96 (0.01)	0.83 (0.03)
S_{A8}	0.94 (0.05)	0.93 (0.03)	0.98 (0.01)	0.95 (0.02)
$S_{A8,G2}$	0.34 (0.11)	0.63 (0.06)	0.64 (0.02)	0.53 (0.04)
S_{A9}	1 (95% LB: 0.84)	0.98 (0.02)	1.00 (<0.01)	0.99 (0.01)
$S_{A9,G2}$	0.36 (0.12)	0.67 (0.06)	0.65 (0.02)	0.56 (0.04)
S_{A10}	0.94 (0.06)	1 (95% LB: 0.95)	0.98 (0.01)	0.97 (0.02)
$S_{A10,G2}$	0.36 (0.12)	0.69 (0.06)	0.65 (0.02)	0.57 (0.04)
S_{A11}	0.94 (0.06)	1 (95% LB: 0.95)	0.97 (0.01)	0.97 (0.02)
$S_{A11,G2}$	0.38 (0.12)	0.69 (0.06)	0.67 (0.02)	0.58 (0.05)
$S_{A12,G2}$	0.34 (0.16)	0.83 (0.06)	0.81 (0.02)	0.66 (0.06)
$S_{A13,G2}$	0.50 (0.25)	0.79 (0.06)	0.87 (0.02)	0.72 (0.09)
S_{B1}	0.99 (0.01)	0.97 (0.01)	1 (95% LB: 0.82)	0.99 (<0.01)
$S_{B2,G2}$	0.43 (0.04)	0.41 (0.03)	0.20 (0.07)	0.35 (0.03)
$S_{B2(SD)}$	0.89 (0.02)	0.86 (0.02)	0.62 (0.14)	0.79 (0.05)
$S_{C1,G2}$				
$S_{C1(SD)}$				
$S_{F1,G2}$	0.50 (0.21)	0.33 (0.11)	0.31 (0.05)	0.38 (0.08)
S_{R1}			0.83 (0.15)	
$\phi_{A1,A0}$	0.08 (0.01)	0.02 (0.01)	0.04 (0.01)	0.05 (0.01)
$\phi_{A1,A2}$	0.76 (0.02)	0.96 (0.01)	0.94 (0.01)	0.88 (0.01)
$\phi_{A1,A5}$	0.48 (0.02)	0.83 (0.02)	0.90 (0.01)	0.74 (0.01)
$\phi_{A1,A6}$	0.44 (0.02)	0.78 (0.02)	0.89 (0.01)	0.70 (0.01)
$\phi_{A12,A13}$	0.44 (0.17)	0.87 (0.05)	0.75 (0.03)	0.69 (0.06)
$\phi_{A12,F2}$		0.11 (0.05)	0.20 (0.02)	0.16 (0.03)
$\phi_{A12,G2}$	0.11 (0.10)	0.07 (0.04)	0.15 (0.02)	0.11 (0.04)
$\phi_{A13,A14}$		0.72 (0.07)	0.81 (0.03)	0.76 (0.04)
$\phi_{A13,B4}$			0.01 (0.01)	
$\phi_{A13,B5}$		0.21 (0.06)	0.10 (0.02)	0.15 (0.03)
$\phi_{A13,C2}$			0.02 (0.01)	
$\phi_{A13,GH}$				
$\phi_{A13,G1}$		0.03[a] (0.03)	0.02[b] (0.01)	0.03 (0.01)
$\phi_{A13,G2}$	0.50 (0.25)	0.79 (0.06)	0.87 (0.02)	0.72 (0.09)

a = includes possibility of passing via OR4 or MR4 on way to JPE/JPW

b = probability of going to JPE/JPW directly without passing OR4 or MR4

Table A2. (Continued)

Parameter	Release 1	Release 2	Release 3	Population Estimate
$\phi_{A14,GH}$				
$\phi_{A14,G1}$		0.95 (0.05)	0.85 (0.03)	0.90 (0.03)
$\phi_{A14,T1}$		0.03 (0.03)	0.11 (0.02)	0.07 (0.02)
$\phi_{B2,B3}$		0.06 (0.01)		
$\phi_{B2,B4}$	0.01 (0.01)	0.04 (0.01)	0 (95% UB: 0.20)	0.02 (0.01)
$\phi_{B2,C2}$	0 (95% UB: 0.02)	0.01 (0.01)	0 (95% UB: 0.20)	0.00 (<0.01)
$\phi_{B2,D1O}$	0.17 (0.03)	0.21 (0.02)	0.19 (0.07)	0.19 (0.03)
$\phi_{B2,D1C}$	0.04 (0.02)	0.03 (0.01)	0.19 (0.07)	0.09 (0.02)
$\phi_{B2,D1}$	0.21 (0.03)	0.24 (0.03)	0.39 (0.14)	0.28 (0.05)
$\phi_{B2,E1}$	0.67 (0.04)	0.57 (0.03)	0.23 (0.12)	0.49 (0.04)
$\phi_{B3,B4}$		0.67 (0.19)		
$\phi_{B4,D1O}$			0.10 (0.04)	
$\phi_{B4,D1C}$			0.10 (0.04)	
$\phi_{B4,D1}$			0.20 (0.08)	
$\phi_{B4,E1}$			0.60 (0.10)	
$\phi_{B4,GH(A)}$				
$\phi_{B4,GH(B)}$				
$\phi_{B4,G1(A)}$			0.04 (0.04)	
$\phi_{B4,G1(B)}$		0.38 (0.17)		
$\phi_{B5,B4}$			0 (95% UB: 0.10)	
$\phi_{B5,C2}$			0 (95% UB: 0.10)	
$\phi_{B5,GH}$				
$\phi_{B5,G1}$		1[a] (95% LB: 0.74)	0.93[b] (0.05)	0.96 (0.02)
$\phi_{C1,B3}$				
$\phi_{C1,B4}$				
$\phi_{C1,C2}$				
$\phi_{C1,D1O}$				
$\phi_{C1,D1C}$				
$\phi_{C1,D1}$				
$\phi_{C1,E1}$				
$\phi_{C2,D1O}$			0.20 (0.06)	
$\phi_{C2,D1C}$			0.20 (0.06)	
$\phi_{C2,D1}$			0.40 (0.11)	
$\phi_{C2,E1}$			0.45 (0.11)	
$\phi_{C2,GH(A)}$				
$\phi_{C2,GH(B)}$				
$\phi_{C2,G1(A)}$			0 (95% UB: 0.14)	
$\phi_{C2,G1(B)}$		0 (95% UB: 0.56)		

a = includes possibility of passing via OR4 or MR4 on way to JPE/JPW

b = probability of going to JPE/JPW directly without passing OR4 or MR4

Table A2. (Continued)

Parameter	Release 1	Release 2	Release 3	Population Estimate
$\phi_{D1O,D2(A)}$			0.82^{cd} (0.09)	
$\phi_{D1O,D2(B)}$	1.05 (0.06)	0.99 (0.02)	0.82^{cd} (0.09)	0.96 (0.04)
$\phi_{D1C,D2(A)}$			0.82^{cd} (0.09)	
$\phi_{D1C,D2(B)}$	1 (95% LB: 0.57)	1 (95% LB: 0.75)	0.82^{cd} (0.09)	0.94 (0.03)
$\phi_{D1,D2(A)}$			0.82^{c} (0.09)	
$\phi_{D1,D2(B)}$	1.04 (0.05)	0.99 (0.02)	0.82^{c} (0.09)	0.95 (0.04)
$\phi_{D2,G2(A)}$			0.33^{c} (0.12)	
$\phi_{D2,G2(B)}$	0.45 (0.08)	0.56 (0.06)	0.33^{c} (0.12)	0.45 (0.05)
$\phi_{E1,E2(A)}$			0.44^{c} (0.10)	
$\phi_{E1,E2(B)}$	0.59 (0.05)	0.54 (0.04)	0.44^{c} (0.10)	0.53 (0.04)
$\phi_{E2,G2(A)}$			0.92^{c} (0.08)	
$\phi_{E2,G2(B)}$	0.85 (0.05)	0.86 (0.04)	0.92^{c} (0.08)	0.88 (0.03)
$\phi_{F1,B4}$			0.21 (0.04)	
$\phi_{F1,C2}$			0.12 (0.03)	
$\phi_{F1,GH}$				
$\phi_{F1,G1}$		0.56^{a} (0.12)	0.21^{b} (0.04)	0.39 (0.06)
$\phi_{F1,G2}$	0.50 (0.20)	0.47 (0.10)	0.31 (0.04)	0.43 (0.08)
$\phi_{F2,A14}$		0.60 (0.22)	0.49 (0.07)	0.55 (0.11)
$\phi_{F2,B4}$			0.07 (0.04)	
$\phi_{F2,B5}$		0 (95% UB: 0.45)	0.15 (0.05)	0.07 (0.02)
$\phi_{F2,C2}$			0.07 (0.04)	
$\phi_{F2,GH}$				
$\phi_{F2,G1}$		0.20^{a} (0.18)	0.13^{b} (0.04)	0.16 (0.09)
$\phi_{G1,G2(A)}$		0.84^{c} (0.05)	0.98 (0.01)	0.91 (0.03)
$\phi_{G1,G2(B)}$		0.84^{c} (0.05)		
$\phi_{G2,G3}$	0.86 (0.04)	0.96 (0.02)	0.99 (0.01)	0.94 (0.02)
$\phi_{T1,G2}$		1 (95% LB: 0.05)	0.91 (0.06)	0.95 (0.03)
ψ_{A1}	0.12 (0.02)	0.23 (0.02)	0.96 (0.01)	0.44 (0.01)
ψ_{A2}	1	1	0.98 (0.01)	0.99 (<0.01)
ψ_{A3}	0.60 (0.13)	0.71 (0.06)	0.75 (0.02)	0.69 (0.05)
ψ_{B1}	0.88 (0.02)	0.77 (0.02)	0.04 (0.01)	0.56 (0.01)
ψ_{B2}	0.99 (0.01)	1	0.87 (0.09)	0.95 (0.03)
ψ_{C2}	0.01 (0.01)	0	0.13 (0.09)	0.05 (0.03)
ψ_{F3}	0.40 (0.13)	0.29 (0.06)	0.25 (0.02)	0.31 (0.05)
ψ_{G1}				
ψ_{H1}				
ψ_{R2}	0	0	0.02 (0.01)	0.01 (<0.01)
P_{A0a}	1	1	0.88 (0.12)	0.96 (0.04)

a = includes possibility of passing via OR4 or MR4 on way to JPE/JPW

b = probability of going to JPE/JPW directly without passing OR4 or MR4

c = parameter equated between submodels Ic and IIa based on likelihood ratio test ($\alpha \geq 0.05$)

d = parameter equated between open and closed gate status based on likelihood ratio test ($\alpha \geq 0.05$)

Table A2. (Continued)

Parameter	Release 1	Release 2	Release 3	Population Estimate
P_{A0b}	0.68 (0.08)	0.60 (0.15)	0.39 (0.11)	0.55 (0.07)
P_{A0}	1	1	0.92 (0.08)	0.97 (0.03)
P_{A2}	1.00 (<0.01)	0.85 (0.02)	0.93 (0.01)	0.93 (0.01)
P_{A3}	0.84 (0.02)	0.30 (0.02)	0.43 (0.02)	0.52 (0.01)
P_{A4}	0.87 (0.02)	0.39 (0.02)	0.45 (0.02)	0.57 (0.01)
P_{A5}	0.96 (0.01)	0.51 (0.03)	0.88 (0.02)	0.78 (0.01)
P_{A6}	1	1	1	1
P_{A7a}	1	0.98 (0.02)	0.99 (0.01)	0.99 (0.01)
P_{A7b}	1	1	1	1
P_{A7}	1	1	1	1
P_{A8}	1	1	1	1
P_{A9}	1	1	0.99 (<0.01)	0.99 (<0.01)
P_{A10}	1	1	1	1
P_{A11}	1	1	1.00 (<0.01)	1.00 (<0.01)
P_{A12a}	1	1		1
P_{A12b}	0.89 (0.10)	1		0.94 (0.05)
P_{A12}	1	1	1.00 (<0.01)	1.00 (<0.01)
P_{A13a}	1	1	0.99 (0.01)	1.00 (<0.01)
P_{A13b}	1	1	1	1
P_{A13}	1	1	1	1
P_{A14a}		1	1	1
P_{A14b}		1	0.97 (0.01)	0.98 (0.01)
P_{A14}		1	1	1
P_{B1a}	1	1	1	1
P_{B1b}	1	1	1	1
P_{B1}	1	1	1	1
P_{B2a}	0.99 (0.01)		0.92 (0.07)	0.96 (0.04)
P_{B2b}	1		1	1
P_{B2}	1	1	1	1
P_{B3a}		1		
P_{B3b}		1		
P_{B3}		1		
P_{B4a}	1		1	1
P_{B4b}	1		1	1
P_{B4}	1	0.75 (0.22)	1	0.92 (0.07)
P_{B5a}		1	1	1
P_{B5b}		1	1	1
P_{B5}		1	1	1
P_{C1a}	1^e	1^e	1	1
P_{C1b}	1^e	1^e	1	1
P_{C1}	1^e	1^e	1	1

e = assumed value; data too sparse to estimate freely

Table A2. (Continued)

Parameter	Release 1	Release 2	Release 3	Population Estimate
P_{C2a}	1^e	1	1	1
P_{C2b}	1^e	1	1	1
P_{C2}	1^e	1	1	1
P_{D1}	0.97 (0.03)	0.94 (0.03)	0.93 (0.06)	0.95 (0.03)
P_{D2}	0.86 (0.08)	0.98 (0.02)	1	0.94 (0.03)
P_{E1}	1	1	1	1
P_{E2}	1	1	1	1
P_{F1a}	1	1	1	1
P_{F1b}	1	1	1	1
P_{F1}	1	1	1	1
P_{F2a}		1		
P_{F2b}		1		
P_{F2}		1	0.98 (0.02)	0.99 (0.01)
P_{G1a}				
P_{G1b}				
P_{G1}		0.94 (0.04)	0.96 (0.01)	0.95 (0.02)
P_{G2}	0.95 (0.03)	0.93 (0.02)	0.93 (0.02)	0.94 (0.01)
P_{G3a}	0.98 (0.02)	0.99 (0.01)	0.94 (0.01)	0.97 (0.01)
P_{G3b}	0.97 (0.02)	0.99 (0.01)	0.99 (0.01)	0.98 (0.01)
P_{G3}	1.00 (<0.01)	1.00 (<0.01)	1.00 (<0.01)	1.00 (<0.01)
P_{H1a}				
P_{H1b}				
P_{H1}				
P_{R1a}	1^e	1^e	1	1
P_{R1b}	1^e	1^e	1	1
P_{R1}	1^e	1^e	1	1
P_{T1a}		1^e	1	1
P_{T1b}		1^e	1	1
P_{T1}		1^e	1	1

e = assumed value; data too sparse to estimate freely

Table A3. Parameter estimates (standard errors or 95% bound [UB = upper bound, LB = lower bound] in parentheses) for tagged juvenile Steelhead released in 2016, including predator-type detections. Parameters without standard errors were estimated at fixed values in the model. Population-level estimates are weighted averages of the available release-specific estimates. Some parameters were not estimable because of sparse data.

Parameter	Release 1	Release 2	Release 3	Population Estimate
S_{A2}	0.74 (0.02)	0.92 (0.02)	0.98 (0.01)	0.88 (0.01)
S_{A3}	0.95 (0.02)	0.99 (0.03)	0.99 (0.01)	0.98 (0.01)
S_{A4}	0.92 (0.02)	0.95 (0.02)	0.97 (0.01)	0.95 (0.01)
S_{A5}	0.92 (0.02)	0.94 (0.02)	1.00 (<0.01)	0.95 (0.01)
S_{A6}	0.97 (0.01)	0.99 (<0.01)	1.00 (<0.01)	0.99 (<0.01)
S_{A7}	0.78 (0.08)	0.81 (0.04)	0.98 (0.01)	0.86 (0.03)
S_{A8}	0.95 (0.05)	0.97 (0.02)	0.99 (<0.01)	0.97 (0.02)
$S_{A8,G2}$	0.29 (0.10)	0.63 (0.06)	0.66 (0.02)	0.53 (0.04)
S_{A9}	1 (95% LB: 0.86)	0.99 (0.01)	0.98 (0.01)	0.99 (0.01)
$S_{A9,G2}$	0.30 (0.10)	0.64 (0.06)	0.67 (0.02)	0.54 (0.04)
S_{A10}	0.95 (0.05)	1 (95% LB: 0.96)	0.99 (0.01)	0.98 (0.02)
$S_{A10,G2}$	0.30 (0.10)	0.65 (0.06)	0.68 (0.02)	0.55 (0.04)
S_{A11}	0.95 (0.05)	1 (95% LB: 0.96)	0.99 (0.01)	0.98 (0.02)
$S_{A11,G2}$	0.32 (0.11)	0.65 (0.06)	0.69 (0.02)	0.55 (0.04)
$S_{A12,G2}$	0.30 (0.15)	0.81 (0.06)	0.83 (0.02)	0.65 (0.05)
$S_{A13,G2}$	0.40 (0.22)	0.77 (0.06)	0.89 (0.02)	0.69 (0.08)
S_{B1}	0.99 (0.01)	0.98 (0.01)	1 (95% LB: 0.82)	0.99 (<0.01)
$S_{B2,G2}$	0.44 (0.04)	0.40 (0.03)	0.25 (0.07)	0.36 (0.03)
$S_{B2(SD)}$	0.91 (0.02)	0.88 (0.02)	0.67 (0.12)	0.82 (0.04)
$S_{C1,G2}$				
$S_{C1(SD)}$				
$S_{F1,G2}$	0.38 (0.17)	0.30 (0.10)	0.31 (0.05)	0.33 (0.07)
S_{R1}			1 (95% LB: 0.65)	
$\phi_{A1,A0}$	0.08 (0.01)	0.02 (0.01)	0.05 (0.01)	0.05 (0.01)
$\phi_{A1,A2}$	0.75 (0.02)	0.96 (0.01)	0.94 (0.01)	0.88 (0.01)
$\phi_{A1,A5}$	0.49 (0.02)	0.83 (0.02)	0.89 (0.01)	0.74 (0.01)
$\phi_{A1,A6}$	0.45 (0.02)	0.78 (0.02)	0.89 (0.01)	0.71 (0.01)
$\phi_{A12,A13}$	0.50 (0.16)	0.87 (0.05)	0.76 (0.03)	0.71 (0.06)
$\phi_{A12,F2}$		0.11 (0.05)	0.20 (0.02)	0.15 (0.03)
$\phi_{A12,G2}$	0.10 (0.09)	0.07 (0.03)	0.15 (0.02)	0.11 (0.03)
$\phi_{A13,A14}$		0.73 (0.07)	0.82 (0.03)	0.77 (0.04)
$\phi_{A13,B4}$			0.01 (0.01)	
$\phi_{A13,B5}$		0.20 (0.06)	0.10 (0.02)	0.15 (0.03)
$\phi_{A13,C2}$			0.02 (0.01)	
$\phi_{A13,GH}$				
$\phi_{A13,G1}$		0.03[a] (0.02)	0.02[b] (0.01)	0.02 (0.01)
$\phi_{A13,G2}$	0.40 (0.22)	0.77 (0.06)	0.89 (0.02)	0.69 (0.08)

a = includes possibility of passing via OR4 or MR4 on way to JPE/JPW

b = probability of going to JPE/JPW directly without passing OR4 or MR4

Table A3. (Continued)

Parameter	Release 1	Release 2	Release 3	Population Estimate
$\phi_{A14,GH}$				
$\phi_{A14,G1}$		0.92 (0.05)	0.86 (0.02)	0.89 (0.03)
$\phi_{A14,T1}$		0.03 (0.03)	0.11 (0.02)	0.07 (0.02)
$\phi_{B2,B3}$		0.06 (0.01)		
$\phi_{B2,B4}$	0.01 (0.01)	0.05 (0.02)	0 (95% UB: 0.18)	0.02 (0.01)
$\phi_{B2,C2}$	0 (95% UB: 0.02)	0.01 (0.01)	0 (95% UB: 0.18)	0.00 (<0.01)
$\phi_{B2,D1O}$	0.17 (0.03)	0.21 (0.02)	0.17 (0.06)	0.18 (0.02)
$\phi_{B2,D1C}$	0.05 (0.02)	0.04 (0.01)	0.17 (0.06)	0.09 (0.02)
$\phi_{B2,D1}$	0.22 (0.03)	0.25 (0.03)	0.34 (0.12)	0.27 (0.04)
$\phi_{B2,E1}$	0.68 (0.04)	0.58 (0.03)	0.33 (0.12)	0.53 (0.04)
$\phi_{B3,B4}$		0.83 (0.22)		
$\phi_{B4,D1O}$			0.12 (0.04)	
$\phi_{B4,D1C}$			0.12 (0.04)	
$\phi_{B4,D1}$			0.24 (0.08)	
$\phi_{B4,E1}$			0.52 (0.09)	
$\phi_{B4,GH(A)}$				
$\phi_{B4,GH(B)}$				
$\phi_{B4,G1(A)}$			0.07 (0.05)	
$\phi_{B4,G1(B)}$		0.30 (0.15)		
$\phi_{B5,B4}$			0.03 (0.03)	
$\phi_{B5,C2}$			0 (95% UB: 0.10)	
$\phi_{B5,GH}$				
$\phi_{B5,G1}$		1^{a} (95% LB: 0.74)	0.97^{b} (0.03)	0.98 (0.02)
$\phi_{C1,B3}$				
$\phi_{C1,B4}$				
$\phi_{C1,C2}$				
$\phi_{C1,D1O}$				
$\phi_{C1,D1C}$				
$\phi_{C1,D1}$				
$\phi_{C1,E1}$				
$\phi_{C2,D1O}$			0.18 (0.05)	
$\phi_{C2,D1C}$			0.18 (0.05)	
$\phi_{C2,D1}$			0.35 (0.11)	
$\phi_{C2,E1}$			0.45 (0.11)	
$\phi_{C2,GH(A)}$				
$\phi_{C2,GH(B)}$				
$\phi_{C2,G1(A)}$			0 (95% UB: 0.14)	
$\phi_{C2,G1(B)}$		0 (95% UB: 0.56)		

a = includes possibility of passing via OR4 or MR4 on way to JPE/JPW

b = probability of going to JPE/JPW directly without passing OR4 or MR4

Table A3. (Continued)

Parameter	Release 1	Release 2	Release 3	Population Estimate
$\phi_{D1O,D2(A)}$			0.83^{cd} (0.09)	
$\phi_{D1O,D2(B)}$	1.08 (0.08)	0.99 (0.02)	0.83^{cd} (0.09)	0.97 (0.04)
$\phi_{D1C,D2(A)}$			0.83^{cd} (0.09)	
$\phi_{D1C,D2(B)}$	0.99 (0.13)	0.91 (0.10)	0.83^{cd} (0.09)	0.91 (0.06)
$\phi_{D1,D2(A)}$			0.83^{cd} (0.09)	
$\phi_{D1,D2(B)}$	1.06 (0.08)	0.98 (0.02)	0.83^{cd} (0.09)	0.96 (0.04)
$\phi_{D2,G2(A)}$			0.31^{c} (0.12)	
$\phi_{D2,G2(B)}$	0.42 (0.09)	0.55 (0.06)	0.31^{c} (0.12)	0.43 (0.05)
$\phi_{E1,E2(A)}$			0.52^{c} (0.09)	
$\phi_{E1,E2(B)}$	0.58 (0.04)	0.52 (0.04)	0.52^{c} (0.09)	0.54 (0.04)
$\phi_{E2,G2(A)}$			0.94^{c} (0.06)	
$\phi_{E2,G2(B)}$	0.86 (0.05)	0.87 (0.04)	0.94^{c} (0.06)	0.89 (0.03)
$\phi_{F1,B4}$			0.21 (0.04)	
$\phi_{F1,C2}$			0.12 (0.03)	
$\phi_{F1,GH}$				
$\phi_{F1,G1}$		0.51^{a} (0.11)	0.20^{b} (0.04)	0.35 (0.06)
$\phi_{F1,G2}$	0.37 (0.17)	0.43 (0.10)	0.31 (0.04)	0.37 (0.07)
$\phi_{F2,A14}$		0.60 (0.22)	0.52 (0.07)	0.56 (0.11)
$\phi_{F2,B4}$			0.09 (0.04)	
$\phi_{F2,B5}$		0 (95% UB: 0.45)	0.13 (0.04)	0.06 (0.02)
$\phi_{F2,C2}$			0.05 (0.03)	
$\phi_{F2,GH}$				
$\phi_{F2,G1}$		0.20^{a} (0.18)	0.13^{b} (0.04)	0.16 (0.09)
$\phi_{G1,G2(A)}$		0.84^{c} (0.05)	0.97 (0.01)	0.90 (0.03)
$\phi_{G1,G2(B)}$		0.84^{c} (0.05)		
$\phi_{G2,G3}$	0.86 (0.04)	0.97 (0.02)	0.98 (0.01)	0.94 (0.02)
$\phi_{T1,G2}$		1 (95% LB: 0.05)	0.92 (0.06)	0.96 (0.03)
ψ_{A1}	0.13 (0.02)	0.23 (0.02)	0.96 (0.01)	0.44 (0.01)
ψ_{A2}	1	1	0.98 (0.01)	0.99 (<0.01)
ψ_{A3}	0.56 (0.12)	0.70 (0.06)	0.74 (0.02)	0.66 (0.04)
ψ_{B1}	0.87 (0.02)	0.77 (0.02)	0.04 (0.01)	0.56 (0.01)
ψ_{B2}	0.99 (0.01)	1	1	1.00 (<0.01)
ψ_{C2}	0.01 (0.01)	0	0	0.00 (<0.01)
ψ_{F3}	0.44 (0.12)	0.30 (0.06)	0.26 (0.02)	0.34 (0.04)
ψ_{G1}				
ψ_{H1}				
ψ_{R2}	0	0	0.02 (0.01)	0.01 (<0.01)
P_{A0a}	1	1	0.92 (0.07)	0.97 (0.02)

a = includes possibility of passing via OR4 or MR4 on way to JPE/JPW

b = probability of going to JPE/JPW directly without passing OR4 or MR4

c = parameter equated between submodels Ic and IIa based on likelihood ratio test ($\alpha \geq 0.05$)

d = parameter equated between open and closed gate status based on likelihood ratio test ($\alpha \geq 0.05$)

Table A3. (Continued)

Parameter	Release 1	Release 2	Release 3	Population Estimate
P_{A0b}	0.68 (0.08)	0.60 (0.15)	0.55 (0.11)	0.61 (0.07)
P_{A0}	1	1	0.97 (0.04)	0.99 (0.01)
P_{A2}	1.00 (<0.01)	0.85 (0.02)	0.93 (0.01)	0.93 (0.01)
P_{A3}	0.84 (0.02)	0.30 (0.02)	0.44 (0.02)	0.53 (0.01)
P_{A4}	0.87 (0.02)	0.39 (0.02)	0.45 (0.02)	0.57 (0.01)
P_{A5}	0.96 (0.01)	0.51 (0.03)	0.88 (0.02)	0.78 (0.01)
P_{A6}	1	1	1	1
P_{A7a}	1	0.98 (0.02)	0.98 (0.01)	0.99 (0.01)
P_{A7b}	1	1	1	1
P_{A7}	1	1	1	1
P_{A8}	1	1	1	1
P_{A9}	1	1	0.99 (0.00)	1.00 (<0.01)
P_{A10}	1	1	1	1
P_{A11}	1	1	1.00 (0.00)	1.00 (<0.01)
P_{A12a}	1	1		1
P_{A12b}	0.90 (0.09)	1		0.95 (0.05)
P_{A12}	1	1	1.00 (<0.01)	1.00 (<0.01)
P_{A13a}	1	1	0.98 (0.01)	0.99 (<0.01)
P_{A13b}	1	1	0.99 (0.01)	1.00 (<0.01)
P_{A13}	1	1	1.00 (<0.01)	1.00 (<0.01)
P_{A14a}		1	1	1
P_{A14b}		1	0.97 (0.01)	0.99 (0.01)
P_{A14}		1	1	1
P_{B1a}	1	1	1	1
P_{B1b}	1	1	1	1
P_{B1}	1	1	1	1
P_{B2a}	0.99 (0.01)		0.93 (0.06)	0.96 (0.03)
P_{B2b}	1		1	1
P_{B2}	1	1	1	1
P_{B3a}		1		
P_{B3b}		1		
P_{B3}		1		
P_{B4a}	1^e		1	1
P_{B4b}	1^e		1	1
P_{B4}	1^e	0.75 (0.22)	1	0.92 (0.07)
P_{B5a}		1	1	1
P_{B5b}		1	1	1
P_{B5}		1	1	1
P_{C1a}	1^e	1^e	1^e	1^e
P_{C1b}	1^e	1^e	1^e	1^e
P_{C1}	1^e	1^e	1^e	1^e

e = assumed value; data too sparse to estimate freely

Table A3. (Continued)

Parameter	Release 1	Release 2	Release 3	Population Estimate
P_{C2a}	1^e	1	1	1
P_{C2b}	1^e	1	1	1
P_{C2}	1^e	1	1	1
P_{D1}	0.97 (0.03)	0.94 (0.03)	0.94 (0.06)	0.95 (0.02)
P_{D2}	0.82 (0.09)	0.97 (0.03)	1	0.93 (0.03)
P_{E1}	1	1	1	1
P_{E2}	1	1	1	1
P_{F1a}	1	1	1	1
P_{F1b}	1	1	1	1
P_{F1}	1	1	1	1
P_{F2a}		1	1	1
P_{F2b}		1	1	1
P_{F2}		1	1	1
P_{G1a}				
P_{G1b}				
P_{G1}		0.94 (0.04)	0.96 (0.01)	0.95 (0.02)
P_{G2}	0.95 (0.03)	0.93 (0.02)	0.93 (0.02)	0.94 (0.01)
P_{G3a}	0.98 (0.02)	0.98 (0.01)	0.94 (0.01)	0.97 (0.01)
P_{G3b}	0.97 (0.02)	0.99 (0.01)	0.99 (0.01)	0.98 (0.01)
P_{G3}	1.00 (<0.01)	1.00 (<0.01)	1.00 (<0.01)	1.00 (<0.01)
P_{H1a}				
P_{H1b}				
P_{H1}				
P_{R1a}	1^e	1^e	1	1
P_{R1b}	1^e	1^e	1	1
P_{R1}	1^e	1^e	1	1
P_{T1a}		1^e	1	1
P_{T1b}		1^e	1	1
P_{T1}		1^e	1	1

e = assumed value; data too sparse to estimate freely