2015 Six-Year Acoustic Telemetry Steelhead Study: Statistical Methods and Results

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Executive Summary

A total of 1,427 acoustic-tagged steelhead were released into the San Joaquin River at Durham Ferry in March and April of 2015: 480 in early March, 478 in late March, and 469 in late April. Detection data were also available from 150 acoustic tags implanted into several species of predatory fish released in the Delta in April 2015. Acoustic tags were detectable on VEMCO hydrophones located at 43 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 2015. 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 0.15 ($\widehat{SE}=$0.03) for the early March release group, to 0.35 ($\widehat{SE}=$0.03) for the late March release group; the overall population estimate (weighted average) across the three releases was 0.23 ($\widehat{SE}=$0.02). The estimated probability of entering Old River at its head was high for the early March release group (0.81, $\widehat{SE}=$ 0.03), the majority of which arrived at the river junction before the barrier was installed at the head of Old River. The probability of entering Old River at its head was considerably lower for the late March (0.59, $\widehat{SE}=$0.03) and April (0.20, $\widehat{SE}=$0.05) releases; the barrier was present for passage of 35% of the late March release group, and 100% of the April release group. Estimates of survival from Mossdale to Chipps Island via the San Joaquin River route (S_A) ranged from 0.19 ($\widehat{SE}=$0.07) for the fish released in early March to 0.46 ($\widehat{SE}=$0.05) for those released in late March; the average over all three release groups was 0.30 ($\widehat{SE}=$0.03). In the Old River route, estimates of survival from Mossdale to Chipps Island (S_B) ranged from 0.05 ($\widehat{SE}=$0.05) for the April release to 0.27 ($\widehat{SE}=$0.04) for the late March release (population estimate = 0.16, $\widehat{SE}=$0.02). The route-specific survival to Chipps Island was significantly different between routes only for the late March release group, when survival was higher in the San Joaquin River route than in the Old River route (P=0.0032).

Travel time from release at Durham Ferry to Chipps Island ranged from 5.0 days to 50.9 days, and averaged 14.3 days ($\widehat{SE} = 0.67$ days) across all three release groups. Average travel time the Chipps Island was shorter for the later release groups: 20.7 days for the early March release, and 10.3 days for the April release. Travel time from release averaged approximately 4 days to the Mossdale receivers, and approximately 9 days to the Turner Cut junction (i.e., either Turner Cut receivers or MacDonald Island receivers).

A barrier was in place (i.e., after barrier closure during installation) at the head of Old River for passage of approximately 34% of the tagged steelhead in the 2015 tagging study. Of the tagged steelhead that arrived at the head of Old River before the barrier closure during installation, all but 22 (8%) 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; no covariates had a statistically significant association with route selection (P≥0.4782 for each covariate). At the Turner Cut junction, all but 11 tagged steelhead selected the San Joaquin River route, resulting in low statistical power to detect associations between route selection and covariates. No associations between route selection at Turner Cut and covariates were statistically significant (P≥0.4017 for each covariate).

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Introduction

A total of 1,427 acoustic-tagged juvenile steelhead were released into the San Joaquin River at Durham Ferry in March and April of 2015: 480 in early March, 478 in late March, and 469 in late April. 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 43 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 150 acoustic tags implanted into several species of predatory fish released in the Delta in April 2015. A rock barrier was installed at the head of Old River in early April 2015; closure of the barrier was on 3 April 2015, and the barrier was breached on 1 June 2015. A rock barrier was installed at False River in 2015, blocking direct access from the San Joaquin River to False River; this barrier was not near completion until late May, by which time all remaining tag detections were observed only in regions upstream of Stockton and at the Central Valley Project. Thus, the False River barrier was not expected to have affected the migration of the tagged steelhead in the 2015 study.

VEMCO acoustic hydrophones and receivers were installed at 43 stations throughout the lower San Joaquin River and Delta in 2015 (Figure 1, Table 1). All of the receiver stations used in 2014 (Buchanan 2018) were also used in 2015. Five new receiver stations were used in 2015: in the San Joaquin River between Durham Ferry and Banta Carbona (BDF1 = model code A3, BDF2 = A4), just upstream of Turner Cut (SJS = A10), and at Disappointment Slough (SJD = A13), and in Columbia Cut (COL = F2).

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 2015, 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. Unlike in previous years, none of the tags used in the release study were deactivated and then later reactivated; all tags 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. 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 would depend on the amount of predation by predatory fish and the spatial distribution of the predatory fish after eating the tagged steelhead. In order 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 2015 data was based on the predator filter designed and used in the analysis of the 2011–2014 data (USBR 2018a, 2018b, 2018c; Buchanan 2018). 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 2015 filter was applied to all detections of all tags implanted in steelhead. Two datasets were then constructed: the full 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 juvenile steelhead (i.e., “steelhead-type”). The survival model was fit to both datasets separately. The results from the analysis of the reduced “steelhead-type” dataset are presented as the final results of the 2015 steelhead 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, or atypical movements within the Delta. 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 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, downloaded from the California Data Exchange Center website (http://cdec.water.ca.gov/selectQuery.html) on 14 September or 22 September 2016, and from the California Water Data Library (www.water.ca.gov/waterdatalibrary/) on 18 July 2016. 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 14 September 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 steelhead. A tag was classified as a predator upon the first exhibition of predator-type behavior, with the acknowledged uncertainty that the steelhead 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. 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 2011–2014 studies were updated to reflect river conditions and observed tag detection patterns in 2015, and to represent transitions observed among the 2015 detection sites (Table 1). The 2015 filter was also expanded to accommodate the new receiver sites in 2015: BDF1, BDF2, SJS, SJD, and COL (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 juvenile steelhead rather than in steelhead predators. More weight was given to 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 2011–2014 predator filters (USBR 2018a, 2018b, 2018c; Buchanan 2018).

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., JPT/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 JPT/JPE/JPW–BBR sites. This group may include tagged fish that migrated from the CCFB entrance to the JPT/JPE/JPW–BBR region in-river, evading detection at the multiple Old River and Middle River receivers north of the CCFB. While this 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., JPT/JPE/JPW–BBR).

Additionally, in 2015, ten acoustic-tagged steelhead were recaptured after release, all in the Mossdale trawl. The tags were recaptured in the trawl 3.5–41.8 days after initial release at Durham Ferry. The 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. 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 and 2014 studies was also used for the 2015 study; no new criteria were developed for the 2015 study. As in the 2014 predator filter, but a change from older filters, the 2015 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, 2012, 2013, and 2014 studies in USBR (2018a, 2018b, 2018c) and Buchanan (2018).

The 2015 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 1,100 hours. The default maximum total visit length at a site was 500 hours (approximately 21 days), although it was considerably longer 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 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 1,100 hours upstream of the head of Old River, 1,000 hours 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), or 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–A13, R1, F1, F2, and B5) were generally not allowed. The exceptions were at the San Joaquin River Shipping Channel (A10), MacDonald Island (A11), Turner Cut (F1), Medford Island (A12), and Disappointment Slough (A13). 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 CVP (E1), the radial gates (D1/D2), Jersey Point (G1), False River (H1), Old River at its mouth (B5), Disappointment Slough (A13), 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. 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 near Stockton and farther upstream 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) = 1,100 hours.

BDF1, BDF2 = Below Durham Ferry 1 (A3) and Below Durham Ferry 2 (A4): allow long residence and transition times and multiple visits; allow longer residence times if the following transition is directed downstream; maximum total visit length = 1,100 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 and A6, 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 for BCA, and 1,100 hours for MOS and HOR.

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 = 500 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 = 55 hours.

ORE = Old River East (B1): require shorter residence times for transitions from SJL and RS5 if the HOR barrier is in place; maximum total visit length = 282 hours. For transitions from ORS and MRH, 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 = 55 hours.

SJNB and RRI = San Joaquin River at Navy Bridge Drive (A9) and Rough and Ready Island (R1): fast transitions moving downstream require positive water velocity. Maximum total visit length = 40 hours.

SJS = San Joaquin River Shipping Channel (A10): 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 (A11): 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 (A12): 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.

SJD = San Joaquin River at Disappointment Slough (A13): 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 = 245 hours. No prior transition to facilities from the lower San Joaquin River if coming from upstream of SJD or from MID.

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. No prior transition to facilities from the lower San Joaquin River.

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 = 275 hours. If coming from MFE/MFW, no prior transition to the facilities from the lower San Joaquin River. If coming from OR4, no prior transition to the Interior Delta from the lower San Joaquin River via the head of Old River.

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, RGU/RGD, or WCL, 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 = 48 hours. If coming from ORE, no prior detection in the northwest Delta.

MR4 = Middle River at Highway 4 (C2): maximum total visit length = 60 hours. If coming from OR4, WCL, or RGU/RGD, no prior detections in the lower San Joaquin River.

MID = Middle River at Middle River (C3): should not move against flow; maximum total visit length = 134 hours. If coming from MR4 or OR4, no prior detection in the lower San Joaquin River; if coming from MFE/MFW or TCE/TCW, no prior detection in northwest Delta.

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 = 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 USBR (2018c) 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.

JPT/JPE/JPW and FRE/FRW = Jersey Point (G1) and False River (H1): no flow/velocity restrictions; maximum total visit length = 140 hours for JPT/JPE/JPW, and 73 hours for FRE/FRW. Maximum cumulative upstream foray length = 25 km if coming from JPT/JPE/JPW, FRE/FRW, or MAT/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 2 hours for SBS; maximum cumulative upstream foray = 25 km.

MAT/MAE/MAW, BBR = Chipps Island (G2) and Benicia Bridge (G3): should not arrive from upstream against strong negative water velocity/flow (MAT/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 SJD or RS10.

Fixed-site receiver detections were available from 150 predatory fish that had been implanted with acoustic tags as part of a predation study conducted by NMFS: 41 Striped Bass *Morone saxatilis*, 62 Largemouth Bass *Micropterus salmoides*, 31 White Catfish *Ameiurus catus*, and 16 Channel Catfish *Ictalurus punctatus*. Releases of tagged predatory fish took place in April of 2015, in reaches of the San Joaquin River between MOS (A6) and RS7 (N4) (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 2 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 2015. 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 10 steelhead tags recaptured after initial release in 2015. These 10 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 or river junction multiple times, the detection history represented the final route of the tagged fish past the receiver or river 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, thereby converting the dual arrays to redundant arrays: the San Joaquin River receivers at Durham Ferry Downstream (A2), Banta Carbona (A5), and Mossdale (A6); the Central Valley Project trash racks (E1); and the radial gates just outside of Clifton Court Forebay (D1). For some release groups, detections were pooled over the three receiver lines at Chipps Island (G2) to improve model fit. Treating the Chipps Island receivers as a redundant array rather than a triple array was possible because 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 (A13); this was a change from previous years, in which T1 detections were omitted from the survival model. 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 2011–2014 steelhead analyses (USBR 2018a, 2018b, 2018c; Buchanan 2018), 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) (Figure 2, Figure 3). Individual receivers comprising dual arrays were identified separately, using “a” and “b” to represent the upstream and downstream receivers, respectively. Receiver lines comprising triple arrays were named in a similar fashion, using “a”, “b”, and “c” for the upstream, intermediate, and downstream receiver lines. All five of the new receiver stations introduced in 2015 (see *Introduction*) were used in the survival model. All tags detected on the Rough and Ready Island receivers at Burns Cutoff (RRI = R1) were later detected either upstream or at the San Joaquin River receivers at Navy Drive Bridge (SJNB = A9), and so RRI was not used in the survival model. The dual array in Old River near its confluence with the San Joaquin River (i.e., Old River mouth, OSJ = B5) was included in the model in 2015, unlike in 2014. As in the past, the receivers located just upstream of the head of Old River (HOR = B0), in Middle River near Mildred Island (MID = C3), and those in Montezuma Slough (MZT = T2) and Spoonbill Slough (SBS = T3) were omitted from the survival model.

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; however, too few tags were detected using Columbia Cut, and so it was excluded from the final model. 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, although it was excluded from the model in 2015 because no tags were detected using it.

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 2015; located downstream of Chipps Island, it was considered to be outside the study area, but facilitated in 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. Unlike in previous years, 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: not used in survival model

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

The release-recapture model used parameters that denote 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. For triple arrays, parameters P_{hia} , P_{hib} , and P_{hic} were used for the upstream, intermediate, and downstream receiver lines, respectively. The "last reach" parameter $\lambda = \phi_{G2,G3} P_{G3}$ represented the joint probability of successfully moving from Chipps Island to Benicia Bridge, and detection at Benicia Bridge. The complement of the last reach parameter, $1-\lambda$, includes the possibility of survival to Benicia Bridge but evading detection there, as well as mortality upstream of Benicia Bridge.

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, and i = ia, ib, ic for the upstream, intermediate downstream receiver lines in a triple 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.

λ = joint transition and detection probability: joint probability of moving downstream from Chipps Island, surviving to Benicia Bridge, and detection at Benicia Bridge, conditional on survival to Chipps Island.

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. This assumption was reasonable in light of high detection probabilities at this site for most release groups ($\hat{P}_{D1}$ = 1 for all release groups with estimates) (Tables A2 and A3).

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. $\phi_{A9,GH}$) 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).

Although the full survival model provides separate estimates for 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 in 2015. Of the 42 steelhead tags observed on the False River receivers, all but two 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: $\phi_{kj,G1} = \phi_{kj,GH}\psi_{G1}$. Because there were some detections at the H1 receivers, it is known that the route selection parameter ψ_{G1} < 1, and that the estimable parameter $\phi_{kj,G1}$ is not equal to $\phi_{kj,GH}$. However, it was not possible to estimate the difference between these parameters.

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. 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 2011–2014 analyses (USBR 2018a, 2018b, 2018c; Buchanan 2018). 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 (A11) and Turner Cut (F1) to Chipps Island were interpreted as survival probabilities ($S_{A11,G2}$ 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 (A12 and A13), as well as the northern Old River site (B5), all of which were omitted from Submodel I because of complex routing in that region. Columbia Cut (F2) was omitted from Submodel II because too few tags were detected at that array. Although in previous years, the Old and Middle River receivers near Highway 4 (B4 and C2) were used in Submodel II, those sites were excluded from that model because detections of sparse detections of Route A tags at those sites in 2015.

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 (JPT/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, SJS, MAC, TCE/TCW, and MAT/MAE/MAW, model codes A8 – A11, F1, and G2), or else were unique to Submodel II (i.e., sites MFE/MFW, SJD, and OSJ = A12, A13, and B5); detection probabilities at these sites were estimated separately for submodels I and II to avoid double-counting tags used in both submodels. Following similar reasoning, the "last reach" parameter (λ), representing the joint probability of transition from Chipps Island to Benicia Bridge and detection at Benicia Bridge, was estimated separately in the two submodels. 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 2015, however, sparse detections at the radial gates from route A tags required using common transition parameters from the radial gates in the two submodels, regardless of the route used to arrive at the gates.

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:

$\psi_{AA} = \psi_{A1}\psi_{A2}$: probability of remaining in the San Joaquin River past both the head of Old River and the Turner Cut Junction,

$\psi_{AF} = \psi_{A1}\psi_{F2}$: 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 $\psi_{B1} = 1 - \psi_{A1}$, $\psi_{F2} = 1 - \psi_{A2}$, 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:

$S_{AA} = S_{A6}S_{A7}S_{A8}S_{A9}S_{A10}S_{A11,G2}$: Delta survival for fish that remained in the San Joaquin River past the head of Old River,

$S_{AF} = S_{A6}S_{A7}S_{A8}S_{A9}S_{A10}S_{F1,G2}$: 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.

In cases where detections were sparse downstream of either site A10 in route A or site B1 in route B, Delta survival could not be estimated for all individual subroutes in the affected primary route.

The parameters $S_{A11,G2}$ and $S_{F1,G2}$ represent the probabilities of getting to Chipps Island (i.e., Mallard Island, site MAT/MAE/MAW) from sites A11 and F1, respectively. Both parameters represent multiple pathways around or through the Delta to Chipps Island (Figure 1). Fish that were detected at the A11 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 $S_{A11,G2}$ 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 of fish that remained in the 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

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

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 estimated on the large routing scale, as well, 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:

$S_A = \psi_{A2} S_{AA} + \psi_{F2} S_{AF}$: 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.

In cases where the subroute-specific survival probabilities could not be estimated, the primary route-specific survival probabilities were defined as $S_A = S_{A6} S_{A7} S_{A8} S_{A9} S_{A10,G2}$ for route A, and $S_B = S_{A6} S_{B1} \left(\psi_{B2} S_{B2,G2} + \psi_{C2} S_{C1,G2} \right)$ for route B, where $S_{A10,G2}$, $S_{B2,G2}$, and $S_{C1,G2}$ were estimated directly from a simplified Submodel I. 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 estimated 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 inriver, 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:

$S_{A(MD)} = \psi_{A2} S_{AA(MD)} + \psi_{F2} S_{AF(MD)}$: 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

$$S_{AA(MD)} = S_{A6}S_{A7}S_{A8}S_{A9}S_{A10}S_{A11(MD)},$$

$$S_{AF(MD)} = S_{A6}S_{A7}S_{A8}S_{A9}S_{A10}\phi_{F1,GH},$$

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

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

The parameter $S_{A11(MD)}$ is derived from the parameters of Submodel II:

$$S_{A11(MD)} = \phi_{A11,GH} + \phi_{A11,A12}S_{A12(MD)} + \phi_{A11,B5}\phi_{B5,GH},$$

where

$$S_{A12(MD)} = \phi_{A12,GH} + \phi_{A12,A13}\phi_{A13,GH} + \phi_{A12,B5}\phi_{B5,GH}.$$

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. Because detections at False River were too sparse to be modeled for all release groups, all available 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. In cases where detections were too sparse at Turner Cut (site F1) in the San Joaquin River route to estimate transition probabilities from that site (i.e., first release groups), no estimates were available of Mid-Delta survival for either the San Joaquin River route or overall.

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

$$S_{A(SD)} = S_{A6}S_{A7}S_{A8}S_{A9}S_{A10}, \text{ and}$$

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

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 (i.e., third 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.

Modifications for Early March Release Group

Most of the fish from the early March 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 group were observed using the Old River route through the Delta. When predator-type detections were excluded, detection 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 mainstem, but Turner Cut detections were too sparse to estimate survival from Turner Cut to Chipps Island. Thus, both Turner Cut and MacDonald Island were omitted from Submodel I, and overall survival was estimated directly from the San Joaquin Shipping Channel receiver (A10) to Chipps Island: $S_{A10,G2}$.

Both Turner Cut and MacDonald Island were used in Submodel II, but detections histories were right-censored at Turner Cut, with no attempt to estimate survival from Turner Cut to Chipps Island. The northern Old River site (B5) was omitted from Submodel II because of sparse detections. The pattern of detections at the two downstream receiver lines at Chipps Island (MAE and MAW) required pooling detections across those two lines in order to fit the model. When predator-type detections were included, it was possible to estimate survival from Turner Cut, and unique detection probabilities were estimated for each of the three lines at Chipps Island; site B5 was omitted from Submodel II, and Benicia Bridge was omitted from both submodels. False River was omitted entirely. Sparse detections of Route A tags at the water export facility sites (D1, D2, E1, and E2) prevented estimation of transition probabilities from those sites for Submodel II.

Modifications for Late March Release Group

Although the majority of tags detected downstream of the head of Old River from the late March release group were observed taking the Old River route, there were enough tags detected in the San Joaquin River route to fit the full model for that route. For both routes, there were too few detections at Benicia Bridge to reliably estimate survival to Chipps Island and the last reach parameter to Benicia Bridge, so site G3 was omitted. When predator-type detections were excluded, no Route A tags were detected at the radial gates (sites D1, D2), so transition probabilities from those sites could not be estimated for Route A fish (Submodel II). When predator-type detections were included, there were too few detections at the Middle River Head (C1) receiver to estimate transition probabilities from that site; detection histories were right-censored at that site. Without transitions from C1, it is not possible to estimate all components of total Delta survival for route B, $S_{B(D)}$; thus, a secondary model was fit using a simplified Submodel I, which estimated survival from ORE (B1) to Chipps Island directly. It was not possible to derive a robust estimate of mid-Delta survival in route B without also assuming that mid-Delta survival from C1 ($S_{C1(MD)}$) was 0. Although that conclusion could not be tested from the tags actually detected at C1 from this release group (when predator-type detections were included), the fact that none of the tags detected at C1 from any release group were subsequently detected anywhere, whether or not predator-type detections were included, provides support for the assumption that survival from C1 to either Jersey Point or Chipps Island was actually 0.

Modifications for April Release Group

The head of Old River barrier was installed for passage of all fish from the April release group when predator-type detections were removed, and for the large majority of April-released fish when predator-type detections were included. Thus, there were few tags observed taking the Old River route, with or without predator-type detections. There were particularly sparse detections at the water export facilities, regardless of migration route. There were also sparse detections at the northern Old River site (B5), so it was omitted from Submodel II. Detections were pooled across all three receiver lines at Chipps Island. Overall, when compared to the previous two release groups, relatively few of the tagged steelhead released in May were detected in the study area.

When predator-type detections were removed, there were too few detections in the Old River route to model reach-specific survival downstream of the head of Middle River. Thus, sites B3, B4, C2, D1, D2, E1, and E2 were all omitted from the model. Furthermore, detection data at Middle River (C1) were too sparse to estimate transition probabilities from that site, so detection histories were right-censored at C1. Mid-Delta survival from Old River South (B2) was estimated directly from the model; estimates of total Delta survival from B2, B1, and overall (S_D) depended on the assumption that the Middle River route and the salvage routes were not viable for this release group. This assumption was confirmed by fitting a simplified Submodel I that omitted sites B2 and C1, in addition to those named above.

There were several more tags observed taking the Old River route when predator-type detections were retained, and it was possible to keep the Old River route detection sites in the model. However, detections at the water facility sites were nevertheless too sparse to estimate transition probabilities from those sites, so detection histories were right-censored at the upstream facility sites (E1, D1). There were no detections at MRH (C1), so it was necessary to assume 100% detection probability at that site. Because all detection histories were censored at the export facilities, the estimability of total Delta survival depended on the assumption that no tagged fish reached Chipps Island via salvage at the water export facilities. Estimates of total Delta survival (based on all detections, including predator-type detections) were confirmed using a simplified Submodel I, which omitted all detections downstream of the head of Middle River (B2, C1) in the Old River Route, and no Submodel II.

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, route selection, and last reach 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 key survival parameter was estimated at 0 or was estimated on the basis of only 0 or 1 detections, 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 either on travel time from other release groups, or from previous years, 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. There were too few detections at the radial gates from the April release group to estimate unique transition probabilities based on gate status; common transition probabilities were fit for the radial gates for that release group when predator-type detections were included, and transitions through the radial gate were not modeled when predator-type detections were excluded. A likelihood ratio test was also used to test for the significance of route effects on the transition probability from Jersey Point to Chipps Island ($\phi_{G1,G2}$). 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 selection 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).

Analysis of Tag Failure

Three in-tank tag-life studies of VEMCO V5 tags were implemented for the 2015 steelhead survival study. The two April studies each used 33 tags that were activated on 2 April 2015; the final detection for both April studies was on 12 June 2015. The May study used 34 tags that were activated on 13 May 2015; the final detection was on 23 July 2015. 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 2015 tag-life study. Each receiver experienced times when no tags were detected, which suggested receiver outage and lack of tag monitoring during those periods. Tag detections were compared across all tags detected on each receiver to identify potential unmonitored periods. Tags whose final detections occurred just prior to the unmonitored periods were interval-censored. This affected one tag (ID 23746) detected on receiver 300959, whose final detection came immediately before an unmonitored period that ran from May 23 to May 27. Interval censoring essentially imputes missing data, in this case either at the beginning of the unmonitored period (i.e., the final tag detection time) or at the end of the unmonitored period. Imputing missing failure times at the time of final tag detection is conservative for estimating tag survival, but non-conservative for estimating fish survival adjusted by tag survival estimates (i.e., the shorter the estimated tag survival, the higher the adjusted fish survival estimate). Imputing missing failure times at the end of the unmonitored period, on the other hand, is non-conservative for tag survival estimation but conservative for fish survival estimation. Because the overall focus of the study is to estimate fish survival, missing tag failure time was imputed at the end of the unmonitored period (May 27, 2015 23:16:34) for this tag. For each tag-life study, the observed tag survival was modeled using the 4-parameter vitality curve (Li and Anderson, 2009), adjusted for interval censoring. Tag failure times were right-censored at day 70 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 pooled 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 inriver 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). Detections from those downstream sites with sparse data were omitted for this test in order to achieve adequate cell counts.

Lack of independence may be caused by differences in survival, route selection, or detection probabilities. 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 indications of possible surgeon effects on survival, they are inconclusive alone; the reason is that consistent differences in cumulative survival can be driven by differences in the first several reaches, which then persist for the cumulative survival estimates through downstream reaches 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 last detection 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 2015 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 (28) tagged steelhead were observed at the upper Old River detection sites when the barrier was in place in 2015. Analysis of route selection at the head of Old River was focused on 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 (A11) 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 2018), 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 3 April 2015, so only 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. Because the estimated detection probabilities at both these sites were 1.0 for all release groups, 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 two 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 22 tags detected at the San Joaquin River receiver (SJL), and 236 tags detected at the Old River receiver (ORE), providing at most 22 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 2015 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, no flow or water velocity data were available from the Lathrop gaging station (SJL) in the San Joaquin River in 2015; this lack of data meant that the flow proportion into the San Joaquin River was also missing for 2015. Flow, velocity, and river stage data were available from the Mossdale gaging station (MSD), and these data were used as covariates in 2015 (Table 2). The OH1 gaging station was located 0.86–0.91 km upstream of the ORE receivers; the SJL gaging station was located 0.30–0.39 km from the SJL receivers. The covariates considered were:

- 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;
- U = Indicator variable defined to be 1 if flow at OH1 was negative, and 0 otherwise
- E_{CVP}, E_{SWP} = Daily export rate at the CVP and SWP at t the estimated time of tag passage of the head of Old River junction, as reported by Dayflow (https://www.water.ca.gov);
- 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;
- L = Fork length at tagging;
- RG = Release group (categorical variable).

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). Estimated detection probabilities were 1.0 for both sites A7 and B1 for all releases, without predator-type detections (Appendix Table A2).

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 family-wise 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 multivariate 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 flow proportion, and together with flow. Exports at CVP and SWP had low correlation (r=0.14) over the time period in question, so CVP and SWP exports were considered in the same models. Flow from the OH1 and MSD gaging stations were moderately correlated (r=0.56), and flow from both stations were considered in the same models. The same is true for velocity. High correlation between river stage measurements among the OH1, MSD, and SJL gaging stations (r≥0.98) meant that river stage from only one of these stations was included in the river stage model; the station used was assessed in the model selection process. The general forms of the four multivariate models were:

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

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

Stage model: $C_{STN} + \Delta C_{STN} + U + day + E_{CVP} + E_{SWP} + P_{CVP} + L + RG$

Flow + Stage model:

$$Q_{OH1} + Q_{MSD} + \Delta Q_{OH1} + \Delta Q_{MSD} + C_{STN} + \Delta C_{STN} + U + day + E_{CVP} + E_{SWP} + P_{CVP} + L + RG,$$

where station STN used in the stage and flow + stage models was determined among MSD, OH1, and SJL in the model selection process.

Backwards selection with F-tests was used to find the most parsimonious model in each category (flow, 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 category (flow, velocity, stage, 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, 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).

Turner Cut Junction

The acoustic receiver arrays MAC (A11) and TCE/TCW (F1) were located 1.1–3.4 km downstream of the Turner Cut junction; detections at the SJS receiver array (A10), 0.38 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 ≤ 5 hours. Also excluded was a single tag whose transition from the MAC receivers to the TCE/TCW receivers exceeded 3 hours. 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. Overall, seven tags were excluded because of the transition type (e.g., repeated visits at MAC), and five tags were excluded because of slow travel. Detections from a total of 75 tags were used in this analysis: 7 from the early March release group, 47 from the late March release group, and 21 from the April release group.

The covariates used in previous years were again used for the 2015 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 A10), 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 acoustic receiver (model code A8) to SJS, daily export rates at the CVP and SWP upon tag detection at the Turner Cut junction, fork length at tagging, release group, and time of day of arrival at the junction. A new covariate in 2015 was the CVP proportion of combined exports from the CVP and SWP, measured on a daily basis. 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 estimated or 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 acoustic receiver (site A8) until the estimated or observed time of tag departure from the SJS receivers;
- 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 (https://www.water.ca.gov);
- 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;

- L = Fork length at tagging;
- RG = Release group (categorical variable).

The TRN gaging station was located 0.13–0.20 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, while 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 2015 analysis, environmental conditions were measured instead at the observed (or estimated) time of tag departure from the SJS (A10) receivers, which exhibited less uncertainty than estimates of junction arrival time.

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 A11 (route A) or site F1 (route F). Estimated detection probabilities were 1.0 for both sites A11 and F1 for all release groups, without predator-type detections (Appendix Table A2).

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 family-wise 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, the covariates were then analyzed together in a series of multivariate regression models. Because of high correlation between flow and velocity measured from the same site, and to a lesser extent, correlation between flow or velocity and river stage, the covariates flow, velocity, and river stage were analyzed in separate models. The exception was that the flow index in the reach from SJG to the TCE/TCW or MAC receivers $\left(Q_{SJG}\right)$ was included in the river stage model. Exports at CVP and SWP had only moderate correlation (r=-0.25) over the time period in question, so CVP and SWP exports were considered in the same 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: $C_{TRN} + Q_{SJG} + \Delta C_{TRN} + U + day + E_{CVP} + E_{SWP} + P_{CVP} + L + RG.$

Backwards selection with F-tests was used to find the most parsimonious model in each category (flow, velocity, and 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, or 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

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

where $\phi_{k2,G2}$ is as defined above, and $\phi_{k2,GH}$, $\phi_{k2,T1}$, and $\phi_{k2,T2}$ are the joint probabilities of surviving from site $k2$ to the Jersey Point/False River junction, Threemile Slough, and Montezuma Slough, respectively, and not going on to Chipps Island. Spoonbill Slough (site T3) would have been included also, but no tags were detected there without subsequent detections at 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, and T1, although only data from tags detected at either D2 or E2 were used to estimate salvage survival. Although site T2 (Montezuma Slough) was designed to be a dual array site, loss of one of the receivers meant it was effectively a single array site, and it was not possible to estimate the detection probability at that site; it was necessary to assume 100% detection probability at site T2. Because there were many tags detected at H1 that were later detected elsewhere and thus were not used in the 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 site T1, to boost the amount of data available to estimate detection probability at that site. 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 a F-test (Sokal and Rohlf 1995). Only survival parameters through 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 (i.e., $\phi_{A1,A2}$), reach-specific survival from Durham Ferry Downstream (A2) to the Turner Cut junction receivers (A11, F1) (i.e., $S_{A2},\ldots,S_{A10}$), overall survival from MacDonald Island (A11) to Chipps Island ($S_{A11,G2}$), 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 test-wise 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% family-wise 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 1,427 tags were released in juvenile steelhead at Durham Ferry in 2015 and used in the survival study. Of these, 1,156 (81%) 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 1,012 (71%) were detected at least once downstream of the release site, and 514 (36%) were detected in the study area from Mossdale to Chipps Island (Table 5). Three hundred fourteen (314) tags were detected upstream of the release site; 170 of these were also detected downstream of the release site.

Overall, there were 305 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. Of the 305 tags detected in the San Joaquin River route, all but one were detected on the receivers near Lathrop, CA (SJL); 260 were detected on one or more of the receivers used in the predator removal study (RS4–RS10); 119 were detected on one or more receivers near Stockton, CA (SJG, SJNB, or RRI); 96 were detected on the receivers near the Turner Cut (SJS, MAC, or TCE/TCW), 75 were detected at Medford Island or Columbia Cut (MFE/MFW or COL), and 75 were also detected at either Disappointment Slough or the northern Old River site (SJD or OSJ) (Table 6). The majority of the tags from the early March release group and the April release group (releases 1 and 3) 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 late March release (release 2) were also assigned to that route for survival analysis (Table 5). Overall, 147 tags were assigned to the San Joaquin River route for the survival model, mostly from the late March release groups (Table 5). Seven additional tags were detected in the San Joaquin River route but were captured in the Mossdale trawl either before or after their San Joaquin River route detections, and their detection histories were right-censored at site A6 (MOS); these seven tags were not included in the total 147 tags assigned to the San Joaquin River route. Of the 147 tags, 16 were detected at the receivers in Turner Cut, although 3 of those tags were subsequently detected in the San Joaquin River downstream of the Turner Cut junction, and 1 tag was subsequently detected in the western Old River and then later near the head of Old River; none of these four tags was assigned to the Turner Cut route for survival analysis (Table 6). Of the 147 tags assigned to the San Joaquin River route, 7 were detected in Columbia Cut (COL, site F2), 5 at the northern Middle River receivers (MID, site C3), 14 northern Old River receivers (OSJ, site B5), 9 at the Old or Middle River receivers near Highway 4 (OR4 and MR4, sites B4 and C2), 8 at West Canal (WCL, site B3), and 8 at the water export facilities (including the radial gates at the entrance to the Clifton Court Forebay) (Table 6). A total of 58 San Joaquin River route tags were detected at the Jersey Point/False River receivers, including 19 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). Twenty-seven (27) tags from the San Joaquin River route were detected at Threemile Slough; each had come from the Disappointment Slough receivers, although three had intervening detections at Jersey Point. A total of 68 San Joaquin River route tags were eventually detected at Chipps Island, including predator-type detections, mostly from the late March release group (Table 6).

The majority of the tags from early March release group that were detected downstream of the head of Old River were detected in the Old River route (141 tags); the late March release group had similar numbers of tags detected in the Old River route as in the San Joaquin River route (129 vs 136), while the April release group had relatively few tags detected in the Old River route (17 tags) (Table 5). All 287 tags detected in the Old River route were detected at the Old River East receivers near the head of Old River; 278 were detected near the head of Middle River, 221 at the receivers at the water export facilities, 156 at West Canal, and 96 at the Old or Middle River receivers near Highway 4 in the interior Delta (Table 6). Two tags observed entering Old River at its head were detected at the northern Middle River receivers (MID), and five at the northern Old River receivers (OSJ) (not shown). The majority of the tags detected at the Old or Middle River receivers in the western portion of the interior Delta (WCL, 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 one or two 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. Some tags detected in the Old River route were subsequently detected upstream of the head of Old River, and were not assigned to the Old River route. In all, 282 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 282 tags, 181 were detected at the CVP trash racks, although only 101 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, 157 of the tags assigned to the Old River route were detected at the radial gates, and only 39 of those detections were available for use in the survival model (Table 6, Table 7). A total of 29 of the Old River route tags were detected at either Jersey Point or False River (Table 6), 27 of which came from Old River at Highway 4, 1 via the CVP, and 1 via the CCFB, before being detected at Jersey Point or False River. A total of 23 tags from the Old River route were detected at False River, but all but one were later detected at Jersey Point or Chipps Island, leaving only 1 False River detection for the survival model (Table 6, Table 7). Of the 282 tags assigned to the Old River route at the head of Old River, 62 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 (one from each route), and one tag was detected at the Spoonbill Slough receiver, from the Old River route. Threemile Slough was used only in the San Joaquin River route; 8 tags from the Old River route were detected at Threemile Slough after detection at either the water export facilities (6 tags) or the Old River receivers near Highway 4 (2 tags) (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 207 of the 1,427 tags (14%) released as being detected in a predator at some point during the study (Table 8). Of the 514 tags detected in the study area (i.e., at Mossdale or points downstream), 139 tags (27%) were classified as being in a predator, although some had also been identified as a predator before entering the study area. A total of 126 tags (25% of 514) were first classified as a predator within the study area. Relatively few (87, 7%) of the 1,156 tags detected upstream of Mossdale were assigned a predator classification in that region; 6 of those 87 tags were first classified as a predator downstream of Mossdale, and then returned to the upstream region, either temporarily or permanently.

Overall, the detection site with the most first-time predator classifications was Banta Carbona (A5; 35 of 626, 5.6%). Within the study area, the detection sites with the largest number of first-time predator-type detections were the CVP trashrack (E1, 19 of 188, 10.1%), West Canal (B3, 15 of 164, 9.1%), and Mossdale (A6, 14 of 514, 2.7%) (Table 8). Nearly equal numbers of predator classifications were assigned to tags on arrival (62) as on departure (64) at the study area sites, collectively. 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 Banta Carbona (A5), the CVP trashrack (E1), the Old River sites from the head of Old River (B1) to Highway 4 (B4), and from Mossdale (A6) through the third predator removal study site (N3) (Table 8). Predator classifications on departure were typically due to long residence times, and were most prevalent at the CVP trashrack, Durham Ferry Upstream (A0), Below Durham Ferry 1 (A3) through the first predator removal study site (N1) and Old River East (B1) (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 141 predatory fish that were tagged and released in the spring of 2015 were later detected during the steelhead survival study. Of the 141 predator tags detected, a total of 112 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 79.4%. When predator tags that had fewer than 5 detections events on the visit scale were omitted, the filter sensitivity increased to 87.1%: 101 of 116 predator tags tested positive as a predator. 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.

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, 1,007 of the 1,427 (71%) tags released were detected downstream of the release site, and 504 (35% of those released) were detected in the study area from Mossdale to Chipps Island (Table 9). A total of 305 tags were detected upstream of the release site with steelhead-type detections; 156 of these were also detected downstream of the release site. With or without the predator-type detections, the late March release group had the most detections in the study area, and the April release group had the fewest (Table 5, Table 9).

The Old River route was used more than the San Joaquin River route for the two 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 (Table 11 vs Table 8), and in the San Joaquin River route overall (Table 9 vs Table 5). The largest change in the number of detections available for the survival analysis occurred at Lathrop (SJL), where the reduced data set had 16 more detections than the full data set that included the predator-type detection (Table 11 vs Table 8). As observed from the full data set including the predator-type detections, the reduced data set with only steelhead-type detections showed that the majority of the tags detected at the receivers in the western and northern portions of the study area used the Old River route at the head of Old River rather than the San Joaquin River route (Table 10). The number of tags detected at Chipps Island changed from 130 when the predator-type detections were included, to 120 when such detections were excluded (Table 6 vs Table 10). Of the 163 tags that assigned to the San Joaquin River route at the head of Old River, 14 were subsequently detected in the interior Delta, 15 were detected in Turner Cut, 7 were detected in Columbia Cut, and 12 were detected at the northern Old River site (OSJ), compared to 127 tags that were detected only in the main stem San Joaquin River downstream of the head of Old River; 54 (33%) of the tags assigned to the San Joaquin River route were detected at Jersey Point, and 64 (39%) were detected at Chipps Island (Table 10). Of the 268 tags assigned to the Old River route at the head of Old River, 163 (61%) were detected at the CVP trash racks, 25 (9%) at Jersey Point, and 56 (21%) at Chipps Island (Table 10). Detection counts used in the survival model largely follow a similar pattern (Table 11).

Tag-Survival Model and Tag-Life Adjustments

Observed tag failure times ranged from 40.43 days to 69.98 days. Model fit was improved by right-censoring failure time data at 69.975 days; there were 17 tags with tag failure times > 69.975 days. Model fit comparisons using AIC to compare analyses that pooled over tag-life study resulted in selection of the pooled model (ΔAIC ≥ 14.8). 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 65.4 days ($\widehat{SE} = 7.6$ days) (Figure 4).

The complete set of detection data, including any detections that may have come from predators, contained several detections that occurred after the tags began dying (Figure 5, Figure 6). The sites with the latest detections were Mossdale and the sites upstream of Mossdale, Lathrop, the CVP trashrack, Chipps Island, and Benicia Bridge (Figure 5, Figure 6). 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 mostly removed (e.g., Figure 7). 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 0.9687, and most were greater than 0.999, out of a possible range of 0 to 1; cumulative tag survival to Chipps Island was estimated at 0.9909 without predator-type detections (0.9897 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 2015.

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 = 0.007, df = 4, P = 1.0000). 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 = 20.914, df = 42, P = 0.9973; Table 13).

Estimates of cumulative fish survival throughout the San Joaquin River route to Chipps Island showed similar patterns of survival across all surgeons. Although surgeon C had consistently lower point estimates of cumulative survival throughout the San Joaquin River route downstream of Banta Carbona, there was no evidence of a statistical difference in cumulative survival to any site in the San Joaquin River route (P ≥ 0.1269 for all sites; Figure 8). The estimate of cumulative survival to Garwood Bridge on the San Joaquin River (SJG) was 0.16 ($\widehat{SE} =$ 0.02) for fish tagged by surgeon C, compared to 0.23 ($\widehat{SE} =$ 0.02) for surgeon A, and 0.21 ($\widehat{SE} =$ 0.02) for surgeon B (Figure 8). Despite the possibility of lower survival of fish tagged by surgeon C in the San Joaquin River route, there was no significant difference in cumulative survival to any sites in that route, and the difference in point estimates had largely disappeared by Chipps Island (P=0.4886; Figure 8). In the Old River route, there was little noticeable difference in cumulative survival to any sites, and the observed differences were not statistically significant for any site (P ≥ 0.6419; Figure 9); in particular, there was no difference in survival to Chipps Island in the Old River route (P=0.8021; Figure 9). Analysis of variance found no effect of surgeon on reach survival in the two routes collectively (P=0.7204). 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=0.9124), or in the Old River route (P=0.9260).

Survival and Route Selection Probabilities

For the two March release groups, likelihood ratio tests found that transitions to the exterior receivers at the Clifton Court Forebay, and on to the interior receivers of the Forebay, did not depend on whether the radial gates were open or closed at the time of arrival at the exterior receivers (P≥0.8649). Detections from the April release group were too sparse to estimate unique transition parameters based on gate status. Thus, the final models used common transition probabilities to and from the radial gate receivers, regardless of gate status; the exception was for the April release group excluding predator-type detections, for which transitions to and from the radial gates were omitted from the model entirely. Likelihood ratio tests found no improvement in model fit from including an effect of route selection at the head of Old River on the transition probability from Jersey Point to Chipps Island, $\phi_{G1,G2}$, (P≥0.2240); a common probability of migrating and surviving from Jersey Point to Chipps Island was estimated for each release group, regardless of route.

Some parameters were unable to be estimated because of sparse detection data. For the early March release group, survival to Chipps Island could not be estimated from Turner Cut when predator-type detections were omitted, or from the northern Old River site (B5). For the late March release group (when predator-type detections were included), and also for the April release group (regardless of predator-type detections), transitions from the head of Middle River (C1) could not be estimated when predator-type detections were included, and estimates of survival through the South Delta and Mid-Delta region were based on the assumption that survival in the Middle River subroute was 0. For the April release group, data were too sparse to estimate detection probabilities at the water facility sites or the Middle River sites; estimates of South Delta survival to those sites (when predator-type detections were included) depended on the assumption of 100% detection probability, and no transition probabilities from those sites could be estimated. When predator-type detections were excluded from the detection data from the April release group, detection data were too sparse to estimate reach-specific transition probabilities or survival in the Old River route downstream of the head of Old River. For all release groups, there were too few detections at False River that were not followed by detections at either Jersey Point or Chipps Island to estimate the route selection probability at the Jersey Point/False River junction. Instead, the joint probability of arriving at the junction between the San Joaquin River and False River and then moving downriver toward Jersey Point (i.e., $\phi_{x,G1} = \phi_{x,GH}\psi_{G1}$) was estimated and reported for transitions from sites x = A11, A12, A13, B4, B5, C2, and F1. However, in some cases, even those parameters could not be estimated because of sparse data. Estimates of Mid-Delta survival should be interpreted as survival to Jersey Point, rather than to the Jersey Point/False River junction.

For the April release group, there were two tagged fish that apparently passed Chipps Island without detection, although the large majority of tags detected at that site were detected on all three lines of the triple array at that site. Thus, the detections from the triple receiver lines were pooled at

Chipps Island to estimate a single detection probability at that site (P_{G2}) for the April release group, to avoid overestimating the detection probability and underestimating Delta survival.

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 0.15 ($\widehat{SE}=$ 0.03) for the early March release group, to 0.35 ($\widehat{SE}=$ 0.03) for the late March release group; the overall population estimate from all three releases (weighted average) was 0.23 ($\widehat{SE}=$ 0.02) (Table 14). The estimated probability of entering Old River at its head was highest for the early March release group (0.81, $\widehat{SE}=$ 0.03), when the barrier was not installed, and noticeably lower for the second two release groups (0.59 and 0.20), which passed mostly after the barrier was in place; the population estimate over all three releases was 0.54 ($\widehat{SE}=$ 0.02) (Table 14). There was a statistically significant preference for the Old River route for both March release groups (P≤0.0054 for each release group), and for the San Joaquin River route for the April release group (P<0.0001). Estimates of survival from Mossdale to Chipps Island via the San Joaquin River route $\left(S_A\right)$ ranged from 0.19 ($\widehat{SE}=$ 0.07) for the early March release group to 0.46 ($\widehat{SE}=$ 0.05) for the late March release group; the population estimate, averaged over all three release groups, was 0.30 ($\widehat{SE}=$ 0.03) overall (Table 14). In the Old River route, estimates of survival from Mossdale to Chipps Island $\left(S_B\right)$ ranged from 0.05 ($\widehat{SE}=$ 0.05) for the April release group to 0.27 ($\widehat{SE}=$ 0.04) for the late March release group (population average = 0.16, $\widehat{SE}=$ 0.02) (Table 14). The route-specific survival to Chipps Island was significantly different between routes for the late March release group, when survival was higher in the San Joaquin River route than in the Old River route (P=0.0032; Table 14). There was no significance difference in survival to Chipps Island between routes for the other two release groups (P≥0.1178; 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=0.0005; 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 late March and April release groups: $\hat{S}_{Total(MD)}=$ 0.21 ($\widehat{SE}=$ 0.03) for late March, and 0.17 ($\widehat{SE}=$ 0.04) 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 the late March release group (P=0.0004), and was higher for fish in the San Joaquin River route (Table 14). However, approximately two-thirds of the Old River route fish from the late 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 present for the majority of fish passing the head of Old River from the late March release group, but nevertheless approximately 59% of fish used the Old River route from that release group. Only 20% 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 (0.17, $\widehat{SE} =$ 0.04, for mid-Delta survival, and 0.20, $\widehat{SE} =$ 0.04, for total Delta survival; Table 14).

Survival was estimated through the South Delta ($S_{A(SD)}$, $S_{B(SD)}$, and $S_{Total(SD)}$) for one or both routes for all three release groups. The "South Delta" region corresponded to the region studied for Chinook salmon survival in the 2009 VAMP study (SJRGA 2010). Survival through the Old River portion of the South Delta ($S_{B(SD)}$), i.e., from Mossdale to the CVP trashracks (CVP), radial gates exterior receivers (RGU), and Highway 4 receivers (OR4, MR4), was estimated for the two March release groups: 0.66 ($\widehat{SE} =$ 0.04) for early March, and 0.73 ($\widehat{SE} =$ 0.04) for late March (Table 14). Survival through the San Joaquin portion of the South Delta ($S_{A(SD)}$), i.e., from Mossdale to MacDonald Island (MAC) or Turner Cut (TCE/TCW), was estimated for all three release groups: 0.31 ($\widehat{SE} =$ 0.08) for early March, 0.61 ($\widehat{SE} =$ 0.05) for late March, and 0.30 ($\widehat{SE} =$ 0.05) for April (average = 0.41, $\widehat{SE} =$ 0.04) (Table 14). Total estimated survival through the entire South Delta region ($S_{Total(SD)}$) was estimable only for the early March (0.60, $\widehat{SE} =$ 0.04) and late March (0.68, $\widehat{SE} =$ 0.03) release groups (Table 14).

Including the predator-type detections in the analysis had a moderate effect on the survival estimates in most regions (Table 15). The largest differences observed were in the South Delta region, where including the predator-type detections increased the survival estimate in the San Joaquin River route from 0.31 ($\widehat{SE} = 0.08$), 0.61 ($\widehat{SE} = 0.05$), and 0.30 ($\widehat{SE} = 0.05$) for the early March, late March, and April release groups, respectively, to 0.44 ($\widehat{SE} = 0.09$), 0.67 ($\widehat{SE} = 0.05$), and 0.37 ($\widehat{SE} = 0.06$) (Table 14, Table 15). The Old River route estimate of South Delta survival increased by approximately 0.04 (5%-6% of estimates without predator-type detections) for the two March release groups, when predator-type detections were included (Table 14, Table 15). Overall, the estimate of total survival through the South Delta increased from 0.60 ($\widehat{SE} = 0.04$) without predator-type detections, to 0.66 ($\widehat{SE} = 0.04$) with predator-type detections, for the early March release group, and from 0.68 ($\widehat{SE} = 0.03$) to 0.73 ($\widehat{SE} =$ 0.03) for the late March release group (Table 14, Table 15). No estimate of South Delta survival was available without predator-type detections for the April release group because of sparse detection data in the South Delta; when predator-type detections were included, total South Delta survival was estimated at 0.33 ($\widehat{SE} = 0.05$) (Table 15).

For estimates of the total survival through the Mid-Delta region (i.e., Mossdale to Jersey Point), the largest change when predator-type detections were included was for the San Joaquin River route survival for the April release group: $\hat{S}_{A(MD)}$ increased from 0.20 ($\widehat{SE} = 0.05$) to 0.25 ($\widehat{SE} = 0.05$) when predator-type detections were included (Table 14, Table 15). The predator filter did not remove detections at Jersey Point for the April release group, but rather increased detections at Mossdale, the upstream boundary of the study Mid-Delta region; the result was an increase in estimated survival to Jersey Point when predator-type detections were included (Table 7, Table 11). Also notable was that it was possible to estimate Mid-Delta survival in the San Joaquin River route for the early March release group when the predator-type detections were included (0.21, $\widehat{SE} = 0.07$), unlike when predator-type detections were excluded. The estimate of total survival from Mossdale to Jersey Point increased from 0.21 ($\widehat{SE} = 0.03$) to 0.24 ($\widehat{SE} = 0.03$) for the late March release group, and from 0.17 ($\widehat{SE} = 0.04$) to 0.19 ($\widehat{SE} = 0.04$) for the April release group when predator type detections were included (Table 14, Table 15); including the predator-type detections provided an estimate of Mid-Delta survival for the early March release group (0.06, $\widehat{SE} = 0.02$; Table 15).

The largest changes in estimates of total Delta survival (S_{Total}) from including the predator-type detections were for the San Joaquin River route: estimates for the three release groups increased from 0.19 ($\widehat{SE} = 0.07$), 0.46 ($\widehat{SE} = 0.05$), and 0.24 ($\widehat{SE} = 0.05$) without the predator-type detections to 0.24 ($\widehat{SE} = 0.08$), 0.52 ($\widehat{SE} = 0.05$) and 0.30 ($\widehat{SE} = 0.06$) when predator-type detections were included (Table 14, Table 15). The effects of including the predator-type detections on estimates in the Old River route were considerably smaller (Table 14, Table 15). In all cases, the change in the point estimate from including the predator-type detections was comparable to or smaller than the standard error. While the phenomenon of lower estimated survival to Mossdale accounts for some of the increase in the estimated total Delta survival for the April release group when predator-type detections were included, the changes observed for the other release groups were driven primarily by the extra 1-3 tag detections used at Chipps Island from the San Joaquin River route when predator-type detection were included (Table 7, Table 11).

The overall pattern of larger effects of including the predator-type detections on estimates of South Delta survival, compared to either Mid-Delta or total Delta survival, suggests that steelhead predators in the Delta move around more within the South Delta than from the South Delta toward Chipps Island. However, there is some evidence of predators moving past Chipps Island, based on the predator filter and resulting survival estimates. Alternatively, 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.

Detection probability estimates were generally high (>0.95) at receiver arrays throughout the Delta (Table A2). The estimated probability of detection at Chipps Island was 1.0 (100%) for both the March release groups, based on the triple array at that site; for the April release group, the estimated detection probability at Chipps Island was 0.89 ($\widehat{SE} = 0.07$), based on comparison of detections at Chipps Island and at Benicia Bridge (Table A2). The estimates of survival to Chipps Island are adjusted for imperfect detection, so the lower detection probability estimated for the April release group was not expected to bias the survival estimate.

Survival estimates in reaches varied throughout the study. For most reaches, the estimated survival was highest for the late March release group (i.e., release 2; Table A2). For the reaches upstream of Mossdale, the survival estimate was lowest for the April release group, such that the total probability of survival from release at Durham Ferry to Mossdale was considerably lower (0.22, $\widehat{SE} =$ 0.02) for April compared to early March (0.36, $\widehat{SE} = 0.02$) or late March (0.46, $\widehat{SE} = 0.02$). This pattern of lower perceived survival to Mossdale in April was observed both with and without the predator-type detections (Table 14, Table 15). Lower river flows and higher water temperatures may have encouraged some steelhead to residualize or delay rearing in April; however, the estimated probability of turning upstream of the release site ($\phi_{A1,A0}$) was comparable for the April release group (0.16, $\widehat{SE} = 0.02$) to that estimated for the March release groups (0.13 to 0.16, $\widehat{SE} = 0.02$) (Table A2), suggesting that any increase in residualism occurred between the release site and Mossdale.

Reach-specific estimates in the San Joaquin River route tended to be less precise (larger standard errors) for the early March and April release groups, when relatively few tags were observed in that route compared to the late March release group (Table A2). Survival from Mossdale through the head of Old River, to the SJL or ORE receivers, had high estimates for the two March release groups (0.95 to 0.96, $\widehat{SE} = 0.01$) and relatively low survival for the April release (0.62; $\widehat{SE} = 0.05$) for all release groups (Table A2). Survival in the San Joaquin River from Lathrop (SJL) to Garwood Bridge (SJG, site A8) varied considerably, from 0.36 ($\widehat{SE} = 0.09$) for the early March release group, to 0.79 ($\widehat{SE} = 0.04$) for the late March release group (Table A2). Reach-specific survival estimates in the reaches between Garwood Bridge and the MacDonald Island/Turner Cut receivers were consistently high (0.88 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 $\phi_{A11,A12}$; estimates were higher for the March release groups (0.78, $\widehat{SE} = 0.12$ for early March, and 0.92, $\widehat{SE} = 0.04$ for late March) than for the April group (0.72, $\widehat{SE} = 0.11$) (Table A2). Most fish at Medford Island continued down the San Joaquin to Disappointment Slough, although some of the late March release group moved past the northern Old River receivers (OSJ, site B5) instead ($\hat{\phi}_{A12,B5}$=0.18, $\widehat{SE} = 0.06$). Total survival from Disappointment Slough to either Jersey Point (G1) or Threemile Slough (T1) was 0.94 to 1.0 for each of the three release groups (Table A2), whereas the estimated transition probability from Jersey Point to Chipps Island ranged from 0.90 to 1.0 (Table A2). All tags detected coming from Disappointment Slough past Threemile Slough were later detected at Chipps Island ($\hat{\phi}_{T1,G2}$ =1.0), although because few tags were detected at Threemile Slough, there was high uncertainty on the transition probability estimate (95% lower bound = 0.23 to 0.76) (Table A2). Despite the relatively low survival in the upstream reaches for the April release group compared to the March release groups, the April release had the highest estimate of total survival to Chipps Island from MacDonald Island: 0.94 ($\widehat{SE} = 0.06$), compared to 0.78 to 0.81 for the March release groups (Table A2). Survival to Chipps Island from Turner Cut could be estimated only for the late March and April release groups and with low precision: 0.60 ($\widehat{SE} = 0.22$) for late March, and 0.33 ($\widehat{SE} = 0.19$) for April (Table A2); the April release group had the highest probability of leaving the San Joaquin River for Turner Cut (0.26; $\widehat{SE} = 0.09$; 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 stable for the two March release groups (0.97 to 0.98, $\widehat{SE} \leq 0.02$), and considerably lower for the April release (0.75, $\widehat{SE} = 0.13$) (Table A2). The April estimate 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. Downstream of ORS, it was not possible to estimate reach-specific survival or transition probabilities from the April group, because the detection data were too sparse in that region. The pattern of transition probability estimates to various detection sites in the Old River route was similar between the two March release groups. For both March release groups, the majority of tags observed downstream of ORS were detected either at the CVP trashracks, or at West Canal (site B3), whose receivers were located north of the radial gates receivers. The transition probability estimates from ORS to the external radial gate receivers (site D1) were moderate: 0.11 to 0.17 ($\widehat{SE} = 0.03$) (Table A2). Very few tags were detected at the Middle River receivers at Highway 4 (site C2). The estimated probability of getting from OR4 (site B4) to Jersey Point was 0.28 for the early March release group, and 0.52 for the late March release group; there was high uncertainty on each estimate ($\widehat{SE} = 0.09$ to 0.11), and the estimate was driven entirely by fish that reached the OR4 receiver via the Old River route. The majority of tagged steelhead from the March release groups that reached the exterior radial gate receiver (D1), and did not return to either the CVP or Highway 4, eventually entered Clifton Court Forebay and were detected on the interior receivers (D2): 0.70 to 0.77. The transition probability from the interior radial gate receivers to Chipps Island, presumably through the forebay and salvage, ranged from 0.07 ($\widehat{SE} = 0.07$) for early March, to

0.20 ($\widehat{SE} = 0.13$) for late March; no estimates were available for April (Table A2). Of the March tagged steelhead that reached the CVP trashracks (E1) without later being detected at the CCFB radial gates (D1, D2) or Highway 4 receivers, less than half were estimated to have survived to the holding tank for both the March release groups (0.36 to 0.37, $\widehat{SE} = 0.07$). From the holding tank to Chipps Island, the transition probability estimate was 0.85 ($\widehat{SE} = 0.10$) for early March, and 0.93 ($\widehat{SE} = 0.06$) for late March; no estimate was available for April. Estimated transition probabilities in the South Delta were comparable when predator-type detections were included (Table A3).

Travel Time

For tags classified as being in steelhead, average travel time through the system from release at Durham Ferry to Chipps Island was 14.34 days ($\widehat{SE} = 0.67$ days) for all three release groups combined (Table 16a). Average travel time to Chipps Island tended to be shorter for later release groups: 20.7 days for the early March group, 14.1 days for the late March group, and 10.3 days for the April group. Average travel time to Chipps Island was 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 16.93 days ($\widehat{SE} =$ 0.97 days) from release at Durham Ferry, compared to an average of 12.21 days ($\widehat{SE} = 0.81$ 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 early March release group (18.4 days, $\widehat{SE} = 2.09$ days) was considerably longer than the average San Joaquin River travel time for the April release group (10.25 days, $\widehat{SE} = 0.43$ days) (Table 16a). Most tags that were observed at Chipps Island arrived within 30 days of release at Durham Ferry. However, there were 10 tags that took 36–51 days, 6 of them via the San Joaquin River route and either Jersey Point or Threemile Slough, and 3 via the Old River and salvage at the export facilities. Travel time from release at Durham Ferry to Chipps Island via salvage at the CVP ranged from 5.0 days to 50.9 days, and was observed only in the two March release groups; only two tags had travel times > 30 days through this migration route, and both were from the early March release group and used the Old River route to the CVP. Only three tags were observed at Chipps Island after presumed salvage at the SWP, all from the March release groups; travel time from Durham Ferry to Chipps Island for these three tags ranged from 9.6 days to 43.4 days.

Average travel time to detection sites upstream of the head of Old River tended to be lower for the late March release group than for either the early March group or the April group, although the difference between the late March and April release groups diminished for sites closer to the head of Old River (Table 16a). For most detection sites downstream of the head of Old River, the average travel times were longest for the early March release group and shortest for the April release group (Table 16a). Travel time from release to the Mossdale receivers averaged approximately 7.7 days for the early March release group, and between 3 and 4 days for the late 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 1.0 days to 41.2 days, and averaged 25.4 days for the early March release, 9.1 days for the late March release, and 6.9 days for the April release. The majority (54 of 87) of the tags detected at the Turner Cut or MacDonald Island receivers came from the late March release group (Table 16a). Travel time from release to the CVP trash racks averaged 7.96 days ($\widehat{SE} = 0.46$ days) over the two March release groups; data were too sparse to estimate travel time for the April release group (Table 16a). Average travel time was approximately six days longer for the early March release group (12.1 days) compared to the late March release (6.1 days) (Table 16a). Only four San Joaquin River route tags were observed at the CVP, with travel time ranging from 18.6 days to 34.4 days. Fewer tags were observed at the radial gates receivers outside Clifton Court Forebay (RGU); average travel time from release was 14.67 days ($\widehat{SE} = 1.55$ days) for the early March release group, and 8.16 days ($\widehat{SE} = 1.29$ days) from the late March release group (Table 16a). Only one tagged fish was observed at the RGU receivers from the San Joaquin River route; that tag was from the April release group, and had travel time 10.1 days from release at Durham Ferry.

Too few San Joaquin River route tags were detected at either of the Highway 4 detection sites (OR4, MR4) to estimate travel time. Of the tags that were detected at those sites from the Old River route, average travel time from Durham Ferry ranged from 7.5 days for the late March release group, to 16.1 days for the early March release group; too few tags were detected at the Highway 4 receivers from the April release group to characterize travel time. Travel time from Durham Ferry to Jersey Point averaged approximately 14 days, mostly from the San Joaquin River route and from the late March release group (Table 16a). Average travel time to Jersey Point was slightly longer via the San Joaquin River route (15.07 days, $\widehat{SE} = 1.02$ days, range = 7.1–44.8 days) than through the Old River route (12.12 days, $\widehat{SE} = 1.15$ days, range = 6.2–41.3 days) (Table 16a).

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 largest change in average travel times seen from including the predator-type detections was at the exterior receivers at the Clifton Court Forebay (RGU), where the average travel time over all release groups was 11.13 days without the predator-type detections, and 13.60 days without those detections (Table 16b). The average travel time from release to Chipps Island via all routes, including the predator-type detections, was 14.92 days ($\widehat{SE} = 0.70$) (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 Middle River site at Highway 4 (MR4) 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 0.02 days (approximately 26 to 35 minutes) from the entrance channel receivers at the Clifton Court Forebay (RGU, gates open) to the interior forebay receivers (RGD), to 8.83 days from RGD 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. Only three tags were detected moving from RGD directly to Chipps Island. Travel times from the San Joaquin River receiver near Lathrop (SJL) to Garwood Bridge (SJG) averaged 1 day (~18 rkm). Average travel time from Old River South (ORS) to the CVP trashracks was approximately 1.7 day (~18 rkm). Average travel time to Chipps Island was approximately 3.3 days from MacDonald Island (~54 rkm via the San Joaquin River), and approximately 4.0 days from Turner Cut (also ~54 rkm via Frank's Tract) (Table 17a). 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

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 369 tags. Of these 369 tags, 253 were estimated to have arrived at the head of Old River junction before closure of the barrier during installation ("before barrier installation"). A total of 22 tags arriving before barrier installation selected the San Joaquin River route (8.7%), whereas a total of 96 tags arriving after barrier installation selected the San Joaquin River route (82.8%) (Figure 10). The remaining analysis used only those tags that arrived before barrier installation.

Old River flow (discharge) at the OH1 gaging station (near the head of Old River) at the estimated time of arrival of the tagged juvenile steelhead at the head of Old River ranged from -1,299 cfs to 1,540 cfs (average = 806 cfs), for study fish that were estimated to have arrived at the river junction before barrier closure on 3 April 2015. The flow at OH1 was negative for 24 of 253 (9%) tags upon arrival at the river junction. Water velocity ranged from -0.78 ft/s to 1.31 ft/s (average = 0.65 ft/s) at tag arrival at the junction. Flow and velocity at OH1 were highly correlated (r=0.98). Export rates averaged 1,523 cfs at CVP, and 674 cfs at SWP, and the average percentage exports through the CVP was 67%, for the estimated time of fish arrival at the head of Old River junction. There was little correlation between total Delta exports and flow into Old River (r=-0.05) upon fish arrival for the pre-barrier component of the release groups.

Of the 253 tags detected at SJL or ORE and used in the route selection analysis at the head of Old River, 4 were estimated to have arrived at head of Old River junction at dawn, 161 during the day, 3 during dusk, and 85 at night. Sixteen of the 22 tagged steelhead that selected the San Joaquin River route arrived during the day, five arrived at night, and one at dusk. Steelhead that entered Old River tended to have more variable measures of CVP export rates, and slightly lower river stage at OH1, but otherwise few differences in conditions based on route selected are obvious (Figure 11). Flow and velocity at the OH1 gaging station in Old River were highly correlated (r=0.98) at the estimated time of tag arrival at the head of Old River junction; thus, no velocity plot is shown. Old River flow at OH1 was only moderately correlated with San Joaquin River flow at Mossdale, measured at the MSD gaging station (r=0.56); however, positive flow at OH1 typically occurred when flow was positive at MSD (Figure 12), and there was little difference in flow at MSD between the tags that selected the Old River route and those that selected the San Joaquin River route (Figure 13).

The majority of steelhead that arrived at the head of Old River junction before barrier closure in 2015 selected the Old River route, regardless of release group (Table 18), river flow (Figure 14), water velocity (Figure 15), river stage (Figure 16), or exports (Figure 17). Of the 253 tags used in the route selection analysis for the head of Old River, 231 (91%) selected Old River. This left a maximum of 21 degrees of freedom for the regression models. Covariate data were unavailable for some tags, which further reduced the available degrees of freedom. The single-variate analyses found no significant associations (α=0.05) between the probability of remaining in the San Joaquin River at the head of Old River and any of the covariates considered ($P \geq 0.4782$ for each covariate; Table 18). This finding is consistent with the lack of variation in covariates observed in Figure 14 through Figure 17, and the simple comparisons shown in Figure 11. While flow at MSD approximately doubled from mid-March to late March and early April, the total flow remained under 1,500 cfs, and the proportion of fish selecting the San Joaquin River route was largely stable regardless of flow (Figure 14). There was considerable variation in export rates during the pre-barrier weeks of the 2015 tagging study, but there was no consistent and coincident pattern of changes in route selection (Figure 17).

Turner Cut

When slow-moving tags and tags coming from either downstream or making repeated visits to the MAC or TCE/TCW receiver sites were removed, route selection data were available for 75 tags. Of these 75 tags, 11 (15%) selected the Turner Cut route, and 64 (85%) 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 -3,741 cfs to 3,201 cfs (average = -12 cfs) in 2015. The flow in Turner Cut was negative (directed into Turner Cut from the San Joaquin River) for 40 of 75 (53%) of the tags detected. Water velocity at TRN ranged from -0.68 ft/s to 0.64 ft/s (average = 0.02 ft/s) at the time of SJS passage in 2015; there was high correlation between river flow and water velocity at the TRN station (r=0.999). River stage at TRN ranged from 6.7 ft to 10.7 ft (average = 8.6 ft) at tag passage of SJS; correlation between river stage and either flow or water velocity was moderate (r=-0.83). The average magnitude (root mean square) of river flow at Garwood Bridge (station SJG) in the San Joaquin River during fish travel from the SJG acoustic receiver to SJS passage ranged from 1,491 cfs to 2,242 cfs (average = 1,860 cfs); data were missing for three tag. Daily export rates at CVP ranged from 240 cfs to 3,340 cfs (average = 954 cfs); SWP export rates were less variable (range 284–745 cfs) and averaged 555 cfs; the CVP proportion of combined export rates ranged from 45% to 92% (average = 63%). There was moderate correlation between either CVP exports or SWP exports and flow at Turner Cut ($|r| \leq 0.15$ for both).

Of the 75 tags detected at MAC or TCE/TCW and used in the route selection analysis at the Turner Cut junction, 1 was estimated to have passed the SJS receivers at dawn, 63 during the day, and 11 at night. Only one (9%) of the 11 tags passing at night, and 10 (16%) of the 64 tags passing during the day, selected the Turner Cut route; the single tag passing at dawn selected the San Joaquin River route. Steelhead that selected the Turner Cut route tended to pass SJS with slightly lower (negative) flow at TRN than those that selected the San Joaquin River route (Figure 18); negative flow at TRN indicated flow directed into Turner Cut from the San Joaquin River. However, there was a high degree of overlap in flow conditions upon SJS passage for both the Turner Cut fish and the San Joaquin River fish (Figure 18). There was little difference in TRN river stage between the Turner Cut fish and the San Joaquin River fish at the time of fish passage of SJS, but Turner Cut fish tended to have a higher 15-minute change in river stage; that pattern is consistent with an incoming tide at the TRN gage; nevertheless, there was considerable overlap in the range of river stage and 15-minute change in river stage data between the fish taking the two routes (Figure 18). River flow during the transition from the Stockton area (SJG) to the Turner Cut junction (SJS), represented by the RMS of river flow at the SJG gage, was more variable for the Turner Cut fish than for the San Joaquin River fish (Figure 18), a result that may be explained by the number of fish taking the Turner Cut route; the same was true of the SWP export rate and CVP percentage of combined exports (Figure 18). On the other hand, fork length tended to be more variable among the fish that selected the San Joaquin River route, which may reflect the relative lack of Turner Cut fish earlier in the season (e.g., Figure 19) when study fish tended to be smaller at tagging.

The majority of the fish detected at either Turner Cut or MacDonald Island in 2015 were observed at MacDonald Island, and most came from the late March release group (Table 11). There was little obvious pattern in variations in route selection and either flow (Figure 19), velocity (Figure 20), river stage (Figure 21), or exports (Figure 22), summarized on the weekly time scale. Although flow, velocity, and river stage at TRN (averaged over tag passage of SJS) varied considerably between weeks, there were few tags detected on the TCE/TCW or MAC receivers during the weeks of peak and minimum TRN flow, velocity, and river stage (Figure 19–Figure 21), leaving lower variability with which to observe associations between conditions and route selection. There was considerable variability in exports throughout the study, but the single week of high exports occurred in mid-March, when only one tag was detected at the receivers near the Turner Cut junction.

Of the 75 tags used in the Turner Cut route selection analysis, 64 (85%) selected the San Joaquin River route, and 11 (15%) selected the Turner Cut route. This left a maximum of 10 degrees of freedom for the regression models. The single-variate analyses found no significant associations (α=0.05) between the probability of remaining in the San Joaquin River at the Turner Cut junction and any of the covariates considered (P≥0.4017 for each covariate; Table 19). The lack of statistical significance of associations between covariates and route selection at Turner Cut may represent lack of a relationship, or alternatively low statistical power resulting from the small sample size (75) available for this analysis and the few degrees of freedom available (10).

Survival through Facilities

Survival through the water export facilities was estimated as the overall probability of reaching either Chipps Island, Jersey Point, False River, Threemile Slough, or Montezuma 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 is conditional on being entrained in the holding tank, while survival for the state facility 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. Estimates were based on the assumption of 100% detection probability at Montezuma Slough, where the single receiver array precluded estimation of detection probability. One tag was detected at the Montezuma Slough receiver; it had previously been detected in the CVP holding tank. Conditional detection probabilities were estimated for all other sites used (G1, G2, H1, and T1). No steelhead-type tags were detected in either the CVP holding tank or the interior radial gates receivers for the third (i.e., April) release group; thus, all results represent only the two March release groups.

Estimated survival from the CVP holding tank to the receivers located near of the salvage release sites (Chipps Island, Jersey Point, False River, Threemile Slough, and Montezuma Slough) ranged from 0.85 ($\widehat{SE} =$ 0.10) for the early March release group, with a 95% profile likelihood interval of (0.60, 0.97), to 1.00 (95% lower bound = 0.82) for the late March release group (Table 20). For the state facility, estimated survival from the radial gates to the receivers near the release sites ranged from 0.07 ($\widehat{SE} =$

0.07) for the early March release group (95% profile likelihood interval = (0.00, 0.28)), to 0.20 ($\widehat{SE} =$ 0.13) for the late March release group (95% profile likelihood interval = (0.04, 0.50); Table 20). Sample sizes were similar for the SWP and CVP analyses for both release groups: 10-14 for SWP, and 13-15 for CVP. However, approximately 90% of the downstream detections (i.e., after release from salvage) came from tags detected at the CVP holding tank. This is consistent with the higher survival estimated from the CVP holding tank compared to the Clifton Court Forebay radial gate (SWP) (Table 20).

Comparison among Release Groups

Analysis of variance found a significant effect of release group on parameter estimates of reach-specific survival and transition probability parameters ($F_{2,24} =$ 3.440, P=0.0486). Pairwise *t*-tests found a significant difference between estimates from the late March and April release groups ($t_{24} =$ -2.622, P=0.0149); the effect was negative, indicating that survival estimates for April were generally lower than for late March. No significance difference between the early March and late March release groups (P=0.2190) or between the early March and April release groups (P=0.1864).

Linear contrasts found that the late March release group had higher survival than either the early March or April release groups for survival from release to Mossdale, route-specific survival in both primary routes to Chipps Island, and overall survival to Chipps Island (P≤0.0003) (Table 21). The early March release group had lower overall survival to Chipps Island (P=0.0013), and the April release group had lower survival from release to Mossdale and in the Old River route to Chipps Island (P≤0.0005) (Table 21).

Discussion

Predator Filter

The 2015 predator filter had lower sensitivity than the 2014 filter. This is partly based on the modifications to the calibration of the 2015 filter to reflect the detection histories of the recapture tags prior to the recapture event. In particular, some recapture tags had lengthy detection histories in the vicinity of the head of Old River. Accommodating that behavior in the predator filter meant that there was a higher potential of misclassifying some actual predators as steelhead. Conversely, several known predators had detection histories that indicated directed movement downstream and past Chipps Island, which is the default expectation of movement of actively migrating steelhead.

Threemile Slough

The Threemile Slough site (model code T1) was not used in detection histories or the survival model in previous years because few tags were detected there (USBR 2018a, 2018b, 2018c; Buchanan 2018). A higher proportion of tags were detected at T1 in 2015 than historically, so T1 was included in detection histories along the route from Disappointment Slough (model code A13) to Chipps Island (G2), as an alternative to routing past Jersey Point (G1). The T1 site was not included on pathways to G2 from any sites other than A13, because all such pathways included intervening detection sites elsewhere.

The survival model was fit both with and without the T1 site along the pathway from A13 to G2. Overall, there was no difference in the through-Delta survival estimates to Chipps Island (S_{Total}) when T1 was included, or in estimates of the transition probability from Jersey Point to Chipps Island ($\phi_{G1,G2}$) (Table 22). However, there were sizeable differences in estimates of the Jersey Point detection probability (P_{G1}), and Delta survival to Jersey Point both along the San Joaquin River route ($S_{A(MD)}$) and overall ($S_{Total(MD)}$). In general, $\hat{P}_{G1}$ was lower, and $\hat{S}_{A(MD)}$ and $\hat{S}_{Total(MD)}$ were higher, when the T1 was excluded, because tagged fish that went to T1 were assumed to have passed Jersey Point without detection. The degree to which $S_{A(MD)}$ and $S_{Total(MD)}$ are overestimated when T1 is excluded reflects the relative use of the Threemile Slough-Sacramento River route past Sherman Island compared to the Jersey Point-San Joaquin River route. Thus, the impact of omitting T1 in previous years is expected to have been primarily an overestimate of survival to the Jersey Point/False River junction along the San Joaquin route, but no bias in survival from Mossdale to Chipps Island, whether along the San Joaquin River or overall, or in the estimated transition probability from Jersey Point to Chipps Island. For example, in 2014, about 10% of the tags detected at both Medford Island and either Jersey Point or Chipps Island were detected at Threemile Slough rather than Chipps Island, compared to approximately 30% in 2015. Thus, a simple estimate of the relative bias in estimates of survival to the Jersey Point/False River junction, caused by omitting Threemile Slough detections from the model, is 10% for 2014. Using this framework, the 2014 population estimate of $S_{A(MD)}$ would have changed from 0.26 to approximately 0.24 if Threemile Slough had been included, a difference that is equivalent to the estimated standard error (0.02) (Buchanan 2018). The estimate of $S_{Total(MD)}$ for the April release group (the only estimate available for that measure in 2014) would have changed from 0.43 ($\widehat{SE} = 0.03$) to approximately 0.39. Estimates of total Delta survival and of the transition probability from Jersey Point to Chipps Island are not expected to have changed.

A primary reason for estimating survival to Jersey Point is to compare to survival estimates from over 20 years of coded wire-tag (CWT) studies of Chinook Salmon, where a survival probability was estimated to Jersey Point from either Mossdale, Durham Ferry, or Dos Reis (near Lathrop) (Brandes and McLain 2001, Newman 2008, SJRGA 2013). The CWT survival estimate was computed as the recovery ratio of fish released upstream (Mossdale, Durham Ferry, or Dos Reis) and recovered at Chipps Island or in ocean fisheries, divided by the recovery ratio of fish released at Jersey Point and recovered at Chipps Island or in ocean fisheries. It is worth noting that the fish released upstream (Mossdale, Durham Ferry, or Dos Reis) had the opportunity of passing Sherman Island via Threemile Slough and the Sacramento River as well as past Jersey Point, whereas the fish released at Jersey Point were expected to move downstream in the San Joaquin River. Thus, the CWT survival estimates experience a similar potential for positive bias, relative to survival to Jersey Point, as that observed from these acoustic-tag data when Threemile Slough detections are excluded from the survival model. On the other hand, under the (untested) assumption that survival from Sherman Island to Chipps Island is the same whether fish pass via the San Joaquin River or via the Sacramento River, then the CWT survival estimate is approximately unbiased for survival to Sherman Island.

Comparison among Release Groups

Estimates of survival through San Joaquin River reaches and the two primary reaches of Old River (i.e., head of Old River to Middle River, and head of Middle River to Chipps Island) were generally lower for the April release group compared to the late March release group, but not consistently different from estimates from the early March release. Examination of the reach-specific survival estimates (Table A2) suggests that it was primarily upstream of the head of Old River where the late March and April release groups differed in survival, and linear contrasts found that the April release group had lower survival than either of the other two release groups in this region (Table 21). The April release group also had lower survival in the Old River route than the other two release groups (Table 21), although that lower survival did not result in lower total Delta survival, perhaps because few April fish used the Old River route.

Water temperatures were considerably higher for the April release groups than for either of the March release groups (Figure 23). Water temperature at the SJL gaging station was averaged for each release group through the time period that extended from the first day of release through the last day of release, and extended by the median observed travel time from release to Chipps Island for the release group: 27 days for the early March release, 17 days for the late March release, and 10 days for the April release. The average temperature at SJL was 18.1°C, 17.6°C, and 21.1°C for the early March, late March, and April release groups, respectively. The April release group also had the lowest flows (average at VNS = 494 cfs), although the early March release group had consistently low flows until the end of the putative migration period (average = 635 cfs) (Figure 24). The late March release group had the highest flows, especially early in the migration period (average = 880 cfs) (Figure 24). Exports were highest in the first part of the early March release group (average combined CVP/SWP export rate = 2,568 cfs for entire early March migration period), and were considerably lower and less variable for the late March (average = 1,519 cfs) and April (1,254 cfs) release groups (Figure 25). In addition, the April release group was the only release for which the head of Old River barrier was installed for all fish as they approached the head of Old River; the barrier installation was complete for approximately 9% and 39% of the early and late March release groups, respectively, as fish from those groups approached the barrier.

Although the point estimates of route-specific survival to Chipps Island were always higher for the San Joaquin River route for all three release groups, the difference was statistically significant only for the late March release group. Thus, it does not appear that significant differences in route survival are related to the presence of the barrier alone. The late March release group was the only group to experience relatively high river discharge early in the release period, and relatively low water temperatures. This pattern, combined with at least partial barrier presence, may account for higher survival in the San Joaquin River route than in the Old River route for the late March release group. The relatively good conditions upstream of the head of Old River for the late March release group may also have contributed to the higher estimates of survival to Mossdale, route-specific survival through the Delta, and overall Delta survival for that release group, compared to the other releases (Table 21).

The early March release group experienced the lowest temperatures observed for all fish in the study, and these relatively low temperatures occurred early in the migration period (Figure 23). However, the fish released in early March also experienced relatively low flow compared to the late March release group (Figure 24), and longer travel times than either of the later release groups (Table 16); overall survival from Mossdale to Chipps Island was significantly lower for the early March release than for the other release groups (Table 21). Most (91%) early March fish encountered Old River before the barrier installation was complete, and the majority of fish from the early March group entered Old

River. However, the Old River route survival to Chipps Island (0.14) was not significantly different from the San Joaquin River route survival to Chipps Island (0.19) for this release group (P=0.5321), so it is not apparent that keeping more fish in the San Joaquin River would have resulted in appreciably higher survival for these fish.

Survival Through Central Valley Project

Survival through the water export facilities was estimable only for the first two release groups; lack of tag detections at the CVP trashracks and radial gates receivers prevented estimating facility survival for the April release group (Table 20). 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. Based on tag detections at Jersey Point, False River, Chipps Island, Threemile Slough, and Montezuma Slough, survival was higher through the CVP facility than through the SWP (Table 20). 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 0.36 to 0.37 ($\widehat{SE} = $0.07) for the two March release groups; no estimate was available for the April release group (Table A2). It is important to note that 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 all Old River route sites outside the CVP (Table A2), which means that the probability $1-\phi_{E1,E2}$ is limited only by the possibility of mortality either between the CVP trashracks and those sites, or between the CVP trashracks and the CVP holding tank. Due to the complex Delta routing and tidal influence in the southwest region of the Delta, it is not possible to estimate 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 although 169 tags were detected at the CVP trashracks (site E1), only 99 of those tags were assigned the trashracks detection for the survival model, implying that 70 tags (41% of 169) departed from the CVP trashracks for other non-CVP sites (i.e., B2, B3, B4, C1, C2, or D1) and successfully reached those sites. While not a reliable estimate of the final probability of leaving the CVP, the high rate of total CVP tags that were later detected elsewhere suggests that the relatively low estimates of $\phi_{E1,E2}$ (0.36–0.37) from this study may include a sizeable contribution from fish that did not finally attempt to pass into the facility. In comparison, in 2014, 93 (96%) of the 96 tags that were ever detected at the CVP trashracks (excluding predator-type detections) were assigned to the CVP route, meaning that they were not later detected elsewhere; nevertheless, the estimates of $\phi_{E1,E2}$ in 2014 were 0.50–0.51 (Buchanan 2018), suggesting considerable mortality either behind the trashracks 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 ($\widehat{SE}=0.10$) for the early March release group, and 0.93 ($\widehat{SE}=0.06$) for the late March release (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 (e.g., Table 20) was relatively high.

The daily export rate at the CVP, on the day of tag detection at the trashracks (site E1), was between 3,100 cfs and 3,400 cfs for 18 of the tags used to estimate $\phi_{E1,E2}$, all of which were from the early March release group (Figure 25); the other 81 tags were all detected at the CVP trashracks on days when the daily export rate was between 800 cfs and 1,000 cfs. A likelihood ratio test found no difference in estimates of $\phi_{E1,E2}$ and $\phi_{E2,G2}$ for conditions of export rates > 3,000 cfs versus export rates < 1,000 cfs upon detection at the CVP trashracks (P=0.1281), pooled over the March releases.

For the early March release group in 2015, the route via the CVP to Chipps Island accounted for approximately 55% of the total survival to Chipps Island: total Delta survival was estimated at 0.15 ($\widehat{SE}=0.03$), and the total probability of getting from Mossdale to Chipps Island via Old River and the CVP was 0.08 ($\widehat{SE}=0.02$). The probability of getting from Mossdale to Chipps Island via the CVP was unchanged for the late March release group (0.08, $\widehat{SE} = 0.02$), but the total survival to Chipps Island via all routes increased considerably to 0.35 ($\widehat{SE} = 0.03$); for this release group, the CVP route accounted for only approximately 22% of the total survival to Chipps Island. For the April release group, total survival to Chipps Island was estimated at 0.20 ($\widehat{SE} = 0.04$), and no tags were observed getting there via the CVP (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 2015, the early March release group had both a relatively high probability of entering Old River at its head (0.81, $\widehat{SE} = 0.03$) and relatively low survival in the San Joaquin River route (0.19, $\widehat{SE} = 0.07$), compared to the late March release group (Table 14); these two factors contributed to the CVP representing a higher proportion of total Delta survival for the early March release group compared to the late March group.

Fish Health Study

A fish health study was conducted by the USFWS California-Nevada Fish Health Center (Nichols 2015) concurrently with the steelhead tagging study. Three groups of 24 yearling steelhead were obtained from the CDWR Mokelumne River Hatchery in March and April 2015. Sampled fish were subject to the same handling, tagging, and transport as the steelhead used in the tagging study. One out of 72 steelhead used in the fish health study (1.4%) died within the 48-hour holding period; this mortality was classified as due to complications from tagging. Overall condition of the three steelhead groups appeared good, and there was no evidence to suspect survival differences between the groups. No significant pathogen infections were detected. Differences in gill NA^{+}/K^{+}-ATPase activity were observed among the sample groups; the differences were small and were not expected to affect migration or survival. More details are available in Nichols (2015).

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Figures

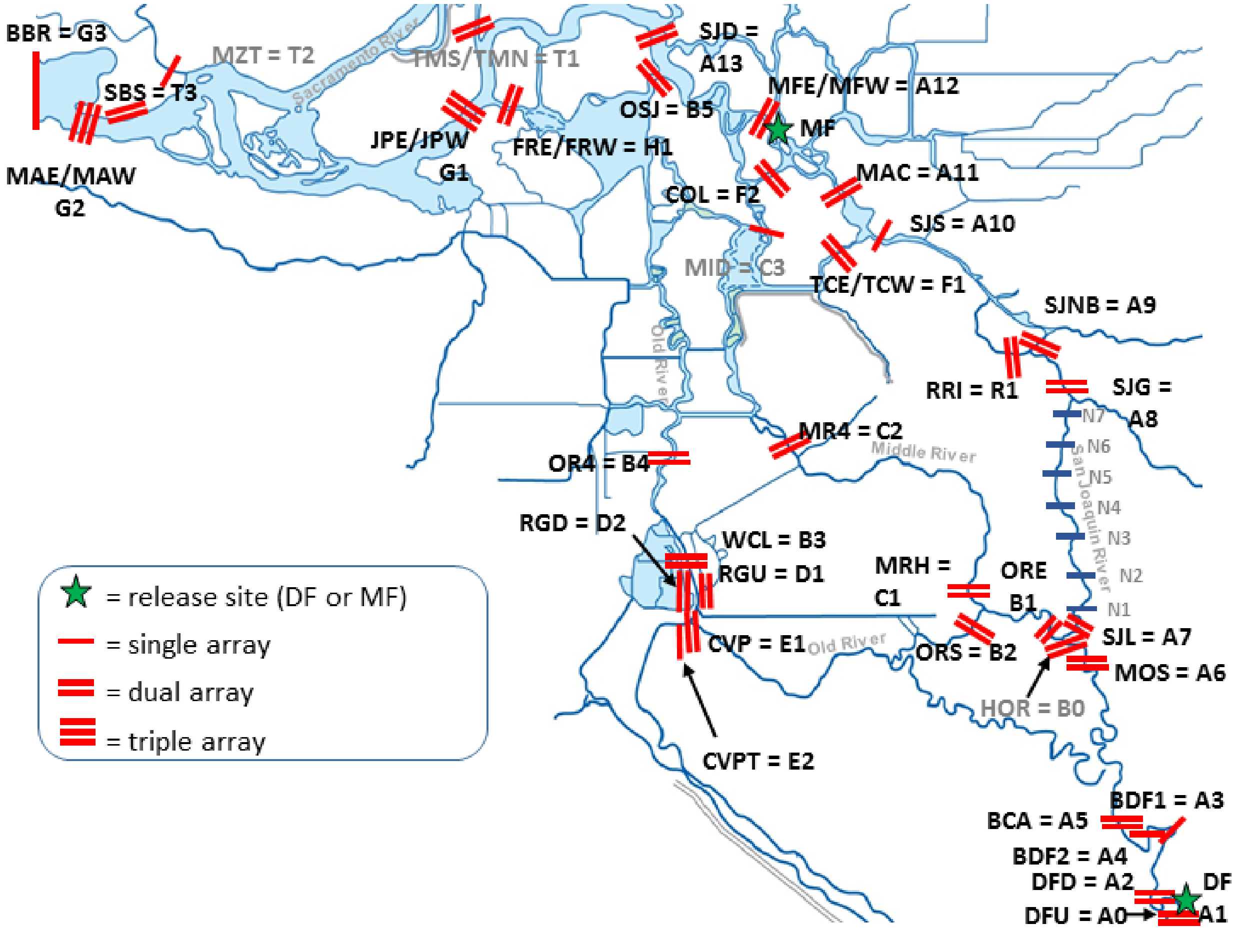

Figure 1. Locations of acoustic receivers and release site used in the 2015 steelhead tagging study, with site code names (3- or 4-letter code) and model code (letter and number string). Site A1 is the release site at Durham Ferry. Sites in gray were omitted from the survival model.

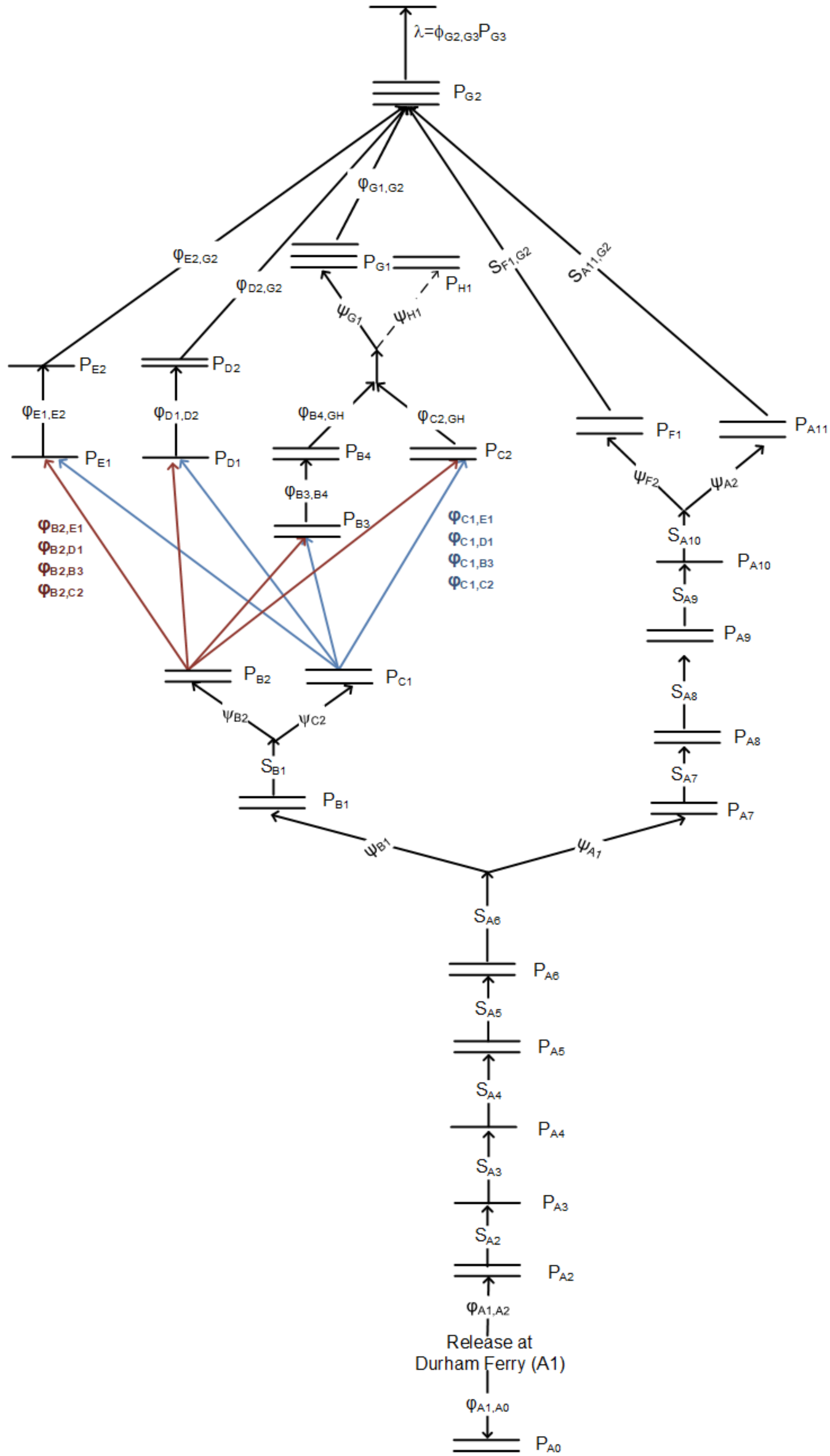

Figure 2. Schematic of 2015 mark-recapture Submodel I with estimable parameters. Single lines denote single-array or redundant double-line telemetry stations, and double or triple lines denote dual-array or triple-array telemetry stations, respectively. Names of telemetry stations correspond to site labels in Figure 1. Migration pathways to sites B3 (WCL), C2 (MR4), D1 (RGU), and E1 (CVP) are color-coded by departure site.

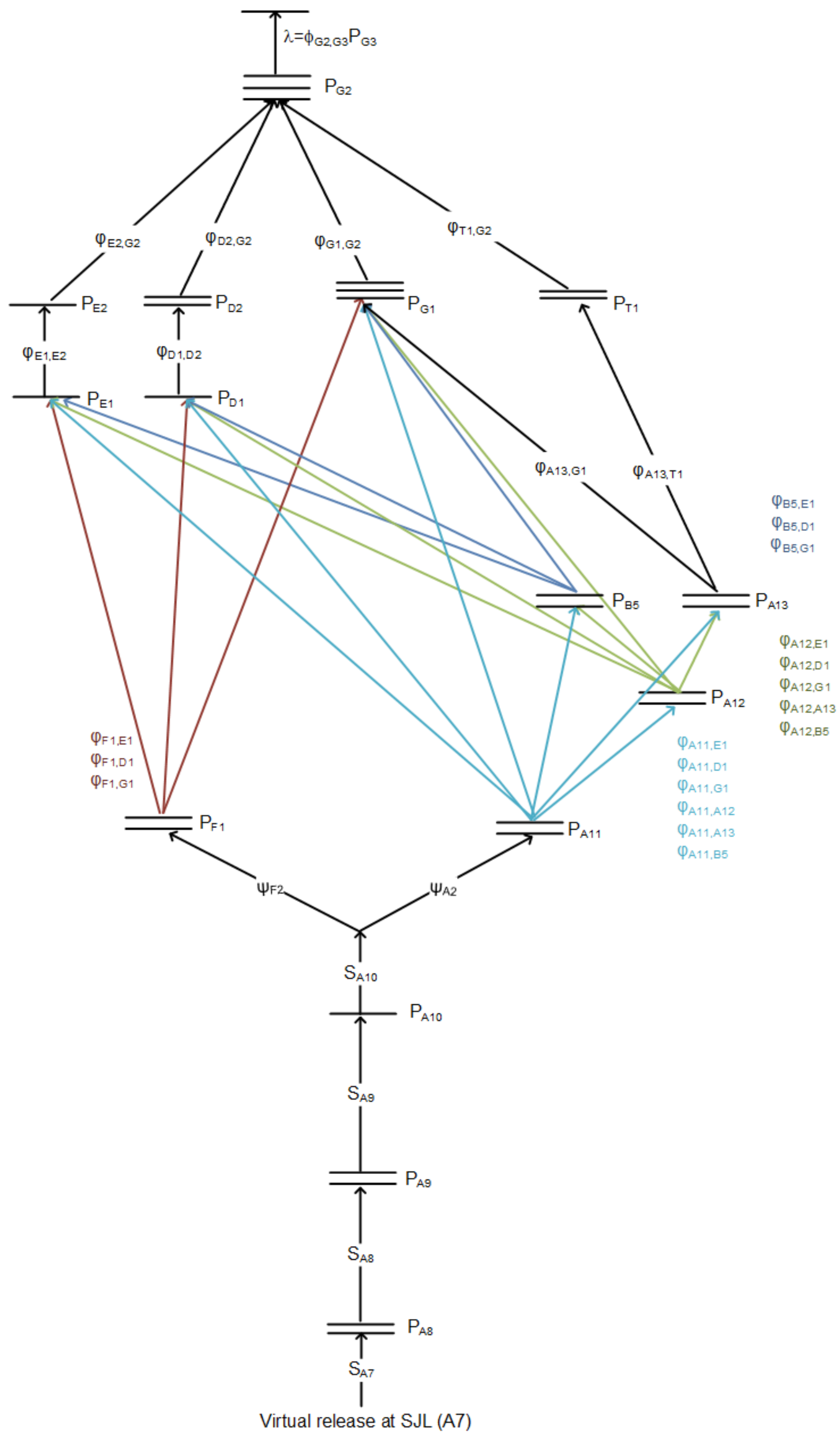

Figure 3. Schematic of 2015 mark-recapture Submodel II with estimable parameters. Single lines denote single-array or redundant double-line telemetry stations, and double or triple lines denote dual-array or triple-array telemetry stations. Names of telemetry stations correspond to site labels in Figure 1. Migration pathways to sites A13 (MFE/MFW), B5 (OSJ), D1 (RGU), E1 (CVP), and the G1-H1 junction (JPE/JPW – FRE/FRW) are color-coded by departure site.

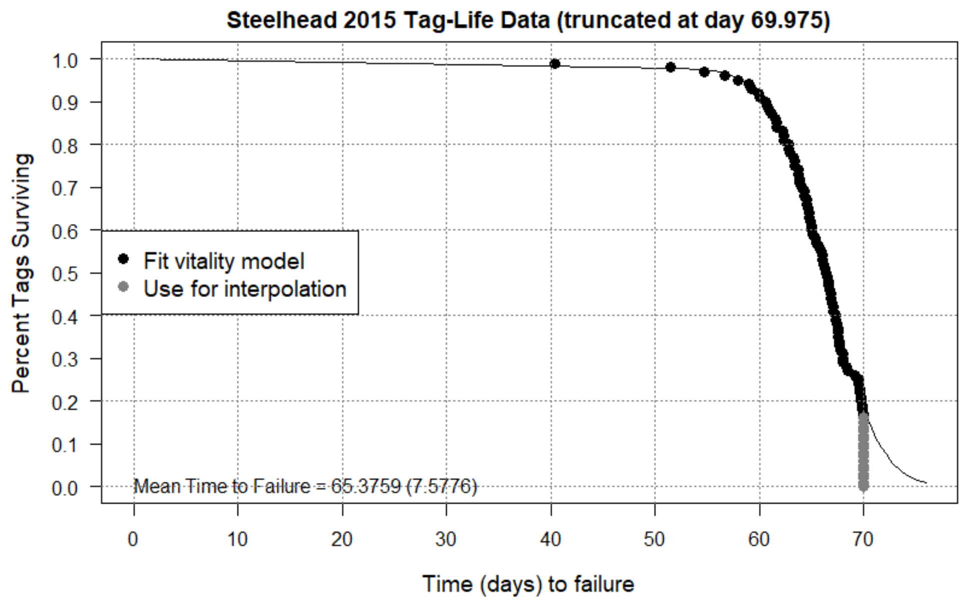

Figure 4. Observed tag failure times from the 2015 tag-life studies (pooled over the April and May studies), and fitted four-parameter vitality curve. Failure times were censored at day 70 to improve fit of the model.

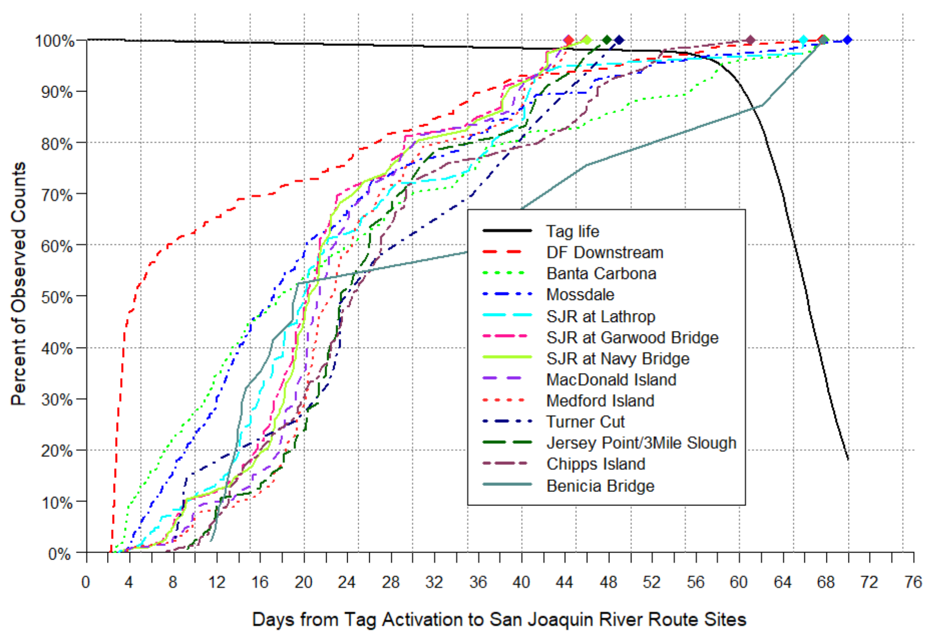

Figure 5. Four-parameter vitality survival curve for tag survival, and the cumulative arrival timing of acoustic-tagged juvenile steelhead at receivers in the San Joaquin River route to Chipps Island in 2015, including detections that may have come from predators; tag-life data were pooled across tag-life studies, and arrival time data were pooled across releases. The tag survival curve was estimated only to day 70, to improve model fit.

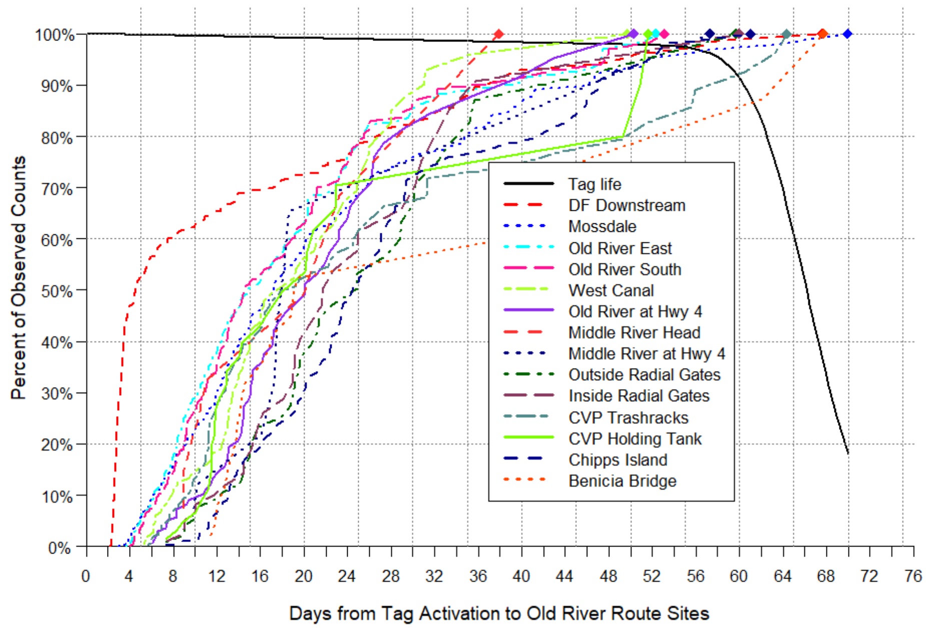

Figure 6. Four-parameter vitality survival curve for tag survival, and the cumulative arrival timing of acoustic-tagged juvenile steelhead at receivers in the Old River route to Chipps Island in 2015, including detections that may have come from predators; tag-life data were pooled across tag-life studies, and arrival time data were pooled across releases. The tag survival curve was estimated only to day 70, to improve model fit.

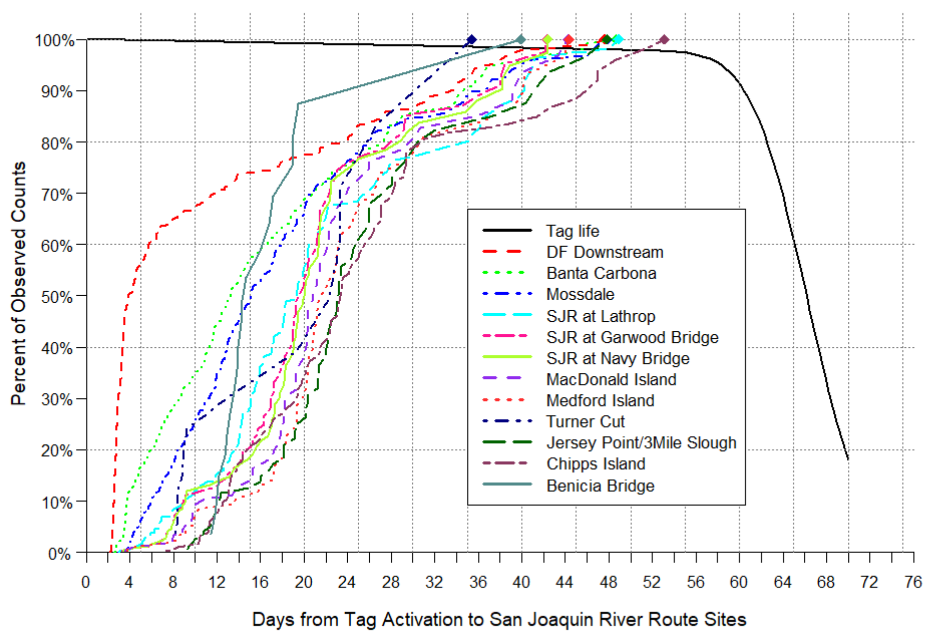

Figure 7. Four-parameter vitality survival curve for tag survival, and the cumulative arrival timing of acoustic-tagged juvenile steelhead at receivers in the San Joaquin River route to Chipps Island in 2015, excluding detections that were deemed to have come from predators; tag-life data were pooled across tag-life studies, and arrival time data were pooled across releases. The tag survival curve was estimated only to day 70, to improve model fit.

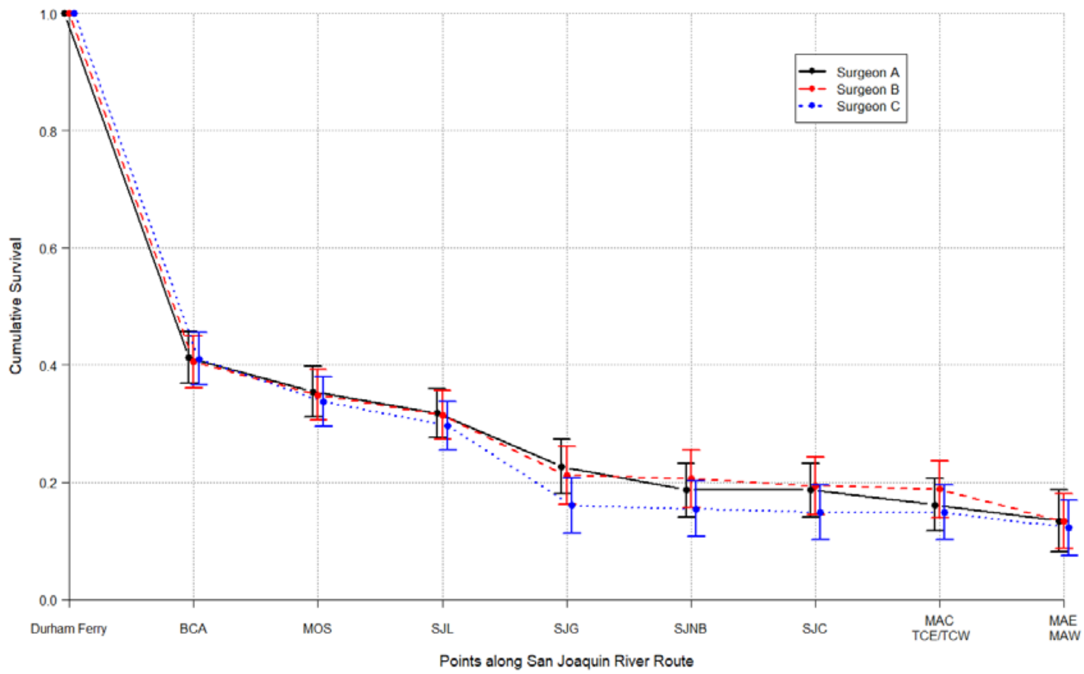

Figure 8. Cumulative survival from release at Durham Ferry to various points along the San Joaquin River route to Chipps Island, by surgeon. Error bars are 95% confidence intervals.

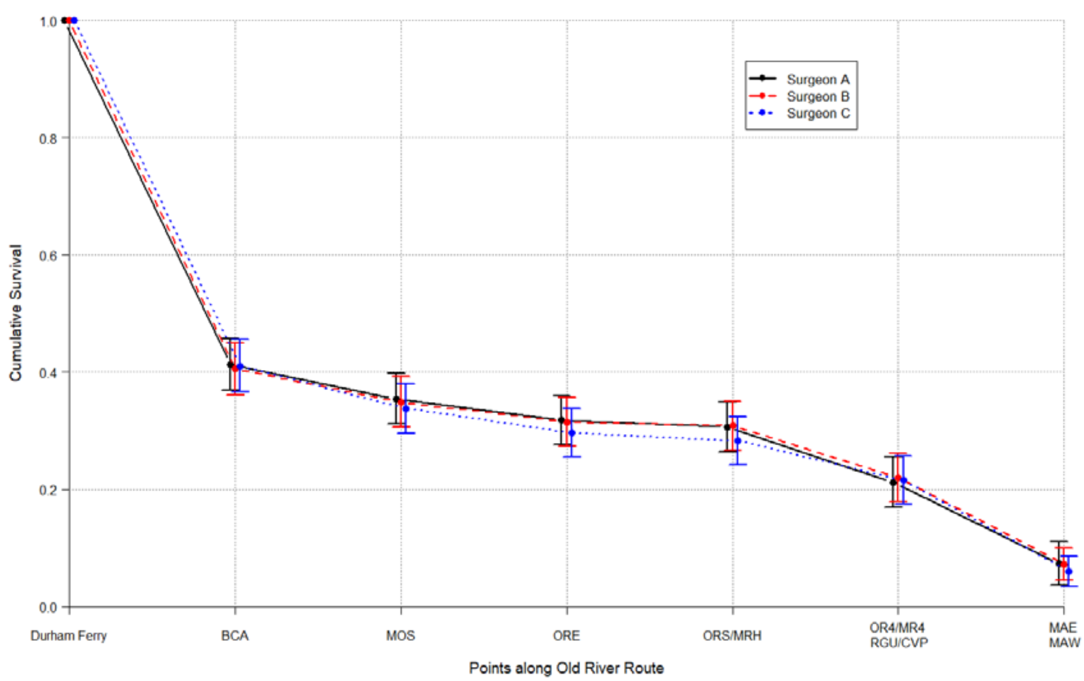

Figure 9. Cumulative survival from release at Durham Ferry to various points along the Old River route to Chipps Island, by surgeon. Error bars are 95% confidence intervals.

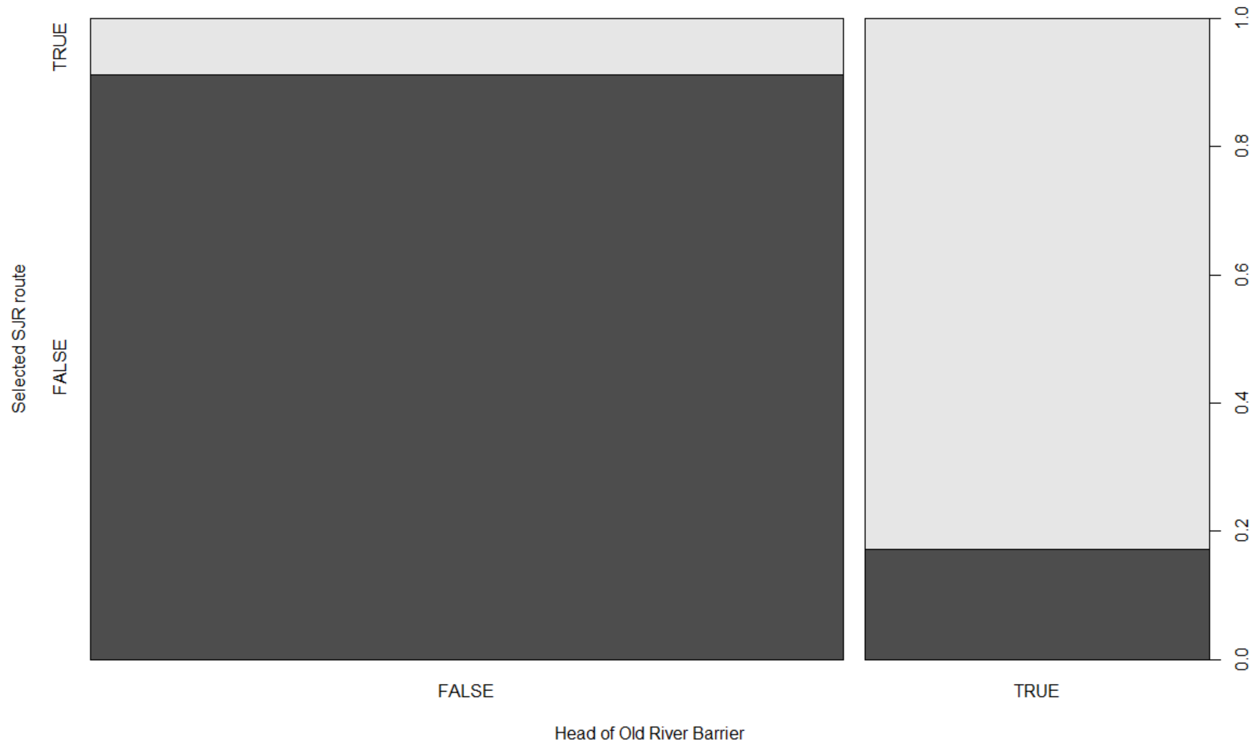

Figure 10. Relative proportions of 369 tags in the head of Old River route selection analysis observed selecting the San Joaquin River route (light shading) based on barrier status at time of arrival at the head of Old River in 2015. The short, dark region, denoting the "barrier" and "Old River route" combination, represented 20 tags.

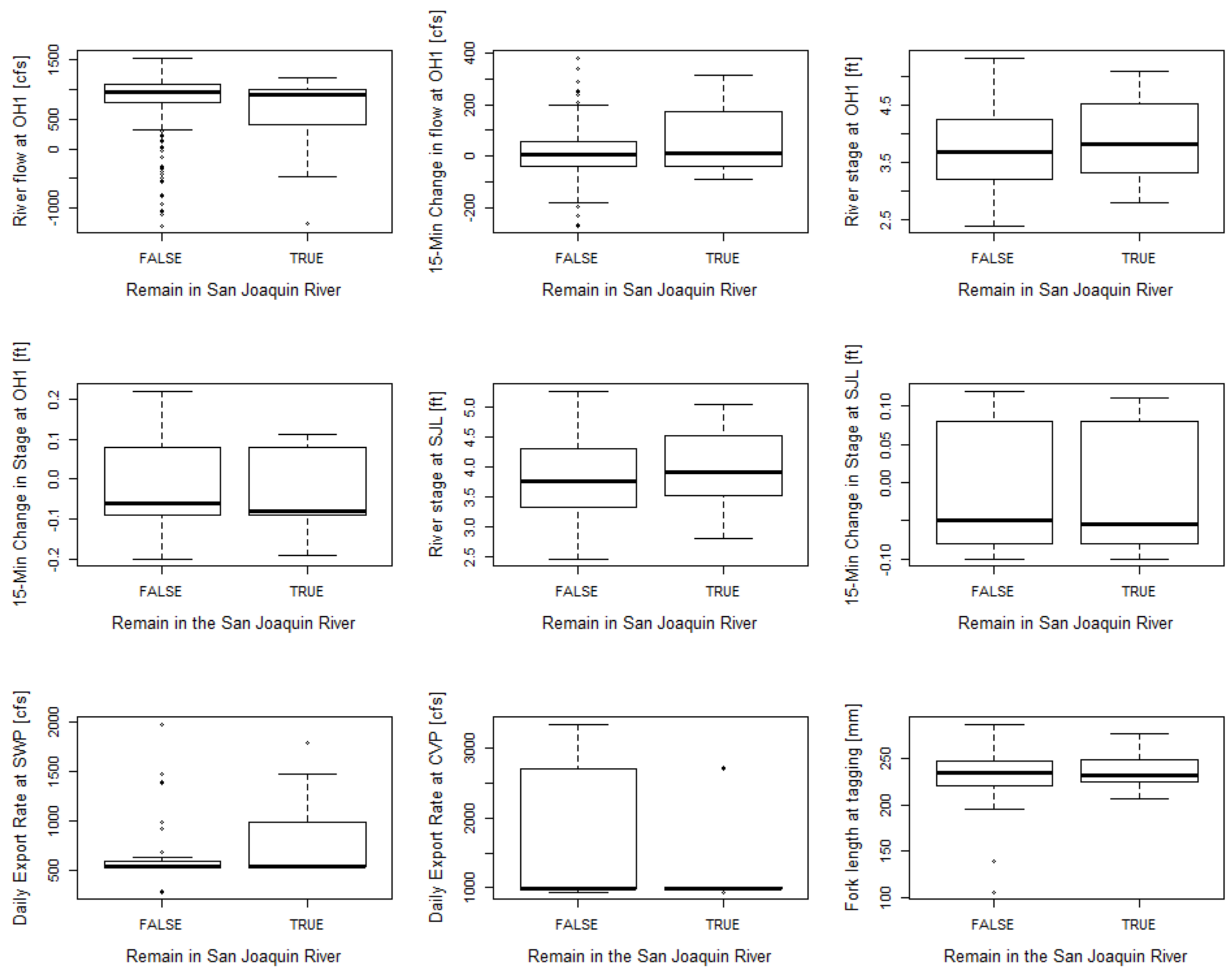

Figure 11. Conditions upon the estimated time of arrival at the head of Old River junction, daily export rates, and fork length at tagging, for steelhead detected at the SJL or ORE receivers and estimated to have arrived at the head of Old River junction before 1500 hours on 3 April 2015 (closure date 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 of 1.5 × the interquartile range.

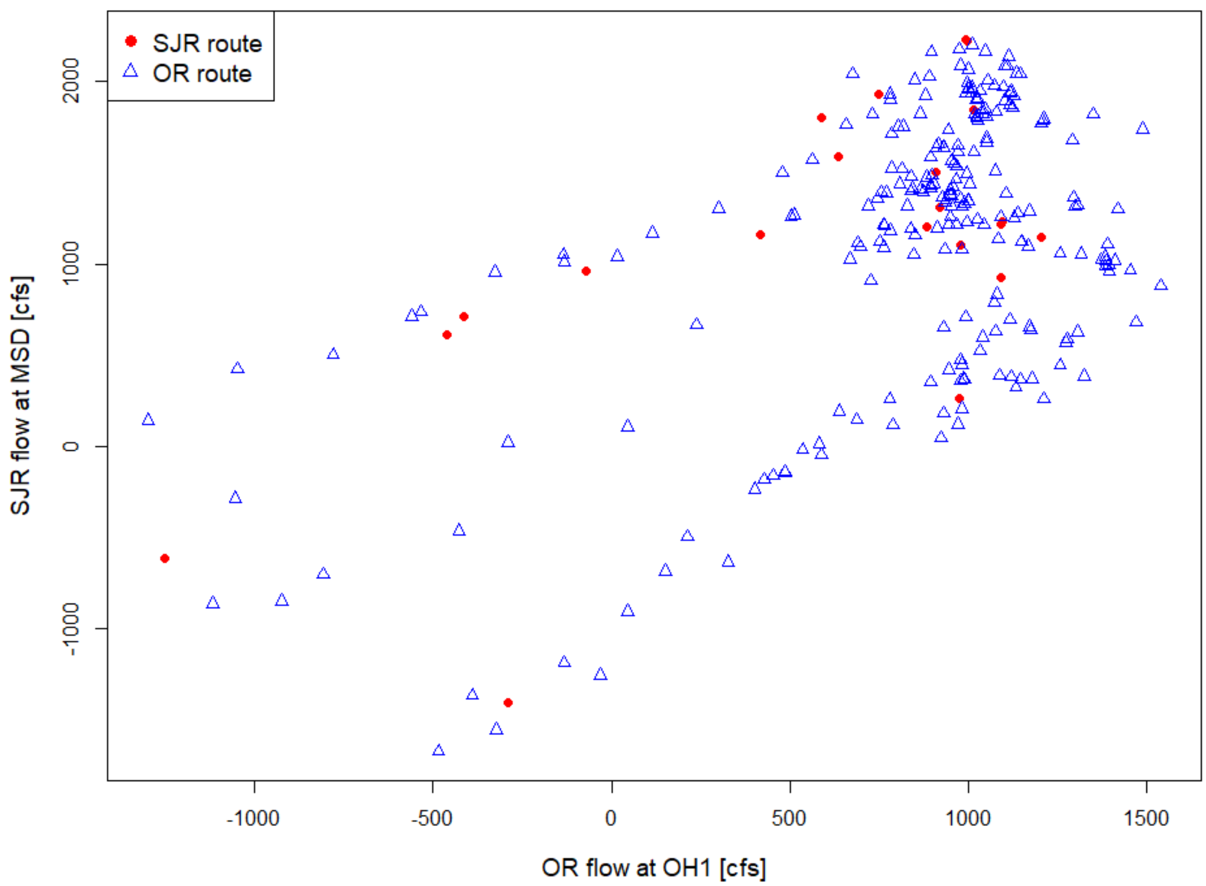

Figure 12. Discharge ("flow") of the Old River ("OR") at the OH1 gaging station, and of the San Joaquin River ("SJR") at the MSD gaging station at the estimated time of arrival at the head of Old River junction of tagged steelhead detected at the SJL (filled circles) or ORE (open triangles) receivers and estimated to have arrived at the head of Old River junction before 1500 hours on 3 April 2015 (barrier closure date).

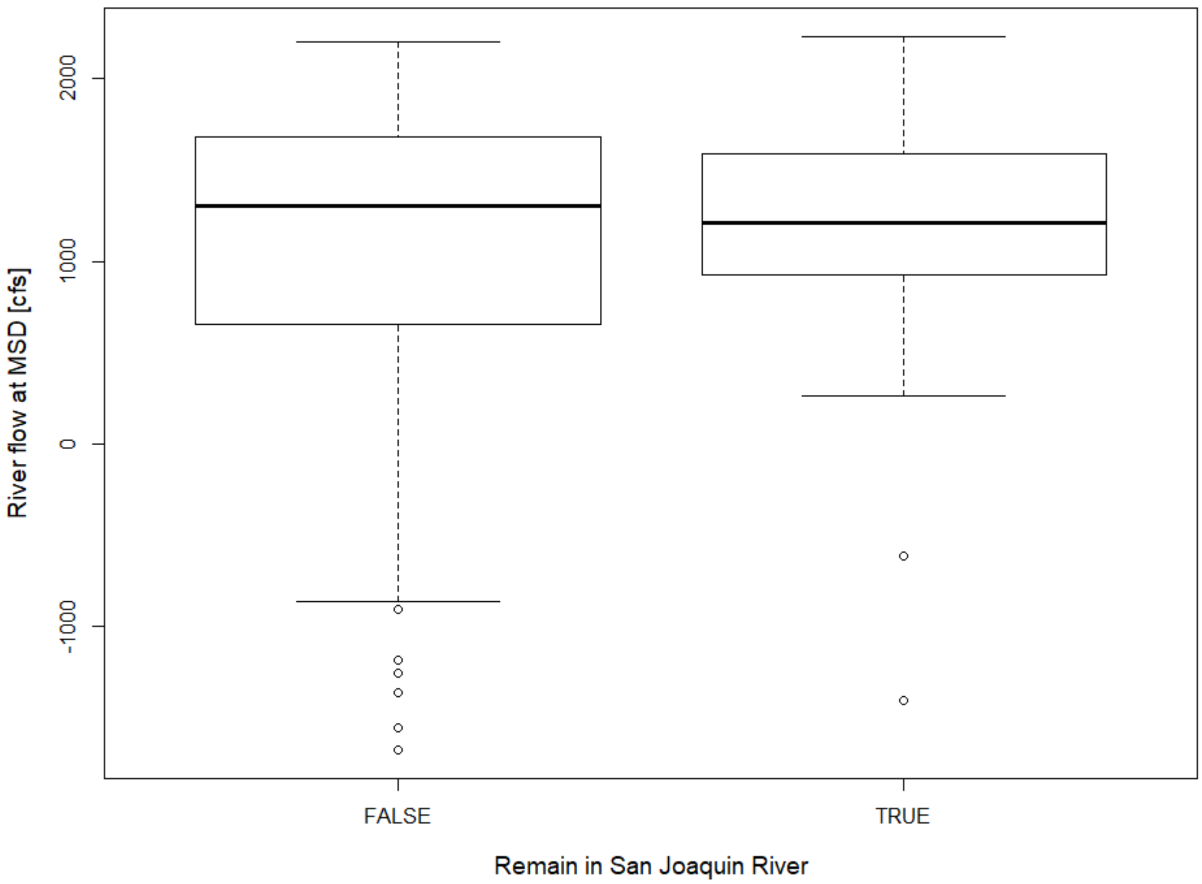

Figure 13. San Joaquin River flow conditions at the MSD gaging station upon the estimated time of arrival at the head of Old River junction, for steelhead detected at the SJL or ORE receivers and estimated to have arrived at that junction before 1500 hours on 3 April 2015 (date of barrier closure). Data represent tags that 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 of 1.5 × the interquartile range.

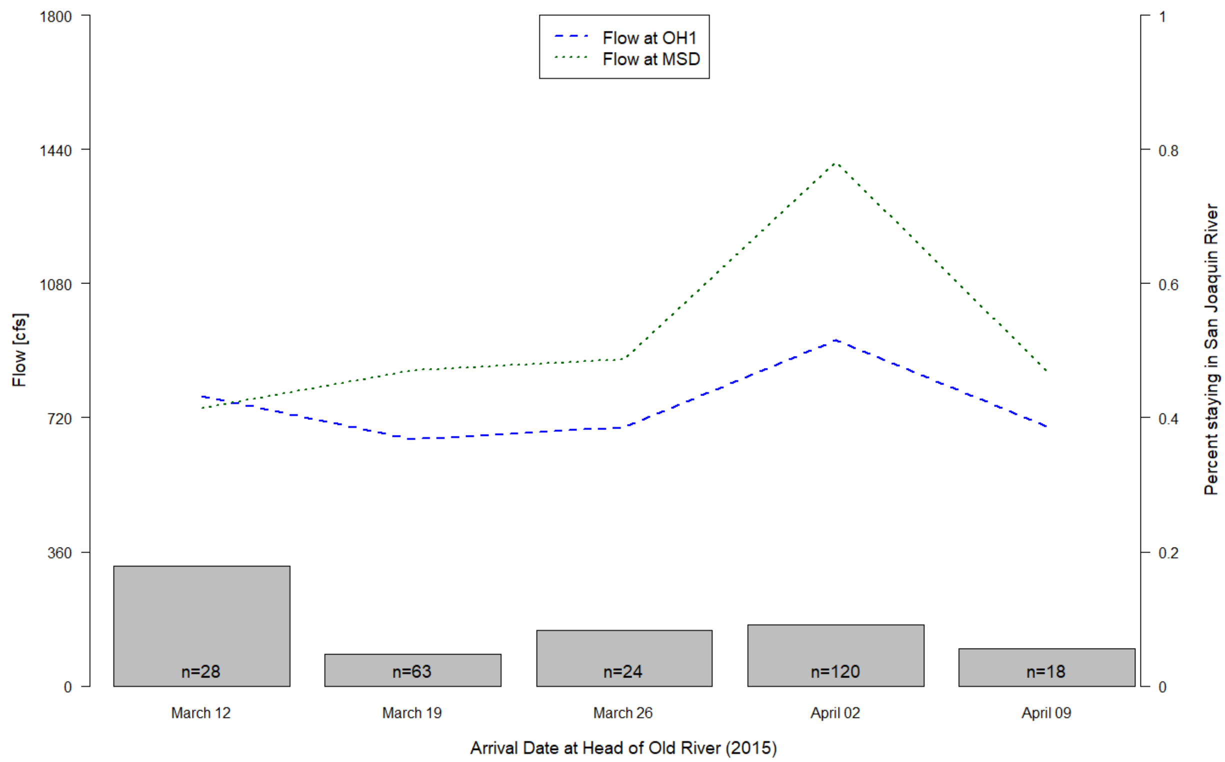

Figure 14. The observed proportion of tagged juvenile steelhead that remained in the San Joaquin River at the head of Old River during the 2015 tagging study (gray bars, representing weekly periods; n = weekly sample size), and the measured flow at the OH1 and MSD gaging stations at the estimated time of fish arrival at the junction, averaged over fish, for steelhead estimated to have arrived at the junction before 1500 hours on 3 April 2015. Proportion of fish remaining in the San Joaquin River is shown only for time periods with at least 10 fish detected.

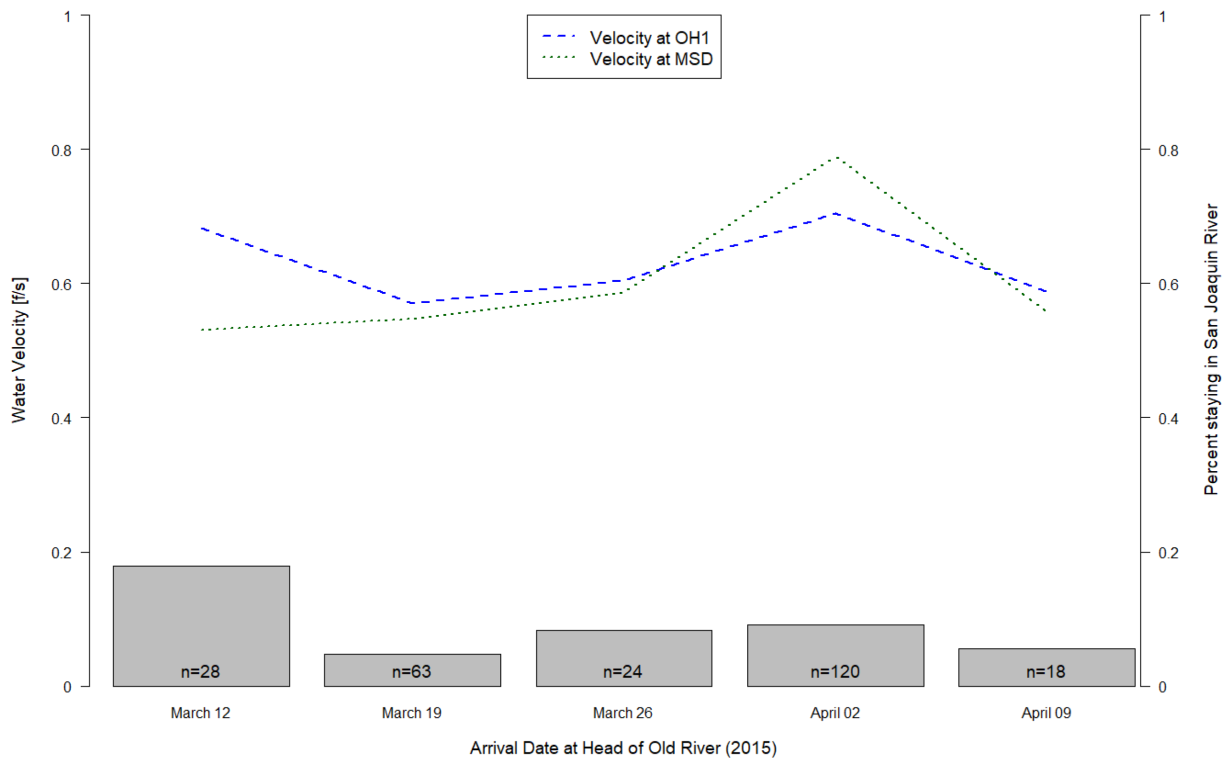

Figure 15. The observed proportion of tagged juvenile steelhead that remained in the San Joaquin River at the head of Old River during the 2015 tagging study (gray bars, representing weekly periods; n = weekly sample size), and the measured water velocity at the OH1 and MSD gaging stations at the estimated time of fish arrival at the junction, averaged over fish, for steelhead estimated to have arrived at the junction before 1500 hours on 3 April 2015. Proportion of fish remaining in the San Joaquin River is shown only for time periods with at least 10 fish detected.

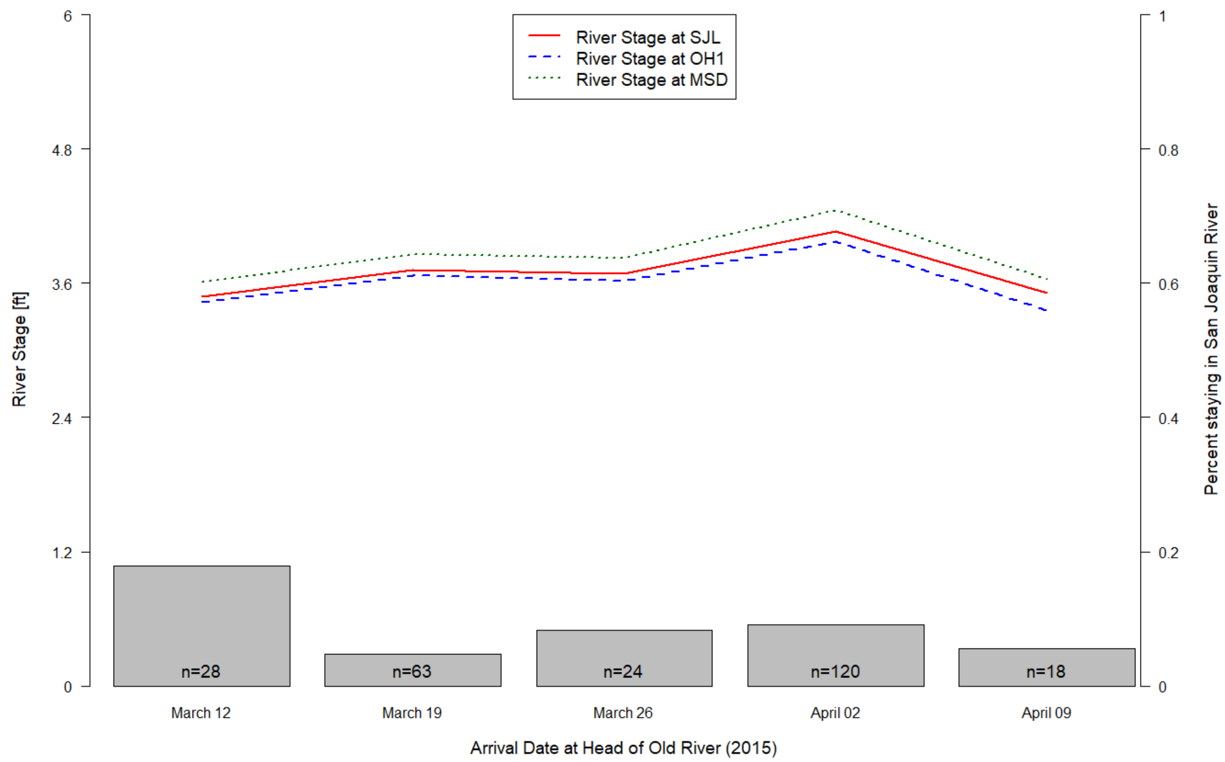

Figure 16. The observed proportion of tagged juvenile steelhead that remained in the San Joaquin River at the head of Old River during the 2015 tagging study (gray bars, representing weekly periods; n = weekly sample size), and the measured river stage at the SJL, OH1, and MSD gaging stations at the estimated time of fish arrival at the junction, averaged over fish, for steelhead estimated to have arrived at the junction before 1500 hours on 3 April 2015. Proportion of fish remaining in the San Joaquin River is shown only for time periods with at least 10 fish detected.

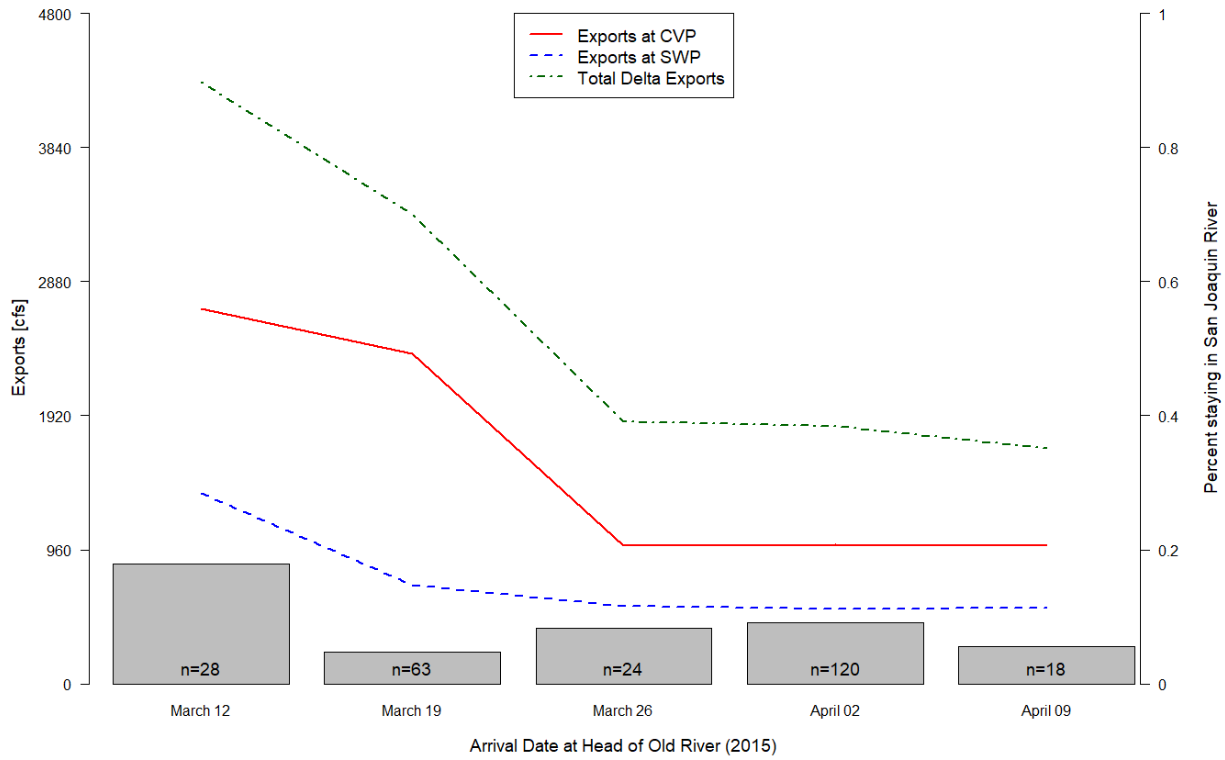

Figure 17. The observed proportion of tagged juvenile steelhead that remained in the San Joaquin River at the head of Old River during the 2015 tagging study (gray bars, representing weekly periods; n = weekly sample size), and the measured daily export rate at CVP, SWP, and total in the Delta on the estimated day of fish arrival at the junction, averaged over fish, for steelhead estimated to have arrived at the junction before 1500 hours on 3 April 2015. Proportion of fish remaining in the San Joaquin River is shown only for time periods with at least 10 fish detected.

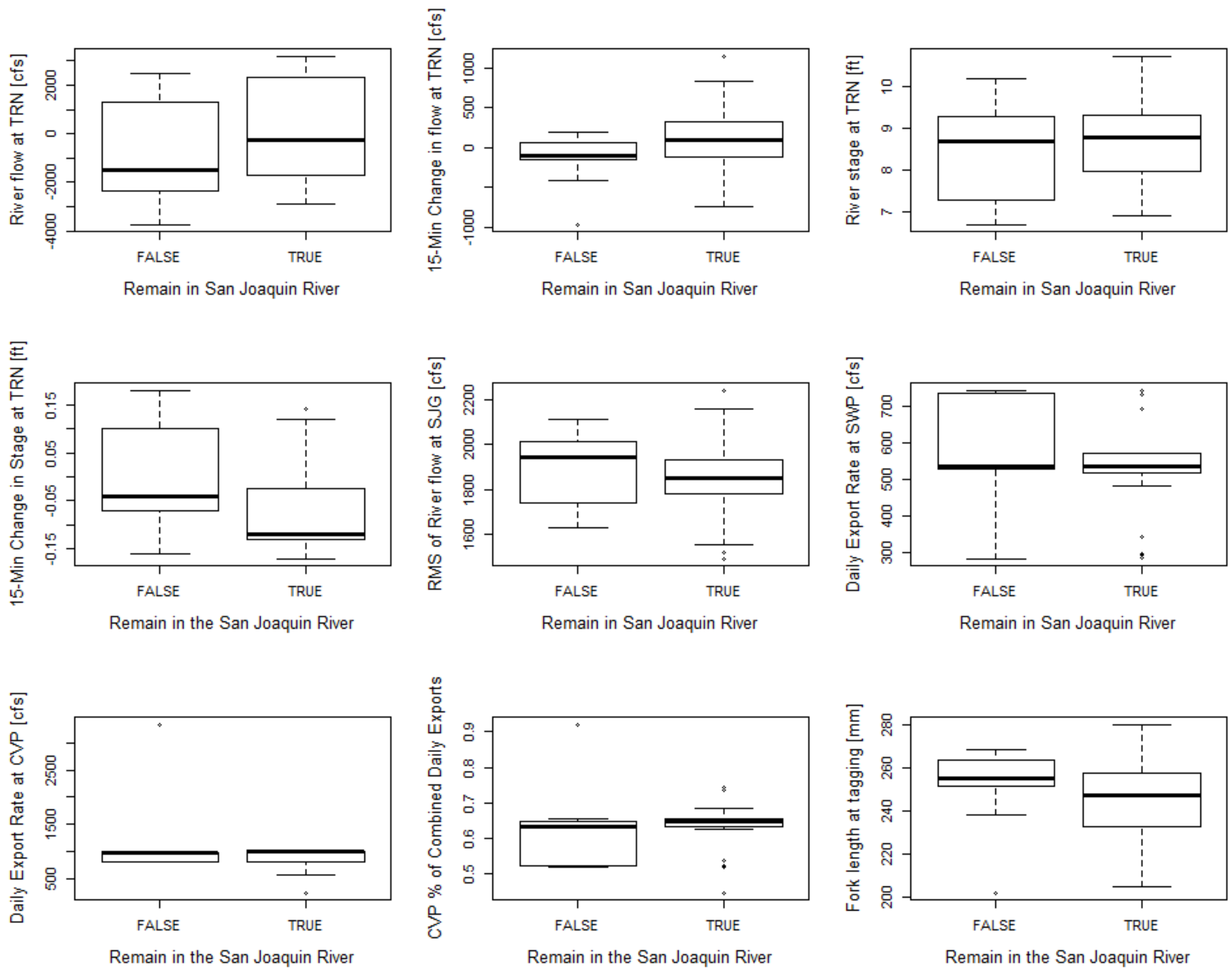

Figure 18. Hydrological conditions upon the estimated time of tag passage at the SJS receiver (0.38 km upstream of the Turner Cut junction), daily export rates, and fork length at tagging, for steelhead detected at the MAC or TCE/TCW receivers. Data represent tags that whose most recent detections were either upstream or in the other river branch, and with travel time ≤5 hours from SJS to either MAC or TCE/TCW, or ≤3 hours from MAC to 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.

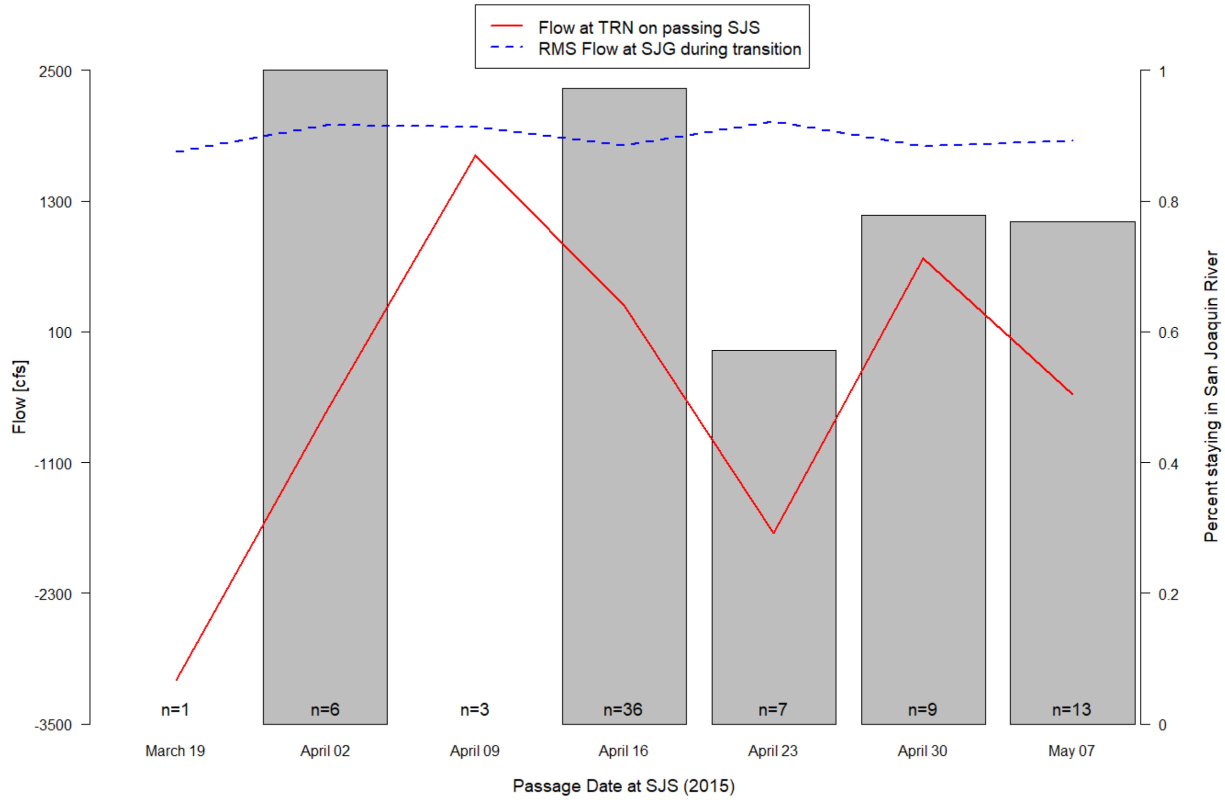

Figure 19. The observed proportion of tagged juvenile steelhead that remained in the San Joaquin River at the Turner Cut junction during the 2015 tagging study (gray bars, representing weekly periods; n = weekly sample size), the measured river discharge (flow) at the TRN gaging station in Turner Cut 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 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.

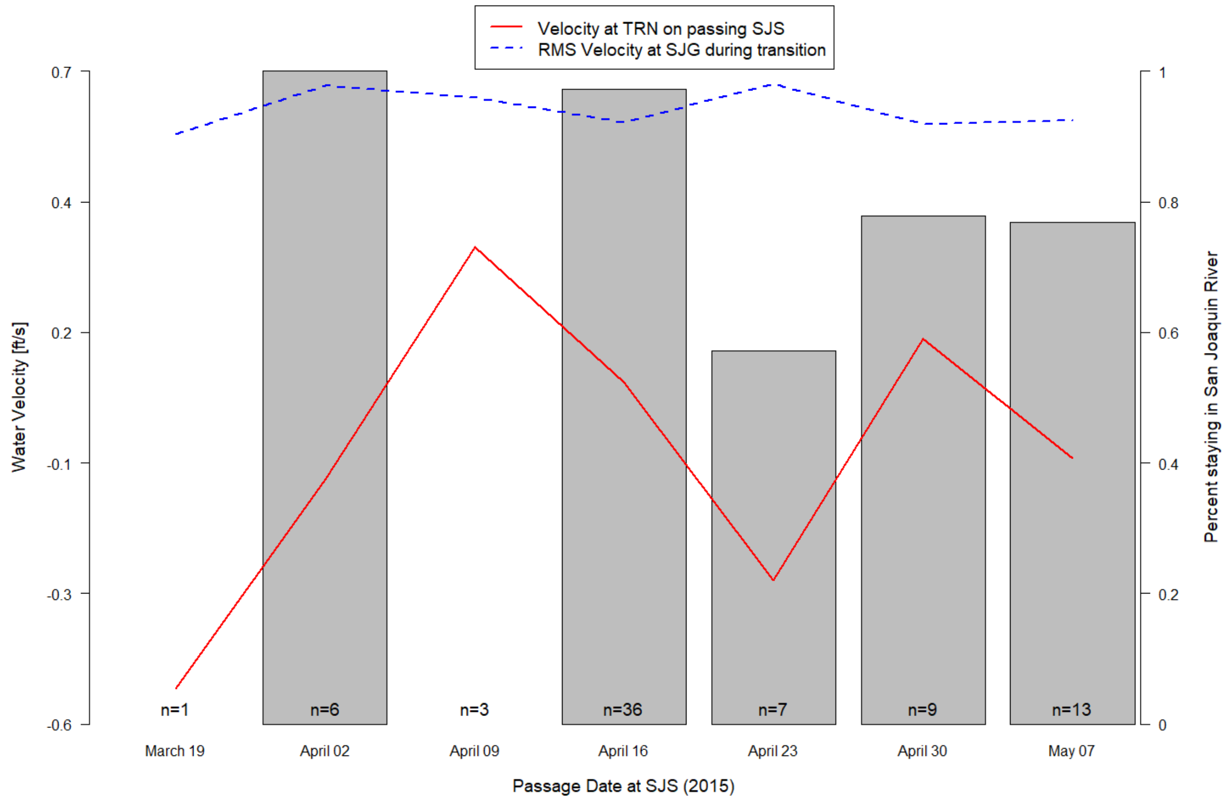

Figure 20. The observed proportion of tagged juvenile steelhead that remained in the San Joaquin River at the Turner Cut junction during the 2015 tagging study (gray bars, representing weekly periods; n = weekly sample size), the measured water velocity at the TRN gaging station in Turner Cut at the 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.

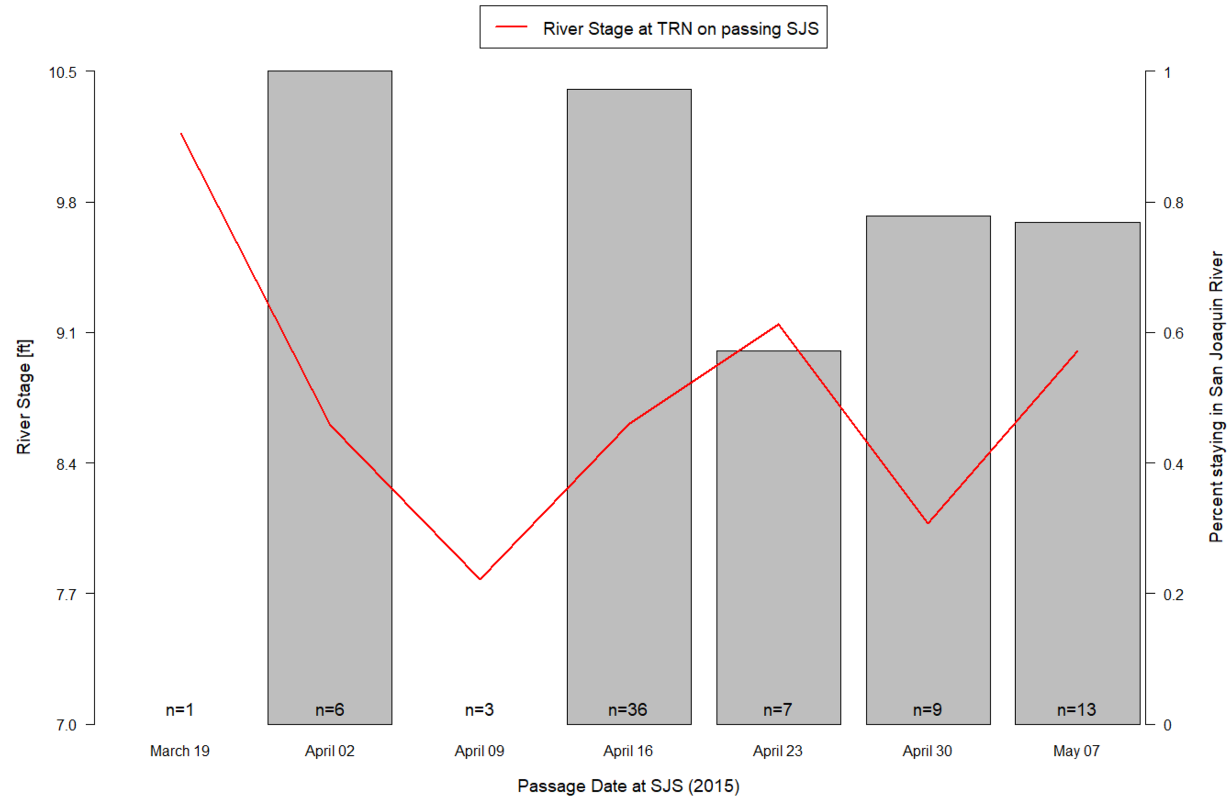

Figure 21. The observed proportion of tagged juvenile steelhead that remained in the San Joaquin River at the Turner Cut junction during the 2015 tagging study (gray bars, representing weekly periods; n = weekly sample size), and the measured river stage at the TRN gaging station in Turner Cut at the 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.

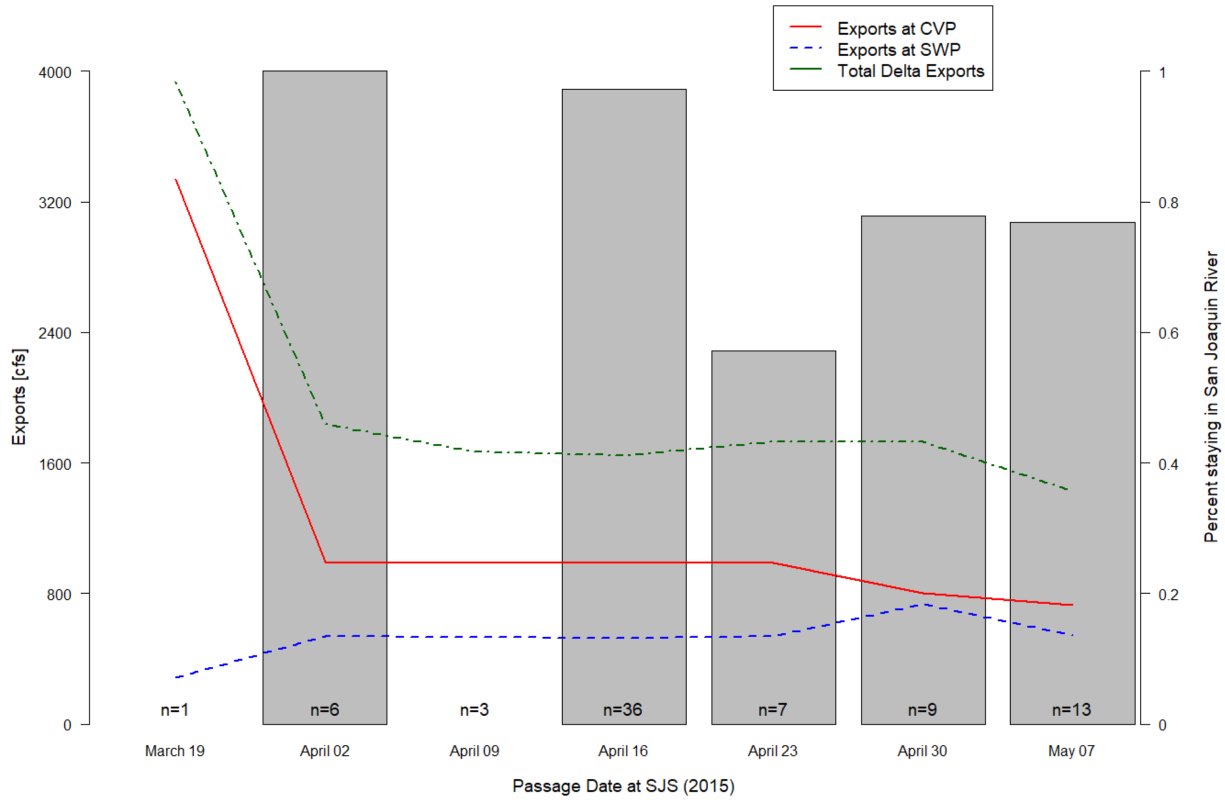

Figure 22. The observed proportion of tagged juvenile steelhead that remained in the San Joaquin River at the Turner Cut junction during the 2015 tagging study (gray bars, representing weekly periods; n = weekly sample size), and the measured daily export rate at CVP, SWP, and total in the Delta at the 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.

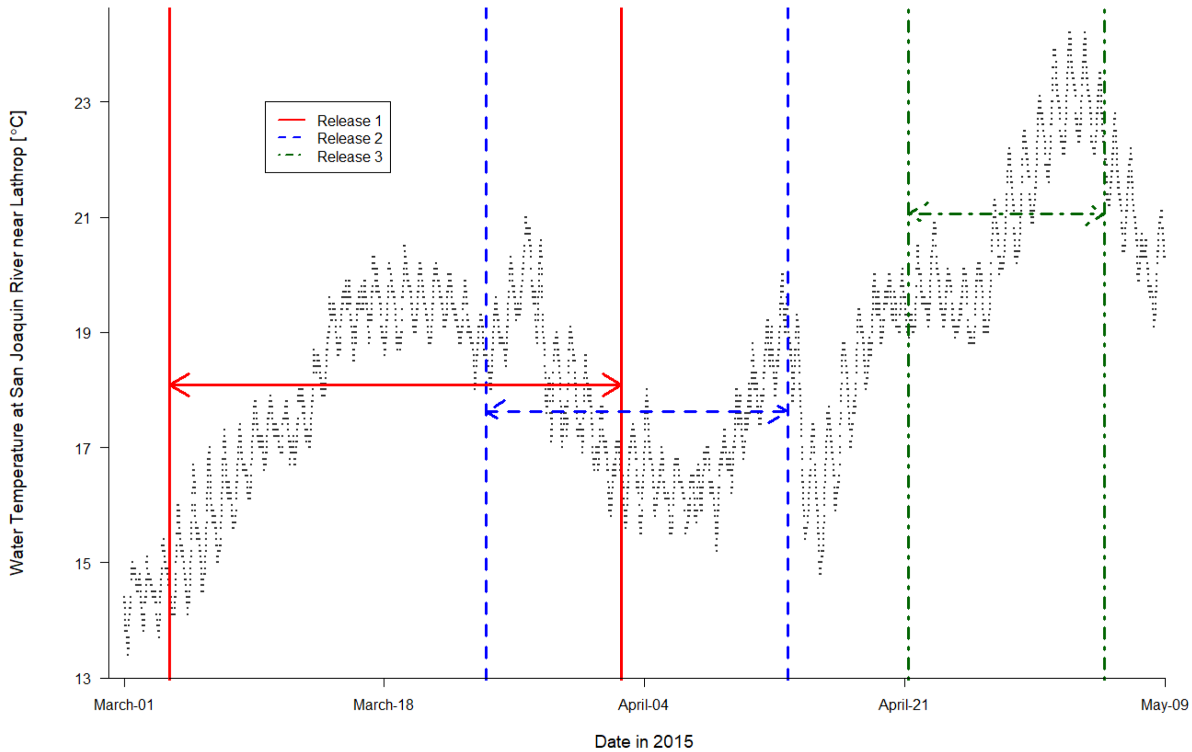

Figure 23. Water temperature at the San Joaquin River gaging station near Lathrop (SJL) during the 2015 study. Vertical lines represent the time period from the first day through the final day of release, plus the median observed travel time to Chipps Island for the release. Arrow height indicates mean temperature: 18.1°C, 17.6°C, and 21.1°C, respectively.

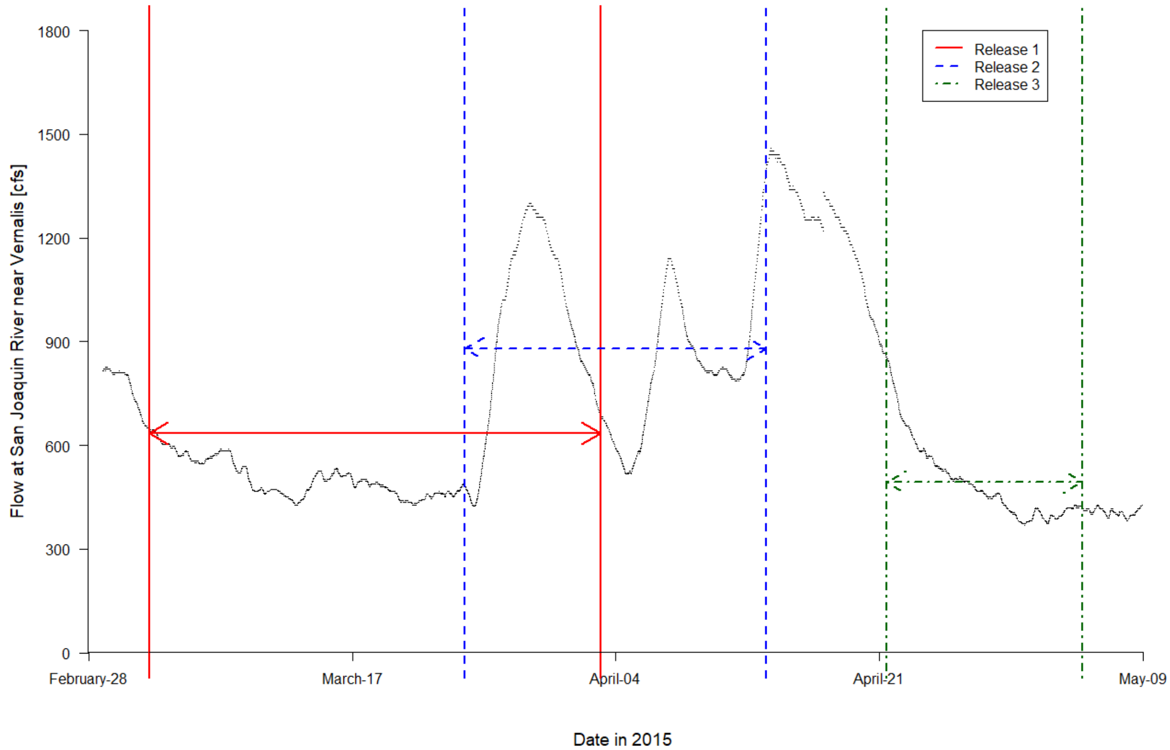

Figure 24. River discharge (flow) measured at the San Joaquin River gaging station near Vernalis (VNS) during the 2015 study. Vertical lines represent the time period from the first day through the final day of release, plus the median observed travel time to Chipps Island for the release. Arrow height indicates mean discharge: 635 cfs, 880 cfs, and 494 cfs, respectively.

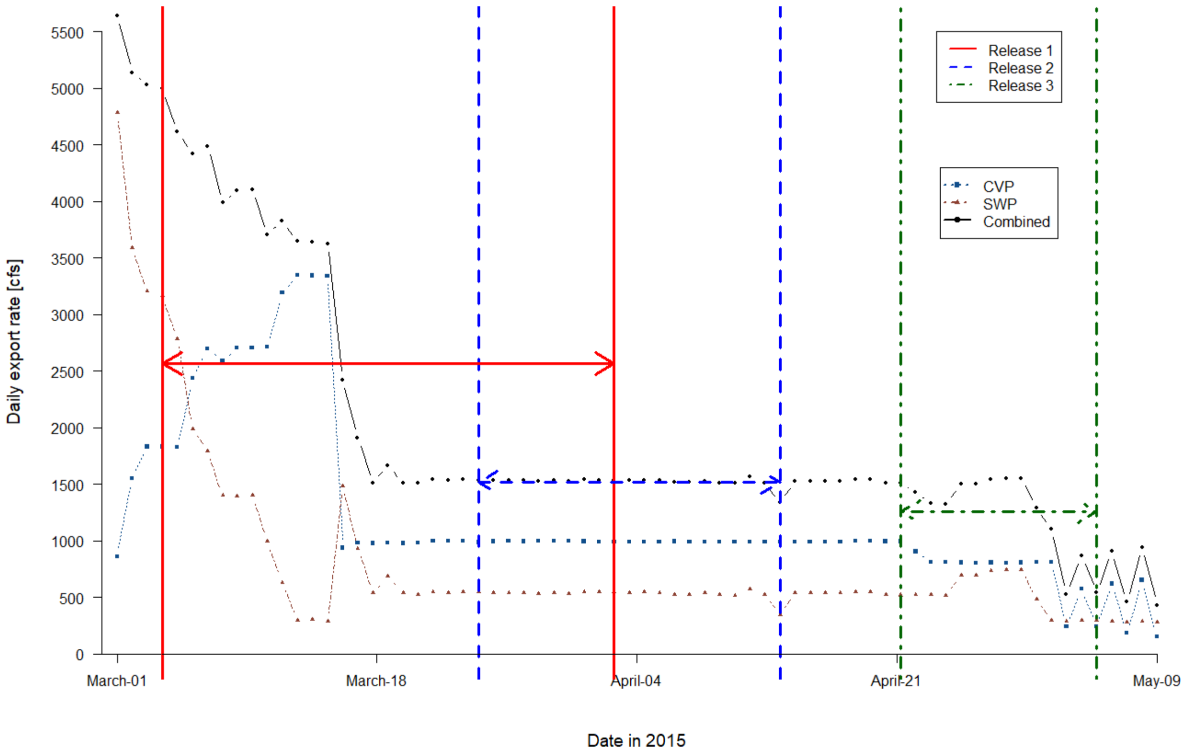

Figure 25. Daily export rate at CVP and SWP during the 2015 study. Vertical lines represent the time period from the first day through the final day of release, plus the median observed travel time to Chipps Island for the release. Arrow height indicates mean combined export rate: 2,568 cfs, 1,519 cfs, and 1,254 cfs, respectively.

Tables

Table 1. Names and descriptions of receivers and hydrophones used in the 2015 steelhead survival study, with receiver codes used in Figure 1, the survival model (Figures 2 – 3), 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.

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° 41.138'N	121° 15.382'W	DFU1	A0a	300982
San Joaquin River near Durham Ferry upstream of the release site, downstream	37° 41.182'N	121° 15.399'W	DFU2	A0b	301509
San Joaquin River near Durham Ferry; release site (no acoustic hydrophone located here)	37° 41.224'N	121° 15.722'W	DF	A1	
San Joaquin River near Durham Ferry downstream of the release site, upstream	37° 41.318'N	121° 16.564'W	DFD1	A2a	300867/460084
San Joaquin River near Durham Ferry downstream of the release site, downstream	37° 41.320'N	121° 16.562'W	DFD2	A2b	460085
San Joaquin River below Durham Ferry 1	37° 43.283'N	121° 15.731'W	BDF1	A3	460035
San Joaquin River below Durham Ferry 2	37° 43.072'N	121° 16.700'W	BDF2	A4	460036
San Joaquin River near Banta Carbona, upstream	37° 43.657'N	121° 17.924'W	BCAU	A5a	300935
San Joaquin River near Banta Carbona, downstream	37° 43.700'N	121° 17.917'W	BCAD	A5b	460021
San Joaquin River near Mossdale Bridge, upstream	37° 47.503'N	121° 18.417'W	MOSU	A6a	300898
San Joaquin River near Mossdale Bridge, downstream	37° 47.552'N	121° 18.406'W	MOSD	A6b	300910
San Joaquin River upstream of Head of Old River, upstream 1 (not used in survival model)	37° 48.349'N	121° 19.057'W	HORU1	B0c	450020
San Joaquin River upstream of Head of Old River, upstream 2 (not used in survival model)	37° 48.355'N	121° 19.121'W	HORU2	B0a	301503/301508/450023
San Joaquin River upstream of Head of Old River, downstream (not used in survival model)	37° 48.350'N	121° 19.182'W	HORD	B0b	301503/301505
San Joaquin River near Lathrop, upstream	37° 48.666'N	121° 19.177'W	SJLU	A7a	301504/301507
San Joaquin River near Lathrop, downstream	37° 48.697'N	121° 19.124'W	SJLD	A7b	301511/301512
Predator Removal Study Site 4 (not used in survival model)	37° 49.116'N	121° 19.050'W	RS4	N1	300870/301166
Predator Removal Study Site 5 (not used in survival model)	37° 49.914'N	121° 18.730'W	RS5	N2	300901/300872
Predator Removal Study Site 6 (not used in survival model)	37° 51.080'N	121° 19.326'W	RS6	N3	300924/300884
Predator Removal Study Site 7 (not used in survival model)	37° 51.871'N	121° 19.418'W	RS7	N4	300917/300879
Predator Removal Study Site 8 (not used in survival model)	37° 53.266'N	121° 19.813'W	RS8	N5	300878/300861

Table 1. (Continued)

Individual Receiver Name and Description	Hydrophone Location		Receiver Code	Survival Model Code	Data Processing Code
	Latitude (°N)	Longitude (°W)			
Predator Removal Study Site 9 (not used in survival model)	37° 54.347'N	121° 19.408'W	RS9	N6	300871/300937
Predator Removal Study Site 10 (not used in survival model)	37° 55.094'N	121° 19.236'W	RS10	N7	300916/300914
San Joaquin River near Garwood Bridge, upstream	37° 56.108'N	121° 19.807'W	SJGU	A8a	300934/300979/ 450047
San Joaquin River near Garwood Bridge, downstream	37° 56.119'N	121° 19.827'W	SJGD	A8b	300873/300908/ 450048
San Joaquin River at Stockton Navy Drive Bridge, upstream	37° 56.798'N	121° 20.393'W	SJNBU	A9a	300877
San Joaquin River at Stockton Navy Drive Bridge, downstream	37° 56.806'N	121° 20.365'W	SJNBD	A9b	300889
Burns Cutoff at Rough and Ready Island, upstream	37° 56.416'N	121° 21.065'W	RRIU	R1a	300904
Burns Cutoff at Rough and Ready Island, downstream	37° 56.408'N	121° 21.076'W	RRID	R1b	300892
San Joaquin River Shipping Channel	37° 59.736'N	121° 26.424'W	SJS	A10	300943/300869/ 300932
San Joaquin River at MacDonald Island, upstream	38° 01.030'N	121° 27.688'W	MACU	A11a	300868/301158
San Joaquin River at MacDonald Island, downstream	38° 01.372'N	121° 27.930'W	MACD	A11b	300899/300859
San Joaquin River near Medford Island, east	38° 03.188'N	121° 30.689'W	MFE	A12a	300875/300866
San Joaquin River near Medford Island, west	38° 03.222'N	121° 30.790'W	MFW	A12b	300905/300863
San Joaquin River near Disappointment Slough, upstream	38° 05.490'N	121° 34.493'W	SJDU	A13a	300933/300897/ 300921
San Joaquin River near Disappointment Slough, downstream	38° 05.537'N	121° 34.515'W	SJDD	A13b	300930/300989/ 300922
Old River East, near junction with San Joaquin, upstream	37° 48.709'N	121° 20.134'W	OREU	B1a	300923/300900
Old River East, near junction with San Joaquin, downstream	37° 48.738'N	121° 20.134'W	ORED	B1b	300891/300864
Old River South, upstream	37° 49.231'N	121° 22.655'W	ORSU	B2a	300980
Old River South, downstream	37° 49.200'N	121° 22.669'W	ORSD	B2b	301154
West Canal, upstream (not used in survival model)	37° 50.783'N	121° 33.572'W	WCLU	B3a	300918
West Canal, downstream (not used in survival model)	37° 50.857'N	121° 33.601'W	WCLD	B3b	301501
Old River at Highway 4, upstream	37° 53.630'N	121° 34.026'W	OR4U	B4a	301510/301502
Old River at Highway 4, downstream	37° 53.702'N	121° 33.990'W	OR4D	B4b	300991/300942

Table 1. (Continued)

Individual Receiver Name and Description	Hydrophone Location		Receiver Code	Survival Model Code	Data Processing Code
	Latitude (°N)	Longitude (°W)			
Old River at the San Joaquin River, upstream (closer to Old River mouth)	38° 03.752'N	121° 34.848'W	OSJU	B5a	300894/300985/300920
Old River at the San Joaquin River, downstream (farther from Old River mouth)	38° 03.696'N	121° 34.917'W	OSJD	B5b	300909/300896/300939
Middle River Head, upstream	37° 49.471'N	121° 22.768'W	MRHU	C1a	300913
Middle River Head, downstream	37° 49.483'N	121° 22.808'W	MRHD	C1b	300990
Middle River at Highway 4, upstream	37° 53.767'N	121° 29.582'W	MR4U	C2a	301159/301157
Middle River at Highway 4, downstream	37° 53.807'N	121 °29.594'W	MR4D	C2b	300882/300938
Middle River at Middle River	38° 00.128'N	121° 30.712'W	MID	C3	300890/300902
Radial Gate at Clifton Court Forebay, upstream (in entrance channel to forebay), array 1	37° 49.801'N	121° 33.397'W	RGU1	D1a	300888
Radial Gate at Clifton Court Forebay, upstream, array 2	37° 49.776'N	121° 33.418'W	RGU2	D1b	301161
Radial Gate at Clifton Court Forebay, downstream (inside forebay), array 1 in dual array	37° 49.816'N	121° 33.450'W	RGD1	D2a	460009/300911
Radial Gate at Clifton Court Forebay, downstream, array 2 in dual array	37° 49.816'N	121° 33.450'W	RGD2	D2b	460010/300881
Central Valley Project trashracks, upstream	37° 49.012'N	121° 33.506'W	CVPU	E1a	460012/460023/301164
Central Valley Project trashracks, downstream	37° 48.999'N	121° 33.536'W	CVPD	E1b	300981
Central Valley Project holding tank	37° 48.951'N	121° 33.548'W	CVPtank	E2	300907
Turner Cut, east (closer to San Joaquin)	37° 59.499'N	121° 27.296'W	TCE	F1a	450043/301162
Turner Cut, west (farther from San Joaquin)	37° 59.478'N	121° 27.328'W	TCW	F1b	450024/300876
Columbia Cut, upstream (closer to San Joaquin)	38° 01.636'N	121° 30.051'W	COLU	F2a	300895/300880
Columbia Cut, downstream (farther from San Joaquin)	38° 01.620'N	121° 30.102'W	COLW	F2b	300986/300931
San Joaquin River at Jersey Point, upstream 1	38° 03.460'N	121° 41.098'W	JPT	G1a	300954/300730/300948/ 300729
San Joaquin River at Jersey Point, east (upstream 2)	38° 03.381'N	121° 41.216'W	JPE	G1b	300712/300718/300728/ 300950
San Joaquin River at Jersey Point, west (downstream)	38° 03.325'N	121° 41.298'W	JPW	G1c	300721/300732/300715/ 300944/300727/ 300714/300717/300724
False River, west (closer to San Joaquin)	38° 03.382'N	121° 39.870'W	FRW	H1a	300719/300956

Table 1. (Continued)

Individual Receiver Name and Description	Hydrophone Location		Receiver Code	Survival Model Code	Data Processing Code
	Latitude (°N)	Longitude (°W)			
False River, east (farther from San Joaquin)	38° 03.380'N	121° 39.824'W	FRE	H1b	300955/300722
Chipps Island (aka Mallard Island), upstream 1	38° 02.852'N	121° 55.833'W	MAT	G2a	301153/300887/300936/300941/300929/300883
Chipps Island (aka Mallard Island), east (upstream 2)	38° 02.885'N	121° 55.847'W	MAE	G2b	301156/300984/300915/300903/300862/300858
Chipps Island (aka Mallard Island), west (downstream)	38° 02.959'N	121° 56.035'W	MAW	G2c	300885/301165/300886/300928/30115/300860/300865/300912/300957/301452/300906/300940
Benicia Bridge	38° 02.440'N	122° 07.409'W	BBR	G3	301486-301493
Threemile Slough, south	38° 06.450'N	121° 41.042'W	TMS	T1a	300726/300723
Threemile Slough, north	38° 06.678'N	121° 40.990'W	TMN	T1b	300731/300720
Montezuma Slough, downstream (not used in survival model)	38° 04.287'N	121° 52.186'W	MZTD	T2b	301163
Spoonbill Slough, upstream (not used in survival model)	38° 03.315'N	121° 53.718'W	SBSU	T3a	300952
Spoonbill Slough, downstream (not used in survival model)	38° 03.326'N	121° 53.733'W	SBSD	T3b	300958

Table 2. Environmental monitoring sites used in predator decision rule and route entrainment analysis for 2015 steelhead survival 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
GLC	37.8201	121.4497	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]
MSD	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	SJS	Yes	Yes	Yes	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
SJL	37.8100	121.3230	SJL, RS4, RS5	No	No	Yes	No	No	Water Library

[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	
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 2015. 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) Near Field	Residence Time[a] (hr) Mid-field	Residence Time[a] (hr) Far-field	Migration Rate[b, c] (km/hr)		Time since last visit (hr)	BLPS (Magnitude)	No. of Visits	No. of Cumulative Upstream Forays
		Maximum	Maximum	Maximum	Minimum	Maximum	Maximum	Maximum	Maximum	Maximum
DFU	DF	200	400	800	0	4			1	0
	DFU	200	400	1,100					2 (3[f])	2
	DFD, BCA	200	400	1,100	0	4			2	2
DFD	DF	300	600	1,100	0	4.5			1	0
	DFU, DFD	300	600 (1,100[f])	1,100	0	4.5 (NA[f])			10	2
	BDF1, BDF2	300	600	1,100	0.1	4			3	2
BDF1	DF	30 (100[f])	60 (200[f])	1,100	0	4.5			1	0
	DFU, DFD	30 (100[f])	60 (200[f])	1,100	0	4.5			5	0
	BDF1	30 (100[f])	310 (680[f])	1,100					5	1
	BDF2	30 (100[f])	60 (200[f])	1,100	0.1	4			3	2
BDF2	DFD, BDF1	75 (100[f])	150 (200[f])	1,100	0	4.5			5	0
	BDF2	30	500	1,100					5	1
	BCA	30	60	1,100	0.1	4.5			3	2
BCA	DF	40 (100[f])	90 (200[f])	1,000	0	4.5			1	0
	DFU	40 (100[f])	90 (200[f])	1,000	0	4.5			1	0
	BDF1, BDF2	40 (100[f])	90 (200[f])	1,000	0	4.5			3	0
	BCA	60 (100[f])	350 (690[f])	1,000					5	1
	MOS	12	41	1,000	0.1	4	100		3	2
MOS	DFD, BDF2, BCA	40 (100[f])	80 (200[f])	1,100		6		4.5	1	0
	MOS	30	300	1,100					5	5
	HOR, RS7	24	48	1,100		6	400	4.5	8	7
SJL	HOR	24	48	96	0.1	6	84	4.5	10	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

Table 3a. (Continued)

Detection Site	Previous Site	Residence Time[a] (hr) Near Field			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
SJL	SJL	5	164	385					6	4
	ORE	5 (1[f])	10 (2[f])	20 (4[f])	0.5	6	20 (15[f])	4.5	3 (0[f])	0
	RS4	20	40	500	0.1	4		4.5	10	10
RS4	SJL	24	48	464	0.05	6	84	4.5	9	0
	RS4	5	69	500					5	3
	ORE	5 (1[f])	10 (2[f])	20 (4[f])	0.8	6	20 (15[f])	4.5	3 (0[f])	0
	RS5, RS6	12	24	500 (100[e])	0.2 (0.4[f])	4	84	4.5	9	9
RS5	RS4	24	48	500	0.1	6	84	4.5	8	0
	RS5	5	69	500					5	3
	RS6, RS8	12	24	500 (100[e])	0.2 (0.7[f])	4	60	4.5	8	8
RS6	RS4, RS5	24	48	500	0.1	6	100	4.5	7	0
	RS6	5	69 (63[f])	500					4	3
	RS7, RS8	12	24	500 (120[e])	0.2 (0.4[f])	4	60	4.5	5	7
RS7	RS6	24	48	500	0.1	6	84	4.5	7	0
	RS7	5	69 (63[f])	500					4	3
	RS8	12	24	500 (100[e])	0.3	4	60	4.5	5	7
RS8	RS6, RS7	24	48	500	0.1	6	84	4.5	7	0
	RS8	5	69 (63[f])	500					4	3
	RS9, RS10	12	24	500 (100[e])	0.2 (0.3[f])	4	60	4.5	5	7
RS9	RS8	24	48	500	0.1	6	84	4.5	7	0
	RS9	5	69 (63[f])	500					4	3
	RS10	12	24	500 (120[e])	0.1	4	60	4.5	5	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"

e = Condition at departure from previous site.

f = See comments for alternate criteria

Table 3a. (Continued)

Detection Site	Previous Site	Residence Time[a] (hr) Near Field	Mid-field	Far-field	Migration Rate[b, c] (km/hr)		Time since last visit (hr)	BLPS (Magnitude)	No. of Visits	No. of Cumulative Upstream Forays
		Maximum	Maximum	Maximum	Minimum	Maximum	Maximum	Maximum	Maximum	Maximum
RS10	RS8, RS9	24	48	500	0.1	6	84	4.5	7	0
	RS10	5	69 (63[f])	500					4	3
	SJG, SJNB, MAT/MAE/ MAW	5 (1[f])	10 (2[f])	500 (150[e])		4	60	4.5	5	7
SJG	RS10	30	60	500	0.1	6	60	4.5	4	0
	SJG	15	89	500					3	3
	SJNB, RRI	10	20	500	0.2	4	60	4.5	5	7
SJNB	SJG	30	60	500	0.1	6 (2[f])	60	4.5	4	0
	SJNB	15	85	500					3	7
	RRI	15	30	500	0.1	6	60		3	0
	SJS	10	20	180	0.3	4	60	4.5	3	7
RRI	SJG	20	40	500	0.1	6 (2[f])	25	4.5	1	0
	RRI	5	65	500					2	7
	SJNB	5	10	500	0.1	6	25		2	0
	SJS	2	4	164	0.3	4	25	4.5	2	7
SJS	RS8, SJNB, RRI	30	60	120	0.1	6	35	4.5	1 (4[f])	0
	SJS	15	79	223					3	7
	MAC, TCE/TCW	20	40	353 (148[f])	0.3 (0.1[f])	4	35	4.5 (5[f])	4	7
MAC	SJS	20	40	301 (276[f])	0.1 (0.3[f])	6	24	4.5	3	0
	MAC	10	74	399					2	4
	TCE/TCW	10	20	306	0.2	6	24		2	1
	MFE/MFW	10	20	500	0.4	4	36	4.5	3	8

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) Near Field	Residence Time[a] (hr) Mid-field	Residence Time[a] (hr) Far-field	Migration Rate[b, c] (km/hr)		Time since last visit (hr)	BLPS (Magnitude)	No. of Visits	No. of Cumulative Upstream Forays
		Maximum	Maximum	Maximum	Minimum	Maximum	Maximum	Maximum	Maximum	Maximum
MAC	COL	10	20	40	0.3	4	24		2	4
MFE/MFW	MAC	20	40	500 (460[f])	0.1 (0.3[f])	6	36	4.5	2	0
	MFE/MFW	10	100	500					2	4
	COL	12	24	500	0.1	6	24		2	1
	SJD	12	24	48	0.7	4	36	4.5	2	4
	OSJ	10	20	40	0.7	4	36	4.5	1	4
SJD	MFE/MFW, MAC, COL	20	40	80	0.3	6	36	4.5	2 (1[f])	0
	SJD	15	105 (65[f])	245 (165[f])					2	4
	OSJ	15	30	192	0.2	4	36		2	2
	MID	20	40	80	0.3	6	36	4.5	1	0
	JPT/JPE/JPW, TMN/TMS	15	30	60		4	36	4.5	2	4
HOR	MOS	25 (100[f])	50 (200[f])	1,100		6		4.5	15	0
	HOR	25	300	1,100					10	10
	SJL	35	70	1100 (120[e])	0.2	6	120	4.5	15	15
	ORE	35 (1[f])	70 (2[f])	1,100	0.2 (0.6[f])	6	120 (5[f])	4.5	5 (0[f])	5
ORE	HOR	15	30	60	0.1	6	25	5	2	0
	ORE	5	70	170					2	1
	SJL, RS5	6 (4[f])	12 (8[f])	24 (16[f])		6	20 (15[f])	5	2	0
	ORS	2	4	282	0.6	4	25	5	2 (1[f])	2 (1[f])
	MRH	2	4	254	0.6	4	25	5	2 (1[f])	2 (1[f])
ORS	ORE	24	48	268	0.1	6	30	4.5	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"

e = Condition at departure from previous site.

f = See comments for alternate criteria

Table 3a. (Continued)

Detection Site	Previous Site	Residence Time[a] (hr) Near Field	Residence Time[a] (hr) Mid-field	Residence Time[a] (hr) Far-field	Migration Rate[b, c] (km/hr)		Time since last visit (hr)	BLPS (Magnitude)	No. of Visits	No. of Cumulative Upstream Forays
		Maximum	Maximum	Maximum	Minimum	Maximum	Maximum	Maximum	Maximum	Maximum
ORS	ORS	12	146	500					4	2
	MRH	12	24	341	0.2	6	30	4.5	2	2
	CVP, WCL RGU/RGD,	12	24	48	0.3	4	30	4.5	2	3
WCL	RGU/RGD	12	24	800	0.2	4.5	100	5	5	0
	CVP	12	24	800	0.1	4	100	4.5	5	0
	ORS	12	24	800	0.1	4	100	4.5	1	0
	WCL	3	102	800					5	4
	MR4	12	24	48	0.2	4	100	4.5	2	0
	OR4	12	24	800	0.2	4	100	4.5	5	7
OR4	WCL	20	40	800	0.05	4	100	4.5	4	0
	OR4	20	170	800					4	4
	MR4	20	40	80	0.1	4	100	4.5	3	0
	MID, TCE/TCW	5	10	20	0.1 (0.2[f])	4	100	4.5	3 (1[f])	0
OSJ	MFE/MFW	15	30	60	0.1 (0.3[f])	6	36	4.5	2	0
	OR4	15	30	60	0.1 (0.3[f])	6	36	4.5	1	0
	OSJ	5	54	138					2	4
	SJD	5	10	275	0.2	4	36	4.5	2	2
MRH	ORE	10	20	240	0.1	6	30	4.5	1	0
	MRH	4	48	312					0	2
	ORS	4	8	500	0.2	6	30	4.5	1	2
MR4	MR4	10	60	130					2	2
	OR4, WCL	10	20	40	0.1	4	100	4.5	1	0
	RGU/RGD	10	20	40	0.1	4	100	4.5	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

Table 3a. (Continued)

Detection Site	Previous Site	Residence Time[a] (hr) Near Field Maximum	Mid-field Maximum	Far-field Maximum	Migration Rate[b, c] (km/hr) Minimum	Maximum	Time since last visit (hr) Maximum	BLPS (Magnitude) Maximum	No. of Visits Maximum	No. of Cumulative Upstream Forays Maximum
MR4	TCE/TCW	10	20	40	0.1	4	100	4.5	1	0
MID	MR4	12	24	274	0.1	4	100	4.5	1	0
	OR4	12	24	48	0.1	4	100	4.5	1	2
	SJD, MFE/MFW	12	24	48	0.1	4	100	4.5	1	0 (3[f])
	MID	12	134	500					3	2
	TCE/TCW	12	24	48	0.1	4	100	4.5	1	0
	COL	12	24	48		4	100	4.5	2	0
RGU/RGD	ORS	80 (336[h]; 800[i])	80 (336[h]; 800[i])	800	0.1	4.5	150	4.5	1	0
	CVP	80 (336[h]; 800[i])	80 (336[h]; 800[i])	800	0.1	4.5	150	4.5	4	0
	WCL	80 (336[h]; 800[i])	80 (336[h]; 800[i])	800	0.1	5	150	4.5	5	4
CVP	ORS	50	100	1,000	0.1	4.5	200	4	1	0
	CVP	40	200	1,000					4	3
	RGU/RGD	50	100	1,000	0.1	4	200	4	4 (1[f])	5
	WCL	50	100	1,000	0.1	4	200	4	4 (1[f])	5
	MR4	50	100	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	96	0.1	6	24	4.5	3	0
	TCE/TCW	12	106	262					2	4
	MAC	12	24	447	0.2	6	24		2	1
COL	MAC	24	48	490	0.1	6	36	4.5	2	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) Near Field	Residence Time[a] (hr) Mid-field	Residence Time[a] (hr) Far-field	Migration Rate[b, c] (km/hr)		Time since last visit (hr)	BLPS (Magnitude)	No. of Visits	No. of Cumulative Upstream Forays
		Maximum	Maximum	Maximum	Minimum	Maximum	Maximum	Maximum	Maximum	Maximum
COL	MFE/MFW	12	24	500	0.1	6	36	4.5	2	1
	MID	12	24	48	0.2	6	36	4.5	2	0
JPT/JPE/ JPW	MFE/MFW, TCE/TCW, OR4	40	80	160	0.1	4.5	30	4.5	1	0
	TMN/TMS	40	80	258	0.1	4.5	30	4.5	2	0
	SJD, OSJ	40	80	160	0.1	4.5	30	4.5	1	0
	JPT/JPE/JPW	20	140	448					3	3
	FRE/FRW	20	140	448	0.1	9	30		3	3
	MAT/MAE/ MAW	2	4	500	1	4	30	4.5	2	3
MAT/MAE/ MAW	RS10, SJD	40	200	500	0.2	4.5	50	4.5	1	0
	CVP, CVPtank	40	200	500		4	50	4.5	1	0
	RGU/RGD	40	200	500		5	50	4.5	1	0
	JPT/JPE/JPW, TMN/TMS, SBS	40	200	500	0.2	4.5	50	4.5	1 (2[f])	0
	MAT/MAE/ MAW	20	100	500					3	3
	BBR	10	50	500	0.2	4.5	50	4.5	3	4
BBR	MAT/MAE/ MAW	40	200	500	0.2	6		4.5	2	0
	MTZ	40	200	500	0.2	6		4.5	1	0
	JPT/JPE/JPW	40	200	500	0.2	6		4.5	1	0
	BBR	10	50	500					3	0
FRE/FRW	OR4, MR4, MID, TCE/TCW	10	20	40	0.1	4.5	15	4.5	1	0
	OSJ	10	20	40	0.1	4.5	15	4.5	2	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

Table 3a. (Continued)

Detection Site	Previous Site	Residence Time[a] (hr) Near Field	Mid-field	Far-field	Migration Rate[b, c] (km/hr)		Time since last visit (hr)	BLPS (Magnitude)	No. of Visits	No. of Cumulative Upstream Forays
		Maximum	Maximum	Maximum	Minimum	Maximum	Maximum	Maximum	Maximum	Maximum
FRE/FRW	JPT/JPE/JPW	10	73	143	0.1	9	15		3	3
FRE/FRW	FRE/FRW	3	73	143					3	3
TMN/TMS	SJD	10	20	40	0.2	4.5	15	4.5	1	0
	RGU/RGD, CVP, CVPtank	10	20	40	0.2 (0.1[f])	4.5	15	4.5	1	4
	TMN/TMS	3	47	111					2	3
	JPT/JPE/JPW	10	20	312	0.2	4.5	15	4.5	2	4
MTZ	CVPtank	5	10	20	0.2	4.5	15	4.5	1	0
	JPT/JPE/JPW	5	10	500	0.2	4.5	15	4.5	1	0
SBS	MAT/MAE/ MAW	1	2	500	0.2	4.5	15	4.5	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 2015. 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	Alternate value if next transition is downstream
	DFD, BCA						Travel time ≤ 300	
DFD	DF						Travel time ≤ 200	
	DFU, DFD						Travel time ≤ 200	Alternate value if coming from DFD
	BDF1, BDF2							
BDF1	DF						Travel time ≤ 700	Alternate value if next transition is downstream
	DFU, DFD						Travel time ≤ 700	Alternate value if next transition is downstream
	BDF1						Travel time ≤ 200 (500[f])	Alternate value if next transition is downstream
	BDF2							Alternate value if next transition is downstream
BDF2	DFD, BDF1						Travel time ≤ 500	Alternate value if next transition is downstream
	BDF2						Travel time ≤ 100	
	BCA							
BCA	DF						Travel time ≤ 500	Alternate value if next transition is downstream
	DFU						Travel time ≤ 500	Alternate value if next transition is downstream
	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.

f = See comments for alternate criteria

Table 3b. (Continued)

Detection Site	Previous Site	Flow[d] (cfs) At arrival	Flow[d] (cfs) At departure[e]	Water Velocity[d] (ft/sec) At arrival	Water Velocity[d] (ft/sec) At departure[e]	Water Velocity[d] (ft/sec) Average during transition	Extra Conditions	Comment
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	DFD, BDF2, BCA						Travel time ≤ 200; allow 3 visits, travel time ≤ 600 if arrival flow ≤ 11,000 cfs	Alternate value if next transition is downstream
	MOS	<14000				<2.7	Travel time ≤ 48	
	HOR, RS7	<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 ≤ 30	
	ORE						Regional residence time ≤ 25 (15[f]) on departure from ORE	Alternate value if HOR barrier
	RS5, RS6							Alternate value if coming from RS6
RS5	RS4							
	RS5						Travel time ≤ 30	
	RS6, RS8							Alternate value if coming from RS8
RS6	RS4, RS5	>-1200						

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)

Detection Site	Previous Site	Flow[d] (cfs) At arrival	Flow[d] (cfs) At departure[e]	Water Velocity[d] (ft/sec) At arrival	Water Velocity[d] (ft/sec) At departure[e]	Water Velocity[d] (ft/sec) Average during transition	Extra Conditions	Comment
RS6	RS6					<1	Travel time ≤ 30 (24[f])	Alternate value if water velocity condition is not met
	RS7, RS8	<1200						Alternate value if coming from RS8
RS7	RS6	>-1200						
	RS7					< 1	Travel time ≤ 30 (24[f])	Alternate value if water velocity condition is not met
	RS8	<1200						
RS8	RS6, RS7	>-1200						
	RS8					<1	Travel time ≤ 30 (24[f])	Alternate value if water velocity condition is not met
	RS9, RS10	<1200						
RS9	RS8							
	RS9					<1	Travel time ≤ 30 (24[f])	Alternate value if water velocity condition is not met
	RS10							
RS10	RS8, RS9							
	RS10					<1	Travel time ≤ 30 (24[f])	Alternate value if water velocity condition is not met
	SJG, SJNB, MAT/MAE/ MAW						Travel time ≤ 12	Alternate value if coming from MAT/MAE/MAW
SJG	RS10	>-1900		>-0.5				

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		
SJG	SJG	<1900 (>-1900)[g]	>-1900 (<1900)[g]	<0.5 (>-0.5)[g]	>-0.5 (<0.5)[g]	<0.8	Travel time ≤ 24	
	SJNB, RRI	<3500	<3500	<1.1	<1.1	<1.1		
SJNB	SJG					>-0.15		Alternate value if water velocity condition is not met
	SJNB						Travel time ≤ 20	
	RRI							
	SJS						Travel time ≤ 40	
RRI	SJG					>-0.15		Alternate value if water velocity condition is not met
	RRI						Travel time ≤ 20	
	SJNB							
	SJS						Travel time ≤ 40	
SJS	RS8, SJNB, RRI							Alternate value if coming from SJNB
	SJS	<3700 (>-3700)[g]	>-3700 (<3700)[g]	<0.18 (>-0.18)[g]	>-0.18 (<0.18)[g]		Travel time ≤ 24	
	MAC, TCE/TCW	<5000	<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							
	MFE/MFW			<0.5				
	COL			<0.5				

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)

Detection Site	Previous Site	Flow[d] (cfs) At arrival	At departure[e]	Water Velocity[d] (ft/sec) At arrival	At departure[e]	Average during transition	Extra Conditions	Comment
MFE/MFW	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	
	OSJ			<0.5		<0.1	Travel time ≤ 12	
SJD	MFE/MFW, MAC, COL	>-27000		>-0.5				Alternate value if coming from MAC
	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
	OSJ				>-0.2		Travel time ≤ 24	
	MID	>-27000		>-0.5				
	JPT/JPE/JPW, TMN/TMS	<27000		<0.5		<0.1 (NA[f])	Travel time ≤ 12	Alternate value if coming from JPT/JPE/JPW
HOR	MOS						Travel time ≤ 50 (≤ 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		Alternate value if HOR barrier
	ORE	< 14000 (5000[f])				< 3	Regional residence time ≤ 120 (15[f]) at departure from ORE	Alternate value if HOR barrier
ORE	HOR							
	ORE						Travel time ≤ 40	

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		
ORE	SJL, RS5	>-200 (>200[f])		>-0.1 (>0.2[f])			Regional residence time ≤ 60 (30[f]) on departure from previous site; travel time ≤ 6	Alternate value if HOR barrier
	ORS	<3000					Travel time ≤ 10	Alternate value if HOR barrier
	MRH	<3000					Travel time ≤ 10	Alternate value if HOR barrier
ORS	ORE						Travel time ≤ 50	
	ORS	<1200 (>-1200)[g]	>-1200 (<1200)[g]	<0.5 (>-0.5)[g]	>-0.5 (<0.5)[g]		Travel time ≤ 100	
	MRH						Travel time ≤ 5	
	CVP, WCL RGU/RGD,					<1.5	Travel time ≤ 70	
WCL	RGU/RGD	>-6000		>-1			Travel time ≤ 12; CCFB inflow ≤ 3000 cfs on departure[e]	
	CVP	>-6000	>-2000	>-1	>-0.8		Travel time ≤ 40; CVP pumping ≤ 4000 cfs on departure[e]	
	ORS	>-6000		>-1				
	WCL						Travel time ≤ 72	
	MR4							
	OR4	<700	<400	<0.1	< 0.3			
OR4	WCL			>-0.8				
	OR4						Travel time ≤ 120	
	MR4						Travel time ≤ 120	
	MID, TCE/TCW		<2500 (NA[f])	<0.8	<0.1 (0.2[f])		Travel time ≤ 120; known presence in detection range ≤ 2	Alternate value if coming from 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)

Detection Site	Previous Site	Flow[d] (cfs): At arrival	Flow[d] (cfs): At departure[e]	Water Velocity[d] (ft/sec): At arrival	Water Velocity[d] (ft/sec): At departure[e]	Water Velocity[d] (ft/sec): Average during transition	Extra Conditions	Comment
OSJ	MFE/MFW			<0.2		0 to 0.1		Alternate value if water velocity condition is not met
	OR4			>-0.2		0 to 0.1		Alternate value if water velocity condition is not met
	OSJ	<5000 (>-5000)[g]	>-5000 (<5000)[g]	<0.2 (>-0.2)[g]	>-0.2 (<0.2)[g]		Travel time ≤ 24	
	SJD			<0.2				
MRH	ORE						Travel time ≤ 50	
	MRH						Travel time ≤ 24	Not allowed
	ORS						Travel time ≤ 5	
MR4	MR4	<6500 (>-6500)[g]	>-6500 (<6500)[g]	<0.5 (>-0.5)[g]	>-0.5 (<0.5)[g]		Travel time ≤ 30	
	OR4, WCL							
	RGU/RGD						CCFB inflow ≤ 3000 cfs on departure[e]	
	TCE/TCW			<0.5	<0.2			
MID	MR4	>-2500		>-0.1			Travel time ≤ 120	
	OR4	>-2500		>-0.1	>-0.8		Travel time ≤ 120	
	SJD, MFE/MFW	<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	
RGU/RGD	ORS							

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)

Detection Site	Previous Site	Flow[d] (cfs) At arrival	Flow[d] (cfs) At departure[e]	Water Velocity[d] (ft/sec) At arrival	Water Velocity[d] (ft/sec) At departure[e]	Water Velocity[d] (ft/sec) Average during transition	Extra Conditions	Comment
RGU/RGD	CVP		>-2000		>-0.8		CVP pumping ≤ 4000 cfs at departure[e]	
	WCL		<3500		<0.6		Travel time ≤ 30	
CVP	ORS							
	CVP						Travel time ≤ 100; CVP pumping ≥ 800 cfs on arrival, and ≤ 1000 on departure from previous visit	
	RGU/RGD	<2000		<0.8			CVP pumping ≥ 800 cfs on arrival	Alternate value if came from lower SJR via Interior Delta
	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		
COL	MAC							
	MFE/MFW							
	MID							
JPT/JPE/ JPW	MFE/MFW, TCE/TCW, OR4							
	TMN/TMS							
	SJD, OSJ							

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)

Detection Site	Previous Site	Flow[d] (cfs) At arrival	Flow[d] (cfs) At departure[e]	Water Velocity[d] (ft/sec) At arrival	Water Velocity[d] (ft/sec) At departure[e]	Water Velocity[d] (ft/sec) Average during transition	Extra Conditions	Comment
JPT/JPE/ JPW	JPT/JPE/JPW						Travel time ≤ 50	
	FRE/FRW						No minimum travel time	
	MAT/MAE/ MAW							
MAT/MAE/ MAW	RS10, SJD			>-1				
	CVP, CVPtank			>-1			Travel time ≤ 60	
	RGU/RGD			>-1			Travel time ≤ 500	
	JPT/JPE/JPW, TMN/TMS, SBS			>-1				Alternate value if coming from SBS
	MAT/MAE/ MAW						Travel time ≤ 24	
	BBR			<1				
BBR	MAT/MAE/ MAW							
	MTZ							
	JPT/JPE/JPW							
	BBR						Travel time ≤ 24	
FRE/FRW	OR4, MR4, MID, TCE/TCW							Alternate value if coming from OR4, MR4, or MID
	OSJ							
	JPT/JPE/JPW						No minimum travel time	
	FRE/FRW						Travel time ≤ 30	
TMN/TMS	SJD		>-27000		>-0.5			
	RGU/RGD, CVP, 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)

Detection Site	Previous Site	Flow[d] (cfs) At arrival	Flow[d] (cfs) At departure[e]	Water Velocity[d] (ft/sec) At arrival	Water Velocity[d] (ft/sec) At departure[e]	Water Velocity[d] (ft/sec) Average during transition	Extra Conditions	Comment
TMN/TMS	JPT/JPE/JPW							
MTZ	CVPtank							
	JPT/JPE/JPW							
SBS	MAT/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.

f = See comments for alternate criteria

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

Table 4. Regions used in the far-field residence time components of the predator filter in 2015.

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

Table 5. Number of tags from each release group that were detected after release in 2015, including predator-type detections and detections omitted from the survival analysis. Releases are: 1 = early March, 2 = late March, 3 = April.

Release Group	1	2	3	Total
Number Released	480	478	469	1,427
Number Detected	391	415	350	1,156
Number Detected Downstream	335	375	302	1,012
Number Detected Upstream of Study Area	391	415	350	1,156
Number Detected in Study Area	181	223	110	514
Number Detected in San Joaquin River Route	69	136	100	305
Number Detected in Old River Route	141	129	17	287
Number Assigned to San Joaquin River Route	27	81	39	147
Number Assigned to Old River Route	139	127	16	282

Table 6. Number of tags observed from each release group at each detection site in 2015, 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.

Detection Site	Site Code	Survival Model Code	Release Group 1	Release Group 2	Release Group 3	Total
Release site at Durham Ferry			480	478	469	1,427
Durham Ferry Upstream	DFU	A0	113	97	104	314
Durham Ferry Downstream	DFD	A2	334	373	302	1009
Below Durham Ferry 1	BDF1	A3	250	281	188	719
Below Durham Ferry 2	BDF2	A4	232	283	174	689
Banta Carbona (Pooled)	BCA	A5	215	256	155	626
Mossdale (Pooled)	MOS	A6	181[a]	223	110[d]	514
Head of Old River (Pooled)	HOR	B0	175[b]	221[c]	104[e]	500
Lathrop, Upstream	SJLU	A7a	69	135	100	304
Lathrop, Downstream	SJLD	A7b	67	134	100	301
Lathrop (Pooled)	SJL	A7	69	135	100	304
Predator Removal Study 4	RS4	N1	50	115	95	260
Predator Removal Study 5	RS5	N2	40	101	83	224
Predator Removal Study 6	RS6	N3	29	97	75	201
Predator Removal Study 7	RS7	N4	23	87	64	174
Predator Removal Study 8	RS8	N5	20	76	50	146
Predator Removal Study 9	RS9	N6	18	73	43	134
Predator Removal Study 10	RS10	N7	17	71	38	126
Garwood Bridge, Upstream	SJGU	A8a	15	71	33	119
Garwood Bridge, Downstream	SJGD	A8b	15	71	33	119
Garwood Bridge (Pooled)	SJG	A8	15	71	33	119
Navy Drive Bridge, Upstream	SJNBU	A9a	15	65	27	107
Navy Drive Bridge, Downstream	SJNBD	A9b	15	64	27	106
Navy Drive Bridge (Pooled)	SJNB	A9	15	65	27	107
Rough and Ready Island, Upstream	RRIU	R1a	2	13	0	15
Rough and Ready Island, Downstream	RRID	R1b	2	13	0	15
Rough and Ready Island (Pooled)	RRI	R1	2	13	0	15
San Joaquin River Shipping Channel	SJS	A10	13	58	25	96
MacDonald Island Upstream	MACU	A11a	12	56	20	88
MacDonald Island Downstream	MACD	A11b	12	54	19	85
MacDonald Island (Pooled)	MAC	A11	12	56	20	88
Turner Cut, Upstream	TCE	F1a	4	7	7	18
Turner Cut, Downstream	TCW	F1b	4	7	7	18
Turner Cut (Pooled)	TCE/TCW	F1	4	7	7	18
Medford Island East	MFE	A12a	8	48	10	66

a = One tagged steelhead was recaptured after detection at MOS and removed from the river.
b = One tagged steelhead was recaptured after detection at HOR and then returned to the river.
c = One tagged steelhead was recaptured after detection at HOR and then returned to the river.
d = Four tagged steelhead were recaptured after detection at MOS and then returned to the river.
e = Three tagged steelhead were recaptured after detection at HOR and then returned to the river.

Table 6. (Continued)

Detection Site	Site Code	Survival Model Code	Release Group 1	2	3	Total
Medford Island West	MFW	A12b	8	48	13	69
Medford Island (Pooled)	MFE/MFW	A12	8	48	13	69
Columbia Cut, Upstream	COLU	F2a	1	3	3	7
Columbia Cut, Downstream	COLD	F2b	1	3	3	7
Columbia Cut (Pooled)	COL	F2	1	3	3	7
Disappointment Slough, Upstream	SJDU	A13a	11	44	14	69
Disappointment Slough, Downstream	SJDD	A13b	11	44	14	69
Disappointment Slough (Pooled)	SJD	A13	11	44	14	69
Old River at the San Joaquin, Upstream	OSJU	B5a	2	15	1	18
Old River at the San Joaquin, Downstream	OSJD	B5b	2	15	1	18
Old River at the San Joaquin (Pooled)	OSJ	B5	2	16	1	19
Old River East, Upstream	OREU	B1a	141	129	17	287
Old River East, Downstream	ORED	B1b	141	129	17	287
Old River East (Pooled)	ORE	B1	141	129	17	287
Old River South, Upstream	ORSU	B2a	137	125	14	276
Old River South, Downstream	ORSD	B2b	137	125	14	276
Old River South (Pooled)	ORS	B2	137	125	14	276
West Canal, Upstream	WCLU	B3a	68	88	8	164
West Canal, Downstream	WCLD	B3b	68	88	8	164
West Canal: SJR Route	WCL	B3	2	5	1	8
West Canal: OR Route	WCL	B3	66	83	6	155
West Canal (Pooled)	WCL	B3	68	88	8	164
Old River at Highway 4, Upstream	OR4U	B4a	40	54	7	101
Old River at Highway 4, Downstream	OR4D	B4b	39	54	7	100
Old River at Highway 4, SJR Route	OR4	B4	2	5	1	8
Old River at Highway 4, OR Route	OR4	B4	38	49	5	92
Old River at Highway 4 (Pooled)	OR4	B4	40	54	7	101
Middle River Head, Upstream	MRHU	C1a	12	10	4	26
Middle River Head, Downstream	MRHD	C1b	12	9	4	25
Middle River Head (Pooled)	MRH	C1	12	10	4	26
Middle River at Highway 4, Upstream	MR4U	C2a	10	9	2	21
Middle River at Highway 4, Downstream	MR4D	C2b	10	8	2	20
Middle River at Highway 4, SJR Route	MR4	C2	1	1	2	4
Middle River at Highway 4, OR Route	MR4	C2	9	8	0	17
Middle River at Highway 4 (Pooled)	MR4	C2	10	9	2	21
Middle River at Middle River	MID	C3	1	4	2	7
Radial Gates Upstream #1	RGU1	D1a	42	70	3	115
Radial Gates Upstream #2	RGU2	D1b	64	89	8	161
Radial Gates Upstream: SJR Route	RGU	D1	1	3	1	5
Radial Gates Upstream: OR Route	RGU	D1	65	86	6	157

Table 6. (Continued)

Detection Site	Site Code	Survival Model Code	Release Group 1	Release Group 2	Release Group 3	Total
Radial Gates Upstream (Pooled)	RGU	D1	66	89	8	163
Radial Gates Downstream #1	RGD1	D2a	17	16	2	35
Radial Gates Downstream #2	RGD2	D2b	17	16	2	35
Radial Gates Downstream: SJR Route	RGD	D2	0	1	1	2
Radial Gates Downstream: OR Route	RGD	D2	17	15	1	33
Radial Gates Downstream (Pooled)	RGD	D2	17	16	2	35
Central Valley Project Trashrack, Upstream	CVPU	E1a	83	99	6	188
Central Valley Project Trashrack, Downstream	CVPD	E1b	80	90	6	176
CVP Trashrack: SJR Route	CVP	E1	2	4	1	7
CVP Trashrack: OR Route	CVP	E1	81	95	5	181
CVP Trashrack (Pooled)	CVP	E1	83	99	6	188
CVP Holding Tank: SJR Route	CVPtank	E2	0	1	0	1
CVP Holding Tank: OR Route	CVPtank	E2	14	15	0	29
CVP Holding Tank	CVPtank	E2	14	16	0	30
Threemile Slough, Upstream	TMS	T1a	5	24	5	34
Threemile Slough, Downstream	TMN	T1b	6	22	4	32
Threemile Slough: SJR Route	TMS/TMN	T1	2	20	5	27
Threemile Slough: OR Route	TMS/TMN	T1	4	4	0	8
Threemile Slough (Pooled)	TMS/TMN	T1	6	24	5	35
Jersey Point Upstream (1)	JPT	G1a	12	54	15	81
Jersey Point East (Upstream 2)	JPE	G1b	12	55	17	84
Jersey Point West	JPW	G1c	12	55	17	84
Jersey Point: SJR Route	JPT/JPE/JPW	G1	6	35	16	57
Jersey Point: OR Route	JPT/JPE/JPW	G1	6	21	1	28
Jersey Point (Pooled)	JPT/JPE/JPW	G1	12	56	17	85
False River West	FRW	H1a	10	26	4	40
False River East	FRE	H1b	10	27	5	42
False River: SJR Route	FRE/FRW	H1	4	10	5	19
False River: OR Route	FRE/FRW	H1	6	17	0	23
False River (Pooled)	FRE/FRW	H1	10	27	5	42
Montezuma Slough (Pooled)	MTZ	T2	0	1	1	2
Spoonbill Slough, Upstream	SBSU	T3a	1	0	0	1
Spoonbill Slough, Downstream	SBSD	T3b	1	0	0	1
Spoonbill Slough (Pooled)	SBS	T3	1	0	0	1
Chipps Island Upstream 1	MAT	G2a	27	80	17	124
Chipps Island East (Upstream 2)	MAE	G2b	26	82	16	124
Chipps Island West	MAW	G2c	28	81	17	126
Chipps Island: SJR Route	MAT/MAE/MAW	G2	7	44	17	68
Chipps Island: OR Route	MAT/MAE/MAW	G2	21	41	0	62
Chipps Island (Pooled)	MAT/MAE/MAW	G2	28	85	17	130

Table 6. (Continued)

Detection Site	Site Code	Survival Model Code	Release Group			Total
			1	2	3	
Benicia Bridge: SJR Route	BBR	G3	0	2	18	20
Benicia Bridge: OR Route	BBR	G3	1	2	1	4
Benicia Bridge	BBR	G3	1	4	19	24

Table 7. Number of tags observed from each release group at each detection site in 2015 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.

Detection Site	Site Code	Survival Model Code	Release Group 1	Release Group 2	Release Group 3	Total
Release site at Durham Ferry			480	478	469	1,427
Durham Ferry Upstream	DFU	A0	71	66	77	214
Durham Ferry Downstream	DFD	A2	319	347	273	939
Below Durham Ferry 1	BDF1	A3	244	261	169	674
Below Durham Ferry 2	BDF2	A4	223	261	154	638
Banta Carbona (Pooled)	BCA	A5	209	246	133	588
Mossdale (Pooled)	MOS	A6	176 (2)	218 (1)	91 (7)	485 (10)
Lathrop, Upstream	SJLU	A7a	25	81	39	145
Lathrop, Downstream	SJLD	A7b	27	81	39	147
Lathrop (Pooled)	SJL	A7	27	81	39	147
Garwood Bridge, Upstream	SJGU	A8a	13	66	26	105
Garwood Bridge, Downstream	SJGD	A8b	13	67	26	106
Garwood Bridge (Pooled)	SJG	A8	13	67	26	106
Navy Drive Bridge, Upstream	SJNBU	A9a	13	62	25	100
Navy Drive Bridge, Downstream	SJNBD	A9b	13	62	25	100
Navy Drive Bridge (Pooled)	SJNB	A9	13	62	25	100
San Joaquin River Shipping Channel	SJS	A10	13	58	23	94
MacDonald Island Upstream	MACU	A11a	8	49	17	74
MacDonald Island Downstream	MACD	A11b	9	52	17	78
MacDonald Island (Pooled)	MAC	A11	9	52	17	78
Turner Cut, Upstream	TCE	F1a	4	5	5	14
Turner Cut, Downstream	TCW	F1b	4	5	5	14
Turner Cut (Pooled)	TCE/TCW	F1	4	5	5	14
Medford Island East	MFE	A12a	8	47	9	64
Medford Island West	MFW	A12b	8	47	12	67
Medford Island (Pooled)	MFE/MFW	A12	8	47	12	67
Columbia Cut, Upstream	COLU	F2a	1[a]	2[a]	3[a]	6
Columbia Cut, Downstream	COLD	F2b	1[a]	2[a]	3[a]	6
Columbia Cut (Pooled)	COL	F2	1[a]	2[a]	3[a]	6
Disappointment Slough, Upstream	SJDU	A13a	7	34	13	54
Disappointment Slough, Downstream	SJDD	A13b	7	35	12	54
Disappointment Slough (Pooled)	SJD	A13	7	35	13	55
Old River at the San Joaquin, Upstream	OSJU	B5a	2[a]	9	1[a]	12
Old River at the San Joaquin, Downstream	OSJD	B5b	2[a]	9	1[a]	12
Old River at the San Joaquin (Pooled)	OSJ	B5	2[a]	9	1[a]	12

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
Old River East, Upstream	OREU	B1a	139	127	16	282
Old River East, Downstream	ORED	B1b	139	127	16	282
Old River East (Pooled)	ORE	B1	139	127	16	282
Old River South, Upstream	ORSU	B2a	129	122	13	264
Old River South, Downstream	ORSD	B2b	130	123	13	266
Old River South (Pooled)	ORS	B2	130	123	13	266
West Canal, Upstream	WCLU	B3a	27	45	5	77
West Canal, Downstream	WCLD	B3b	26	45	4	75
West Canal: OR Route	WCL	B3	27	45	5	77
Old River at Highway 4, Upstream	OR4U	B4a	26	38	5	69
Old River at Highway 4, Downstream	OR4D	B4b	26	37	5	68
Old River at Highway 4, SJR Route	OR4	B4	2[a]	5[a]	1[a]	8
Old River at Highway 4, OR Route	OR4	B4	24	33	4	61
Old River at Highway 4 (Pooled)	OR4	B4	26	38	5	69
Middle River Head, Upstream	MRHU	C1a	5	2	0	7
Middle River Head, Downstream	MRHD	C1b	5	2	0	7
Middle River Head (Pooled)	MRH	C1	5	2	0	7
Middle River at Highway 4, Upstream	MR4U	C2a	5	3	1	9
Middle River at Highway 4, Downstream	MR4D	C2b	5	3	1	9
Middle River at Highway 4, SJR Route	MR4	C2	0[a]	0[a]	1[a]	1
Middle River at Highway 4, OR Route	MR4	C2	5	3	0	8
Middle River at Highway 4 (Pooled)	MR4	C2	5	3	1	9
Radial Gates Upstream #1	RGU1	D1a	19	15	1	35
Radial Gates Upstream #2	RGU2	D1b	22	17	2	41
Radial Gates Upstream: SJR Route	RGU	D1	0	1	1 (1)	2 (1)
Radial Gates Upstream: OR Route	RGU	D1	22	16	1 (1)	39 (1)
Radial Gates Upstream (Pooled)	RGU	D1	22	17	2 (2)	41 (2)
Radial Gates Downstream #1	RGD1	D2a	16	16	2	34
Radial Gates Downstream #2	RGD2	D2b	16	16	2	34
Radial Gates Downstream: SJR Route	RGD	D2	0	1	1 (1)	2 (1)
Radial Gates Downstream: OR Route	RGD	D2	16	15	1 (1)	32 (1)
Radial Gates Downstream (Pooled)	RGD	D2	16	16	2 (2)	34 (2)
Central Valley Project Trashrack, Upstream	CVPU	E1a	51	51	1	103
Central Valley Project Trashrack, Downstream	CVPD	E1b	49	44	1	94

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
CVP Trashrack: SJR Route	CVP	E1	1	2	0	3
CVP Trashrack: OR Route	CVP	E1	51	49	1 (1)	101 (1)
CVP Trashrack (Pooled)	CVP	E1	52	51	1 (1)	104 (1)
CVP Holding Tank: SJR Route	CVPtank	E2	0	1	0	1
CVP Holding Tank: OR Route	CVPtank	E2	14	15	0	29
CVP Holding Tank	CVPtank	E2	14	16	0	30
Threemile Slough, Upstream	TMS	T1a	2	12	3	17
Threemile Slough, Downstream	TMN	T1b	2	12	2	16
Threemile Slough: SJR Route	TMS/TMN	T1	2	12	3	17
Jersey Point Upstream (1)	JPT	G1a	11	50	14	75
Jersey Point East (Upstream 2)	JPE	G1b	11	51	16	78
Jersey Point West	JPW	G1c	11	51	16	78
Jersey Point: SJR Route	JPT/JPE/JPW	G1	6	32	15	53
Jersey Point: OR Route	JPT/JPE/JPW	G1	5	20	1	26
Jersey Point (Pooled)	JPT/JPE/JPW	G1	11	52	16	79
False River West	FRW	H1a	2[a]	0[a]	0[a]	2
False River East	FRE	H1b	2[a]	0[a]	0[a]	2
False River: SJR Route	FRE/FRW	H1	1[a]	0[a]	0[a]	1
False River: OR Route	FRE/FRW	H1	1[a]	0[a]	0[a]	1
False River (Pooled)	FRE/FRW	H1	2[a]	0[a]	0[a]	2
Chipps Island Upstream 1	MAT	G2a	25	79	17	121
Chipps Island East (Upstream 2)	MAE	G2b	24	82	16	122
Chipps Island West	MAW	G2c	28	85	17	130
Chipps Island: SJR Route	MAT/MAE/MAW	G2	7	44	17	68
Chipps Island: OR Route	MAT/MAE/MAW	G2	21	41	0	62
Chipps Island (Pooled)	MAT/MAE/MAW	G2	28	85	17	130
Benicia Bridge: SJR Route	BBR	G3	0[a]	2[a]	18	20
Benicia Bridge: OR Route	BBR	G3	1[a]	2[a]	1	4
Benicia Bridge	BBR	G3	1[a]	4[a]	19	24

a = detections were not used in the survival model

Table 8. Number of tags from each release group in 2015 first classified as in a predator at each detection site, based on the predator filter. Releases are: 1 = early March, 2 = late March, 3 = April.

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
Durham Ferry Upstream	DFU	A0	7	0	1	8	5	0	6	11
Durham Ferry Downstream	DFD	A2	2	1	0	3	1	0	0	1
Below Durham Ferry 1	BDF1	A3	6	1	1	8	1	2	1	4
Below Durham Ferry 2	BDF2	A4	2	4	0	6	1	3	1	5
Banta Carbona	BCA	A5	5	7	12	24	3	0	8	11
Mossdale	MOS	A6	1	2	3	6	3	2	3	8
Head of Old River	HOR	B0	1	1	2	4	1	1	3	5
Lathrop	SJL	A7	0	1	0	1	2	1	1	4
Predator Removal Study 4	RS4	N1	1	1	0	2	0	3	2	5
Predator Removal Study 5	RS5	N2	2	1	0	3	1	0	2	3
Predator Removal Study 6	RS6	N3	1	1	2	4	1	0	1	2
Predator Removal Study 7	RS7	N4	0	0	0	0	0	1	0	1
Predator Removal Study 8	RS8	N5	0	2	1	3	0	0	1	1
Predator Removal Study 9	RS9	N6	0	0	0	0	0	0	0	0
Predator Removal Study 10	RS10	N7	0	0	0	0	0	1	0	1
Garwood Bridge	SJG	A8	0	1	0	1	0	1	0	1
Navy Drive Bridge	SJNB	A9	0	0	0	0	0	0	1	1
Rough and Ready Island	RRI	R1	0	0	0	0	0	0	0	0
San Joaquin River Shipping Channel	SJS	A10	1	0	0	1	0	0	0	0
MacDonald Island	MAC	A11	0	0	0	0	0	0	0	0
Medford Island	MFE/MFW	A12	0	0	0	0	0	0	0	0
San Joaquin River at Disappointment Slough	SJD	A13	0	0	0	0	0	0	0	0
Old River East	ORE	B1	3	0	2	5	2	1	1	4
Old River South	ORS	B2	1	5	0	6	1	0	0	1
West Canal	WCL	B3	3	5	0	8	3	3	1	7
Old River at Highway 4	OR4	B4	3	1	0	4	0	0	1	1
Old River at the San Joaquin	OSJ	B5	0	0	0	0	0	0	0	0
Middle River Head	MRH	C1	1	2	0	3	2	0	1	3
Middle River at Highway 4	MR4	C2	0	0	0	0	0	0	0	0
Middle River at Middle River	MID	C3	0	0	0	0	0	0	0	0
Radial Gates Upstream	RGU	D1	0	0	0	0	2	0	0	2
Radial Gates Downstream	RGD	D2	0	1	0	1	0	0	0	0
Central Valley Project Trashrack	CVP	E1	2	2	2	6	7	6	0	13
Central Valley Project Holding Tank	CVPtank	E2	0	0	0	0	0	0	0	0
Turner Cut	TCE/TCW	F1	0	0	0	0	0	0	0	0
Columbia Cut	COL	F2	0	0	0	0	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
Jersey Point	JPT/JPE/ JPW	G1	0	0	0	0	0	0	0	0
Chipps Island	MAT/MAE/ MAW	G2	1	1	0	2	1	0	0	1
Benicia Bridge	BBR	G3	1	0	0	1	0	0	0	0
False River	FRE/FRW	H1	0	0	0	0	0	0	0	0
Threemile Slough	TMS/TMN	T1	1	0	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			45	40	26	111	37	25	34	96

Table 9. Number of tags from each release group that were detected after release in 2015, excluding predator-type detections and detections omitted from the survival analysis. Releases are: 1 = early March, 2 = late March, 3 = April.

Release Group	1	2	3	Total
Number Released	480	478	469	1,427
Number Detected	391	415	350	1,156
Number Detected Downstream	330	375	302	1,007
Number Detected Upstream of Study Area	391	415	350	1,156
Number Detected in Study Area	172	222	110	504
Number Detected in San Joaquin River Route	62	134	100	296
Number Detected in Old River Route	136	127	12	275
Number Assigned to San Joaquin River Route	31	85	47	163
Number Assigned to Old River Route	131	125	12	268

Table 10. Number of tags observed from each release group at each detection site in 2015, 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.

Detection Site	Site Code	Survival Model Code	Release Group 1	Release Group 2	Release Group 3	Total
Release site at Durham Ferry			480	478	469	1,427
Durham Ferry Upstream	DFU	A0	112	91	102	305
Durham Ferry Downstream	DFD	A2	330	373	302	1005
Below Durham Ferry 1	BDF1	A3	243	281	188	712
Below Durham Ferry 2	BDF2	A4	222	283	174	679
Banta Carbona (Pooled)	BCA	A5	204	283	155	613
Mossdale (Pooled)	MOS	A6	172[a]	222	110[d]	504
Head of Old River (Pooled)	HOR	B0	166[b]	220[c]	104[e]	490
Lathrop, Upstream	SJLU	A7a	62	133	100	295
Lathrop, Downstream	SJLD	A7b	60	132	100	292
Lathrop (Pooled)	SJL	A7	62	133	100	295
Predator Removal Study 4	RS4	N1	43	113	94	250
Predator Removal Study 5	RS5	N2	33	99	82	214
Predator Removal Study 6	RS6	N3	23	96	75	194
Predator Removal Study 7	RS7	N4	17	87	64	168
Predator Removal Study 8	RS8	N5	15	76	50	141
Predator Removal Study 9	RS9	N6	13	72	43	128
Predator Removal Study 10	RS10	N7	13	70	38	121
Garwood Bridge, Upstream	SJGU	A8a	12	68	32	112
Garwood Bridge, Downstream	SJGD	A8b	12	67	32	111
Garwood Bridge (Pooled)	SJG	A8	12	68	32	112
Navy Drive Bridge, Upstream	SJNBU	A9a	12	61	27	100
Navy Drive Bridge, Downstream	SJNBD	A9b	12	60	27	99
Navy Drive Bridge (Pooled)	SJNB	A9	12	61	27	100
Rough and Ready Island, Upstream	RRIU	R1a	2	11	0	13
Rough and Ready Island, Downstream	RRID	R1b	2	11	0	13
Rough and Ready Island (Pooled)	RRI	R1	2	11	0	13
San Joaquin River Shipping Channel	SJS	A10	11	55	25	91
MacDonald Island Upstream	MACU	A11a	9	53	20	82
MacDonald Island Downstream	MACD	A11b	9	51	19	79
MacDonald Island (Pooled)	MAC	A11	9	53	20	82
Turner Cut, Upstream	TCE	F1a	2	7	7	16
Turner Cut, Downstream	TCW	F1b	2	7	7	16
Turner Cut (Pooled)	TCE/TCW	F1	2	7	7	16
Medford Island East	MFE	A12a	7	46	10	63

a = One tagged steelhead was recaptured after detection at MOS and removed from the river.

b = One tagged steelhead was recaptured after detection at HOR and then returned to the river.

c = One tagged steelhead was recaptured after detection at HOR and then returned to the river.

d = Four tagged steelhead were recaptured after detection at MOS and then returned to the river.

e = Three tagged steelhead were recaptured after detection at HOR and then returned to the river.

Table 10. (Continued)

Detection Site	Site Code	Survival Model Code	Release Group 1	Release Group 2	Release Group 3	Total
Medford Island West	MFW	A12b	7	46	13	66
Medford Island (Pooled)	MFE/MFW	A12	7	46	13	66
Columbia Cut, Upstream	COLU	F2a	1	3	3	7
Columbia Cut, Downstream	COLD	F2b	1	3	3	7
Columbia Cut (Pooled)	COL	F2	1	3	3	7
Disappointment Slough, Upstream	SJDU	A13a	10	41	14	65
Disappointment Slough, Downstream	SJDD	A13b	10	41	14	65
Disappointment Slough (Pooled)	SJD	A13	10	41	14	65
Old River at the San Joaquin, Upstream	OSJU	B5a	1	12	1	14
Old River at the San Joaquin, Downstream	OSJD	B5b	1	12	1	14
Old River at the San Joaquin (Pooled)	OSJ	B5	1	13	1	15
Old River East, Upstream	OREU	B1a	136	127	12	275
Old River East, Downstream	ORED	B1b	136	127	12	275
Old River East (Pooled)	ORE	B1	136	127	12	275
Old River South, Upstream	ORSU	B2a	129	122	9	260
Old River South, Downstream	ORSD	B2b	129	122	9	260
Old River South (Pooled)	ORS	B2	129	122	9	260
West Canal, Upstream	WCLU	B3a	60	82	5	147
West Canal, Downstream	WCLD	B3b	60	82	5	147
West Canal: SJR Route	WCL	B3	1	5	1	7
West Canal: OR Route	WCL	B3	59	77	4	140
West Canal (Pooled)	WCL	B3	60	82	5	147
Old River at Highway 4, Upstream	OR4U	B4a	29	46	5	80
Old River at Highway 4, Downstream	OR4D	B4b	28	46	5	79
Old River at Highway 4, SJR Route	OR4	B4	1	4	2	7
Old River at Highway 4, OR Route	OR4	B4	28	42	3	73
Old River at Highway 4 (Pooled)	OR4	B4	29	46	5	80
Middle River Head, Upstream	MRHU	C1a	11	10	2	23
Middle River Head, Downstream	MRHD	C1b	11	9	2	22
Middle River Head (Pooled)	MRH	C1	11	10	2	23
Middle River at Highway 4, Upstream	MR4U	C2a	7	7	2	16
Middle River at Highway 4, Downstream	MR4D	C2b	7	7	2	16
Middle River at Highway 4, SJR Route	MR4	C2	0	1	2	3
Middle River at Highway 4, OR Route	MR4	C2	7	6	0	13
Middle River at Highway 4 (Pooled)	MR4	C2	7	7	2	16
Middle River at Middle River	MID	C3	1	4	2	7
Radial Gates Upstream #1	RGU1	D1a	37	61	3	101
Radial Gates Upstream #2	RGU2	D1b	57	83	5	145
Radial Gates Upstream: SJR Route	RGU	D1	1	2	1	4
Radial Gates Upstream: OR Route	RGU	D1	58	81	4	143

Table 10. (Continued)

Detection Site	Site Code	Survival Model Code	Release Group 1	Release Group 2	Release Group 3	Total
Radial Gates Upstream (Pooled)	RGU	D1	59	83	5	147
Radial Gates Downstream #1	RGD1	D2a	14	10	0	24
Radial Gates Downstream #2	RGD2	D2b	14	10	0	24
Radial Gates Downstream: SJR Route	RGD	D2	0	0	0	0
Radial Gates Downstream: OR Route	RGD	D2	14	10	0	24
Radial Gates Downstream (Pooled)	RGD	D2	14	10	0	24
Central Valley Project Trashrack, Upstream	CVPU	E1a	73	92	4	169
Central Valley Project Trashrack, Downstream	CVPD	E1b	70	83	4	157
CVP Trashrack: SJR Route	CVP	E1	1	4	1	6
CVP Trashrack: OR Route	CVP	E1	72	88	3	163
CVP Trashrack (Pooled)	CVP	E1	73	92	4	169
CVP Holding Tank: SJR Route	CVPtank	E2	0	1	0	1
CVP Holding Tank: OR Route	CVPtank	E2	13	14	0	27
CVP Holding Tank	CVPtank	E2	13	15	0	28
Threemile Slough, Upstream	TMS	T1a	4	22	5	31
Threemile Slough, Downstream	TMN	T1b	5	20	4	29
Threemile Slough: SJR Route	TMS/TMN	T1	2	19	5	26
Threemile Slough: OR Route	TMS/TMN	T1	3	3	0	6
Threemile Slough (Pooled)	TMS/TMN	T1	5	22	5	32
Jersey Point Upstream (1)	JPT	G1a	11	49	15	75
Jersey Point East (Upstream 2)	JPE	G1b	11	50	17	78
Jersey Point West	JPW	G1c	11	51	17	79
Jersey Point: SJR Route	JPT/JPE/JPW	G1	5	33	16	54
Jersey Point: OR Route	JPT/JPE/JPW	G1	6	18	1	25
Jersey Point (Pooled)	JPT/JPE/JPW	G1	11	51	17	79
False River West	FRW	H1a	9	24	4	37
False River East	FRE	H1b	9	25	5	39
False River: SJR Route	FRE/FRW	H1	3	9	5	17
False River: OR Route	FRE/FRW	H1	6	16	0	22
False River (Pooled)	FRE/FRW	H1	9	25	5	39
Montezuma Slough (Pooled)	MTZ	T2	0	1	1	2
Spoonbill Slough, Upstream	SBSU	T3a	1	0	0	1
Spoonbill Slough, Downstream	SBSD	T3b	1	0	0	1
Spoonbill Slough (Pooled)	SBS	T3	1	0	0	1
Chipps Island Upstream 1	MAT	G2a	25	73	17	115
Chipps Island East (Upstream 2)	MAE	G2b	25	74	16	115
Chipps Island West	MAW	G2c	26	74	17	117
Chipps Island: SJR Route	MAT/MAE/MAW	G2	6	41	17	64
Chipps Island: OR Route	MAT/MAE/MAW	G2	20	36	0	56
Chipps Island (Pooled)	MAT/MAE/MAW	G2	26	77	17	120

Table 10. (Continued)

Detection Site	Site Code	Survival Model Code	Release Group 1	Release Group 2	Release Group 3	Total
Benicia Bridge: SJR Route	BBR	G3	0	1	18	19
Benicia Bridge: OR Route	BBR	G3	0	0	1	1
Benicia Bridge	BBR	G3	0	1	19	20

Table 11. Number of tags observed from each release group at each detection site in 2015 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.

Detection Site	Site Code	Survival Model Code	Release Group 1	Release Group 2	Release Group 3	Total
Release site at Durham Ferry			480	478	469	1,427
Durham Ferry Upstream	DFU	A0	75	62	75	212
Durham Ferry Downstream	DFD	A2	316	351	275	942
Below Durham Ferry 1	BDF1	A3	238	265	172	675
Below Durham Ferry 2	BDF2	A4	214	266	158	638
Banta Carbona (Pooled)	BCA	A5	197	246	140	583
Mossdale (Pooled)	MOS	A6	170 (2)	221 (1)	102 (7)	493 (10)
Lathrop, Upstream	SJLU	A7a	30	85	47	162
Lathrop, Downstream	SJLD	A7b	31	85	47	163
Lathrop (Pooled)	SJL	A7	31	85	47	163
Garwood Bridge, Upstream	SJGU	A8a	11	67	28	106
Garwood Bridge, Downstream	SJGD	A8b	11	66	28	105
Garwood Bridge (Pooled)	SJG	A8	11	67	28	106
Navy Drive Bridge, Upstream	SJNBU	A9a	11	59	26	96
Navy Drive Bridge, Downstream	SJNBD	A9b	11	59	26	96
Navy Drive Bridge (Pooled)	SJNB	A9	11	59	26	96
San Joaquin River Shipping Channel	SJS	A10	11	55	24	90
MacDonald Island Upstream	MACU	A11a	7	46	17	70
MacDonald Island Downstream	MACD	A11b	8	49	17	74
MacDonald Island (Pooled)	MAC	A11	8	49	17	74
Turner Cut, Upstream	TCE	F1a	2 (2)	5	6	13 (2)
Turner Cut, Downstream	TCW	F1b	2 (2)	5	6	13 (2)
Turner Cut (Pooled)	TCE/TCW	F1	2 (2)	5	6	13 (2)
Medford Island East	MFE	A12a	7	45	9	61
Medford Island West	MFW	A12b	7	45	12	64
Medford Island (Pooled)	MFE/MFW	A12	7	45	12	64
Columbia Cut, Upstream	COLU	F2a	1[a]	2[a]	3[a]	6
Columbia Cut, Downstream	COLD	F2b	1[a]	2[a]	3[a]	6
Columbia Cut (Pooled)	COL	F2	1[a]	2[a]	3[a]	6
Disappointment Slough, Upstream	SJDU	A13a	7	33	13	53
Disappointment Slough, Downstream	SJDD	A13b	7	34	12	53
Disappointment Slough (Pooled)	SJD	A13	7	34	13	54
Old River at the San Joaquin, Upstream	OSJU	B5a	1[a]	8	1[a]	10
Old River at the San Joaquin, Downstream	OSJD	B5b	1[a]	8	1[a]	10
Old River at the San Joaquin (Pooled)	OSJ	B5	1[a]	8	1[a]	10

a = detections were not used in the survival model

Table 11. (Continued)

Detection Site	Site Code	Survival Model Code	Release Group 1	Release Group 2	Release Group 3	Total
Old River East, Upstream	OREU	B1a	131	125	12	268
Old River East, Downstream	ORED	B1b	131	125	12	268
Old River East (Pooled)	ORE	B1	131	125	12	268
Old River South, Upstream	ORSU	B2a	120	118	8	246
Old River South, Downstream	ORSD	B2b	121	119	8	248
Old River South (Pooled)	ORS	B2	121	119	8	248
West Canal, Upstream	WCLU	B3a	24	46	4[a]	74
West Canal, Downstream	WCLD	B3b	23	46	4[a]	73
West Canal: OR Route	WCL	B3	24	46	4[a]	74
Old River at Highway 4, Upstream	OR4U	B4a	19	35	4[a]	58
Old River at Highway 4, Downstream	OR4D	B4b	19	34	4[a]	57
Old River at Highway 4, SJR Route	OR4	B4	1[a]	4[a]	2[a]	7
Old River at Highway 4, OR Route	OR4	B4	18	31	2[a]	51
Old River at Highway 4 (Pooled)	OR4	B4	19	35	4[a]	58
Middle River Head, Upstream	MRHU	C1a	6	4	1 (1)	11 (1)
Middle River Head, Downstream	MRHD	C1b	6	4	1 (1)	11 (1)
Middle River Head (Pooled)	MRH	C1	6	4	1 (1)	11 (1)
Middle River at Highway 4, Upstream	MR4U	C2a	6	3	1[a]	10
Middle River at Highway 4, Downstream	MR4D	C2b	6	3	1[a]	10
Middle River at Highway 4, SJR Route	MR4	C2	0[a]	1[a]	1[a]	2
Middle River at Highway 4, OR Route	MR4	C2	6	2	0[a]	8
Middle River at Highway 4 (Pooled)	MR4	C2	6	3	1[a]	10
Radial Gates Upstream #1	RGU1	D1a	17	11	1[a]	29
Radial Gates Upstream #2	RGU2	D1b	20	13	1[a]	34
Radial Gates Upstream: SJR Route	RGU	D1	0	0	1[a]	1
Radial Gates Upstream: OR Route	RGU	D1	20	13	0[a]	33
Radial Gates Upstream (Pooled)	RGU	D1	20	13	1[a]	34
Radial Gates Downstream #1	RGD1	D2a	14	10	0[a]	24
Radial Gates Downstream #2	RGD2	D2b	14	10	0[a]	24
Radial Gates Downstream: SJR Route	RGD	D2	0	0	0[a]	0
Radial Gates Downstream: OR Route	RGD	D2	14	10	0[a]	24
Radial Gates Downstream (Pooled)	RGD	D2	14	10	0[a]	24
Central Valley Project Trashrack, Upstream	CVPU	E1a	47	52	0[a]	99
Central Valley Project Trashrack, Downstream	CVPD	E1b	45	45	0[a]	90

a = detections were not used in the survival model

Table 11. (Continued)

Detection Site	Site Code	Survival Model Code	Release Group 1	Release Group 2	Release Group 3	Total
CVP Trashrack: SJR Route	CVP	E1	1	3	0[a]	4
CVP Trashrack: OR Route	CVP	E1	46	49	0[a]	95
CVP Trashrack (Pooled)	CVP	E1	47	52	0[a]	99
CVP Holding Tank: SJR Route	CVPtank	E2	0	1	0[a]	1
CVP Holding Tank: OR Route	CVPtank	E2	13	14	0[a]	27
CVP Holding Tank	CVPtank	E2	13	15	0[a]	28
Threemile Slough, Upstream	TMS	T1a	2	11	3	16
Threemile Slough, Downstream	TMN	T1b	2	11	2	15
Threemile Slough: SJR Route	TMS/TMN	T1	2	11	3	16
Jersey Point Upstream (1)	JPT	G1a	10	45	14	69
Jersey Point East (Upstream 2)	JPE	G1b	10	46	16	72
Jersey Point West	JPW	G1c	10	47	16	73
Jersey Point: SJR Route	JPT/JPE/JPW	G1	5	30	15	50
Jersey Point: OR Route	JPT/JPE/JPW	G1	5	17	1	23
Jersey Point (Pooled)	JPT/JPE/JPW	G1	10	47	16	73
False River West	FRW	H1a	2[a]	0[a]	0[a]	2
False River East	FRE	H1b	2[a]	0[a]	0[a]	2
False River: SJR Route	FRE/FRW	H1	1[a]	0[a]	0[a]	1
False River: OR Route	FRE/FRW	H1	1[a]	0[a]	0[a]	1
False River (Pooled)	FRE/FRW	H1	2[a]	0[a]	0[a]	2
Chipps Island Upstream 1	MAT	G2a	23	72	17	112
Chipps Island East (Upstream 2)	MAE	G2b	23	74	16	113
Chipps Island West	MAW	G2c	26	77	17	120
Chipps Island: SJR Route	MAT/MAE/MAW	G2	6	41	17	64
Chipps Island: OR Route	MAT/MAE/MAW	G2	20	36	0	56
Chipps Island (Pooled)	MAT/MAE/MAW	G2	26	77	17	120
Benicia Bridge: SJR Route	BBR	G3	0	1[a]	18	19
Benicia Bridge: OR Route	BBR	G3	0	0[a]	1	1
Benicia Bridge	BBR	G3	0	1[a]	19	20

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 2015 tagging study. Releases are: 1 = early March, 2 = late March, 3 = April.

Surgeon	Release Group 1	2	3	Total Tags
A	160	159	157	476
B	160	159	156	475
C	160	160	156	476
Total Tags	480	478	469	1427

Table 13. Release size and counts of juvenile Steelhead tag detections at key detection sites by surgeon in 2015, excluding predator-type detections. * = omitted from chi-square test of independence because of low counts.

Detection Site	Surgeon A	B	C
Release at Durham Ferry	476	475	476
Below Durham Ferry 1 (BDF1)	227	223	225
Below Durham Ferry 2 (BDF2)	219	207	212
Banta Carbona (BCA)	196	192	195
Mossdale (MOS)	168	165	160
Lathrop (SJL)	63	52	48
Garwood Bridge (SJG)	45	35	26
Navy Bridge (SJNB)	37	34	25
Shipping Channel (SJS)	32	33	25
MacDonald Island (MAC)	28	25	21
Turner Cut (TCE/TCW)*	4	6	3
Medford Island (MFE/MFW)	24	20	20
Columbia Cut (COL)*	1	4	1
Disappointment Slough	21	16	17
Old River Mouth (OSJ)*	3	4	3
Old River East (ORE)	84	96	88
Old River South (ORS)	79	89	80
West Canal (WCL)	26	27	21
Old River at Highway 4 (OR4)	18	24	16
Middle River Head (MRH)*	2	5	4
Middle River at Highway 4 (MR4)*	3	3	4
Clifton Court Forebay Exterior (RGU)	7	14	13
Clifton Court Forebay Interior (RGD)	6	8	10
Central Valley Project Trash Rack (CVP)	32	34	33
Central Valley Project Holding Tank (CVPtank)	9	11	8
Threemile Slough (TMN/TMS)*	6	7	3
Jersey Point (JPT/JPE/JPW)	25	24	24
Chipps Island (MAT/MAE/MAW)	40	44	36
Benicia Bridge (BBR)	4	8	8

Table 14. Performance metric estimates (standard error in parentheses) for tagged juvenile Steelhead released in the 2015 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 = early March, 2 = late March, 3 = April.

Parameter	Release Group			Population Estimate
	1[a]	2	3[b]	
ψ_{AA}	0.15 (0.03)	0.37 (0.03)	0.59 (0.08)	0.37 (0.03)
ψ_{AF}	0.04 (0.03)	0.04 (0.02)	0.21 (0.07)	0.09 (0.03)
ψ_{BB}	0.77 (0.03)	0.57 (0.03)	0.18 (0.05)	0.51 (0.02)
ψ_{BC}	0.04 (0.02)	0.02 (0.01)	0.02 (0.02)	0.03 (0.01)
S_{AA}	0.25 (0.08)	0.47 (0.05)	0.29 (0.05)	0.34 (0.04)
S_{AF}	NA	0.37 (0.14)	0.10 (0.06)	0.23[c] (0.08)
S_{BB}	0.15 (0.03)	0.28 (0.04)	0.06 (0.06)	0.16 (0.02)
S_{BC}	0	0	NA	0[c]
ψ_A	0.19[d] (0.03)	0.41[d] (0.03)	0.80[e] (0.05)	0.46 (0.02)
ψ_B	0.81[d] (0.03)	0.59[d] (0.03)	0.20[e] (0.05)	0.54 (0.02)
S_A	0.19 (0.07)	0.46[f] (0.05)	0.24 (0.05)	0.30[f] (0.03)
S_B	0.14 (0.03)	0.27[f] (0.04)	0.05 (0.05)	0.16[f] (0.02)
S_{Total}	0.15 (0.03)	0.35 (0.03)	0.20 (0.04)	0.23 (0.02)
$S_{A(MD)}$[g]	NA	0.34[f] (0.05)	0.20 (0.05)	0.27[cf] (0.03)
$S_{B(MD)}$[g]	0.04 (0.02)	0.13[f] (0.03)	0.05 (0.05)	0.07[f] (0.02)
$S_{Total(MD)}$[g]	NA	0.21 (0.03)	0.17 (0.04)	0.19[c] (0.02)
$S_{A(SD)}$	0.31 (0.08)	0.61 (0.05)	0.30 (0.05)	0.41 (0.04)
$S_{B(SD)}$	0.66 (0.04)	0.73 (0.04)	NA	0.70[c] (0.03)
$S_{Total(SD)}$	0.60 (0.04)	0.68 (0.03)	NA	0.64[c] (0.02)
ϕ_{A1A6}	0.36 (0.02)	0.46 (0.02)	0.22 (0.02)	0.35 (0.01)

a = there were too few tags detected in route A (San Joaquin River Route) to estimate survival within the Turner Cut subroute, or survival through the Mid Delta region

b = there were too few tags detected in route B (Old River Route) to estimate survival in the Middle River subroute, or survival through the South Delta region

c = population estimate is based on only two release groups

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=0.05) (tested only for Delta and Mid-Delta survival)

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

Table 15. Performance metric estimates (standard error in parentheses) for tagged juvenile Steelhead released in the 2015 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 = early March, 2 = late March, 3 = April.

Parameter	Release Group 1	2[a]	3[ab]	Population Estimate
ψ_{AA}	0.12 (0.03)	0.36 (0.03)	0.55 (0.08)	0.34 (0.03)
ψ_{AF}	0.05 (0.02)	0.03 (0.01)	0.16 (0.06)	0.08 (0.02)
ψ_{BB}	0.80 (0.03)	0.60 (0.03)	0.29 (0.06)	0.57 (0.03)
ψ_{BC}	0.03 (0.01)	0.01 (0.01)	0	0.01 (0.01)
S_{AA}	0.35 (0.09)	0.52 (0.05)	0.35 (0.06)	0.41 (0.04)
S_{AF}	0	0.54 (0.13)	0.15 (0.08)	0.23 (0.05)
S_{BB}	0.15 (0.03)	0.31 (0.04)	0.04 (0.04)	0.17 (0.02)
S_{BC}	0	NA	NA	NA
ψ_A	0.17[c] (0.03)	0.39[c] (0.03)	0.71[d] (0.06)	0.42[c] (0.03)
ψ_B	0.83[c] (0.03)	0.61[c] (0.03)	0.29[d] (0.06)	0.58[c] (0.03)
S_A	0.24 (0.08)	0.52[e] (0.05)	0.30[e] (0.06)	0.36[e] (0.04)
S_B	0.14 (0.03)	0.31[e] (0.04)	0.04[e] (0.04)	0.16[e] (0.02)
S_{Total}	0.16 (0.03)	0.39 (0.03)	0.23 (0.05)	0.26 (0.02)
$S_{A(MD)}$[f]	0.21[e] (0.07)	0.38[e] (0.05)	0.25 (0.05)	0.28[e] (0.04)
$S_{B(MD)}$[f]	0.03[e] (0.02)	0.15[e] (0.03)	0.04 (0.04)	0.08[e] (0.02)
$S_{Total(MD)}$[f]	0.06 (0.02)	0.24 (0.03)	0.19 (0.04)	0.16 (0.02)
$S_{A(SD)}$	0.44 (0.09)	0.67 (0.05)	0.37 (0.06)	0.50 (0.04)
$S_{B(SD)}$	0.71 (0.04)	0.76 (0.04)	0.25 (0.08)	0.57 (0.03)
$S_{Total(SD)}$	0.66 (0.04)	0.73 (0.03)	0.33 (0.05)	0.58 (0.02)
ϕ_{A1A6}	0.37 (0.02)	0.46 (0.02)	0.19 (0.02)	0.34 (0.01)

a = there were too few tags detected in route B (Old River Route) to estimate survival in the Middle River subroute; route B survival estimates through the Mid-Delta and South Delta regions were based on assumption that Middle River subroute survival = 0

b = survival estimates through the South Delta for route B and total were based on the assumption of 100% detection probability at water export facilities

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

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

e = 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)

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

Table 16a. Average travel time in days (harmonic mean) of acoustic-tagged juvenile Steelhead from release at Durham Ferry during the 2015 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 = early March, 2 = late March, 3 = April.

	Without Predator-Type Detections							
	All releases		1		2		3	
Detection Site and Route	N	Travel Time	N	Travel Time	N	Travel Time	N	Travel Time
Durham Ferry Upstream (DFU)	212	0.37 (0.06)	75	0.43 (0.10)	62	0.80 (0.16)	75	0.24 (0.06)
Durham Ferry Downstream (DFD)	942	0.12 (<0.01)	316	0.15 (0.01)	351	0.09 (<0.01)	275	0.18 (0.01)
Below Durham Ferry 1 (BDF1)	675	0.65 (0.03)	238	1.33 (0.14)	265	0.46 (0.03)	172	0.60 (0.04)
Below Durham Ferry 2 (BDF2)	638	0.81 (0.04)	214	1.61 (0.18)	266	0.60 (0.04)	158	0.75 (0.05)
Banta Carbona (BCA)	583	1.61 (0.08)	197	3.50 (0.38)	246	1.24 (0.09)	140	1.29 (0.10)
Mossdale (MOS)	493	4.11 (0.21)	170	7.74 (0.54)	221	3.18 (0.24)	102	3.57 (0.28)
Lathrop (SJL)	163	6.25 (0.80)	31	11.67 (2.52)	85	6.40 (1.52)	47	4.63 (0.40)
Garwood Bridge (SJG)	106	7.81 (1.15)	11	22.55 (4.81)	67	8.18 (1.93)	28	5.72 (0.38)
Navy Drive Bridge (SJNB)	96	7.74 (1.19)	11	22.76 (4.88)	59	8.06 (2.04)	26	5.65 (0.36)
San Joaquin Shipping Channel (SJS)	90	8.82 (1.34)	11	25.19 (4.37)	55	8.90 (2.19)	24	6.69 (0.34)
MacDonald Island (MAC)	74	8.87 (1.55)	8	29.66 (4.28)	49	8.65 (2.19)	17	7.06 (0.51)
Turner Cut (TCE/TCW)	13	9.74 (1.51)	2	16.14 (8.20)	5	19.97 (1.16)	6	6.25 (0.13)
Turner Cut Junction (MAC or TCE/TCW)	87	8.99 (1.37)	10	25.40 (4.61)	54	9.13 (2.22)	23	6.83 (0.36)
Medford Island (MFE/MFW)	64	9.30 (1.76)	7	34.59 (2.50)	45	8.92 (2.27)	12	7.35 (0.56)
Disappointment Slough (SJD)	54	14.84 (1.08)	7	31.60 (4.71)	34	18.39 (0.52)	13	8.30 (0.65)
Old River at the San Joaquin (OSJ)	10	5.67 (2.42)	NA	NA	8	5.03 (2.36)	NA	NA
Old River East (ORE)	268	4.54 (0.23)	131	8.52 (0.50)	125	3.00 (0.16)	12	5.92 (0.95)
Old River South (ORS)	248	5.16 (0.26)	121	9.40 (0.55)	119	3.47 (0.18)	8	9.33 (1.19)
West Canal (WCL)	74	7.64 (0.61)	24	14.17 (1.13)	46	5.98 (0.51)	NA	NA
Old River at Highway 4 (OR4), OR Route	51	9.32 (0.82)	18	15.57 (1.26)	31	7.46 (0.73)	NA	NA
Middle River Head (MRH)	11	8.32 (0.89)	6	10.14 (2.01)	4	6.82 (0.32)	1	6.96 (NA)
Middle River at Highway 4 (MR4), OR Route	8	13.20 (2.49)	6	17.93 (2.50)	2	7.36 (0.17)	NA	NA
Radial Gates Upstream (DFU), SJR Route	1	10.11 (NA)	0	NA	0	NA	NA	NA
Radial Gates Upstream (DFU), OR Route	33	11.17 (1.22)	20	14.67 (1.55)	13	8.16 (1.29)	NA	NA
Radial Gates Upstream (DFU)	34	11.13 (1.18)	20	14.67 (1.55)	13	8.16 (1.29)	NA	NA
Radial Gates Downstream (DFD), SJR Route	0	NA	0	NA	0	NA	NA	NA

Table 16a. (Continued)

Detection Site and Route	Without Predator-Type Detections							
	All releases		1		2		3	
	N	Travel Time	N	Travel Time	N	Travel Time	N	Travel Time
Radial Gates Downstream (DFD), OR Route	24	11.42 (1.25)	14	14.42 (1.69)	10	8.84 (1.36)	NA	NA
Radial Gates Downstream (DFD)	24	11.42 (1.25)	14	14.42 (1.69)	10	8.84 (1.36)	NA	NA
Central Valley Project Trashrack (CVP), SJR Route	4	25.45 (3.46)	1	34.45 (NA)	3	23.41 (3.18)	NA	NA
Central Valley Project Trashrack (CVP), OR Route	95	7.73 (0.44)	46	11.92 (0.71)	49	5.81 (0.35)	NA	NA
Central Valley Project Trashrack (CVP)	99	7.96 (0.46)	47	12.08 (0.74)	52	6.08 (0.39)	NA	NA
Central Valley Project Holding Tank (CVPtank), SJR Route	1	18.63 (NA)	0	NA	1	18.63 (NA)	NA	NA
Central Valley Project Holding Tank (CVPtank), OR Route	27	10.32 (0.87)	13	13.08 (1.67)	14	8.63 (0.82)	NA	NA
Central Valley Project Holding Tank (CVPtank)	28	10.48 (0.88)	13	13.08 (1.67)	15	8.95 (0.88)	NA	NA
Jersey Point (JPT/JPE/JPW), SJR Route	50	15.07 (1.02)	5	30.39 (5.83)	30	19.48 (0.95)	15	9.29 (0.43)
Jersey Point (JPT/JPE/JPW), OR Route	23	12.12 (1.15)	5	23.90 (3.47)	17	10.48 (0.92)	1	14.78 (NA)
Jersey Point (JPT/JPE/JPW)	73	13.99 (0.78)	10	26.76 (3.14)	47	14.87 (1.01)	16	9.51 (0.48)
Chipps Island (MAT/MAE/MAW), SJR Route	64	16.93 (0.97)	6	35.33 (5.92)	41	21.00 (0.72)	17	10.25 (0.43)
Chipps Island (MAT/MAE/MAW), OR Route	56	12.21 (0.81)	20	18.40 (2.09)	36	10.29 (0.68)	0	NA
Chipps Island (MAT/MAE/MAW)	120	14.34 (0.67)	26	20.69 (2.27)	77	14.12 (0.84)	17	10.25 (0.43)
Benicia Bridge (BBR)	20	12.07 (0.67)	0	NA	NA	NA	19	11.66 (0.50)

Table 16b. Average travel time in days (harmonic mean) of acoustic-tagged juvenile Steelhead from release at Durham Ferry during the 2015 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 = early March, 2 = late March, 3 = April.

	With Predator-Type Detections							
	All releases		1		2		3	
Detection Site and Route	N	Travel Time	N	Travel Time	N	Travel Time	N	Travel Time
Durham Ferry Upstream (DFU)	214	0.38 (0.06)	71	0.43 (0.10)	66	0.85 (0.17)	77	0.24 (0.06)
Durham Ferry Downstream (DFD)	939	0.12 (<0.01)	319	0.15 (0.01)	347	0.09 (0.01)	273	0.18 (0.01)
Below Durham Ferry 1 (BDF1)	674	0.67 (0.03)	244	1.39 (0.15)	261	0.47 (0.03)	169	0.62 (0.05)
Below Durham Ferry 2 (BDF2)	638	0.84 (0.04)	223	1.68 (0.19)	261	0.60 (0.04)	154	0.78 (0.06)
Banta Carbona (BCA)	588	1.70 (0.09)	209	3.72 (0.41)	246	1.26 (0.09)	133	1.39 (0.12)
Mossdale (MOS)	485	4.16 (0.22)	176	8.05 (0.58)	218	3.16 (0.24)	91	3.53 (0.30)
Lathrop (SJL)	147	6.07 (0.84)	27	12.23 (3.14)	81	6.26 (1.52)	39	4.30 (0.40)
Garwood Bridge (SJG)	106	7.99 (1.20)	13	24.20 (4.81)	67	8.25 (1.96)	26	5.63 (0.39)
Navy Drive Bridge (SJNB)	100	8.06 (1.25)	13	24.41 (4.87)	62	8.32 (2.07)	25	5.66 (0.38)
San Joaquin Shipping Channel (SJS)	94	9.22 (1.41)	13	27.26 (4.52)	58	9.20 (2.22)	23	6.73 (0.35)
MacDonald Island (MAC)	78	9.19 (1.59)	9	30.49 (4.07)	52	8.98 (2.23)	17	7.06 (0.51)
Turner Cut (TCE/TCW)	14	11.57 (2.07)	4	23.32 (9.22)	5	19.97 (1.16)	5	6.34 (0.12)
Turner Cut Junction (MAC or TCE/TCW)	92	9.48 (1.45)	13	27.85 (4.44)	57	9.44 (2.26)	22	6.88 (0.38)
Medford Island (MFE/MFW)	67	9.59 (1.80)	8	35.11 (2.29)	47	9.17 (2.30)	12	7.35 (0.56)
Disappointment Slough (SJD)	55	14.97 (1.09)	7	31.60 (4.71)	35	18.56 (0.54)	13	8.30 (0.65)
Old River at the San Joaquin (OSJ)	12	6.55 (2.76)	NA	NA	9	5.51 (2.55)	NA	NA
Old River East (ORE)	282	4.76 (0.25)	139	8.98 (0.53)	127	3.06 (0.17)	16	7.10 (1.21)
Old River South (ORS)	266	5.44 (0.27)	130	9.77 (0.57)	123	3.59 (0.19)	13	9.56 (1.37)
West Canal (WCL)	77	7.94 (0.66)	27	14.81 (1.19)	45	6.08 (0.55)	5	10.55 (2.63)
Old River at Highway 4 (OR4), OR Route	61	10.15 (0.88)	24	17.20 (1.59)	33	7.74 (0.78)	4	11.27 (1.42)
Middle River Head (MRH)	7	9.88 (2.02)	5	12.65 (3.43)	2	6.38 (0.35)	0	NA
Middle River at Highway 4 (MR4), OR Route	8	12.84 (2.31)	5	17.28 (2.98)	3	8.99 (1.98)	0	NA
Radial Gates Upstream (DFU), SJR Route	2	18.94 (5.26)	0	NA	1	26.23 (NA)	1	14.82 (NA)
Radial Gates Upstream (DFU), OR Route	39	13.41 (1.33)	22	15.92 (1.87)	16	10.73 (1.60)	1	26.77 (NA)
Radial Gates Upstream (DFU)	41	13.60 (1.31)	22	15.92 (1.87)	17	11.12 (1.66)	2	19.08 (5.48)
Radial Gates Downstream (DFD), SJR Route	2	19.62 (5.01)	0	NA	1	26.35 (NA)	1	15.63 (NA)

Table 16b. (Continued)

Detection Site and Route	All releases		With Predator-Type Detections 1		2		3	
	N	Travel Time	N	Travel Time	N	Travel Time	N	Travel Time
Radial Gates Downstream (DFD), OR Route	32	12.90 (1.39)	16	15.61 (1.97)	15	10.58 (1.63)	1	26.86 (NA)
Radial Gates Downstream (DFD)	34	13.17 (1.38)	16	15.61 (1.97)	16	10.99 (1.70)	2	19.76 (5.22)
Central Valley Project Trashrack (CVP), SJR Route	3	25.64 (5.80)	1	42.83 (NA)	2	21.35 (3.22)	0	NA
Central Valley Project Trashrack (CVP), OR Route	101	8.57 (0.54)	51	13.36 (0.95)	49	6.19 (0.42)	1	22.48 (NA)
Central Valley Project Trashrack (CVP)	104	8.74 (0.55)	52	13.54 (0.97)	51	6.37 (0.44)	1	22.48 (NA)
Central Valley Project Holding Tank (CVPtank), SJR Route	1	18.63 (NA)	0	NA	1	18.63 (NA)	0	NA
Central Valley Project Holding Tank (CVPtank), OR Route	29	10.76 (0.95)	14	13.79 (1.88)	15	8.93 (0.87)	0	NA
Central Valley Project Holding Tank (CVPtank)	30	10.92 (0.95)	14	13.79 (1.88)	16	9.23 (0.93)	0	NA
Jersey Point (JPT/JPE/JPW), SJR Route	53	15.54 (1.06)	6	31.84 (5.44)	32	19.90 (0.98)	15	9.29 (0.43)
Jersey Point (JPT/JPE/JPW), OR Route	26	12.59 (1.16)	5	23.90 (3.47)	20	11.18 (1.02)	1	14.78 (NA)
Jersey Point (JPT/JPE/JPW)	79	14.42 (0.81)	11	27.66 (3.18)	52	15.31 (1.02)	16	9.51 (0.48)
Chipps Island (MAT/MAE/MAW), SJR Route	68	17.43 (1.00)	7	36.23 (5.35)	44	21.45 (0.76)	17	10.25 (0.43)
Chipps Island (MAT/MAE/MAW), OR Route	62	12.88 (0.87)	21	19.02 (2.21)	41	11.05 (0.78)	0	NA
Chipps Island (MAT/MAE/MAW)	130	14.92 (0.70)	28	21.58 (2.37)	85	14.76 (0.87)	17	10.25 (0.43)
Benicia Bridge (BBR)	24	13.79 (1.17)	NA	NA	NA	NA	19	11.66 (0.50)

Table 17a. Average travel time in days (harmonic mean) of acoustic-tagged juvenile Steelhead through the San Joaquin River Delta river reaches during the 2015 tagging study, without predator-type detections. Standard errors are in parentheses. * = all routes combined between upstream and downstream boundaries. Reaches that were not modeled for individual release groups were excluded. Releases are: 1 = early March, 2 = late March, 3 = April. See Table 17b for travel time through reaches with predator-type detections.

Reach		Without Predator-Type Detections							
		All releases		1		2		3	
Upstream Boundary	Downstream Boundary	N	Travel Time	N	Travel Time	N	Travel Time	N	Travel Time
Durham Ferry (Release)	DFU	212	0.37 (0.06)	75	0.43 (0.10)	62	0.80 (0.16)	75	0.24 (0.06)
	DFD	942	0.12 (<0.01)	316	0.15 (0.01)	351	0.09 (<0.01)	275	0.18 (0.01)
DFD	BDF1	674	0.31 (0.01)	238	0.61 (0.06)	264	0.25 (0.02)	172	0.23 (0.02)
BDF1	BDF2	619	0.05 (<0.01)	213	0.07 (<0.01)	248	0.05 (<0.01)	158	0.05 (<0.01)
BDF2	BCA	581	0.23 (0.01)	197	0.29 (0.02)	244	0.20 (0.01)	140	0.22 (0.02)
BCA	MOS	493	1.00 (0.05)	170	1.01 (0.07)	221	0.90 (0.07)	102	1.31 (0.17)
MOS	SJL	163	0.43 (0.05)	31	0.51 (0.12)	85	0.39 (0.07)	47	0.47 (0.12)
	ORE	268	0.29 (0.02)	131	0.28 (0.02)	125	0.28 (0.02)	12	0.73 (0.39)
SJL	SJG	106	1.07 (0.08)	11	1.56 (0.22)	67	1.09 (0.12)	28	0.93 (0.11)
SJG	SJNB	96	0.08 (0.01)	11	0.10 (0.03)	59	0.08 (0.01)	26	0.08 (0.01)
SJNB	SJS	90	0.54 (0.04)	11	0.86 (0.16)	55	0.49 (0.05)	24	0.60 (0.08)
SJS	MAC	74	0.11 (0.01)	8	0.21 (0.06)	49	0.10 (0.01)	17	0.10 (0.02)
	TCE/TCW	13	0.10 (0.03)	2	0.21 (0.11)	5	0.21 (0.14)	6	0.07 (0.02)
MAC	MFE/MFW	64	0.20 (0.02)	7	0.23 (0.06)	45	0.20 (0.03)	12	0.20 (0.04)
	SJD*	54	0.63 (0.14)	7	1.10 (0.13)	34	0.58 (0.19)	13	0.61 (0.12)
	OSJ*	10	0.79 (0.16)	0	NA	8	0.77 (0.19)	0	NA
	JPT/JPE/JPW*	39	1.97 (0.12)	5	1.97 (0.37)	22	1.95 (0.16)	12	1.99 (0.24)
	RGU*	0	NA	0	NA	0	NA	0	NA
	CVP*	0	NA	0	NA	0	NA	0	NA
MFE/MFW	SJD	47	0.32 (0.04)	6	0.61 (0.13)	31	0.35 (0.06)	10	0.21 (0.04)
	OSJ	10	0.47 (0.08)	0	NA	8	0.46 (0.09)	0	NA
	JPT/JPE/JPW*	31	1.63 (0.12)	4	1.55 (0.36)	19	1.58 (0.14)	8	1.78 (0.30)

Table 17a. (Continued)

Reach		Without Predator-Type Detections							
		All releases		1		2		3	
Upstream Boundary	Downstream Boundary	N	Travel Time	N	Travel Time	N	Travel Time	N	Travel Time
MFE/MFW	RGU*	0	NA	0	NA	0	NA	0	NA
	CVP*	0	NA	0	NA	0	NA	0	NA
SJD	JPT/JPE/JPW	36	0.89 (0.10)	5	0.53 (0.21)	21	1.05 (0.09)	10	0.92 (0.13)
	TMN/TMS	16	0.84 (0.14)	2	0.89 (0.07)	11	0.77 (0.17)	3	1.18 (0.31)
TCE/TCW	JPT/JPE/JPW	4	2.06 (0.97)	0	NA	2	7.22 (3.68)	2	1.20 (0.38)
	RGU	1	3.50 (NA)	0	NA	0	NA	0	NA
	CVP	4	2.57 (0.71)	0	NA	3	3.16 (1.12)	0	NA
OSJ	JPT/JPE/JPW	7	0.58 (0.12)	0	NA	6	0.73 (0.04)	0	NA
ORE	ORS	248	0.31 (0.01)	121	0.32 (0.02)	119	0.30 (0.02)	8	0.69 (0.14)
	MRH	11	0.71 (0.15)	6	0.62 (0.17)	4	0.79 (0.25)	1	1.73 (NA)
ORS	WCL	74	2.13 (0.15)	24	2.12 (0.23)	46	2.10 (0.19)	0	NA
	OR4	51	2.87 (0.23)	18	2.73 (0.33)	31	2.92 (0.33)	0	NA
	MR4	8	5.11 (0.66)	6	5.44 (0.97)	2	4.31 (0.35)	0	NA
	RGU	33	2.09 (0.26)	20	2.29 (0.31)	13	1.84 (0.40)	0	NA
	CVP	95	1.65 (0.11)	46	1.72 (0.18)	49	1.60 (0.14)	0	NA
WCL	OR4	51	0.30 (0.04)	18	0.37 (0.10)	31	0.25 (0.04)	0	NA
OR4 via OR	JPT/JPE/JPW	22	2.37 (0.36)	5	4.32 (1.52)	16	2.07 (0.34)	0	NA
MRH	WCL	0	NA	0	NA	0	NA	0	NA
	OR4	0	NA	0	NA	0	NA	0	NA
	MR4	0	NA	0	NA	0	NA	0	NA
	RGU	0	NA	0	NA	0	NA	0	NA
	CVP	0	NA	0	NA	0	NA	0	NA
MR4 via OR	JPT/JPE/JPW	1	4.13 (NA)	0	NA	1	4.13 (NA)	0	NA
RGU via OR	RGD	24	0.02 (0.01)	14	0.02 (0.01)	10	0.02 (0.01)	0	NA
RGU via SJR	RGD	0	NA	0	NA	0	NA	0	NA
CVP via OR	CVPtank	27	0.08 (0.02)	13	0.06 (0.03)	14	0.11 (0.04)	0	NA
CVP via SJR	CVPtank	1	0.08 (NA)	0	NA	1	0.08 (NA)	0	NA

Table 17a. (Continued)

Reach		Without Predator-Type Detections							
		All releases		1		2		3	
Upstream Boundary	Downstream Boundary	N	Travel Time	N	Travel Time	N	Travel Time	N	Travel Time
JPT/JPE/JPW	MAT/MAE/MAW* (Chipps Island)	69	1.07 (0.07)	9	1.14 (0.14)	46	1.05 (0.10)	14	1.11 (0.08)
TMN/TMS		16	1.19 (0.09)	2	1.83 (1.10)	11	1.11 (0.08)	3	1.19 (0.25)
MAC		59	3.26 (0.14)	6	3.61 (0.51)	38	3.28 (0.19)	15	3.11 (0.22)
MFE/MFW		51	2.90 (0.12)	5	3.07 (0.57)	35	2.91 (0.14)	11	2.80 (0.25)
SJD		49	2.24 (0.11)	6	2.22 (0.43)	31	2.30 (0.14)	12	2.13 (0.16)
TCE/TCW		5	3.98 (0.92)	0	NA	3	5.51 (2.20)	2	2.81 (<0.01)
OSJ		7	1.90 (0.15)	0	NA	6	1.94 (0.18)	0	NA
OR4		21	3.92 (0.50)	5	6.07 (1.97)	16	3.53 (0.47)	0	NA
MR4		1	4.62 (NA)	0	NA	1	4.62 (NA)	0	NA
RGD		3	8.83 (3.78)	1	30.51 (NA)	2	6.52 (1.99)	0	NA
CVPtank		25	1.14 (0.19)	11	1.20 (0.23)	14	1.10 (0.28)	0	NA
MAT/MAE/MAW	BBR	18	0.64 (0.16)	0	NA	0	NA	17	0.62 (0.16)

Table 17b. Average travel time in days (harmonic mean) of acoustic-tagged juvenile Steelhead through the San Joaquin River Delta river reaches during the 2015 tagging study, with predator-type detections. Standard errors are in parentheses. * = all routes combined between upstream and downstream boundaries. Reaches that were not modeled for individual release groups were excluded. Releases are: 1 = early March, 2 = late March, 3 = April. See Table 17a for travel time through reaches without predator-type detections.

Reach		With Predator-Type Detections							
		All releases		1		2		3	
Upstream Boundary	Downstream Boundary	N	Travel Time	N	Travel Time	N	Travel Time	N	Travel Time
Durham Ferry (Release)	DFU	214	0.38 (0.06)	71	0.43 (0.10)	66	0.85 (0.17)	77	0.24 (0.06)
	DFD	939	0.12 (<0.01)	319	0.15 (0.01)	347	0.09 (0.01)	273	0.18 (0.01)
DFD	BDF1	672	0.31 (0.01)	243	0.58 (0.06)	260	0.26 (0.02)	169	0.23 (0.02)
BDF1	BDF2	619	0.05 (<0.01)	222	0.07 (<0.01)	243	0.05 (<0.01)	154	0.05 (<0.01)
BDF2	BCA	586	0.24 (0.01)	209	0.29 (0.02)	244	0.20 (0.01)	133	0.23 (0.02)
BCA	MOS	485	0.98 (0.05)	176	1.01 (0.07)	218	0.89 (0.07)	91	1.23 (0.17)
MOS	SJL	147	0.41 (0.05)	27	0.51 (0.14)	81	0.37 (0.06)	39	0.42 (0.11)
	ORE	282	0.31 (0.02)	139	0.30 (0.02)	127	0.29 (0.02)	16	0.92 (0.48)
SJL	SJG	106	1.05 (0.09)	13	1.51 (0.20)	67	1.06 (0.12)	26	0.90 (0.11)
SJG	SJNB	100	0.08 (0.01)	13	0.09 (0.02)	62	0.08 (0.01)	25	0.08 (0.01)
SJNB	SJS	94	0.56 (0.05)	13	0.93 (0.17)	58	0.50 (0.05)	23	0.61 (0.09)
SJS	MAC	78	0.11 (0.01)	9	0.18 (0.05)	52	0.10 (0.01)	17	0.10 (0.02)
	TCE/TCW	14	0.15 (0.04)	4	0.21 (0.06)	5	0.21 (0.14)	5	0.09 (0.03)
MAC	MFE/MFW	67	0.20 (0.02)	8	0.18 (0.05)	47	0.20 (0.03)	12	0.20 (0.04)
	SJD*	55	0.63 (0.14)	7	1.10 (0.13)	35	0.59 (0.19)	13	0.61 (0.12)
	OSJ*	12	0.82 (0.14)	0	NA	9	0.80 (0.18)	0	NA
	JPT/JPE/JPW*	39	1.97 (0.12)	5	1.97 (0.37)	22	1.95 (0.16)	12	1.99 (0.24)
	RGU*	1	3.72 (NA)	0	NA	1	3.72 (NA)	0	NA
	CVP*	0	NA	0	NA	0	NA	0	NA
MFE/MFW	SJD	48	0.33 (0.04)	6	0.61 (0.13)	32	0.36 (0.06)	10	0.21 (0.04)
	OSJ	12	0.51 (0.08)	0	NA	9	0.48 (0.09)	0	NA
	JPT/JPE/JPW*	31	1.63 (0.12)	4	1.55 (0.36)	19	1.58 (0.14)	8	1.78 (0.30)

Table 17b. (Continued)

Reach		With Predator-Type Detections							
		All releases		1		2		3	
Upstream Boundary	Downstream Boundary	N	Travel Time	N	Travel Time	N	Travel Time	N	Travel Time
MFE/MFW	RGU*	1	3.58 (NA)	0	NA	1	3.58 (NA)	0	NA
	CVP*	0	NA	0	NA	0	NA	0	NA
SJD	JPT/JPE/JPW	36	0.89 (0.10)	5	0.53 (0.21)	21	1.05 (0.09)	10	0.92 (0.13)
	TMN/TMS	17	0.85 (0.14)	2	0.89 (0.07)	12	0.79 (0.16)	3	1.18 (0.31)
TCE/TCW	JPT/JPE/JPW	5	2.48 (1.21)	0	NA	3	8.62 (3.46)	2	1.20 (0.38)
	RGU	1	8.22 (NA)	0	NA	0	NA	1	8.22 (NA)
	CVP	3	3.05 (1.00)	1	4.30 (NA)	2	2.67 (1.18)	0	NA
OSJ	JPT/JPE/JPW	9	0.64 (0.12)	0	NA	7	0.72 (0.04)	0	NA
ORE	ORS	266	0.32 (0.01)	130	0.32 (0.02)	123	0.30 (0.02)	13	0.57 (0.11)
	MRH	7	0.76 (0.16)	5	0.86 (0.26)	2	0.60 (0.17)	0	NA
ORS	WCL	77	2.12 (0.15)	27	2.15 (0.25)	45	2.16 (0.21)	5	1.71 (0.55)
	OR4	61	3.11 (0.26)	24	3.28 (0.45)	33	3.10 (0.35)	4	2.41 (0.89)
	MR4	8	5.61 (1.03)	5	5.68 (1.53)	3	5.49 (1.54)	0	NA
	RGU	39	2.55 (0.35)	22	2.55 (0.39)	16	2.42 (0.60)	1	12.94 (NA)
	CVP	101	1.80 (0.12)	51	2.02 (0.20)	49	1.62 (0.15)	0	NA
WCL	OR4	61	0.31 (0.04)	24	0.37 (0.09)	33	0.26 (0.04)	4	0.50 (0.37)
OR4 via OR	JPT/JPE/JPW	25	2.52 (0.37)	5	4.32 (1.52)	19	2.27 (0.36)	1	2.54 (NA)
MRH	WCL	0	NA	0	NA	0	NA	0	NA
	OR4	0	NA	0	NA	0	NA	0	NA
	MR4	0	NA	0	NA	0	NA	0	NA
	RGU	0	NA	0	NA	0	NA	0	NA
	CVP	0	NA	0	NA	0	NA	0	NA
MR4 via OR	JPT/JPE/JPW	1	4.13 (NA)	0	NA	1	4.13 (NA)	0	NA
RGU via OR	RGD	32	0.02 (<0.01)	16	0.02 (0.01)	15	0.02 (0.01)	0	NA
RGU via SJR	RGD	2	0.22 (0.16)	0	NA	1	0.12 (NA)	0	NA
CVP via OR	CVPtank	29	0.09 (0.03)	14	0.07 (0.03)	15	0.12 (0.04)	0	NA
CVP via SJR	CVPtank	1	0.08 (NA)	0	NA	1	0.08 (NA)	0	NA

Table 17b. (Continued)

Reach		With Predator-Type Detections							
		All releases		1		2		3	
Upstream Boundary	Downstream Boundary	N	Travel Time	N	Travel Time	N	Travel Time	N	Travel Time
JPT/JPE/JPW	MAT/MAE/MAW* (Chipps Island)	75	1.09 (0.07)	10	1.13 (0.12)	51	1.08 (0.10)	14	1.11 (0.08)
TMN/TMS		17	1.18 (0.09)	2	1.83 (1.10)	12	1.12 (0.07)	3	1.19 (0.25)
MAC		62	3.27 (0.14)	7	3.61 (0.43)	40	3.28 (0.18)	15	3.11 (0.22)
MFE/MFW		54	2.91 (0.12)	6	3.14 (0.49)	37	2.90 (0.14)	11	2.80 (0.25)
SJD		50	2.24 (0.11)	6	2.22 (0.43)	32	2.29 (0.14)	12	2.13 (0.16)
TCE/TCW		6	4.56 (1.20)	0	NA	4	6.64 (2.64)	2	2.81 (<0.01)
OSJ		9	1.92 (0.14)	0	NA	7	1.88 (0.15)	0	NA
OR4		24	4.14 (0.50)	5	6.07 (1.97)	19	3.82 (0.49)	0	NA
MR4		1	4.62 (NA)	0	NA	1	4.62 (NA)	0	NA
RGD		5	12.41 (5.12)	2	31.80 (1.34)	3	8.82 (3.77)	0	NA
CVPtank		26	1.17 (0.19)	11	1.22 (0.24)	15	1.14 (0.28)	0	NA
MAT/MAE/MAW	BBR	22	0.72 (0.17)	0	NA	0	NA	17	0.62 (0.16)

Table 18. Results of single-variate analyses of 2015 route selection at the head of Old River, for tags estimated to have arrived at the river junction before 1500 on 3 April 2015 (date of barrier closure). The values df1, df2 are degrees of freedom for the F-test. Covariates are ordered by P-value and F statistic.

	F-test			
Covariate	*F*	df1	df2	*P*
Negative velocity at OH1	0.5225	1	20	0.4782
Negative flow at OH1	0.5225	1	20	0.4782
Change in flow at OH1	0.5180	1	19	0.4804
Velocity at OH1	0.4819	1	20	0.4955
Change in velocity at OH1	0.4426	1	19	0.5138
Flow at OH1	0.4409	1	20	0.5143
Exports at SWP	0.2396	1	20	0.6298
CVP Proportion of Exports	0.1975	1	20	0.6615
Stage at SJL	0.1814	1	20	0.6748
Stage at MSD	0.1740	1	20	0.6810
Stage at OH1	0.1623	1	20	0.6913
Arrive at junction during day	0.1205	1	20	0.7321
Exports at CVP	0.0856	1	20	0.7729
Release Group	0.0429	1	20	0.8380
Change in stage at OH1	0.0320	1	20	0.8559
Arrive at junction during twilight	0.0325	1	20	0.8587
Fork Length	0.0128	1	20	0.9110
Velocity at MSD	0.0089	1	20	0.9259
Time of day of arrival	0.1398	3	18	0.9438
Change in stage at SJL	0.0050	1	20	0.9445
Total Exports in Delta	0.0023	1	20	0.9625
Flow at MSD	0.0001	1	20	0.9924

Table 19. Results of single-variate analyses of 2015 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.

	F-test			
Covariate	*F*	df1	df2	*P*
Change in flow at TRN	0.7746	1	9	0.4017
Change in velocity at TRN	0.7706	1	9	0.4029
Total Exports in Delta	0.7395	1	9	0.4121
Change in stage at TRN	0.7134	1	9	0.4202
Exports at CVP	0.3895	1	9	0.5480
Flow at TRN	0.3258	1	9	0.5821
Velocity at TRN	0.2965	1	9	0.5993
Fork Length	0.1803	1	9	0.6810
Exports at SWP	0.1333	1	9	0.7235
Release Group	0.2547	2	8	0.7812
Negative flow at TRN	0.0810	1	9	0.7824
Leave SJS during day	0.0749	1	9	0.7905
Velocity during transition from SJG	0.0592	1	9	0.8132
Stage at TRN	0.0511	1	9	0.8261
Flow during transition from SJG	0.0371	1	9	0.8515
CVP Proportion of Exports	0.0045	1	9	0.9480

Table 20. 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 2015, excluding predator-type detections (95% profile likelihood interval, 95% lower bound [LB], or sample size (n) in parentheses). Population estimate is based on data pooled from all releases. * = receiver sites indicating survival were G1, G2, G3, H1, T1, T2. Estimates are based on assumption of 100% detection probability at T2.

Facility	Upstream Model Site Code	Release Group 1	Release Group 2	Release Group 3	Population Estimate
CVP	E2	0.85 (0.60, 0.97)	1 (n=15, 95% LB: 0.82)	NA (n=0)	0.93 (0.80, 0.99)
SWP	D2	0.07 (0.00, 0.28)	0.20 (0.04, 0.50)	NA (n=0)	0.13 (0.03, 0.29)

Table 21. 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 family-wise α=0.10. Releases are: 1 = early March, 2 = late March, 3 = April.

Parameter	Release Group 1	Release Group 2	Release Group 3
ϕ_{A1A6}	0.02 (0.03)	0.18* (0.03)	-0.19* (0.02)
S_A	-0.16 (0.08)	0.25* (0.07)	-0.09 (0.06)
S_B	-0.02 (0.04)	0.17* (0.05)	-0.16* (0.06)
S_{Total}	-0.12* (0.04)	0.17* (0.04)	-0.05 (0.05)

* = significant difference from 0 for family-wise α=0.10

Table 22. Estimates of model parameters and performance measures from release-recapture models with and without detections from Threemile Slough (model code T1) for tagging juvenile Steelhead released in the 2015 study. Predator-type detections were excluded. Standard errors or 95% lower bound (LB) are in parentheses.

	Release 1		Release 2		Release 3	
Parameter	With T1	Without T1	With T1	Without T1	With T1	Without T1
$\phi_{A13,G1}$	0.71 (0.17)	1 (95% LB: 0.67)	0.62 (0.08)	0.94 (0.04)	0.77 (0.12)	1 (95% LB: 0.82)
$\phi_{A13,T1}$	0.29 (0.17)	NA	0.32 (0.08)	NA	0.23 (0.12)	NA
$\phi_{G1,G2}$	0.90 (0.10)	0.91 (0.09)	0.98 (0.02)	0.98 (0.02)	1 (95% LB: 0.94)	1 (95% LB: 0.94)
$\phi_{T1,G2}$	1 (95% LB: 0.23)	NA	1 (95% LB: 0.76)	NA	1 (95% LB: 0.44)	NA
P_{G1}	1	0.83 (0.11)	1	0.86 (0.05)	1	0.89 (0.07)
S_A	0.19 (0.07)	0.19 (0.07)	0.46 (0.05)	0.46 (0.05)	0.24 (0.05)	0.24 (0.05)
S_B	0.14 (0.03)	0.15 (0.03)	0.27 (0.04)	0.27 (0.04)	0.05 (0.05)	0.05 (0.05)
S_{Total}	0.15 (0.03)	0.15 (0.03)	0.35 (0.03)	0.35 (0.03)	0.20 (0.04)	0.20 (0.04)
$S_{A(MD)}$	NA	0.22 (0.07)	0.34 (0.05)	0.46 (0.05)	0.20 (0.05)	0.24 (0.05)
$S_{B(MD)}$	0.04 (0.02)	0.04 (0.02)	0.13 (0.03)	0.13 (0.03)	0.05 (0.05)	0.05 (0.05)
$S_{Total(MD)}$	NA	0.07 (0.02)	0.21 (0.03)	0.26 (0.03)	0.17 (0.04)	0.20 (0.04)

Appendix A. Survival Model Parameters

Table A1. Definitions of parameters used in the release-recapture survival model in the 2015 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)
$S_{A8,G2}$	Overall survival from Garwood Bridge (SJG) to Chipps Island (MAT/MAE/MAW) (derived from Submodel I)
S_{A9}	Probability of survival from Navy Drive Bridge (SJNB) to San Joaquin River Shipping Channel (SJS)
$S_{A9,G2}$	Overall survival from Navy Drive Bridge (SJNB) to Chipps Island (MAT/MAE/MAW) (derived from Submodel I)
S_{A10}	Probability of survival from San Joaquin River Shipping Channel (SJS) to MacDonald Island (MAC) or Turner Cut (TCE/TCW)
$S_{A10,G2}$	Overall survival from San Joaquin River Shipping Channel (SJS) to Chipps Island (MAT/MAE/MAW) (Submodel I*)
$S_{A11,G2}$	Overall survival from MacDonald Island (MAC) to Chipps Island (MAT/MAE/MAW) (Submodel I)
$S_{A12,G2}$	Overall survival from Medford Island (MFE/MFW) to Chipps Island (MAT/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 (MAT/MAE/MAW) (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 (MAT/MAE/MAW) (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 (MAT/MAE/MAW) (Submodel I)
$\phi_{A1,A0}$	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; $= \phi_{A1,A2} S_{A2} S_{A3} S_{A4} S_{A5}$
$\phi_{A11,A12}$	Joint probability of moving from MAC toward MFE/MFW, and surviving from MAC to MFE/MFW (Submodel II)
$\phi_{A11,A13}$	Joint probability of moving from MAC directly toward SJD, and surviving from MAC to SJD (Submodel II)
$\phi_{A11,B5}$	Joint probability of moving from MAC directly toward OSJ, and surviving from MAC to OSJ (Submodel II)
$\phi_{A11,D1O}$	Joint probability of moving from MAC directly toward RGU, surviving to RGU, and arriving when the radial gates are open (Submodel II)
$\phi_{A11,D1C}$	Joint probability of moving from MAC directly toward RGU, surviving to RGU, and arriving when the radial gates are closed (Submodel II)
$\phi_{A11,D1}$	Joint probability of moving from MAC directly toward RGU and surviving to RGU (Submodel II)
$\phi_{A11,E1}$	Joint probability of moving from MAC directly toward CVP and surviving to CVP (Submodel II)
$\phi_{A11,GH}$	Joint probability of moving from MAC directly toward Jersey Point (JPT/JPE/JPW) or False River (FRE/FRW), and surviving JPT/JPE/JPW or FRE/FRW (Submodel II)
$\phi_{A11,G1}$	Joint probability of moving from MAC directly toward Jersey Point (JPT/JPE/JPW) and surviving to JPT/JPE/JPW (Submodel II); $= \phi_{A11,GH}\psi_{G1(A)}$
$\phi_{A12,A13}$	Joint probability of moving from MFE/MFW toward SJD, and surviving from MFE/MFW to SJD (Submodel II)

Table A1. (Continued)

Parameter	Definition
$\phi_{A12,B5}$	Joint probability of moving from MFE/MFW directly toward OSJ, and surviving from MFE/MFW to OSJ (Submodel II)
$\phi_{A12,D1O}$	Joint probability of moving from MFE/MFW directly toward RGU, surviving to RGU, and arriving when the radial gates are open (Submodel II)
$\phi_{A12,D1C}$	Joint probability of moving from MFE/MFW directly toward RGU, surviving to RGU, and arriving when the radial gates are closed (Submodel II)
$\phi_{A12,D1}$	Joint probability of moving from MFE/MFW directly toward RGU and surviving to RGU (Submodel II)
$\phi_{A12,E1}$	Joint probability of moving from MFE/MFW directly toward CVP and surviving to CVP (Submodel II)
$\phi_{A12,GH}$	Joint probability of moving from MFE/MFW directly toward Jersey Point (JPT/JPE/JPW) or False River (FRE/FRW), and surviving to JPT/JPE/JPW or FRE/FRW (Submodel II)
$\phi_{A12,G1}$	Joint probability of moving from MFE/MFW directly toward Jersey Point (JPT/JPE/JPW) and surviving to JPT/JPE/JPW (Submodel II); = $\phi_{A12,GH}\psi_{G1(A)}$
$\phi_{A13,GH}$	Joint probability of moving from SJD toward Jersey Point (JPT/JPE/JPW) or False River (FRE/FRW), and surviving to JPT/JPE/JPW or FRE/FRW (Submodel II)
$\phi_{A13,G1}$	Joint probability of moving from SJD toward Jersey Point (JPT/JPE/JPW) and surviving to JPT/JPE/JPW (Submodel II); = $\phi_{A13,GH}\psi_{G1(A)}$
$\phi_{A13,T1}$	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
$\phi_{B2,C2}$	Joint probability of moving from ORS toward MR4, and surviving from ORS to MR4
$\phi_{B2,D1O}$	Joint probability of moving from ORS toward RGU, surviving to RGU, and arriving when the radial gates are open
$\phi_{B2,D1C}$	Joint probability of moving from ORS toward RGU, surviving to RGU, and arriving when the radial gates are closed
$\phi_{B2,D1}$	Joint probability of moving from ORS toward RGU, and surviving from ORS to RGU
$\phi_{B2,E1}$	Joint probability of moving from ORS toward CVP, and surviving from ORS to CVP
$\phi_{B2,G1}$	Joint probability of moving from ORS toward JPT/JPE/JPW, and surviving from ORS to JPT/JPE/JPW (Submodel I*)
$\phi_{B3,B4}$	Joint probability of moving from WCL toward OR4, and surviving from WCL to OR4 (Submodel I)
$\phi_{B4,GH}$	Joint probability of moving from OR4 toward Jersey Point (JPT/JPE/JPW) or False River (FRE/FRW), and surviving from OR4 to JPT/JPE/JPW or FRE/FRW (Submodel I)
$\phi_{B4,G1}$	Joint probability of moving from OR4 toward Jersey Point (JPT/JPE/JPW) and surviving from OR4 to JPT/JPE/JPW (Submodel I); = $\phi_{B4,GH}\psi_{G1(B)}$
$\phi_{B5,D1O}$	Joint probability of moving from OSJ toward RGU, surviving to RGU, and arriving when the radial gates are open (Submodel II)
$\phi_{B5,D1C}$	Joint probability of moving from OSJ toward RGU, surviving to RGU, and arriving when the radial gates are closed (Submodel II)
$\phi_{B5,D1}$	Joint probability of moving from OSJ toward RGU and surviving to RGU (Submodel II)
$\phi_{B5,E1}$	Joint probability of moving from OSJ toward CVP and surviving to CVP (Submodel II)
$\phi_{B5,GH}$	Joint probability of moving from OSJ toward Jersey Point (JPT/JPE/JPW) or False River (FRE/FRW), and surviving to JPT/JPE/JPW or FRE/FRW (Submodel II)
$\phi_{B5,G1}$	Joint probability of moving from OSJ toward Jersey Point (JPT/JPE/JPW) and surviving to JPT/JPE/JPW (Submodel II); = $\phi_{B5,GH}\psi_{G1(A)}$
$\phi_{C1,B3}$	Joint probability of moving from MRH toward WCL, and surviving from MRH to WCL
$\phi_{C1,C2}$	Joint probability of moving from MRH toward MR4, and surviving from MRH to MR4
$\phi_{C1,D1O}$	Joint probability of moving from MRH toward RGU, surviving to RGU, and arriving when the radial gates are open
$\phi_{C1,D1C}$	Joint probability of moving from MRH toward RGU, surviving to RGU, and arriving when the radial gates are closed
$\phi_{C1,D1}$	Joint probability of moving from MRH toward RGU, and surviving from MRH to RGU
$\phi_{C1,E1}$	Joint probability of moving from MRH toward CVP, and surviving from MRH to CVP
$\phi_{C1,G1}$	Joint probability of moving from MRH toward JPT/JPE/JPW, and surviving from MRH to JPT/JPE/JPW (Submodel I*)
$\phi_{C2,GH}$	Joint probability of moving from MR4 toward Jersey Point (JPT/JPE/JPW) or False River (FRE/FRW), and surviving from MR4 to JPT/JPE/JPW or FRE/FRW (Submodel I)

Table A1. (Continued)

Parameter	Definition
$\phi_{C2,G1}$	Joint probability of moving from MR4 toward Jersey Point (JPT/JPE/JPW) and surviving from MR4 to JPT/JPE/JPW (Submodel I); = $\phi_{C2,GH}\psi_{G1(B)}$
$\phi_{D1O,D2}$	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 (equated between submodels I and II)
$\phi_{D1C,D2}$	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 (equated between submodels I and II)
$\phi_{D1,D2}$	Joint probability of moving from RGU toward RGD, and surviving from RGU to RGD (equated between submodels I and II)
$\phi_{D1O,G2}$	Joint probability of moving from RGU toward Chipps Island (MAT/MAE/MAW) via CCFB and surviving to MAT/MAE/MAW, conditional on arrival at RGU when radial gates are open (equated between submodels); = $\phi_{D1O,D2}\phi_{D2,G2}$
$\phi_{D1C,G2}$	Joint probability of moving from RGU toward Chipps Island (MAT/MAE/MAW) via CCFB and surviving to MAT/MAE/MAW, conditional on arrival at RGU when radial gates are closed (equated between submodels); = $\phi_{D1C,D2}\phi_{D2,G2}$
$\phi_{D1,G2}$	Joint probability of moving from RGU toward Chipps Island (MAT/MAE/MAW) via CCFB and surviving to MAT/MAE/MAW (equated between submodels); = $\phi_{D1,D2}\phi_{D2,G2}$
$\phi_{D2,G2}$	Joint probability of moving from RGD toward Chipps Island (MAT/MAE/MAW) and surviving from RGD to MAT/MAE/MAW (equated between submodels I and II)
$\phi_{E1,E2}$	Joint probability of moving from CVP toward CVPtank and surviving from CVP to CVPtank (equated between submodels I and II)
$\phi_{E2,G2}$	Joint probability of moving from CVPtank toward Chipps Island (MAT/MAE/MAW) and surviving from CVPtank to MAT/MAE/MAW (equated between submodels I and II)
$\phi_{F1,D1O}$	Joint probability of moving from TCE/TCW toward RGU, surviving to RGU, and arriving when the radial gates are open (Submodel II)
$\phi_{F1,D1C}$	Joint probability of moving from TCE/TCW toward RGU, surviving to RGU, and arriving when the radial gates are closed (Submodel II)
$\phi_{F1,D1}$	Joint probability of moving from TCE/TCW toward RGU and surviving to RGU (Submodel II)
$\phi_{F1,E1}$	Joint probability of moving from TCE/TCW toward CVP and surviving to CVP (Submodel II)
$\phi_{F1,GH}$	Joint probability of moving from TCE/TCW toward Jersey Point (JPT/JPE/JPW) or False River (FRE/FRW), and surviving to JPT/JPE/JPW or FRE/FRW (Submodel II)
$\phi_{F1,G1}$	Joint probability of moving from TCE/TCW toward Jersey Point (JPT/JPE/JPW) and surviving to JPT/JPE/JPW (Submodel II); = $\phi_{F1,GH}\psi_{G1(A)}$
$\phi_{G1,G2(A)}$	Joint probability of moving from JPT/JPE/JPW toward Chipps Island (MAT/MAE/MAW), and surviving to MAT/MAE/MAW (Submodel II [route A])
$\phi_{G1,G2(B)}$	Joint probability of moving from JPT/JPE/JPW toward Chipps Island (MAT/MAE/MAW), and surviving to MAT/MAE/MAW (Submodel I [route B])
$\phi_{T1,G2}$	Joint probability of moving from TMS/TMN toward Chipps Island (MAT/MAE/MAW), and surviving to MAT/MAE/MAW (Submodel II)
λ	Joint probability of moving from Chipps Island (MAT/MAE/MAW) toward Benicia Bridge (BBR), surviving from MAT/MAE/MAW to BBR, and detection at BBR; = $\phi_{G2,G3}$ P_{G3}
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 the junction with Turner Cut; = 1 - ψ_{F2}
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_{F2}	Probability of entering Turner Cut at the junction with the San Joaquin River; = 1 - ψ_{A2}
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}
P_{A0a}	Conditional probability of detection at DFU1
P_{A0b}	Conditional probability of detection at DFU2

Table A1. (Continued)

Parameter	Definition
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_{A8a}	Conditional probability of detection at SJGU
P_{A8b}	Conditional probability of detection at SJGD
P_{A8}	Conditional probability of detection at SJG (either SJGU or SJGD)
P_{A9a}	Conditional probability of detection at SJNBU
P_{A9b}	Conditional probability of detection at SJNBD
P_{A9}	Conditional probability of detection at SJNB (either SJNBU or SJNBD)
P_{A10}	Conditional probability of detection at SJS
P_{A11a}	Conditional probability of detection at MACU
P_{A11b}	Conditional probability of detection at MACD
P_{A11}	Conditional probability of detection at MAC (either MACU or MACD)
P_{A12a}	Conditional probability of detection at MFE
P_{A12b}	Conditional probability of detection at MFW
P_{A12}	Conditional probability of detection at MFE/MFW (either MFE or MFW)
P_{A13a}	Conditional probability of detection at SJDU
P_{A13b}	Conditional probability of detection at SJDD
P_{A13}	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
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

Table A1. (Continued)

Parameter	Definition
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 (either RGU1 or RGU2)
P_{D2a}	Conditional probability of detection at RGD1
P_{D2b}	Conditional probability of detection at RGD2
P_{D2}	Conditional probability of detection at RGD (either RGD1 or RGD2)
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_{G1a}	Conditional probability of detection at JPT
P_{G1b}	Conditional probability of detection at JPE
P_{G1c}	Conditional probability of detection at JPW
P_{G1}	Conditional probability of detection at JPT/JPE/JPW (either JPT, JPE, or JPW)
P_{G2a}	Conditional probability of detection at MAT
P_{G2b}	Conditional probability of detection at MAE
P_{G2c}	Conditional probability of detection at MAW
P_{G2}	Conditional probability of detection at MAT/MAE/MAW (either MAT, MAE, or MAW)
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_{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 2015, 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.

	Release Group			
Parameter	1	2	3	Population Estimate
S_{A2}	0.76 (0.02)	0.81 (0.02)	0.63 (0.03)	0.73 (0.01)
S_{A3}	0.90 (0.02)	0.94 (0.01)	0.92 (0.02)	0.92 (0.01)
S_{A4}	0.92 (0.02)	0.92 (0.02)	0.89 (0.03)	0.91 (0.01)
S_{A5}	0.86 (0.02)	0.90 (0.02)	0.73 (0.04)	0.83 (0.02)
S_{A6}	0.96 (0.01)	0.95 (0.01)	0.62 (0.05)	0.85 (0.02)
S_{A7}	0.36 (0.09)	0.79 (0.04)	0.60 (0.07)	0.58 (0.04)
S_{A8}	1 (95% LB: 0.77)	0.88 (0.04)	0.93 (0.05)	0.94 (0.02)
$S_{A8,G2}$	0.55 (0.15)	0.61 (0.06)	0.64 (0.09)	0.60 (0.06)
S_{A9}	1 (95% LB: 0.77)	0.93 (0.03)	0.92 (0.05)	0.95 (0.02)
$S_{A9,G2}$	0.55 (0.15)	0.70 (0.06)	0.69 (0.09)	0.65 (0.06)
S_{A10}	0.91 (0.09)	0.98 (0.02)	0.96 (0.04)	0.95 (0.03)
$S_{A10,G2}$	0.55 (0.15)	0.75 (0.06)	0.75 (0.09)	0.68 (0.06)
$S_{A11,G2}$	0.81 (0.12)	0.78 (0.06)	0.94 (0.06)	0.84 (0.05)
$S_{A12,G2}$	0.80 (0.14)	0.79 (0.06)	1 (95% LB: 0.89)	0.86 (0.05)
S_{B1}	0.97 (0.02)	0.98 (0.01)	0.75 (0.13)	0.90 (0.04)
$S_{B2,G2}$	0.16 (0.03)	0.30 (0.04)	0.13 (0.12)	0.20 (0.04)
$S_{B2(SD)}$	0.74 (0.04)	0.80 (0.04)		0.77 (0.03)
$S_{C1,G2}$	0 (95% UB: 0.39)	0 (95% UB: 0.53)		0
$S_{C1(SD)}$	0 (95% UB: 0.39)	0 (95% UB: 0.53)		0
$S_{F1,G2}$		0.60 (0.22)	0.33 (0.19)	0.47 (0.15)
$\phi_{A1,A0}$	0.16 (0.02)	0.13 (0.02)	0.16 (0.02)	0.15 (0.01)
$\phi_{A1,A2}$	0.66 (0.02)	0.74 (0.02)	0.59 (0.02)	0.66 (0.01)
$\phi_{A1,A3}$	0.50 (0.02)	0.60 (0.02)	0.37 (0.02)	0.49 (0.01)
$\phi_{A1,A4}$	0.45 (0.02)	0.56 (0.02)	0.34 (0.02)	0.45 (0.01)
$\phi_{A11,A12}$	0.87 (0.12)	0.92 (0.04)	0.71 (0.11)	0.83 (0.06)
$\phi_{A11,A13}$	0.13 (0.12)	0.06 (0.03)	0.18 (0.09)	0.12 (0.05)
$\phi_{A11,B5}$		0 (95% UB: 0.06)		
$\phi_{A11,D1O}$	0	0		0
$\phi_{A11,D1C}$	0	0		0
$\phi_{A11,D1}$	0 (95% UB: 0.31)	0 (95% UB: 0.06)		0
$\phi_{A11,E1}$	0 (95% UB: 0.31)	0 (95% UB: 0.06)		0
$\phi_{A11,GH}$				
$\phi_{A11,G1}$	0 (95% UB: 0.31)	0 (95% UB: 0.06)	0.06 (0.06)	0.02 (0.02)
$\phi_{A12,A13}$	0.86 (0.13)	0.69 (0.07)	0.83 (0.11)	0.79 (0.06)
$\phi_{A12,B5}$		0.18 (0.06)		
$\phi_{A12,D1O}$	0	0		0
$\phi_{A12,D1C}$	0	0		0
$\phi_{A12,D1}$	0 (95% UB: 0.34)	0 (95% UB: 0.06)		0

Table A2. (Continued)

Parameter	Release Group 1	Release Group 2	Release Group 3	Population Estimate
$\phi_{A12,E1}$	0 (95% UB: 0.34)	0 (95% UB: 0.06)		0
$\phi_{A12,GH}$				
$\phi_{A12,G1}$	0 (95% UB: 0.34)	0.02 (0.02)	0.17 (0.11)	0.06 (0.04)
$\phi_{A13,GH}$				
$\phi_{A13,G1}$	0.71 (0.17)	0.62 (0.08)	0.77 (0.12)	0.70 (0.07)
$\phi_{A13,T1}$	0.29 (0.17)	0.32 (0.08)	0.23 (0.12)	0.28 (0.07)
$\phi_{B2,B3}$	0.20 (0.04)	0.39 (0.04)		0.29 (0.03)
$\phi_{B2,C2}$	0.05 (0.02)	0.02 (0.01)		0.03 (0.01)
$\phi_{B2,D1O}$	0.08 (0.02)	0.05 (0.01)		0.07 (0.01)
$\phi_{B2,D1C}$	0.08 (0.02)	0.05 (0.01)		0.07 (0.01)
$\phi_{B2,D1}$	0.17 (0.03)	0.11 (0.03)		0.14 (0.02)
$\phi_{B2,E1}$	0.38 (0.04)	0.41 (0.05)		0.40 (0.03)
$\phi_{B2,G1}$	0.04 (0.02)	0.14 (0.03)	0.13 (0.12)	0.10 (0.04)
$\phi_{B3,B4}$	0.75 (0.09)	0.67 (0.07)		0.71 (0.06)
$\phi_{B4,GH}$				
$\phi_{B4,G1}$	0.28 (0.11)	0.52 (0.09)		0.40 (0.07)
$\phi_{B5,D1O}$		0		
$\phi_{B5,D1C}$		0		
$\phi_{B5,D1}$		0 (95% UB: 0.31)		
$\phi_{B5,E1}$		0 (95% UB: 0.31)		
$\phi_{B5,GH}$				
$\phi_{B5,G1}$		0.75 (0.15)		
$\phi_{C1,B3}$	0	0		0
$\phi_{C1,C2}$	0	0		0
$\phi_{C1,D1O}$	0	0		0
$\phi_{C1,D1C}$	0	0		0
$\phi_{C1,D1}$	0	0		0
$\phi_{C1,E1}$	0	0		0
$\phi_{C1,G1}$	0	0		0
$\phi_{C2,GH}$				
$\phi_{C2,G1}$	0 (95% UB: 0.39)	0.50 (0.35)		0.25 (0.18)
$\phi_{D1O,D2}$	0.70 (0.10)	0.77 (0.12)		0.73 (0.08)
$\phi_{D1C,D2}$	0.70 (0.10)	0.77 (0.12)		0.73 (0.08)
$\phi_{D1,D2}$	0.70 (0.10)	0.77 (0.12)		0.73 (0.08)
$\phi_{D1O,G2}$	0.05 (0.05)	0.15 (0.10)		0.10 (0.06)
$\phi_{D1C,G2}$	0.05 (0.05)	0.15 (0.10)		0.10 (0.06)
$\phi_{D1,G2}$	0.05 (0.05)	0.15 (0.10)		0.10 (0.06)
$\phi_{D2,G2}$	0.07 (0.07)	0.20 (0.13)		0.14 (0.07)
$\phi_{E1,E2}$	0.36 (0.07)	0.37 (0.07)		0.37 (0.05)
$\phi_{E2,G2}$	0.85 (0.10)	0.93 (0.06)		0.89 (0.06)
$\phi_{F1,D1O}$		0		

Table A2. (Continued)

Parameter	Release Group 1	2	3	Population Estimate
$\phi_{F1,D1C}$		0		
$\phi_{F1,D1}$		0 (95% UB: 0.45)		
$\phi_{F1,E1}$		0.60 (0.22)		
$\phi_{F1,GH}$				
$\phi_{F1,G1}$		0.40 (0.22)	0.33 (0.19)	0.37 (0.15)
$\phi_{G1,G2(A)}$	0.90 (0.10)	0.98 (0.02)	1 (95% LB: 0.94)	0.96 (0.03)
$\phi_{G1,G2(B)}$	0.90 (0.10)	0.98 (0.02)	1 (95% LB: 0.94)	0.96 (0.03)
$\phi_{T1,G2}$	1 (95% LB: 0.23)	1 (95% LB: 0.76)	1 (95% LB: 0.44)	1.00 (<0.01)
λ	0.00 (<0.01)		1	0.49 (<0.01)
ψ_{A1}	0.19 (0.03)	0.41 (0.03)	0.80 (0.05)	0.46 (0.02)
ψ_{A2}	0.80 (0.13)	0.91 (0.04)	0.74 (0.09)	0.82 (0.05)
ψ_{B1}	0.81 (0.03)	0.59 (0.03)	0.20 (0.05)	0.54 (0.02)
ψ_{B2}	0.95 (0.02)	0.97 (0.02)	0.89 (0.10)	0.94 (0.04)
ψ_{C2}	0.05 (0.02)	0.03 (0.02)	0.11 (0.10)	0.06 (0.04)
ψ_{F2}	0.20 (0.13)	0.09 (0.04)	0.26 (0.09)	0.18 (0.05)
ψ_{G1}				
ψ_{H1}				
P_{A0a}	0.93 (0.03)	0.97 (0.02)	0.97 (0.02)	0.96 (0.01)
P_{A0b}	0.97 (0.02)	0.95 (0.03)	0.93 (0.03)	0.95 (0.02)
P_{A0}	1.00 (<0.01)	1.00 (<0.01)	1.00 (<0.01)	1.00 (<0.01)
P_{A2}	1	0.99 (<0.01)	1	1.00 (<0.01)
P_{A3}	1.00 (<0.01)	0.93 (0.02)	1	0.97 (0.01)
P_{A4}	1	0.99 (0.01)	1	1.00 (<0.01)
P_{A5}	1	1	1	1
P_{A6}	1	1	1	1
P_{A7a}	0.97 (0.03)	1	1	0.99 (0.01)
P_{A7b}	1	1	1	1
P_{A7}	1	1	1	1
P_{A8a}	1	1	1	1
P_{A8b}	1	0.99 (0.01)	1	1.00 (<0.01)
P_{A8}	1	1	1	1
P_{A9a}	1	1	1	1
P_{A9b}	1	1	1	1
P_{A9}	1	1	1	1
P_{A10}	1	1	1	1
P_{A11a}	0.87 (0.12)	0.94 (0.03)	1	0.94 (0.04)
P_{A11b}	1	1	1	1
P_{A11}	1	1	1	1
P_{A12a}	1	1	0.75 (0.12)	0.92 (0.04)
P_{A12b}	1	1	1	1
P_{A12}	1	1	1	1

Table A2. (Continued)

Parameter	Release Group 1	Release Group 2	Release Group 3	Population Estimate
P_{A13a}	1	0.97 (0.03)	1	0.99 (0.01)
P_{A13b}	1	1	0.92 (0.07)	0.97 (0.02)
P_{A13}	1	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)	0.99 (0.01)	1	0.99 (<0.01)
P_{B2b}	1	1	1	1
P_{B2}	1	1	1	1
P_{B3a}	1	1		1
P_{B3b}	0.96 (0.04)	1		0.98 (0.02)
P_{B3}	1	1		1
P_{B4a}	1	1		1
P_{B4b}	1	0.97 (0.03)		0.98 (0.02)
P_{B4}	1	1		1
P_{B5a}		1		
P_{B5b}		1		
P_{B5}		1		
P_{C1a}	1	1	1[a]	1
P_{C1b}	1	1	1[a]	1
P_{C1}	1	1	1[a]	1
P_{C2a}	1	1		1
P_{C2b}	1	1		1
P_{C2}	1	1		1
P_{D1}	1	1		1
P_{D2a}	1	1		1
P_{D2b}	1	1		1
P_{D2}	1	1		1
P_{E1}	1	1		1
P_{E2}	0.79 (0.11)	0.78 (0.10)		0.78 (0.07)
P_{F1a}	1	1	1	1
P_{F1b}	1	1	1	1
P_{F1}	1	1	1	1
P_{G1a}	1	0.96 (0.03)	0.87 (0.08)	0.94 (0.03)
P_{G1b}	1	0.98 (0.02)	1	0.99 (0.01)
P_{G1c}	1	1	1	1
P_{G1}	1	1	1	1
P_{G2a}	0.88 (0.06)	0.93 (0.03)		0.91 (0.03)
P_{G2b}	0.88 (0.06)	0.96 (0.02)		0.92 (0.03)
P_{G2c}	0.96 (0.04)	0.96 (0.02)		0.96 (0.02)

a = assumed value; data too sparse to estimate freely

Table A2. (Continued)

Parameter	Release Group 1	2	3	Population Estimate
P_{G2}	1.00 (<0.01)	1.00 (<0.01)	0.89 (0.07)	0.97 (0.02)
P_{H1a}				
P_{H1b}				
P_{H1}				
P_{T1a}	1	1	1	1
P_{T1b}	1	1	0.67 (0.27)	0.89 (0.09)
P_{T1}	1	1	1	1

Table A3. Parameter estimates (standard errors or 95% bound [UB = upper bound, LB = lower bound] in parentheses) for tagged juvenile Steelhead released in 2015, 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.

	Release Group			
Parameter	1	2	3	Population Estimate
S_{A2}	0.77 (0.02)	0.81 (0.02)	0.62 (0.03)	0.73 (0.01)
S_{A3}	0.91 (0.02)	0.94 (0.02)	0.91 (0.02)	0.92 (0.01)
S_{A4}	0.95 (0.02)	0.94 (0.02)	0.86 (0.03)	0.92 (0.01)
S_{A5}	0.84 (0.03)	0.89 (0.02)	0.69 (0.04)	0.80 (0.02)
S_{A6}	0.95 (0.02)	0.96 (0.01)	0.66 (0.05)	0.86 (0.02)
S_{A7}	0.47 (0.09)	0.83 (0.04)	0.67 (0.08)	0.65 (0.04)
S_{A8}	1 (95% LB: 0.80)	0.93 (0.03)	0.96 (0.04)	0.96 (0.02)
$S_{A8,G2}$	0.54 (0.14)	0.66 (0.06)	0.69 (0.09)	0.63 (0.06)
S_{A9}	1 (95% LB: 0.80)	0.94 (0.03)	0.92 (0.05)	0.95 (0.02)
$S_{A9,G2}$	0.54 (0.14)	0.71 (0.06)	0.72 (0.09)	0.66 (0.06)
S_{A10}	1 (95% LB: 0.80)	0.98 (0.02)	0.96 (0.04)	0.98 (0.02)
$S_{A10,G2}$	0.54 (0.14)	0.76 (0.06)	0.78 (0.09)	0.69 (0.06)
$S_{A11,G2}$	0.78 (0.14)	0.77 (0.06)	0.94 (0.06)	0.83 (0.05)
$S_{A12,G2}$	0.82 (0.12)	0.81 (0.06)	1.00 (<0.01)	0.87 (0.05)
S_{B1}	0.97 (0.01)	0.98 (0.01)	0.81 (0.10)	0.92 (0.03)
$S_{B2,G2}$	0.16 (0.03)	0.33 (0.04)	0.08 (0.07)	0.19 (0.03)
$S_{B2(SD)}$	0.79 (0.04)	0.82 (0.03)	0.46 (0.14)	0.69 (0.05)
$S_{C1,G2}$	0 (95% UB: 0.45)			
$S_{C1(SD)}$	0 (95% UB: 0.45)			
$S_{F1,G2}$	0 (95% UB: 0.52)	0.80 (0.18)	0.40 (0.22)	0.40 (0.09)
$\phi_{A1,A0}$	0.15 (0.02)	0.14 (0.02)	0.16 (0.02)	0.15 (0.01)
$\phi_{A1,A2}$	0.67 (0.02)	0.73 (0.02)	0.58 (0.02)	0.66 (0.01)
$\phi_{A1,A3}$	0.51 (0.02)	0.59 (0.02)	0.36 (0.02)	0.49 (0.01)
$\phi_{A1,A4}$	0.47 (0.02)	0.55 (0.02)	0.33 (0.02)	0.45 (0.01)
$\phi_{A11,A12}$	0.89 (0.10)	0.90 (0.04)	0.71 (0.11)	0.83 (0.05)
$\phi_{A11,A13}$	0.11 (0.10)	0.06 (0.03)	0.18 (0.09)	0.11 (0.05)
$\phi_{A11,B5}$		0 (95% UB: 0.06)		
$\phi_{A11,D1O}$	0	0	0	0
$\phi_{A11,D1C}$	0	0	0	0
$\phi_{A11,D1}$	0 (95% UB: 28)	0 (95% UB: 0.05)	0 (95% UB: 0.15)	0
$\phi_{A11,E1}$	0 (95% UB: 28)	0 (95% UB: 0.05)	0 (95% UB: 0.15)	0
$\phi_{A11,GH}$				
$\phi_{A11,G1}$	0 (95% UB: 28)	0 (95% UB: 0.06)	0.06 (0.06)	0.02 (0.02)
$\phi_{A12,A13}$	0.75 (0.15)	0.68 (0.07)	0.83 (0.11)	0.75 (0.07)
$\phi_{A12,B5}$		0.19 (0.06)		
$\phi_{A12,D1O}$	0	0.01 (0.01)	0	0.00 (<0.01)
$\phi_{A12,D1C}$	0	0.01 (0.01)	0	0.00 (<0.01)
$\phi_{A12,D1}$	0 (95% UB: 31)	0.02 (0.02)	0 (95% UB: 0.20)	0.01 (0.01)

Table A3. (Continued)

Parameter	Release Group 1	Release Group 2	Release Group 3	Population Estimate
$\phi_{A12,E1}$	0 (95% UB: 31)	0 (95% UB: 0.06)	0 (95% UB: 0.20)	0
$\phi_{A12,GH}$				
$\phi_{A12,G1}$	0.13 (0.12)	0.02 (0.02)	0.17 (0.11)	0.10 (0.05)
$\phi_{A13,GH}$				
$\phi_{A13,G1}$	0.71 (0.17)	0.60 (0.08)	0.77 (0.12)	0.69 (0.07)
$\phi_{A13,T1}$	0.29 (0.17)	0.34 (0.08)	0.23 (0.12)	0.29 (0.07)
$\phi_{B2,B3}$	0.21 (0.04)	0.37 (0.04)	0.38 (0.13)	0.32 (0.05)
$\phi_{B2,C2}$	0.04 (0.02)	0.02 (0.01)	0 (95% UB: 0.19)	0.02 (0.01)
$\phi_{B2,D1O}$	0.09 (0.02)	0.07 (0.02)	0.04 (0.04)	0.06 (0.01)
$\phi_{B2,D1C}$	0.09 (0.02)	0.07 (0.02)	0.04 (0.04)	0.06 (0.01)
$\phi_{B2,D1}$	0.17 (0.03)	0.13 (0.03)	0.08 (0.07)	0.13 (0.03)
$\phi_{B2,E1}$	0.40 (0.04)	0.40 (0.04)	0.08 (0.07)	0.29 (0.03)
$\phi_{B2,G1}$	0.04 (0.02)	0.16 (0.03)	0.08 (0.07)	0.09 (0.03)
$\phi_{B3,B4}$	0.89 (0.06)	0.73 (0.07)	0.80 (0.18)	0.81 (0.07)
$\phi_{B4,GH}$				
$\phi_{B4,G1}$	0.21 (0.08)	0.58 (0.09)	0.25 (0.22)	0.35 (0.08)
$\phi_{B5,D1O}$		0		
$\phi_{B5,D1C}$		0		
$\phi_{B5,D1}$		0 (95% UB: 0.28)		
$\phi_{B5,E1}$		0 (95% UB: 0.28)		
$\phi_{B5,GH}$				
$\phi_{B5,G1}$		0.78 (0.14)		
$\phi_{C1,B3}$	0			
$\phi_{C1,C2}$	0			
$\phi_{C1,D1O}$	0			
$\phi_{C1,D1C}$	0			
$\phi_{C1,D1}$	0			
$\phi_{C1,E1}$	0			
$\phi_{C1,G1}$	0			
$\phi_{C2,GH}$				
$\phi_{C2,G1}$	0 (95% UB: 0.44)	0.33 (0.27)		0.17 (0.14)
$\phi_{D1O,D2}$	0.73 (0.10)	0.94 (0.06)		0.83 (0.06)
$\phi_{D1C,D2}$	0.73 (0.10)	0.94 (0.06)		0.83 (0.06)
$\phi_{D1,D2}$	0.73 (0.10)	0.94 (0.06)		0.83 (0.06)
$\phi_{D1O,G2}$	0.09 (0.06)	0.18 (0.10)		0.14 (0.06)
$\phi_{D1C,G2}$	0.09 (0.06)	0.18 (0.10)		0.14 (0.06)
$\phi_{D1,G2}$	0.09 (0.06)	0.18 (0.10)		0.14 (0.06)
$\phi_{D2,G2}$	0.13 (0.08)	0.19 (0.10)		0.16 (0.07)
$\phi_{E1,E2}$	0.34 (0.07)	0.40 (0.07)		0.37 (0.05)
$\phi_{E2,G2}$	0.79 (0.11)	0.94 (0.06)		0.86 (0.06)
$\phi_{F1,D1O}$	0	0	0.10 (0.09)	0.03 (0.03)

Table A3. (Continued)

Parameter	Release Group 1	Release Group 2	Release Group 3	Population Estimate
$\phi_{F1,D1C}$	0	0	0.10 (0.09)	0.03 (0.03)
$\phi_{F1,D1}$	0 (95% UB: 0.52)	0 (95% UB: 0.45)	0.20 (0.18)	0.07 (0.06)
$\phi_{F1,E1}$	0.25 (0.22)	0.40 (0.22)	0 (95% UB: 0.42)	0.22 (0.10)
$\phi_{F1,GH}$				
$\phi_{F1,G1}$	0 (95% UB: 0.52)	0.60 (0.22)	0.40 (0.22)	0.33 (0.10)
$\phi_{G1,G2(A)}$	0.91 (0.09)	0.98 (0.02)	1 (95% LB: 0.94)	0.96 (0.03)
$\phi_{G1,G2(B)}$	0.91 (0.09)	0.98 (0.02)	1 (95% LB: 0.94)	0.96 (0.03)
$\phi_{T1,G2}$	1 (95% LB: 0.23)	1 (95% LB: 0.78)	1 (95% LB: 0.45)	1
λ			1	
ψ_{A1}	0.17 (0.03)	0.39 (0.03)	0.71 (0.06)	0.42 (0.03)
ψ_{A2}	0.69 (0.13)	0.91 (0.04)	0.77 (0.09)	0.79 (0.05)
ψ_{B1}	0.83 (0.03)	0.61 (0.03)	0.29 (0.06)	0.58 (0.03)
ψ_{B2}	0.96 (0.02)	0.98 (0.01)	1	0.98 (0.01)
ψ_{C2}	0.04 (0.02)	0.02 (0.01)	0	0.02 (0.01)
ψ_{F2}	0.31 (0.13)	0.09 (0.04)	0.23 (0.09)	0.21 (0.05)
ψ_{G1}				
ψ_{H1}				
P_{A0a}	0.90 (0.04)	0.97 (0.02)	0.97 (0.02)	0.94 (0.02)
P_{A0b}	0.94 (0.03)	0.94 (0.03)	0.93 (0.03)	0.94 (0.02)
P_{A0}	0.99 (<0.01)	1.00 (<0.01)	1.00 (<0.01)	1.00 (<0.01)
P_{A2}	1.00 (<0.01)	0.99 (0.01)	1	1.00 (<0.01)
P_{A3}	1.00 (<0.01)	0.93 (0.02)	1	0.97 (0.01)
P_{A4}	1	0.99 (0.01)	1	1.00 (<0.01)
P_{A5}	1	1	1	1
P_{A6}	1	1	1	1
P_{A7a}	0.93 (0.05)	1	1	0.98 (0.02)
P_{A7b}	1	1	1	1
P_{A7}	1	1	1	1
P_{A8a}	1	0.99 (0.01)	1	1.00 (<0.01)
P_{A8b}	1	1	1	1
P_{A8}	1	1	1	1
P_{A9a}	1	1	1	1
P_{A9b}	1	1	1	1
P_{A9}	1	1	1	1
P_{A10}	1	1	1	1
P_{A11a}	0.89 (0.10)	0.94 (0.03)	1	0.94 (0.04)
P_{A11b}	1	1	1	1
P_{A11}	1	1	1	1
P_{A12a}	1	1	0.75 (0.12)	0.92 (0.04)
P_{A12b}	1	1	1	1
P_{A12}	1	1	1	1

Table A3. (Continued)

Parameter	Release Group 1	2	3	Population Estimate
P_{A13a}	1	0.97 (0.03)	1	0.99 (0.01)
P_{A13b}	1	1	0.92 (0.07)	0.97 (0.02)
P_{A13}	1	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)	0.99 (0.01)	1	0.99 (<0.01)
P_{B2b}	1	1	1	1
P_{B2}	1	1	1	1
P_{B3a}	1	1	1	1
P_{B3b}	0.96 (0.04)	1	0.80 (0.18)	0.92 (0.06)
P_{B3}	1	1	1	1
P_{B4a}	1	1	1	1
P_{B4b}	1	0.97 (0.03)	1	0.99 (0.01)
P_{B4}	1	1	1	1
P_{B5a}		1		
P_{B5b}		1		
P_{B5}		1		
P_{C1a}	1	1	1[a]	1
P_{C1b}	1	1	1[a]	1
P_{C1}	1	1	1[a]	1
P_{C2a}	1	1	1[a]	1
P_{C2b}	1	1	1[a]	1
P_{C2}	1	1	1[a]	1
P_{D1}	1	1	1[a]	1
P_{D2a}	1	1		1
P_{D2b}	1	1		1
P_{D2}	1	1		1
P_{E1}	1	1	1[a]	1
P_{E2}	0.79 (0.11)	0.79 (0.09)		0.79 (0.07)
P_{F1a}	1	1	1	1
P_{F1b}	1	1	1	1
P_{F1}	1	1	1	1
P_{G1a}	1	0.96 (0.03)	0.88 (0.08)	0.95 (0.03)
P_{G1b}	1	0.98 (0.02)	1	0.99 (0.01)
P_{G1c}	1	0.98 (0.02)	1	0.99 (0.01)
P_{G1}	1	1.00 (<0.01)	1	1.00 (<0.01)
P_{G2a}	0.89 (0.06)	0.93 (0.03)		0.91 (0.03)
P_{G2b}	0.86 (0.07)	0.96 (0.02)		0.91 (0.03)
P_{G2c}	0.96 (0.04)	0.95 (0.02)		0.96 (0.02)

a = assumed value; data too sparse to estimate freely

Table A3. (Continued)

Parameter	Release Group 1	2	3	Population Estimate
P_{G2}	1.00 (<0.01)	1.00 (<0.01)	0.89 (0.07)	0.97 (0.02)
P_{H1a}				
P_{H1b}				
P_{H1}				
P_{T1a}	1	1	1	1
P_{T1b}	1	1	0.67 (0.27)	0.89 (0.09)
P_{T1}	1	1	1	1