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NMFS Biological Opinion RPA IV.2.2: 2011 Six-Year Acoustic Telemetry Steelhead Study

U.S. Department of the Interior
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COVER

High water conditions at Durham Ferry on May 21, 2011. Photograph by J. Israel

DISCLAIMER

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Contents

Executive Summary

The 2011 Six Year Study in the San Joaquin River and Bay-Delta was conducted between March and June 2011. The study included five releases of acoustically tagged steelhead from Durham Ferry. Descriptive attributes of relevant flow, temperature, and export operation were characterized based on average travel time of steelhead throughout the entire study period. Multiple battery life tests, multiple fish health assessments, and a tag retention study reduced uncertainty in experimental factors influencing the reach-specific survival and route entrainment results estimated from the release-recapture model used in 2011. A predator filter was applied to the data that classified each detection as likely to have come from a steelhead versus a predatory fish, based on multiple scales of detection history travel time, residency, and pattern. Survival and route entrainment estimates were similar regardless of whether they were made with or without the predator detections. Survival from Mossdale to Chipps Island ranged from 0.38 to 0.69 and 0.39 to 0.71, when predator-type detections were excluded and included respectively. Steelhead survival through the federal facility to western Delta receivers was greater than through the state fish collection facilities and ranged from 0.88 to 1.0 and 0.38 and 0.79, respectively. Route entrainment into the South Delta via Old River ranged from 0.47 to 0.51 and via Turner Cut ranged from 0.09 to 0.32. There appears little covariation and no significant relationship between the probability of remaining in the San Joaquin River and hydrologic measures such as flow and flow proportion remaining in the San Joaquin River at the head of Old River in 2011. Average travel time through the Delta was approximately 11 days with no differences among the releases, although travel time to Jersey Point tended to be longer along the Old River route than in the San Joaquin River route. Numerous objectives were developed as part of the Six Year Study in its requirements in the 2009 National Marine Fisheries Service Biological Opinion on the Long term Operation of the Central Valley Project and State Water Project, but given the limited sample size from the first year (n = 5), these analyses are reserved for consideration until completion of three years of the multi-year study.

Introduction

The 2009 NOAA National Marine Fisheries Service's (NMFS) Biological Opinion (BO) on Long Term Operations of the Central Valley Project (CVP) and State Water Project (SWP) includes a Reasonable and Prudent Alternative (RPA) action to undertake experiments utilizing acoustically-tagged salmonids to confirm proportional causes of mortality due to flows, exports, and other project and non-project adverse effects on steelhead smolts out-migrating from the San Joaquin Basin and through the southern Delta. The BO clearly stated that continuing the VAMP study, in place of conducting this six-year study in 2010, could be done, which was done by the U.S. Bureau of Reclamation (Reclamation) and DWR. The study in 2011 coincided with different periods of operations and focus on clipped hatchery steelhead (*Oncorhynchus mykiss*), but also evaluated fall run Chinook salmon (*O. tshawytscha*) as surrogates for hatchery steelhead smolts. The study period of interest was between March 1 and June 15, which coincided with a majority (~ 60%) of *O. mykiss* outmigration from the Stanislaus River (Figure 1) and recoveries of steelhead smolts in trawling at Mossdale (Figure 2). This period was to include changes in CVP/SWP operations that may include reductions in exports, reductions in reverse flows in Old and Middle rivers (OMR), and San Joaquin River pulse outflows to assess the influence of flow and exports on juvenile steelhead route entrainment and survival (Figure 3).

The NMFS BO includes two actions that influence CVP/SWP export and discharges through the San Joaquin River and Old and Middle River corridors. Action IV.2.1 identifies targeted levels of export volume dependent on San Joaquin discharge at Vernalis, which may increase with San Joaquin inflow volume during wetter periods (Figure 3). This action is calendar based and occurs between April 1 and May 31. The purpose of this action is to increase survival of emigrating salmonids by reducing fishes' vulnerability to entrainment into the south Delta and at the CVP/SWP facilities by increasing the San Joaquin inflow to export ratio. Action IV.2.3 identifies targeted discharges through the Old and Middle River corridor. Similar to Action IV.2.1, this action attempts to increase survival of emigrating salmonids by reducing their vulnerability to entrainment into the south Delta and pumps. The initial level of -5,000 cfs through Old and Middle rivers is calendar-based and runs between January 1 and June 15, but increased entrainment of ESA-listed salmonids ESUs and steelhead can require modifying hydraulic conditions in the Old and Middle River corridor so that the net downstream flow is greater than -5,000 cfs and meets targets of -3,500cfs and -2,500cfs.

Chinook salmon acoustic telemetry studies have occurred in the San Joaquin River and south Delta for the Vernalis Adaptive Management Plan (VAMP) and South Delta Temporary Barriers BO. VAMP provided increased San Joaquin basin tributary inflows in some years between 2000 and 2011, and released coded wire tagged (CWT, 2000-2006) and acoustically tagged fish (2006-2011) to monitor the influence of flow on San Joaquin River fall run Chinook salmon survival. These studies have demonstrated fall run Chinook salmon select routes in similar proportion to the flow entering each route, and low survival in the south Delta in the San Joaquin River (Holbrook et al. 2008, Vogel 2010, SJRGA 2010).

This study is different than the VAMP study in its conceptual model, potential timing, potential spatial scale, and species utilized to investigate survival in the San Joaquin River and south Delta. In 2011, the study plan was coordinated with the VAMP and South Delta Temporary Barriers fish monitoring studies to simultaneous release juvenile steelhead and fall-run Chinook salmon to examine questions concerning surrogacy and species-specific route selection and survival estimates, as well as the physical and nonphysical barriers placed in the south Delta during salmonid outmigration.

Steelhead in the San Joaquin River belong to the Southern Sierra Nevada Diversity Group of the Central Valley steelhead Distinct Population Segment (DPS). Significant variation in juvenile size and age at outmigration, river residency, and reproductive age has been noted in Central Valley steelhead. Steelhead spawn in Central Valley tributaries during the winter and spring. Steelhead smolts emigrate during high flows in the winter and spring, and use the lower San Joaquin River and Delta for migration. On the Sacramento River, acoustically-tagged juvenile steelhead smolts can take days to over a month to emigrate from the upper Sacramento River through the Delta (P. Sandstrom, UC Davis, pers. comm.). Recent monitoring has detected small, non-hatchery origin steelhead populations in the Stanislaus, Tuolumne, and Merced rivers (Zimmerman et al 2009, McEwan 2001). Genetic studies have not observed significant genetic divergence among hatchery and natural steelhead or *O. mykiss* populations below dams on the Sacramento and San Joaquin rivers (Nielsen et al 2005, Garza and Pearse 2009). Because naturally emigrating *O. mykiss* are rare, this study used the closest hatchery stock of steelhead, from the Mokelumne River Fish Hatchery. Recent review panels have suggested that Chinook salmon are a poor surrogate for steelhead (DSP 2009); thus the potential to run simultaneous survival studies of juvenile Chinook salmon and steelhead smolts as a part of this study was a first step in evaluating the effect of river and delta water operations and habitat on steelhead, and in determining if previous results for Chinook salmon are informative for steelhead.

Salmonids in the San Joaquin River basin were once abundant and widely distributed, but currently face numerous limiting factors. The NMFS Central Valley Recovery Plan identified that 'Very High' stressors on juvenile steelhead outmigration on the San Joaquin River include habitat availability, changes in hydrology, water temperature, reverse flow conditions, contaminants, habitat degradation, and entrainment. It is possible that reduced survival of emigrating steelhead smolts may be the greatest management concern to preserving anadromy in *O. mykiss* (Satterthwaite et al. 2010). Many of these stressors can be studied using acoustic telemetry, and a conceptual model demonstrates how Delta water operations, tributary water operations, and habitat influence survival of emigrating smolts (Figure 3). This conceptual model has guided specific hypotheses and investigations during the duration of the study.

Water operations for fish protection in the San Joaquin River include increasing river flows during salmonid emigration, reducing export diversions and reverse flows, and directing fish away from the south delta diversion facilities via physical and nonphysical barriers. NMFS (2009) identified flow at Vernalis, export volume, and the ratio of Vernalis flow-to-export as priority variables to test during this study.

An independent peer review of this study's proposal was undertaken by two Science Advisors with expertise in acoustic telemetry technology and statistical modeling of release-recapture experiments, via the Delta Science Program. This study was designed to evaluate juvenile steelhead route selection at channel divergences in the south Delta and along the mainstem San Joaquin River, and how San Joaquin River tributary inflow and south delta water operations influence survival in specific reaches and through the Delta to Chipps Island. We will examine a set of abiotic and biotic variables as part of a conceptual model during the first three years to further hone hypotheses surrounding juvenile steelhead survival (Figure 3). To facilitate this, the study plan in 2011 was coordinated with juvenile steelhead releases for the California

Department of Water Resources' South Delta Temporary Barriers study to evaluate three hydrodynamic periods in the San Joaquin River over the 14-week study period.

2011 Study Questions

In 2011, results were collected to evaluate a number of questions:

1. What is the survival of emigrating steelhead smolts through the mainstem of the San Joaquin River downstream to Chipps Island?
2. What is the survival of emigrating steelhead smolts through the south Delta to Chipps Island?

Survival through the Delta was measured from Mossdale to Chipps Island using acoustic tags and a dual array of receivers at Chipps Island. In 2011, five releases of tagged fish at Durham Ferry were made, although estimates of survival started at Mossdale. For each release group, reach-specific survival rates and river conditions are described. For each release group, the migration route probabilities and their 95% confidence interval are estimated. Survival along each migration route was estimated for each release group, as well as a population-level survival estimate. These results are included in this report.

3. What influence do exports and flows have on emigrating steelhead smolt survival and route selection through the south Delta to Chipps Island?

Flow variation and volume, as well as export volume, varied during the five releases of juvenile steelhead used in the 2011 study. Route-specific survival of each release group and the travel time of these release groups were estimated for multiple routes. The river discharge conditions and daily export conditions during the travel times for each release are considered as potential variables affecting survival. The probability of migrating into the South Delta through Old and Middle Rivers and also Turner Cut are considered as a function of export and flow summary metrics. Statistical tests to assess these relationships will be further examined after three years of results to incorporate a greater range of export and flow values than experienced during the study in 2011.

4. Are juvenile fall run Chinook salmon reasonable surrogates for juvenile steelhead?

To evaluate this question, four releases of juvenile Chinook salmon and five releases of juvenile steelhead were paired in the lower San Joaquin River during 2011. The species' responses during 2011 are compared but additional replicates were completed in 2012, and will further evaluate the question. These results will be presented in the report including 2012 results.

5. What is the travel time of steelhead through different migratory routes in the San Joaquin River and south Delta?

Travel times for each release group through different migratory routes were measured. These results are included in this report.

Environmental and Operations Conditions

River flow conditions were collected from DAYFLOW, Central Valley Office, and CDEC databases (Table 1) during the 11 day period after the first day of each release. Eleven days were used because this was the average travel time between Mossdale and Chipps Island for tagged steelhead in 2011.

Steelhead Telemetry Methods

Sample size estimation

Modeling of Chinook salmon survival in the San Joaquin River and Delta (Buchanan 2010) was used to determine the minimum number of steelhead to be released at Durham Ferry for this study. While the parameter estimates used to determine the release sizes are from past fall run Chinook survival studies, it is assumed steelhead will show similar movement and survival patterns. Buchanan (2010) derived release size estimates for two overall survival values while leaving route selection proportions at Head of Old River constant and a high detection probability at Chipps Island. Given these assumptions, Buchanan (2010) recommended a sample size of 475 for estimating survival to Chipps down the Old River and San Joaquin routes if survival in the Old River route is low (0.05). Additionally, if survival between Durham Ferry and Chipps Island is higher (0.15) and survival between Durham Ferry and the Old River junction is high (0.9) a release of 475 at Durham Ferry would be able to detect a 50% difference between survival in the San Joaquin River and Old River routes. Thus, a minimum release group of 475 at Durham Ferry was estimated to provide accurate information about route entrainment and survival for juvenile steelhead survival. To keep the number of fish in each release group equal the total release group size was increased to 480. To evaluate intra-annual survival under different tributary flow during 2011 with varying south Delta export and flow conditions and facility operations (i.e. nonphysical barriers), the six-year study plan and DWR South Delta Temporary Barrier studies both attempted releases of this size. This approach was designed to provide independent measures of survival under different flow, export, and CVP and SWP operations.

Study Fish

A total of 2500 steelhead smolts from the Mokelumne River Hatchery were requested for this study to assure sufficient numbers for tagging training, release groups, and tag retention study. In 2011, fish were tagged at the DWR Collection, Handling, Transport, and Release Laboratory (CHTR Lab).

Fish surgery training

A 5-day surgery training session was conducted at the tagging facility. Individuals previously trained for tagging were given a refresher course during the first two days of each training session. After the refresher course, assistants joined the taggers for 3 additional days of training. Surgical procedures and surgeons for juvenile steelhead and Chinook salmon were the same in 2011 to reduce differential tagging effects between species.

Transmitter Programming

In 2011, steelhead smolts were tagged by surgical insertion of HTI 795 LD acoustic tags expected to last up to 80 days. Programming occurred the day prior to tagging. The tag codes were well-distributed across the various release groups to avoid confounding the effect of release timing with the effect of tag code on survival. Transmitters were soaked for at least 24 hours prior to programming. After programming, tags were sniffed in a cup of water using an HTI sniffer and monitored through at least three transmission cycles. At least 5 attempts were made to program each tag. Following successful programming, each tag was placed in a uniquely coded vial. Because the tags have no external identifiers, the codes on the vials were used to track individual tags. During 2008 and 2010, VAMP encountered some HTI tags that passed activation and sniffing, but then could not be heard. To address this, the study team briefly listened to activated tags prior to surgical implantation in study fish to confirm tag function and programming.

Transmitter Implantation and Validation

During 2011, training and tagging operations occurred at the DWR Collection, Handling, and Transport Laboratory for tagging steelhead. Steelhead tagging occurred between March 21 and May 19 for the 6 Year Study and May 21 and June 16 for the South Delta TBP Study (Table 2). Feed was withheld from study fish for 24 hours prior to transmitter implantation.

During each tagging session, fish were surgically implanted with an HTI acoustic transmitter following procedures bases on a standard operation procedure (SOP) develop by the USGS's Columbia River Research Laboratory. The SOP directed all aspects of the tagging operation and several quality assurance checks were made during each tagging session to ensure compliance with the SOP guidelines SJRGA 2013, Appendix F).

Prior to implantation, fish were anesthetized in 70 mg/L tricane methanesulfonate buffered with an equal concentration of sodium bicarbonate until they lost equilibrium. Fish were removed from anesthesia, and were measured (fork length (FL) to the nearest mm) and weighed (the nearest 0.1g). The HTI Model 795 LD acoustic tag used for this study weighed 1.0g (range 0.94 to 1.09) and was 21.0 mm long with a diameter of 6.8 mm. No minimum or maximum fish weight criteria were used.

Two sutures were used to close the incision; typical surgery times were less than 3 minutes. Fish were then placed into 19L (5 gal) buckets with aerators following recovery from anesthesia to ensure survival and normal swimming behavior. Each bucket was labeled with a unique code. An HTI model 291 (four-port) receiver was used to confirm that tags were working correctly immediately after tagging. A total of three tags were found to be non-functional; two in the fish tagged for the six year study and one in a fish tagged for the South Delta TBP study. All fish with non-functional tags were removed from the study and euthanized. Fish were transferred from the 19L buckets into 68 L (18 gallon) perforated totes for transport; each tote contained three fish.

Transport

Juvenile steelhead were transported to the release site via two large compartmentalized tanks (Table 2). A total of approximately 120 fish were transported each day. The group was split in half for transport with 60 steelhead transported twice a day. Steelhead were held in 68 L (18 gallon) perforated containers. Water temperature and DO were measured in the transport tank after loading, just prior to transport to the release site (Table 3). During transport, oxygen was bubbled into the transport tanks to assure that dissolved oxygen levels were adequate. Both temperature and DO levels were also checked after transport (Table 3). Once fish arrived on-site, they were moved from the tanks in the truck to the river. River temperature and DO were measured immediately before fish were transferred to the holding tanks (Table 3).

Once at the release site, each 68 L (18 gallon) numbered tote was carried to the river and poured into a designated, numbered holding container. Four or five numbered totes were emptied into each 166 L (44 gallon) numbered holding container. The 166-L (44-gallon) container held approximately 132 L (35 gallons) of water. These containers were held in the river with PVC floats attached to a tether line. Once fish were placed into each holding container the lid was securely attached with four bolts and wingnuts. Initially, a total of 15 steelhead trout were held in each 44 gallon container for releases in March; however, the number was reduced to 12 fish per container for all subsequent releases. Once all fish were transferred to the in-river holding containers, they were held for a minimum of 24 hours prior to release.

Releases

A total of five steelhead releases were made between March 22 and June 18 at Durham Ferry (RM 68; Table 2). Each release was made up of approximately 480 fish spread out over 4 days of tagging and transport, except the last release only included 285 fish released over three days. Releases were made every 6 hours over a 24-hour period, after fish had been held at the holding site for 24 hours. Fish tagged in the morning were released at 1500, 2100, 0300 and 0900 starting the day after tagging and transport. Fish tagged in the afternoon fish were released at 1800, 0000, 0600, 1200 starting the day after tagging and transport.

For the first steelhead release, a boat was used to transport the tagged fish downstream prior to release. However, it was determined after the initial releases that the flows were too high to safely allow field personnel to use the boat. For this reason, fish were released from shore for the four remaining releases of the study.

Immediately prior to release, each container was checked for any dead or impaired fish. There were no dead or impaired steelhead collected prior to fish being transferred to the holding containers in 2011; however, there were seven steelhead mortalities observed prior to release (Table 2). At the time of release each holding container was inverted to allow the fish to swim into the river. The time of release was then recorded. As the holding containers were flipped back over, they were inspected to make sure that none of the released fish were left in the container. Once on land, the crew removed tags from any mortalities and labeled them. Tags were taken back to the tagging facility to be read using the acoustic tag reader.

Dummy tagged fish

In order to evaluate the effects of tagging, transportation and holding, several groups of fish were implanted with inactive or dummy transmitters. Dummy tags were interspersed randomly into the tagging order for each release group. Three dummy tagged fish were tagged and transported with the study fish to the release site for each transport group, both in the morning and afternoon (six dummy tagged fish per day). The two transported dummy tag groups (three individuals per group) were held in the same holding container at the release site. In addition, two groups of 12 dummy tagged fish (twelve in the morning and twelve in the afternoon) were transported on March 24 and May 17 for fish health studies (Table 2). Procedures for tagging these fish, transporting them to the release site, and holding them at the release site were the same as for fish with active transmitters. Dummy-tagged fish were evaluated for condition and mortality or used for fish health studies after being held at the release site for approximately 48 hours.

After dummy-tagged fish were held for 48 hours, they were examined for mortality, then euthanized with MS-222, measured (FL to nearest mm) and qualitatively examined for percent scale loss, body color, fin hemorrhaging, eye quality, gill coloration and vigor (Table 4). Pictures of the sutures were taken of each dummy tagged fish. Dummy tags were removed for reuse.

A total of 60 steelhead were evaluated for mortality and condition after being held for 48 hours. Only one of the 60 dummy-tagged fish was found dead when evaluated after 48 hours during the 6 year study in 2011 (Table 5). All remaining fish were found swimming vigorously, had normal gill coloration, normal eye quality and body coloration and no fin hemorrhaging with the exception of May 4 and May 5 groups. On May 4, one fish had light body color and bulging eyes. On May 5, the single mortality had pale gills and fin hemorrhaging and two others had light colored gill filaments. Also, there was one fish on May 5 with bulging eyes. Mean scale loss for all fish assessed ranged from 4.3 to 43.4%. None of the examined fish had loose sutures or hemorrhaging around the sutures. These data indicate that some fish used for these studies in 2011 had higher levels of scale loss than would be exhibited in a natural population. The higher scale loss did not appear to cause significant short term mortality of the fish held for the 48 hours with only one mortality out of 60 (Table 5).

The large size of the steelhead in this study may have contributed to higher scale loss through contact with the containers. The size of the transport containers was 68 L (18 gallons); with three fish held in each container. After being transported in these containers they were transferred to a perforated 167 L (44 gallon) holding container. There were only six dummy tagged steelhead in each of the 167 L (44 gallon) holding containers which was not anticipated to cause the high scale loss observed. However, there seemed to be significant variability in scale loss across groups (Table 5), suggesting scale loss may have been associated with changing physiological or environmental condition instead of transport and holding containers, given the consistent use of containers in each transport step. A general pathogen and physiological screening was conducted on dummy-tagged fish from 2 of the 12 groups of the 6 year study release groups (summarized in Appendix B).

Tag Retention Study

Survival and delayed mortality of tagged fish are important factors to consider in any tagging study. To monitor the effects of surgical implantation of acoustic tags on fish mortality, dummy tags were surgically implanted into 24 steelhead. Surgical implantation of tags into the retention fish was completed following the same SOP as for fish that were tagged and released as part of the study. The retention fish were kept in an aerated holding tank and fed once daily. On July 15, 2011, DWR biologists evaluated these fish for tag retention and healing after 116 days. Steelhead were euthanized and external and internal observations made to evaluate healing and recovery. Photographs were taken and observations recorded on a standardized data sheet.

Of the 24 steelhead examined, all survived until the evaluation day. Only 3 of the 24 tagged fish still had at least one suture present. This was to be expected, as it can take some time for the sutures to be absorbed or expelled. Suture sites were examined and rated those sites on a scale from 0 (no irritation) to 4 (ulcerated). A minimal amount of irritation was seen, and all cases were mild to moderate. Four out of 24 fish showed some level of irritation at suture sites. In 35% of the fish, tearing or scarring was seen. Though signs of fungus or disease were seen in two fish, neither was due to the tagging process. The incision sites were rated on a scale of 0 to 4 for incision closure, where 0 was completely closed with no overlap and 4 indicated that the incision was completely open or overlapped. In every fish, all of the incisions had healed, with no sign of inflammation, and the suture patterns were still intact.

Tag retention fish were dissected to observe tag placement and how the tags interacted with tissues and organs. In most cases the tags were located directly under the incision; however some tags had shifted slightly anterior or posterior to of the incision. There were no signs of tag encapsulations in any of the fish. In one case, no tag was found in the fish. It is uncertain what may have happened.

Receiver Deployment and Maintenance

Each tagged fish released as part of these studies was detected and uniquely identified as it passed acoustic receivers placed at various locations throughout the Delta. The hydrophone receiver network shown in Figure 4 was similar to that developed in 2010 for the VAMP study but receiver sites were added at Jersey Point, False River and Paradise Cut in 2011. Principal objectives of the hydrophone layout for 2011 were to: (1) obtain steelhead survival estimates through the Delta from Durham Ferry and Mossdale to Chipps Island; (2) obtain estimates of steelhead survival in key reaches of the Delta in the Old River and San Joaquin River routes; and (3) obtain fish route "selection" probabilities at critical flow splits (i.e., head of Old River and Turner Cut) (Figure 5). In addition, receivers were added just upstream and downstream of the release site. A dual receiver was deployed upstream of the release site to identify steelhead tags that moved upstream (i.e. residualized). The dual receiver deployed just downstream of the release site was used to verify that tags were still working at the time of release as the tagged fish passed the receivers just downstream of the release site.

Due to the extremely high water during the study period, the need arose for additional sites to be installed at locations where fish passage was normally not possible. This was necessary to make sure that fish were not moving into potential immigration pathways that were not set up with receivers. One such location was Paradise Cut. When flows at Vernalis rose above 18,000 cfs, water from the San Joaquin River was able to flow over the rock weir the head of Paradise Cut. Flows reached 18,000 cfs on March 26 and remained above this level until May 2. This situation would have allowed fish to migrate through Paradise Cut and end up in Old River. Three additional receiver sites were added to document fish that did migrate through Paradise Cut: two inside of Paradise Cut and one in the San Joaquin just downstream of the head of Paradise Cut. Installation of receivers at these sites was conducted on April 12 and April 13, approximately two weeks after the flows rose above 18,000 cfs, so it is possible some fish from the first release on March 22, used Paradise Cut before these receivers were installed.

Installation and maintenance of the upstream acoustic receivers was performed by the Stockton Fish and Wildlife Office's (STFWO) Delta Juvenile Fish Monitoring Program (DJFMP). While most of the initial equipment setup was the same as in the 2010 VAMP, two new components were added: the use of solar power and telemetry of sites. The use of solar power allowed the sites to run continuously throughout the experiment without replacing batteries, while the use of telemetry equipment allowed remote access to all sites via an FTP internet site. Downstream receiver sites (Jersey Point and Chipps Island) were installed, monitored, and maintained by USGS – Sacramento office. Six other Delta receiver sites were maintained by California Department of Water Resources.

With the assistance of personnel from USGS – Columbia River Research Lab, 22 acoustic telemetry sites within the San Joaquin River and Delta were installed (Figure 4). Installation of receivers occurred in early February, with the exception of the Paradise Cut sites (Table 6). A number of site locations were changed from sites used in 2010. The site (SJLU, SJLD) on the mainstem San Joaquin River just downstream of the Head of Old River (HOR) junction was relocated closer to the junction to reduce the risk of mortality between the junction and the receiver. Receivers were turned on during receiver optimization procedures, which concluded on March 3, 2011. Sites remained operational until July 15, 2011. Receivers were removed starting mid-July.

Hydrophones were deployed in key areas, based on channel width, depth and in-water noise interference. Tag drags were conducted to make sure that each hydrophone was able to pick up a signal from a nearby acoustic tag. Hydrophone locations were marked with an onboard GPS unit (Lowrance HDS-5). Each site contained an acoustic hydrophone, acoustic receiver, input/output box and four, 12V deep-cycle batteries to power the equipment. These batteries were trickle-charged with the addition of a four-panel solar array. The solar panels used were Sharp 80 watt off-module solar panels mounted on 1 ½" x 1 ½" x 10' angle iron. Sites that were co-located (redundant arrays) also required a four-panel solar array. The solar panels maintained the charge on the batteries and ran the electronic components. All equipment was housed in two metal job boxes. In past years, receivers were cooled by water; however, with the addition of sensitive electronic equipment, small 4" electric fans were used. A phidget box was installed to monitor the condition of all electronic components. Cross-sectional depth profiles were measured at each site to ensure that riverbed topography did not obscure direct passage of acoustic signals from transmitters to the hydrophones. Continuously pinging "beacon" tags were programmed and anchored underwater near each site throughout the study period in order to verify that each receiver was operating properly.

In previous years, each receiver site would have to be visited daily so that data from the receivers could be downloaded to a laptop by field personnel. For the studies in 2011, the use of telemetry equipment allowed data from each site to download automatically. An antenna and an air card were attached and plugged into each receiver, and data from the receiver were automatically downloaded to a laptop computer (netbook). The data were then transferred to an FTP site which could then be remotely accessed through the internet from any location. This system allowed personnel to examine the data from any site, remotely monitor site performance, and check for corrupt files. If a problem was observed, crew were sent to the site to correct the problem. While this system worked, the remoteness of sites created serious air card connectivity issues, and crew had to visit some sites almost daily to correct problems. A booster antenna and a software program to reboot the computer helped to solve some of these problems. In addition, some equipment was replaced during the course of the season (solar module controller). Due to the high flows, beacon tags and hydrophones needed to be moved on occasion. Maintenance of the receivers ranged from rebooting the computer to changing out hydrophones and receivers.

Several sites required field crews to use research vessels to allow access for maintenance. Sites that were accessible only by boat included Mossdale (MOS), Old River (OREU, ORED), San Joaquin River (SJLU, SJLD), Stockton Waste Water Treatment Facility (STS), Navy Drive Bridge (STN), channel markers 16 (C16) and 18 (C18), Medford Island (MFE, MFW), Turner Cut (TCS, TCN) and False River (FRE, FRW). Two sites were accessible by vehicle: Banta Carbona (BCA) and Threemile Slough (TMS, TMN). Another 10 sites were maintained by DWR personnel, including those at the federal fish salvage facilities (CVP, CVPtank) and the radial gates at the entrance to Clifton Court Forebay (RGU, RGD) and outside the State Water Project facility (SWP; Figure 4). Personnel from USGS in Sacramento deployed two four-port receivers and one single-port receiver near Chipps Island (CHP_e, CHP_w, CHP_n) and a second set of four port receivers at Jersey Point (JPTE, JPTW; Table 6, Figure 4).

Statistical Methods

Data Processing

The University of Washington received the database of tagging and release data from Andrea Fuller (FISHBIO). The tagging database included the date and time of tagging surgery for each tagged steelhead released in 2011, 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, tag batch, and any notes about fish condition were included, as well as the survival status of the fish at the time of release. Tag period and subcode were recorded as well, and were used to uniquely identify each fish released. Tagging data were summarized according to release group and tagger, and were cross-checked with Andrea Fuller (FISHBIO) and Pat Brandes (USFWS) for quality control.

Acoustic tag detection data collected at individual monitoring sites (Table 6) were transferred to the USGS Columbia River Research Lab (CRRL) in Cook, Washington. A multiple-step process was used to identify and verify detections of fish in the data files. Both the vendor's software (MarkTags) and an algorithm developed at USGS (FishCount) were used to process the raw detections, resulting in a combination of manual and automated proofing methods to identify valid tag detections. For more detailed information on the processing methods used by the USGS, see SJRGA (2013, Chapter 5). Additional manual proofing of tag detections from the Chipps Island receivers was performed by the USFWS.

The University of Washington received the primary database of auto-processed detection data from the USGS lab in Cook, WA, and the manually processed detection data from the USFWS office in Stockton. These data included the date, time, location, and tag period and subcode of each valid detection of the acoustic steelhead tags on the fixed site receivers. The period and subcode indicate the acoustic tag ID, and were used to identify tag activation time, tag release time, and release group from the tagging database.

The auto-processed and manually processed databases were both cleaned to remove obviously invalid detections. The University of Washington identified potentially invalid detections based on unreasonable travel times or unlikely transitions between detections, and queried the processor (USGS or USFWS) about the discrepancy. All corrections were noted and made to the database. After cleaning both the auto-processed and the manually processed databases, the two databases were merged to form the complete database of detections. All subsequent analysis was based on this merged database.

The information for each tag in the merged database included the date and time of the beginning and end of the period within the hourly Raw Acoustic Telemetry (RAT) file when the tag was detected. The cleaned hourly detections were converted to detections denoting the beginning and end of receiver "visits," where consecutive visits to a receiver were separated either by a gap of 12 hours or more between detections on the receiver, or by detection on a different receiver. Detections from receivers in dual or redundant arrays were pooled for this purpose.

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 removed from the dataset.

The predator filter was based on the predator analyses presented by Vogel (2010, 2011), as well as conversations among the authors with other fisheries biologists familiar with the San Joaquin River and Delta regions (e.g., Dave Vogel, Mark Bowen, Brent Bridges, Mike Cane, Jack Ingram, Mike Marshall, Phil Sandstrom, and Jason Romine). The overall structure of the predator filter was similar to that of the predator filter used in analysis of the VAMP acoustic tagging study in recent years (SJRGA 2010, 2011). The filter was applied to all detections of all tags. Two data sets were then constructed: the full data set including all detections, including those classified as coming from predators (i.e., "predator-type"), and the reduced data set, restricted to those detections classified as coming from live steelhead smolts (i.e., "smolt-type"). The survival model was fit to both data sets separately. The results from the analysis of the reduced "smolt-type" data set are presented as the final results of the 2011 OCAP tagging study. Results from analysis of the full data set including "predator-type" detections were used to indicate the degree of uncertainty in survival estimates arising from the predator decision process.

Unlike the predator filter used in analysis of acoustic-tagging studies of juvenile Chinook salmon (VAMP), the predator filter used for steelhead tagging data must account for the possibility of extended rearing by steelhead in the Delta before eventual outmigration, and 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, after allowing for extended rearing.

Even with these more 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 Delta survival from Mossdale to Chipps Island, because such a steelhead would not appear in the dataset at Mossdale and also 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, atypical movements within the Delta, or a combination of all three. 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 and is presented as the final results. The second approach used all detection data.

The predator filter was based on assumed behavioral differences between actively migrating steelhead smolts and predators such as striped bass and white catfish. 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 7), as available, downloaded from the California Data Exchange Center website (http://cdec.water.ca.gov/selectQuery.html) on 10 April 2012. All detections were considered when implementing the decision process, including detections from acoustic receivers that were not otherwise used in the survival model.

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

A tag could be given a predator classification at a detection site either on arrival or on departure from the site. A tag classified as being in a predator because of long travel time or movement against the flow was generally given a predator classification upon arrival at the detection site. On the other hand, a tag classified as being in a predator because of long residence time near a receiver was given 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 detection at that site from the reduced data set. However, all subsequent detections were removed from the reduced data set.

Criteria for distinguishing between steelhead detections and predator detections were partially based on observed behavior of tags in fish that were assumed 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. The steelhead tagged in this study ranged in size at tagging from 149 to 396 mm in fork length (mean = 276.7 mm). Predators large enough to eat juvenile steelhead of this size were expected to be too large to fit through the louvers before the entrance to the holding tanks at the SWP. Previous fish samples collected from the SWP holding tanks confirm that large predators are rare in the holding tanks, although they do occur (personal communication, Mike Cane). Steelhead predators were more likely to have entered the holding tanks at the CVP, where some predators reside behind the trashrack and may enter the facility during times when the louvers are raised for cleaning, however, it was considered unlikely for a steelhead tag observed in the CVP holding tank to be in a predator.

Acoustic receivers were stationed inside the holding tanks at CVP, and tags that were observed in the holding tanks and then observed at either Chipps Island, Jersey Point, or False River were assumed to have been transported. Acoustic receivers were not placed in the holding tanks at the SWP, and so fish transported from the SWP were identified with less certainty. It was assumed that tags were transported from the 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 then detected at either Chipps Island, Jersey Point, or False River. This group may include tagged fish that migrated from the CCFB entrance to the Jersey Point/False River/Chipps Island area in river, if they evaded detection at the Old River and Middle River receivers near Highway 4. 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 (Jersey Point, etc.).

Tags assumed 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 interpreting data from detection sites in the western portion of the study area, and less helpful for detection sites in the San Joaquin River downstream of Stockton.

The predator filter used various criteria on several spatial and temporal scales. Criteria fit under several categories, described in more detail below: fish speed, residence time, upstream transitions, other unexpected transitions, travel time since release, and movements against flow. Each criterion was applied to each tag detection on the "visit" time scale (Table 8). The visit time scale was used in the survival model, with consecutive visits at a given detection site separated by a time gap of at least 12 hours or by detection elsewhere. For each visit detection, a "predator score" was assigned based on the number of criteria yielding a positive predator classification. Separate scores were assigned depending on whether the tag was classified as a predator on arrival or on departure from the detection site. The final predator classification for a given visit-level detection was based on the "arrival" and "departure" predator scores. The detection was classified as coming from a predator on arrival at the detection site if the "arrival" predator score was ≥ 2. Likewise, the detection was classified as coming from a predator on departure from the detection site if the total predator score ("arrival" + "departure") was ≥ 2, or if the detection was previously classified as coming from a predator on arrival. All detections of a tag subsequent to its first predator designation were also classified as coming from a predator.

The scoring method was used to avoid placing undue weight on any single criterion. However, extra weight was given to the residence time criteria at the radial gates into the Clifton Court Forebay (sites RGU and RGD, model codes D1 and D2) in scoring, because very long residence time at these sites was both considered to be an indicator of predation and unlikely to be accompanied by other predation indicators. Several methods of final predator classification using the predator scores were considered, and results were compared against the full detection histories of numerous tags with a variety of types of detection histories before settling on the above method.

Criterion: Fish Speed

Fish speed was measured in two ways for each transition between detection sites and for each tag: average migration rate through the reach, and average body lengths per second through the reach. Migration rate was measured for all transitions except for return visits to the same site. Body lengths per second was calculated based on migration rate, but accounted for water velocity and fish length at tagging.

Migration rate was defined as distance traveled divided by travel time (km/hr). Reach distances were approximated using hydrophone latitude and longitude locations and the ruler tool in Google Earth. For transitions with multiple possible pathways, the pathway deemed most likely was used. Travel time was measured as the difference between the time of final detection at the prior detection site and the time of first detection at the later detection site. The range of acceptable migration rate values was specified for each observed tag transition, allowing for a wider range in reaches with more complicated hydrology (e.g., downstream reaches and those near the water export facilities) (Table 8). For upstream-directed transitions, the acceptable minimum migration rate was calculated based on the joint assumptions that (1) non-rearing steelhead moving upstream on the scale of the study reaches were pushed upstream by reverse flow caused primarily by incoming tide, and (2) it was unlikely that tidal influences would affect smolt migration over a long time period in a given reach. Thus, maximum travel times on many upstream-directed transitions were set at 12 – 15 hours, allowing for non-linear or punctuated smolt movement. The minimum migration rate for upstream-directed transitions was calculated based on this maximum travel time. The maximum travel time was extended for some sites where steelhead were expected to reside longer (e.g., in the San Joaquin River upstream of Old River, and in Old River near the head of Middle River and near the water export facilities). Also, it was assumed that a tag that moved faster on an upstream transition than during its previous downstream transition through the same reach was likely to be in a predator. This assumption was relaxed in the western and northern regions of the study area, near the water export facilities, Old River North (near Highway 4), Jersey Point, False River, Threemile Slough, and Chipps Island.

Fish speed may be affected by water velocity. Thus, the perceived migration rate (as defined above) was adjusted first by the average measured water velocity in the reach during the fish transition through the reach, and then by the size of the fish at tagging. The adjusted fish velocity (V_{FA}) was defined by $V_{FA} = m_r - V_w$, where m_r is the signed (i.e., +/-) migration rate and V_w is the signed average water velocity through the reach during the tag transition through the reach. Both migration rate and water velocity were signed (e.g., assigned + or -) to represent direction, with downstream (toward the ocean) assigned the positive direction and upstream negative. Thus, for fish moving downstream, $V_{FA} < 0$ indicates a fish moving slower than the water velocity, and $V_{FA} > 0$ indicates a fish moving faster than the water velocity. Water velocity was measured at the nearest fixed-point environmental monitoring station, using data available from CDEC at http://cdec.water.ca.gov. In some cases, this station was adjacent to the acoustic receivers located at the upstream or downstream boundary of the reach; in other cases, this station was in the vicinity of the reach, but not actually in it. Each value of V_{FA} was then divided by measured body length of the study fish at tagging to produce body lengths per second (BL/S): $BL/S = V_{FA}/FL$, where FL = fish length at tagging. The values of BL/S may be either positive or negative, depending on whether the fish moved downstream or upstream and whether it moved faster than the observed water velocity. Observed measures of BL/S ranged from -6.5 to 6.7 (mean = -0.8). Hawkins and Quinn (1996) reported critical swimming speeds (a measurement of fish swimming capability against a current) up to 7.5 – 7.9 BL/S for steelhead measuring approximately 100 mm. It was expected that the larger size of the fish used in this study (mean FL = 276.7 mm) would result in a lower maximum BL/S sustainable over the spatial scale of a reach (Brett 1965). The maximum absolute value of BL/S suitable for juvenile steelhead was set at 4.5 (i.e., $-4.5 \leq BL/S \leq 4.5$) at most sites, to take account of uncertainty in the actual water velocity through the reach in question. Some sites had tighter BL/S limits, based on observed values (e.g., $-3 \leq BL/S \leq 3$ in Old River and interior Delta reaches, and $-2 \leq BL/S \leq 2$ during transitions to the Central Valley Project).

Criterion: Residence Time

Residence time was measured on three spatio-temporal scales. The near-field residence time was the duration of the visit-level detection event, where consecutive visits at a given acoustic array (i.e., a dual or redundant array, or a single line of hydrophones) were separated either by a time gap of ≥ 12 hours or by detection elsewhere. The near-field residence time allowed for short-term delays in migration due to tidal influence (e.g., being pushed back into range of the receiver by reverse flow) and short-term rearing in the close vicinity of the receiver. Maximum near-field residence times allowed for smolts were set by reviewing observed residence times in comparison with criteria used in analysis of Chinook detection data (SJRGA 2010, 2013, Table 5-6), but more flexible criteria were used for steelhead (Table 8). In addition, the hydraulic conditions upon arrival at the site were considered, and longer residence times were allowed for smolts that arrived during flood tide or encountered reverse flow conditions. Discussions with steelhead biologists familiar with the Delta also informed the near field residence time criteria.

The mid-field residence time was the time delay from the first detection at a site to the time of the last detection there before detection elsewhere. That is, the mid-field residence time removed the 12-hour limit on detection gaps at a site used to define near-field residence time. Whereas the near-field residence time measured the time a tagged fish spent in or near the detection field of a receiver array, the mid-field residence time measured the time the tagged fish spent in the neighborhood of the site without detection elsewhere. Criteria for mid-field residence time were determined by near-field residence time criteria and the number of visits allowed.

The far-field residence time measured the time a tagged fish spent in the broader region of the study area. Regions were:

- San Joaquin River upstream of the head of Old River,
- San Joaquin River from the head of Old River through the Stockton receivers,
- San Joaquin River from the Turner Cut junction through Medford Island,
- Old River from its head to the Middle River junction,
- Old River from the head of Middle River to Highway 4 (including the water export facilities),
- Middle River from its head to Highway 4, and
- San Joaquin or Sacramento River from Threemile Slough to Chipps Island, including Jersey Point and False River.

Maximum regional residence times allowed for smolts were set at 1,000 hours for the San Joaquin River upstream of the head of Old River and at the Central Valley Project; up to 500 hours in the San Joaquin River downstream of the head of Old River, in Old River and Middle River east of the water export facilities, and at Jersey Point, False River, and Chipps Island; and 800 hours in the western portions of Old River (including the radial gates at the entrance to Clifton Court Forebay).

Criterion: Upstream Transitions

It was assumed that most juvenile steelhead were actively migrating toward the ocean, with some steelhead temporarily rearing in the Delta before outmigrating. The upstream transition criterion was spatially explicit; with the maximum number of upstream forays and upstream river kilometers allowed for juvenile steelhead determined by the location in the study area. Upstream transition criteria were relaxed in the presence of reverse river flow, and allowed for multi-directional movement in the neighborhood of the water export facilities in the southwestern region of the study area. Larger numbers of upstream forays were allowed as steelhead moved into the Delta and encountered more complex hydrodynamics. Steelhead were not expected to make lengthy upstream movements in the San Joaquin River after entering the Delta (i.e., downstream of Mossdale), and upstream transitions from the Delta region of the study area back into the riverine section of the San Joaquin River (i.e., upstream of Mossdale) were considered evidence of predation. A maximum of 25 upstream river kilometers was imposed on all upstream transitions between Chipps Island, Jersey Point, False River, and Threemile Slough, and a maximum of 20 upstream river kilometers was imposed throughout the rest of the study area.

Criterion: Unexpected Transitions

Certain transitions were observed in the data but were unexpected for steelhead. Such unexpected transitions included those from the water export facilities to the Jersey Point/False River region, followed by transitions back upstream in the San Joaquin River to the Medford Island or Stockton region. Extended “cycling” through the Delta was considered evidence of either predation or residualization, and tags exhibiting this type of behavior were classified as predators because they did not appear to conform to the expected behavior of outmigrating steelhead smolts. It was also assumed that steelhead were unlikely to leave the Clifton Court Forebay through the radial gates after first entering there, although this behavior did not automatically classify a tag as in a predator. The tags assumed to have been transported from the holding tanks were used to form the basis for expected behavior, although some of these tags were also observed in cycling behavior following transport and release into the western Delta from Threemile Slough to Chipps Island. Such detections were reviewed in detail with steelhead biologists familiar with the Delta and the Clifton Court Forebay area.

Criterion: Travel Time since Release

The maximum overall travel time since release at Durham Ferry was set at 1,000 hours (approximately 42 days). This assumption was assessed by comparisons with observed detection histories. Tags with longer detection histories typically violated multiple predator filter criteria. Stricter criteria for some upstream detection sites were determined by criteria for migration rate, residence time, and the number of visits allowed.

Criterion: Movements against Flow

It was assumed that juvenile steelhead usually moved with downstream-directed flow, or during periods of slack or flood tide. Arrival at a detection site or departure from a detection site against relatively strong flow (i.e., against the direction of flow and not near slack or flood tide) was considered evidence of predation. Dual or redundant acoustic arrays aided in determination of fish direction, but depended on high detection probabilities and non-identical detection areas.

Spatially Explicit Predator Filter Approach

The criteria used in the predator filter were spatially explicit, with different limits defined for different receivers and transitions (Table 8). The overall approach to various regions is described here.

DFU, DFD = Durham Ferry Upstream (A0) and Durham Ferry Downstream (A2): ignore flow and velocity measures, allow long residence and transition times and multiple visits.

BCA, PCO, MOS = Banta Carbona (A3), Paradise Cut Outside (A4), and Mossdale (A5): allow longer residence time if next transition is directed downstream; may have extra visits if arrival flow is low.

SJL = San Joaquin River near Lathrop (A6): allow longer travel time if low flow during transition; upstream transitions from Stockton sites are not allowed.

ORE = Old River East (B1): allow longer residence time if arrive at low velocity; allow longer travel time if no extremes in water velocity during transition.

STS = Stockton South (A7): allow longer residence time if arrive at peak low tide (low velocity, low change in river stage); repeat visits or transitions from upstream require arrival flow/velocity to be opposite direction from flow/velocity on previous departure.

STN = Stockton North (A8): allow longer residence time if arrive at low velocity or flow.

C18/C16 = Channel Markers 18 and 16 (A9): allow more flexibility (longer residence time, transition time) if transition water velocity was low and positive for downstream transitions, or low and negative for upstream transitions.

MFE/MFW = Medford Island East and West (A10): transitions from Middle River North (C2) must have departed C2 with very low or positive flow/velocity; transitions from Radial Gates (D) not allowed.

TCN/TCS = Turner Cut North and South (F1): should not move against flow; transitions from False River are not allowed.

ORS = Old River South (B2): allow longer transition times from ORE if mean water velocity during transition was low; allow long residence times if coming from upstream/San Joaquin; require shorter residence times if coming from CVP; transitions from Radial Gates (D) and northern Delta Old and Middle River sites (B3, C2) are not allowed.

MRS = Middle River South (C1): shorter residence times than ORS; repeat visits are not allowed.

MRN = Middle River North (C2): should not move against flow on repeat visits; should arrive on negative/low water velocity if arriving from San Joaquin (Stockton); if arrive from water export facilities, should not have left against high pumping (E1) or Clifton Court Forebay inflow (D).

CVP = Central Valley Project (E1): maximum residence time depends on previous site; allow transition from CVPtank back to CVP; transitions from Banta Carbona and upstream allowed only for first release group (when Paradise Cut was open); allow multiple visits.

CVPtank = Central Valley Project holding tank (E2): assume that steelhead can leave tank and return (personal communication, Brent Bridges, USBR).

ORN = Old River North (B3): allow many visits; should not arrive against flow or water velocity; upstream movement from Jersey Point allowed if negative flow on arrival.

RGU/RGD = Radial Gates Upstream/Downstream (D1, D2 = D):

- Assume steelhead smolts can move from D2 back to D1
- Assume steelhead smolts can hold in place during gate opening
- No distinction between near-field and mid-field visit (i.e., gap in detection does not define new visit)
- Residence time may include time spent in river between first arrival at radial gates (RG) and final departure from RG (with no detection elsewhere during "visit")
- Maximum residence time = 80 hours (3.3 days), accounting for gaps in detection, unless:
- if detected at D2 before D1:
    - if the large majority (>80%) of residence time was spent inside CCFB (i.e., at D2, allowing for gaps in detection), then maximum combined residence time = 336 hours (14 days); tags with longer combined residence times appear to have spent a long time inside CCFB before returning to OR, look like predators
    - otherwise = 800 hours (33 days); these tags spent some time in CCFB, then returned to the entrance channel or river, and eventually returned to radial gates; allow longer residence time than those that spent most of visit inside CCFB.

JPT = Jersey Point (G1): no flow/velocity restrictions; allowed for transition from Threemile Slough (TMS/TMN)

FRE/FRW = False River East and West (H1): no flow/velocity restrictions; allowed for transition from TMS/TMN

Constructing Detection Histories

For each tag, the detection data summarized on the "visit" scale was converted to a detection history ("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. Detections were pooled from the multiple receivers located at the Central Valley Project trash racks (CVP). Additionally, detections from the receivers comprising certain dual arrays were pooled, thereby converting the dual arrays to redundant arrays: the San Joaquin River near Lathrop (SJL), Old River East near the head of Old River (ORE), and the radial gates just outside of Clifton Court Forebay (RGU). For some release groups, the receivers comprising the dual array just downstream of the initial release site (DFD) were also pooled in order to achieve a better model fit. The status of the radial gates (opened or closed) was denoted in detection histories that included the receivers just outside the radial gates (RGU).

Survival Model

A multi-state statistical release-recapture model was developed and used to estimate the joint probability of migrating and surviving (i.e., perceived survival) of steelhead smolts through the study area. The release-recapture model is 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 4 shows the layout of the receivers using both descriptive labels for site names and the code names used in the survival model (Table 6). The survival model estimates the joint probability of migrating and surviving through the study area to the primary exit point at Chipps Island (Figure 5- Figure 7). Individual receivers comprising dual arrays were identified separately, where “a” represented the upstream receiver and “b” represented the downstream receiver.

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, A5), then the multi-state statistical release-recapture model estimated perceived survival rather than 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 and past the city of Stockton. Downstream of Stockton, fish in the San Joaquin River route may have remained in the San Joaquin River 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. Of these four exit points from the San Joaquin River between Stockton and Jersey Point, only Turner Cut was monitored and assigned a route name (F, a subroute of route A). Fish that entered the interior Delta from any of these exit points 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 upstream of Chipps Island. All of these possibilities were included in both subroute F and route A.

For fish that entered Old River at its distributary point on the San Joaquin River just upstream of Lathrop (route B), they may have migrated to Chipps Island either by moving northward in either Old or Middle river 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 trashracks (entrance to the facility) 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 encountered was Paradise Cut (Route P), which is accessible from the San Joaquin River between Durham Ferry and Banta Carbona during high water conditions. During all but extremely high water conditions, Paradise Cut is inaccessible. Fish that entered Paradise Cut may have entered Old River downstream of its junction with Middle River, and then moved either to the water export facilities or to downstream reaches of Old River or Middle River. Because Paradise Cut originates upstream of Mossdale Bridge, it is located outside of the study area, and was monitored in order to account for entrainment into that route. Another departure point from the San Joaquin River was False River, just downstream 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 en 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), while Chipps Island (the final exit point) was included in all previously named routes and subroutes except routes P and H. Thus, Jersey Point and Chipps Island were given their own route name (G). An additional set of receivers located in Threemile Slough (Route T) and a single receiver in the Delta Mendota Canal (accessed via Route E) were not used in the survival model. 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: survival
G = Jersey Point, Chipps Island: survival, exit point
H = False River: exit point
P = Paradise Cut: survival, exit point
T = Threemile Slough: not used in survival model

The release-recapture model used parameters that denote the probability of detection (P_{hi}), 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 movement and survival ($\phi_{kj,hi}$) (Figure 6–Figure 8, Table A1). Unique detection probabilities were estimated for the individual receivers in a dual array, with P_{hia} representing the detection probability of the upstream array at station *i* in route *h*, and P_{hib} representing the detection probability of the downstream array.

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 receivers in a dual array, respectively.
>
> S_{hi} = perceived survival probability: joint probability of migration and survival from telemetry station *i* to *i*+1 within route *h*, conditional on surviving to station *i*.
>
> ψ_{hl} = route entrainment 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 entrainment, and survival; the probability of migrating, surviving, and moving from station *j* in route *k* to station *i* in route *h*, conditional on survival to station *j* in route *k*.

The transition parameters involving the receivers outside Clifton Court Forebay (site D1, RGU) depended on the status of the radial gates upon tag arrival at D1. Although fish that arrive at D1 when the gates are closed cannot immediately enter the gates to reach site D2 (RGD), they may linger in the area until the gates open. Thus, parameters $\phi_{B2,D1O}$, $\phi_{B3,D1O}$, $\phi_{C1,D1O}$, $\phi_{C2,D1O}$, and $\phi_{D1O,D2}$ represent transition to and from site D1 when the gates are open, and parameters $\phi_{B2,D1C}$, $\phi_{B3,D1C}$, $\phi_{C1,D1C}$, $\phi_{C2,D1C}$, 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 ($\hat{P}_{D1} \geq 0.80$ for all release groups) (Tables A1, A2 [Appendix A]) in 2011.

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 4). 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. Once at the junction between the San

Joaquin River and False River, fish in the San Joaquin River may either exit to False River or remain in the San Joaquin River to reach Jersey Point. Alternatively, fish that approached the San Joaquin from the interior Delta through False River may either move downstream in the San Joaquin to Jersey Point, or else move upstream away from Jersey Point (deemed less likely for migrating smolts). The complex tidal forces present in this region prevent distinguishing between smolts using False River as an exit from the San Joaquin and smolts using False River as an entrance to the San Joaquin. Thus, we have only the information that a fish was at False River, but not its direction. Regardless of which approach the fish used to reach this junction, the $\phi_{kj,GH}$ parameter (e.g. $\phi_{A9,GH}$, $\phi_{B3,GH}$, or $\phi_{C2,GH}$) 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 5).

For fish that exited the San Joaquin River for the interior Delta downstream of Stockton the parameters $\phi_{B3,D1O}$, $\phi_{B3,D1C}$, $\phi_{B3,E1}$, $\phi_{C2,D1O}$, $\phi_{C2,D1C}$, and $\phi_{C2,E1}$ represent the joint probability of moving from either site B3 or C2 toward to the export facilities and surviving. Similar parameters were not estimated for fish that reached the B3 or C2 sites via Old River within Route B, but rather transition to the export facilities within route B was estimated directly from the head of Middle River (sites B2 and C1) using parameters $\phi_{B2,D1O}$, $\phi_{B2,D1C}$, $\phi_{B2,E1}$, $\phi_{C1,D1O}$, $\phi_{C1,D1C}$, and $\phi_{C1,E1}$. Both routes A and B were used to estimate northward transition probabilities from sites B3 and C2 in the interior Delta to the junction with Jersey Point and False River: $\phi_{B3,GH}$ and $\phi_{C2,GH}$. Likewise, both routes A and B were used to estimate transitions at or within the export facility sites (i.e., $\phi_{D1O,D2}$, $\phi_{D1C,D2}$, and $\phi_{E1,E2}$), as well as transition probabilities from the interior receivers at these sites to Chipps Island (i.e., $\phi_{D2,G2}$ and $\phi_{E2,G2}$). Unique transition probabilities were estimated for route A compared to route B, although common detection probabilities were estimated at shared sites in these two routes.

For fish that reached the interior receivers at the Clifton Court Forebay (CCFB; site 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 5). Some salvaged and transported smolts were released in the San Joaquin River upstream of 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 released in the Sacramento River moved toward Chipps Island without passing Jersey Point and the False River junction, it was not possible to estimate the transition probability to Chipps Island via Jersey Point for salvaged fish. Thus, in the full survival model, 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 Channel Markers on the San Joaquin River, Turner Cut, and Medford Island, 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. 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 through the interior Delta to Chipps Island (Figure 5). Submodel I modeled overall survival from the Turner Cut/Channel Marker region of the San Joaquin River to Chipps Island using parameters $S_{F1,G2}$ and $S_{A9,G2}$, respectively, and omitted detection site A10 (Medford Island). Submodel I modeled detailed subroutes in route B for fish that entered Old River at its upstream junction with the San Joaquin River, including subroutes C, D, and E (i.e., through Middle River and/or the state and federal water export facilities) (Figure 5). Submodel I also included the Paradise Cut route from the San Joaquin River upstream of Mossdale to points in the Delta downstream of the Head of Middle River (Figure 5). 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 (SJL) to model the detailed routing from the lower San Joaquin River near the Channel Markers and Turner Cut through or around the interior Delta to Jersey Point and Chipps Island (Figure 6). Submodel II included the Medford Island detection site (A10), which was omitted from Submodel I because of complex routing in that region.

The two submodels I and II were fit concurrently using common detection probabilities at certain shared receivers: B3 (ORN), C2 (MRN), D1 (RGU), D2 (RGD), E1 (CVP), E2 (CVPtank), G1 (JPT), 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, with detections coming from Route B fish in Submodel I and from Route A fish in Submodel II. Detections at all other sites included in Submodel II either included the same fish as in Submodel I (i.e., sites STS [A7], STN [A8], C16/C18 [A9], TCN/TCS [F1], and CHP [G2]), or else were unique to Submodel II (i.e., site MFE/MFW [A10]); detection probabilities at these sites were estimated separately for submodels I (if included) and II to avoid "double-counting" tags used in both submodels.

A third model (Model III) was fit to data from the fifth and final release group, released in June 2011 and consisting of only 285 tagged fish. Sparse detection data in the interior Delta and lower San Joaquin River prevented estimation of all model parameters from submodels I and II. However, it was possible to estimate overall probability of survival to Chipps Island, and various reach survival and transition probabilities, as well as the route entrainment probability at the head of Old River. Model III removed detection sites in the lower San Joaquin River (A9, A10, G1), interior Delta (B2, B3, C1, C2), Turner Cut (F1), and False River (H1), but included routes through the water export facilities (D1, E1) (Figure 7).

In addition to the model parameters, derived performance metrics measuring migration route probabilities and survival were estimated as functions of the model parameters. Both route entrainment 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 entrainment and route-specific survival were also estimated for the major subroutes of routes A and B. 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 Turner Cut Junction, and B or C at the head of Middle River. Thus, the route entrainment probabilities for the subroutes were:

$\psi_{AA} = \psi_{A2}\psi_{A3}$: probability of remaining in the San Joaquin River past the head of Old River and the Turner Cut Junction,

$\psi_{AF} = \psi_{A2}\psi_{F3}$: probability of remaining in the San Joaquin River past the head of Old River, and exiting to the interior Delta at Turner Cut,

$\psi_{BB} = \psi_{B2}\psi_{B3}$: probability of entering Old River at the head of Old River, and remaining in Old River past the head of Middle River,

$\psi_{BC} = \psi_{B2}\psi_{C3}$: probability of entering Old River at the head of Old River, and entering Middle River at the head of Middle River,

where $\psi_{B2} = 1 - \psi_{A2}$, $\psi_{F3} = 1 - \psi_{A3}$, and $\psi_{C3} = 1 - \psi_{B3}$.

The probability of surviving from the entrance of the Delta near Mossdale Bridge (site A5, MOS) to Chipps Island was estimated as the product of the survival probabilities that trace that pathway:

$S_{AA} = S_{A5}S_{A6}S_{A7}S_{A8}S_{A9,G2}$: Delta survival for fish that remained in the San Joaquin River past the head of Old River and Turner Cut,

$S_{AF} = S_{A5}S_{A6}S_{A7}S_{A8}S_{F1,G2}$: Delta survival for fish that entered Turner Cut from the San Joaquin River,

$S_{BB} = S_{A5}S_{B1}S_{B2,G2}$: Delta survival for fish that entered Old River at its head, and remained in Old River past the head of Middle River,

$S_{BC} = S_{A5}S_{B1}S_{C1,G2}$: Delta survival for fish that entered Old River at its head, and entered Middle River at its head.

The parameters $S_{A9,G2}$ and $S_{F1,G2}$ represent the probability of getting to Chipps Island from A9 and F1, respectively. Both parameters represent multiple pathways around or through the Delta to Chipps Island (Figure 4). Fish that were detected at the A9 receivers (Channel Markers) 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 included in the $S_{A9,G2}$ and $S_{F1,G2}$ parameters, and were estimated directly using Submodel I.

Survival probabilities $S_{B2,G2}$ and $S_{C1,G2}$ represented survival of fish to Chipps Island that remained in the Old River at B2 (ORS), or entered the Middle River at C1 (MRS), 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 4). Because there were many unmonitored river junctions 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 could be estimated to the next receivers along a route (i.e., the $\varphi_{kj,hi}$ parameters defined above and in Figure 5). The overall survival probability from B2 ($S_{B2,G2}$) or C1 ($S_{C1,G2}$) to Chipps Island was defined by summing products of the $\varphi_{kj,hi}$ parameters:

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

$$S_{C1,G2} = \left(\phi_{C1,D1O}\phi_{D1O,D2} + \phi_{C1,D1C}\phi_{D1C,D2}\right)\phi_{D2,G2} + \phi_{C1,E1}\phi_{E1,E2}\phi_{E2,G2} + \left(\phi_{C1,B3}\phi_{B3,GH} + \phi_{C1,C2}\phi_{C2,GH}\right)\psi_{G1}\phi_{G1,G2}$$

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 B3 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 $\phi_{B3,GH}$ and $\phi_{C2,GH}$, representing the probability of moving from site B3 or C2, respectively, to the False River junction with the San Joaquin.

Both route entrainment 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 entrainment parameters were defined as:

$\psi_A = \psi_{A2}$: probability of remaining in the San Joaquin River at the head of Old River

$\psi_B = \psi_{B2}$: probability of entering Old River at the head of Old River.

The probability of surviving from the entrance of the Delta (site A5, 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-entrainment probabilities:

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

$S_B = \psi_{B3}S_{BB} + \psi_{C3}S_{BC}$: Delta survival for fish that entered Old River at the head of Old River.

Using the estimated migration route probabilities and route-specific survival for these two primary routes (A and B), survival of the population from A5 (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 in river, without being trucked from either of the water export facilities. The route-specific Mid-Delta survival for the large-scale San Joaquin River and Old River routes was defined as follows:

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

$S_{B(MD)} = \psi_{B3} S_{BB(MD)} + \psi_{C3} S_{BC(MD)}$: Mid-Delta survival for fish that entered Old River at its head, where

$$S_{AA(MD)} = S_{A5} S_{A6} S_{A7} S_{A8} \left[\phi_{A9,GH} + \phi_{A9,A10} \phi_{A10,GH} + \left(\phi_{A9,B3} + \phi_{A9,A10} \phi_{A10,B3} \right) \phi_{B3,GH} + \left(\phi_{A9,C2} + \phi_{A9,A10} \phi_{A10,C2} \right) \phi_{C2,GH} \right],$$

$$S_{AF(MD)} = S_{A5} S_{A6} S_{A7} S_{A8} \left[\phi_{F1,GH} + \phi_{F1,B3} \phi_{B3,GH} + \phi_{F1,C2} \phi_{C2,GH} \right],$$

$$S_{BB(MD)} = S_{A5} S_{B1} \left(\phi_{B2,B3} \phi_{B3,GH} + \phi_{B2,C2} \phi_{C2,GH} \right), \text{ and}$$

$$S_{BC(MD)} = S_{A5} S_{B1} \left(\phi_{C1,B3} \phi_{B3,GH} + \phi_{C1,C2} \phi_{C2,GH} \right).$$

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.

Survival was also estimated through the southern portions of the Delta ("Southern Delta" or SD), within each primary route and overall:

$$S_{A(SD)} = S_{A5} S_{A6} S_{A7} S_{A8}, \text{ and}$$

$$S_{B(SD)} = S_{A5} S_{B1} \left(\psi_{B3} S_{B2(SD)} + \psi_{C3} S_{C1(SD)} \right),$$

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

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

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

Total survival through the Southern Delta was defined as:

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

The probability of reaching Mossdale from the release point at Durham Ferry, ϕ_{A1A5}, was defined as the product of the intervening reach survival probabilities and the probability of remaining in the San Joaquin River at Paradise Cut:

$$\phi_{A1A5} = \phi_{A1A2} S_{A2} S_{A3} \psi_{A1} S_{A4}.$$

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

In cases where sparse detection data prevented fitting the full model (i.e., both Submodel I and Submodel II), some parameters were inestimable. This was the case for the final release group (released in mid-June), which used fewer fish than previous release groups. In such cases, routing and survival estimates were available on the larger spatial scales but not on the smaller spatial scales. Overall Delta survival, route entrainment at the head of Old River, and route-specific survival in the primary routes were estimated and reported in this case.

Individual detection histories (i.e., capture histories) were constructed for each tag as described above. Each detection history consisted of one or more fields representing initial release (field 1) and the sites where the tag was detected, in chronological order. Detection on both receivers in a dual array was denoted by the code “ab”, detection on only the upstream receiver was denoted “a0”, and detection on only the downstream receiver was denoted “b0.” For example, the detection history DF A2a0 A4 A6 A7 A8 A9ab A10b0 G1a0 G2ab represented a tag that was released at Durham Ferry and detected at the first (but not the second) receiver just downstream of the release site (A2a0), on the San Joaquin River site just downstream of Paradise Cut (A4), on at least one of the receivers at Lathrop (A6b0, site SJLD), on both receivers near Stockton (A7, A8), on both receivers at the Channel Marker just downstream of Turner Cut (A9ab), on the second receiver located at Medford Island (A10b0), on the first receiver at Jersey Point (G1a0), and at both receivers at Chipps Island (G2ab). In Submodel I, the detections at A10 and G1 were not modeled, yielding Submodel I probability

$$\phi_{A1,A2}P_{A2a}\left(1-P_{A2b}\right)S_{A2}\left(1-p_{A3}\right)S_{A3}\psi_{A1}P_{A4}S_{A4}\left(1-P_{A5}\right)S_{A5}\psi_{A2}P_{A6}S_{A6}P_{A7}S_{A7}P_{A8}S_{A8}\psi_{A3}P_{A9a}P_{A9b}S_{A9,G2}P_{G2a}P_{G2b}.$$

In Submodel II, this detection history was parameterized starting at the virtual release at site A6 and included detections at A10 and G1:

$$S_{A6}P_{A7}S_{A7}P_{A8}S_{A8}\psi_{A3}P_{A9a}P_{A9b}\phi_{A9,A10}\left(1-P_{A10a}\right)P_{A10b}\phi_{A10,GH}\psi_{G1}P_{G1a}\left(1-P_{G1b}\right)\phi_{G1,G2}P_{G2a}P_{G2b}.$$

Another example is the detection history DF A2ab A5 A6 A8 F1a0 B3b0 E1 E2 G2ab. A fish with this detection history was released at Durham Ferry, migrated downstream in the San Joaquin River past the head of Old River with detections at the receivers just downstream of Durham Ferry (A2ab), Mossdale (A5), Lathrop (A6), and Stockton North (A8), then exited the San Joaquin River at Turner Cut with detection only on the first receiver there (F1a0), went southwest to the Old River North receivers near Highway 4 with detection only on the downstream receiver (B3b0), then went to the Central Valley Project trashracks and holding tank (E1, E2), and finally on to Chipps Island with detection on both lines (G2ab). This detection history is modeled partially in Submodel I and partially in Submodel II. In Submodel I, the probability is parameterized as follows:

$$\begin{aligned}&\phi_{A1,A2}P_{A2a}P_{A2b}S_{A2}\left(1-P_{A3}\right)S_{A3}\psi_{A1}\left(1-P_{A4}\right)S_{A4}P_{A5}S_{A5}\psi_{A2}P_{A6}S_{A6}\left(1-P_{A7}\right)S_{A7}P_{A8}\\&\times S_{A8}\psi_{F3}P_{F1a}\left(1-P_{F1b}\right)S_{F1,G2}P_{G2a}P_{G2b}.\end{aligned}$$

In Submodel II, the detection history is parameterized:

$$S_{A6}\left(1-P_{A7}\right)S_{A7}P_{A8}S_{A8}\psi_{F3}P_{F1a}\left(1-P_{F1b}\right)\phi_{F1,B3}\left(1-P_{B3a}\right)P_{B3b}\phi_{B3,E1}P_{E1}\phi_{E1,E2}P_{E2}\phi_{E2,G2}P_{G2a}P_{G2b}.$$

A third example is the detection history DF A3 A4 A5 B2ab D1O D2b0. A fish with this detection history was released at Durham Ferry, migrated downstream without detection on the dual array just downstream of Durham Ferry but with detection at Banta Carbona (A3), the San Joaquin site just downstream of Paradise Cut (A4), and the site near Mossdale Bridge (A5), entered Old River without detection until the array in Old River just past the head of Middle River (B2ab), and then moved to Clifton Court Forebay with detections on one or more of the receivers outside the radial gates when the gates were open (D1O), and finally on the second receiver inside the radial gates. The tag was not detected again after passing the inside receiver (D2b0). The probability of having this detection history is (in Submodel I)

$$\phi_{A1,A2}\left(1-P_{A2a}\right)\left(1-P_{A2b}\right)S_{A2}P_{A3}S_{A3}\psi_{A1}P_{A4}S_{A4}P_{A5}S_{A5}\psi_{B2}\left(1-P_{B1}\right)S_{B1}\psi_{B3}$$
$$\times P_{B2a}P_{B2b}\phi_{B2,D1O}P_{D1O}\phi_{D1O,D2}\left(1-P_{D2a}\right)P_{D2b}\chi_{D2},$$

where

$$\chi_{D2}=1-\phi_{D2,G2}+\phi_{D2,G2}\left(1-P_{G2a}\right)\left(1-P_{G2b}\right)$$

is the probability of not being detected again after reaching site D2. This detection history is not represented in Submodel II.

A fourth example of a detection history is DF A2b0 A3 A5 B1 C1 B3ab H1a0. A fish with this detection history moved downstream after release at Durham Ferry, with detection on the second of the two receivers at the downstream Durham Ferry site (A2b0), at Banta Carbona (A3), and at Mossdale (A5). The fish then entered Old River with detection on one or more of the receivers at ORE (B1), entered Middle River (C1), moved to the Old River site near Highway 4 and was detected on both receivers there (B3ab), and finally was last detected on the first receiver of the dual array located at False River (H1a0). The probability of this detection history occurring is parameterized as follows (in Submodel I):

$$\phi_{A1,A2}\left(1-P_{A2a}\right)P_{A2b}S_{A2}P_{A3}S_{A3}\psi_{A1}\left(1-P_{A4}\right)S_{A4}P_{A5}S_{A5}\psi_{B2}P_{B1}$$
$$\times S_{B1}\psi_{C3}P_{C1}\phi_{C1,B3}P_{B3a}P_{B3b}\phi_{B3,GH}\psi_{H1}P_{H1a}\left(1-P_{H1b}\right).$$

Another example is the detection history DF A2ab P1ab B3b0 G2a0, from a fish that was detected at both receivers just downstream of the release site (A2ab), entered Paradise Cut and was detected on both receivers there, survived to exit Paradise Cut on the northern end and eventually made its way to the Old River receivers near Highway 4 where it was detected on the second but not the first receiver (B3b0), and then reached Chipps Island with detection on only the first receiver (G2a0). The probability of this detection history is (in Submodel I)

$$\phi_{A1,A2}P_{A2a}P_{A2b}S_{A2}\left(1-P_{A3}\right)S_{A3}\psi_{P1}P_{P1a}P_{P1b}\phi_{P1,B3}\left(1-P_{B3a}\right)P_{B3b}$$
$$\times\phi_{B3,GH}\psi_{G1}\left(1-P_{G1a}\right)\left(1-P_{G1b}\right)\phi_{G1,G2}P_{G2a}\left(1-P_{G2b}\right).$$

Finally, a fish that went upstream from the release site (e.g., a residualizing steelhead) may have the detection history DF A0ab, with probability $\phi_{A1,A0}P_{A0a}P_{A0b}$.

Under the assumptions of common survival, route entrainment, 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 each possible capture history.

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 and Skalski 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, and detection probabilities were fixed to 1.0 or 0.0 as appropriate, based on the observed detections. The model was fit separately for each release, as well as for certain pooled groups of releases. For each release, the complete data set that included possible detections from predatory fish was analyzed separately from the reduced data set restricted to detections classified as steelhead smolt detections.

Population-level estimates of parameters and performance measures, representing all five release groups, were estimated as weighted averages of the release-specific estimates, using weights proportional to release size. Parameter and performance measure estimates representing 2-4 release groups were estimated by pooling the data from the pertinent release groups before fitting the model. This is approximately equivalent to calculating a weighted average of the release-specific estimates, with weights proportional to release size, in the case where all releases considered provide each parameter estimate. In the event that some parameters are inestimable from particular releases because of sparse data, pooling across release groups provides more robust parameter estimates than a weighted average. Population-level measures were not estimated directly from pooling all five release groups because of the expected large differences in performance between the first release group (released in March) and the remaining four release groups (released in May and June). The central and northern Delta receivers were not used to model the migration for the final release group (June) because of sparse data, and the Paradise Cut receivers were omitted from the first release group (March) because they were installed after the first release date.

The significance of the radial gates status on arrival at the outside receiver (RGU, site D1) was assessed for the first release group alone and for the final 4 release groups pooled, using a difference in Akaike Information Criterion (AIC) $\geq$ 2 to indicate a significant difference in model fit (Burnham and Anderson 2002). If the effect of the gates had been found to be insignificant using this criterion, then a simplified model would have been used for parameter estimation in which $\varphi_{B2,D1O} = \varphi_{B2,D1C}$, $\varphi_{C1,D1O} = \varphi_{C1,D1C}$, $\varphi_{B3,D1O} = \varphi_{B3,D1C}$, $\varphi_{C2,D1O} = \varphi_{C2,D1C}$ and $\varphi_{D1O,D2} = \varphi_{D1C,D2}$. In each case, however, the gate status was found to have a significant effect on model fit, and so the full model that incorporated gate status was used for parameter estimation. For each model, goodness-of-fit was assessed visually using Anscombe residuals (McCullagh and Nelder 1989). The effect of including detection histories with large Anscombe residuals on estimates of parameters and performance metrics was assessed for each release group.

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:

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

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. Survival estimates to Jersey Point and False River ($S_{A(MD)}$, $S_{B(MD)}$, and $S_{total(MD)}$) were also compared in this way. Also tested was whether tagged steelhead smolts showed a preference for either the San Joaquin River route or the Old River route using a two-sided *Z*-test with the test statistic:

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

Statistical significance was tested at the 5% level (p=0.05).

Analysis of Tag Failure

The first of three tag-life studies began on March 21, 2011, with the last tag failure recorded on July 6, 2011. The second tag-life study began on May 23, 2011, and the last tag failure was recorded on September 8, 2011. The third tag-life study began on June 15, 2011, and the last tag failure was recorded on November 1, 2011. Observed tag survival was modeled using the 4-parameter vitality curve (Li and Anderson, 2009).

Receiver malfunction during the March tag-life study resulted in missing failure times for 8 tags, yielding interval-censored failure time data for these 8 tags (e.g., failure for 4 tags occurred sometime between June 10, 2011, 5:00 PM, and June 13, 2011, 11:00 PM). Several statistical approaches were compared to account for the missing failure times. The selected approach censored the missing values with no attempt to impute the missing failure times. For more information about the approaches considered, see SJRGA (2013, Chapter 5). A single tag in the June tag-life study was never detected, and was removed from analysis.

Tag life was expected to vary with both tag period and water temperature. Differences in observed tag life were investigated both among the March, May, and June tag-life studies, and among tags with different periods. For each tag-life study, the observed tag survival data and the fit of the estimated tag survival model to the data were examined visually. In particular, two methods of stratifying the combined tag survival data from the two tag-life studies were compared: (1) stratify by study month (i.e., March vs. May vs. June) and group across all tag periods, and (2) stratify by tag period (i.e., 5000-7999 vs. 8000-11000) and group across month. Stratifying by both study month and tag period resulted in small sample sizes, and so was not considered. Stratifying by either tag period or study month had no significant effect on fit of the tag survival model, and so tag failure times from all three tag-life studies and across all periods were pooled for modeling tag survival. For more detailed information on comparisons of tag-failure data using different stratifications, see SJRGA (2011, Chapter 5).

The fitted tag survival model 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. In order to account for possible differences in travel time to Chipps Island using the various routes (e.g., San Joaquin route and Old River route), travel time and the probability of tag survival to Chipps Island were estimated separately for the different routes. Subroutes using truck transport were handled separately from subroutes using only in-river travel. Standard errors of the tag-adjusted fish survival and transition probabilities were estimated using the inverse Hessian matrix of the fitted joint fish-tag survival model. The additional uncertainty introduced by variability in tag survival parameters was not estimated, with the result that standard errors may have been slightly low. In previous studies, however, variability in tag-survival parameters has been observed to contribute little to the uncertainty in the fish survival estimates when compared with other, modeled sources of variability (Townsend et al., 2006); thus, the resulting bias in the standard errors was expected to be small.

Analysis of Tagger Effects

Tagger effects were analyzed using 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 tagger was tested using a chi-squared test ($p=0.05$; Sokal and Rohlf, 1995). Lack of independence may be caused by differences in survival, route entrainment, or detection probabilities. The reduced data set (without predator detections), pooled over release groups, was used for this analysis.

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. The harmonic mean was used to summarize travel times.

Route Entrainment Analysis

The effects of changes in hydrologic conditions on route entrainment at the head of Old River were explored using statistical generalized linear models (GLMs) with a binomial error structure and logit link (McCullagh and Nelder, 1989). Acoustic tag detections used in this analysis were restricted to those detected at either of the acoustic receiver arrays just downstream of the head of Old River: site SJL (model code A6) or site ORE (code B1). Predator-type detections were excluded because there was very little difference in route entrainment probabilities with and without predator-type detections. Detections from 2,194 tags were used in this analysis.

Hydrologic conditions were represented in several ways, primarily total river flow (discharge) and water velocity. Flow and water velocity were recorded at 15-minute intervals at DWR gaging stations located just downstream of the head of Old River in both the San Joaquin River (station SJL) and Old River (station OH1) (Table 7). Conditions measured at the SJL station were labeled route A, and conditions at the OH1 station were labeled route B.

For each tag, conditions were measured at the estimated time of arrival of the tagged fish at the gaging station in its route. Time of arrival had to be estimated because the acoustic receivers were located at some distance downstream from the gaging stations (0.34 to 0.93 km). Arrival time for tag i (t_i) was estimated based on the first-order assumption of constant movement during the transition from the previous detection site.

The gaging stations typically recorded flow and velocity measurements every 15 minutes. Some observations were missing. In 2011, measurements at the SJL station occurred every 3 hours before May 20. Linear interpolation was used to estimate the flow and velocity conditions at the time of tag arrival at the gaging station:

$$Q_{ih} = w_i Q_{t_1(i)h} + (1 - w_i) Q_{t_2(i)h}$$
$$V_{ih} = w_i V_{t_1(i)h} + (1 - w_i) V_{t_2(i)h}$$

where $Q_{t_1(i)h}$ $\left(V_{t_1(i)h}\right)$ and $Q_{t_2(i)h}$ $\left(V_{t_2(i)h}\right)$ are the two observed measures of flow (velocity) at the gaging station in route h $(h = A, B)$ nearest in time to the time t_i of tag i arrival such that $t_1 \le t_i \le t_2$. The weights w_i were defined as

$$w_i = \frac{t_{2(i)} - t_i}{t_{2(i)} - t_{1(i)}},$$

and resulted in weighting Q_{ih} and V_{ih} toward the closest flow or velocity observation.

In cases with a short time delay between consecutive flow and velocity observations (i.e., $t_2 - t_1 \le 60$ minutes), the change in conditions between the two time points was used to represent the tidal stage (Perry et al. 2010):

$$\Delta Q_{ih} = Q_{t_2(i)h} - Q_{t_1(i)h}$$
$$\Delta V_{ih} = V_{t_1(i)h} - V_{t_1(i)h}$$

for h = route A or B, and tag i.

The proportion of total flow entering each river at the time of tag arrival was measured as

$$pQ_{iA} = \begin{cases} \dfrac{Q_{iA}}{Q_{iA} + Q_{iB}}, & \text{for } Q_{iA} \ge 0 \\ 0, & \text{for } Q_{iA} < 0 \end{cases}$$

into the San Joaquin River, and

$$pQ_{iB} = 1 - Q_{iA} \text{ into Old River.}$$

It was assumed that the direction of flow at the Old River gaging station (OH1) was always positive, i.e., directed away from the head of Old River. This was the case throughout the tagging study in 2011. Thus, flow proportion values of 0 into the San Joaquin River indicated negative flow into the San Joaquin River and positive flow into Old River.

As with measures of flow and velocity, the flow proportion into the San Joaquin River was measured at the two time points before and after tag arrival: $pQ_{t_1(i)A}$ and $pQ_{t_2(i)A}$. If $t_2 - t_1 \leq 30$ minutes, then the change in flow proportion into the San Joaquin River at the time of arrival of tag i was measured by

$$\Delta pQ_{iA} = pQ_{t_2(i)A} - pQ_{t_1(i)A}.$$

Flow reversal in the San Joaquin River was represented by the indicator variable U (Perry et al. 2010):

$$U_i = \begin{cases} 1, & for\ Q_{iA} < 0 \\ 0, & for\ Q_{iA} \geq 0 \end{cases}$$

Daily export rate was measured at the Central Valley Project (E_{iCVP}), the State Water Project (E_{iSWP}), and totaled throughout the Delta (E_{iTot}) (data downloaded from DayFlow on October 26, 2012). Fork length at tagging L_i and release group RG_i were also considered. All continuous covariates were standardized, i.e.,

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

for the observation x of covariate j from tag i.

The form of the generalized linear model was

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

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).

Single-variate regression was performed first, and covariates were ranked by P-values from the appropriate F-test (McCullagh and Nelder 1989). Covariates found to be significant alone

$(\alpha = 0.05)$ were then analyzed together in a series of multivariate regression models. Because of high correlation between flow and velocity, flow and velocity models were considered separately. Likewise, exports at CVP and SWP were considered separately. The general forms of the three multivariate models were:

Flow model: $Q_A + Q_B + \Delta Q_A + \Delta Q_B + U_A + E_{Tot} + L + RG$

Flow proportion model: $pQ_A + \Delta pQ_A + U_A + E_{Tot} + L + RG$

Velocity model: $V_A + V_B + \Delta V_A + \Delta V_B + U_A + E_{Tot} + L + RG.$

Backwards selection with F-tests was used to find the most parsimonious model that explained the most variation in the data (McCullagh and Nelder 1989). AIC was used to select among the flow, flow proportion, and velocity models. Model fit was assessed by grouping data into discrete classes according to the independent covariate, and comparing predicted and observed frequencies of route entrainment 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 facilities to release after salvage and trucking on the San Joaquin or Sacramento rivers. Overall facility survival from the receivers at site $k2$, $S_{k2(facility)}$ $(k = D, E)$, was defined as

$$S_{k2(facility)} = \phi_{k2,GH} + \phi_{k2,G2},$$

where $\phi_{k2,G2}$ is as defined above, and $\phi_{k2,GH}$ is the joint probability of surviving from site $k2$ to the Jersey Point/False River junction and not going on to Chipps Island. The parameter $S_{E2(facility)}$ is survival from entering the holding tanks at the Central Valley Project to release from the truck, while the parameter $S_{D2(facility)}$ is survival from arrival inside the radial gates at the Clifton Court Forebay to release from the truck. The subset of detection histories that included detection at site $k2$ $(k = D, E)$ were used for this analysis.

Results

Detections of Acoustic-Tagged Fish

There were 2,196 tags released in juvenile steelhead at Durham Ferry in 2011. This number includes two tags that could not be verified, and thus were not released (Table 2) but were erroneously included in the tagging database and used for the subsequent analyses. We do not anticipate any significant changes in survival due to including these two fish in the survival modeling.

Of these, 2,159 (98%) were detected on one or more receivers either upstream or downstream of the release group (Table 10), including any predator-type detections. A total of 2,026 tags (92%)

were detected at least once downstream of the release site, and 1,242 (57%) were detected in the study area from Mossdale to Chipps Island (Table 10). A higher proportion of the first release group (72%) was detected in the study area than of the later release groups (36% - 55%).

Overall, there were 641 tags detected on one or more receivers in the San Joaquin River route downstream of the head of Old River (Table 10). In general, tag detections decreased within each migration route as distance from the release point increased. Of these 641 tags, 609 were detected on the receivers near Lathrop; 569 were detected on one or both of the receivers near Stockton; 531 were detected on the receivers near the Channel Markers in the San Joaquin River or in Turner Cut; and 314 were detected at Medford Island (Table 11). Not all of the 641 tags detected in the San Joaquin River downstream of the head of Old River were assigned to that route for the survival model, because some were subsequently detected in the Old River route or upstream of Old River. Overall, 593 tags were assigned to the San Joaquin River route for the survival model (Table 10). Of these 593 tags, 128 were observed exiting the San Joaquin River at Turner Cut, 93 were observed at the Old or Middle River North receivers in the interior Delta near Highway 4, and 77 were observed at the water export facilities receivers (including the radial gates at the entrance to the Clifton Court Forebay) (Table 11). Over 300 San Joaquin River route tags were detected at the Jersey Point/False River receivers (323), 122 of these tags were detected on the False River receivers (Table 11). However, the majority of the tags detected at False River were later detected either at Jersey Point or Chipps Island, and so only 5 San Joaquin River tags were used in the survival model at False River (Table 12). A total of 364 San Joaquin River route tags were eventually detected at Chipps Island, including predator-type detections (Table 11).

A total of 610 tags were detected in the Old River route, with 581 of which were detected at the Old River East receivers near the head of Old River, 553 were detected near the head of Middle River, and 474 were detected either at the receivers at the water export facilities, or at the Old or Middle River North receivers near Highway 4 in the interior Delta (Table 10, Table 11). Only 35 tags were detected on the Middle River South receivers, near the head of Middle River; 48 tags appear to have reached the Middle River North receivers via either Old River or Middle River. A total of 188 tags were observed at the Old River North receivers coming from the upper Old River region, although some of these tags were subsequently detected at the Central Valley Project trashracks or the Clifton Court Forebay radial gates.

Some of the 610 tags detected in the Old River route were assigned to the San Joaquin River route for the survival model because they were subsequently detected in the San Joaquin River after their Old River route detections. In all, 560 tags were assigned to the Old River route at the head of Old River based on the full sequence of tag detections (Table 10). Of these 560 tags, 187 were detected at the Old River North receivers, although only 121 of these Old River North detections were used in the survival model because the others were later detected at the water export facilities or the Middle River North receivers (Table 11, Table 12). Likewise, while 156 tags from the Old River route were detected at the Central Valley Project, only 92 were used in the survival model there because the others were subsequently detected either at the radial gates or at the Old River North or Middle River North receivers. Of the 254 Old River route tags detected at the radial gates, 235 were used in the survival model there. A total of 173 Old River route tags were detected at the Jersey Point/False River receivers. Despite the fact that 105 Old River route tags were detected at False River, the majority of them were later detected at either

Jersey Point or Chipps Island, and so only 4 Old River route tags were modeled at False River in the survival model. Of the 560 tags assigned to the Old River route at the head of Old River, 327 were detected at Chipps Island, including predator-type detections. Two tags reached Chipps Island without prior detection in either route.

Some receiver locations were used in the predator filter but were purposely omitted from the survival model. The receiver located in the Delta Mendota Canal (DMC) recorded detections of 10 tags, 4 of which were subsequently detected on the CVP receivers. Seventy-three (73) tags were detected on the Threemile Slough receivers: 48 tags came directly from the San Joaquin River receivers (Medford Island, Channel Markers), 20 from Jersey Point or False River, 3 from the Old River North or Middle River North receivers, and 2 from the salvage facilities. A total of 262 tags were detected on the Chipps Island North receivers (CHPn). Because of this receiver's proximity to the entrance to Spoonbill Creek, these detections were omitted from the survival model. All but 22 of the 262 tags detected at CHPn were also detected on the Chipps Island array receivers used in the survival model.

The predator filter used to distinguish between detections of juvenile steelhead and detections of predatory fish that had eaten the tagged steelhead classified 435 of the 2,196 tags (20%) released as being detected in a predator at some point during the study (Table 13). Of the 1,242 tags detected in the study area (i.e., at Mossdale or points downstream), 190 tags (15%) were classified as being in a predator at some point in the study area. The region upstream of Mossdale had a large percentage of tags (245 of 2,150 tags, or 11%) classified as in a predator at some point (Table 13). Within the study area, the detection sites with the largest number of first-time predator-type detections were Mossdale (39 of 888, 4%), Old River East (48 of 581, 8%), and Old River South (26 of 530, 5%). Most predator classifications were assigned to tags on arrival at the detection site in question because of unexpected travel time or unexpected transitions between detection sites, with the result that predator-type detections at those sites were removed from the survival model. Predator classifications on departure from a detection site were typically because of long residence times, and were most prevalent upstream of the study area, at Mossdale, and at Old River East (Table 13).

When the detections classified as coming from predators were removed from the detection data, somewhat fewer detections were available for survival analysis (Table 14, Table 15, and Table 16). With the predator-type detections removed, 2,015 of the 2,196 (92%) tags released were detected downstream of the release site, and 1,218 (55% of those released) were detected in the study area from Mossdale to Chipps Island (Table 14). The March release group had a higher percentage (72%) of tags released subsequently detected within the study area than the later release groups (36% to 55%), and the June release group had the lowest percentage (36%). Slightly more steelhead were observed using the San Joaquin River route at the head of Old River (591) than the Old River route (569) (Table 14). As observed from the full data set including the predation-type detections, the reduced data set with only steelhead-type detections showed that the majority of the tagged steelhead that arrived at the Old River North receivers came via the Old River route (186) rather than the San Joaquin River route (58), although the San Joaquin River route numbers increased throughout the season (Table 15). However, equal numbers of tagged steelhead (98) arrived at the Middle River North receivers from the two routes, with more steelhead arriving there from the Old River route in the March release group, and more arriving via the San Joaquin River route in the May and June release groups (Table

15). No steelhead from the March release group arrived at the water export facilities via the San Joaquin River route, but numbers increased for the May and June releases (Table 15). The largest numbers of tagged steelhead arriving at Jersey Point, False River, and Chipps Island came from the March release group, and the smallest from the June release group (which was only approximately 60% the size of the earlier release groups) (Table 15). After detection histories were condensed to the final passages past each site and junction, the numbers of detections at certain sites decreased. This was especially the case at False River, where a total of 218 tagged steelhead were detected, but only 9 detections were modeled there because the majority of False River detections were followed by detections at either Jersey Point or Chipps Island (Table 15, Table 16). Detection counts at Middle River North were fewer after multiple passages were removed, as well, as many tagged steelhead detected there were subsequently detected at either Old River North, or at the water export facilities (Table 16).

Tagger Effects

Fish in the release groups were not evenly distributed across tagger (Table 17); a chi-squared test found a lack of independence of tagger across release groups (*P*<0.0001). The lack of independence was caused by the low numbers of fish tagged by tagger C in the second release group, which left the other taggers with more fish to tag for that release group. There was good distribution of taggers across the remaining release groups, however (*P*=1.0), and of taggers A, B, and D across fish within the second release group itself (*P*=0.9911). The distribution of tags detected at various key detection sites was well-distributed across taggers, showing no evidence of a tagger effect on survival, route entrainment, or detection probabilities at these sites (χ^2 = 49.2415, df = 63, *P*=0.8976; Table 18).

Tag-Survival Model and Tag-Life Adjustments

The Akaike Information Criterion (AIC) indicated that pooling data from all three tag-life studies and also across all tag periods (AIC = 18.9) was preferable to stratifying by either study month (AIC =50.2) or by tag period (AIC = 35.0). Thus, a single tag survival model was fitted and used to adjust fish survival estimates for premature tag failure. The estimated mean time to tag failure was 83.1 days (*SE*=15.5; “SE” = estimated standard error) (Figure 8). The complete set of detection data, including detections classified as coming from predators, included some detections that occurred well after the tags began dying (Figure 9, Figure 10). The late arrival times of tagged steelhead to various receivers occurred at the receivers located just downstream of the Durham Ferry release site (site DFD), at Paradise Cut, at Mossdale, and at Chipps Island (Old River route): the latest tags arrived between 65 and 80 days after release (Figure 9, Figure 10). The long detection histories and late detections observed at these sites were interpreted as likely to have come from predatory fish that had eaten the study fish. When the detections classified as coming from predators were removed, most of the remaining detections occurred well before tags in the tag-life study started dying. However, the downstream receivers at Durham Ferry (site DFD) retained several late-arriving detections, with the final tag arriving at day 68 after tag activation (Figure 11). Arrival distributions to sites downstream of the head of Old River were considerably shorter without the predator-type detections than with such detections (Figure 11, Figure 12). Tag-life corrections were made to survival estimates for both sets of detections (with and without predator-type detections). The majority of the estimates of acoustic tag survival through individual reaches in the study area were greater than 0.99, out of a possible range of 0 – 1; with the minimum tag reach survival was estimated at 0.93 (Turner Cut to False River including 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.

Survival and Route Entrainment Probabilities

Results are reported on the population level as weighted averages of the release-specific results for all five release groups. Additionally, results are reported for the March release group (group 1) separately from the May and June release groups (groups 2 – 5, pooled), and for each release group singly.

The model selection process identified the most parsimonious model that adequately fit the data, based on AIC. For both the reduced data set without predator-type detections, and the full data set that included predator-type detections, the most appropriate model estimated unique transition parameters to and from the receivers located outside the radial gates at the Clifton Court Forebay depending on gate status (i.e., AIC was smaller with gate effect). This was true for the March release group alone (ΔAIC= 32.2 without predator-type detections, and ΔAIC = 33.5 with predator type detections), and for the May and June release groups pooled (ΔAIC = 125.7 without predator-type detections, and ΔAIC = 128.6 with predator type detections).

Some parameters were unable to be estimated for certain release groups because of sparse data. In particular, the Paradise Cut receivers were installed after the first release group was released in March, and also after Paradise Cut itself became inaccessible to fish because the river flows had decreased below 18,000 cfs (Mike Archer, personal communication) (Figure 13). This meant that none of the Paradise Cut receivers (PCIa, PCIb, and PCO) were available for the first release group because the majority had already passed that region by the time the receivers were in place. As a result, for the first release group it was impossible to estimate either the route entrainment probability ψ_{P1} into Paradise Cut or its complement ψ_{A1}, the probability of staying in the San Joaquin River at Paradise Cut. It was also not possible to estimate survival to Paradise Cut, or survival from Paradise Cut to downstream detection sites, for the first release group. Instead, transition probabilities from Banta Carbona to the downstream detection sites were estimated directly in the survival model: $\phi_{A3,A5} = S_{A3}\psi_{A1}S_{A4}$ is the overall probability of getting from Banta Carbona (site A3) to Mossdale (A5), and $\phi_{A3,hi} = S_{A3}\psi_{P1}\phi_{P1,hi}$ is the joint probability of surviving from Banta Carbona to Paradise Cut, entering Paradise Cut, and reaching site i in route h, for hi = E1, D1O, D1C, B3, and C2 (Figure 5).

For the May and June release groups, the receiver located outside Paradise Cut (PCO, site A4) was available, but the interior receivers PCIa and PCIb were not available because Paradise Cut was inaccessible. In this case, the probability of remaining in the San Joaquin River at Paradise Cut was fixed to $\psi_{A1} = 1$ and its complement $\psi_{P1} = 0$. Likewise, transition probabilities for Paradise Cut fish to downstream sites in the Old River route were also fixed to 0: $\phi_{P1,hi} = 0$ for hi = E1, D1O, D1C, B3, and C2 (Figure 5). The probabilities of surviving from Banta Carbona to Paradise (S_{A3}) and from Paradise Cut to Mossdale (S_{A4}) were estimable for these release groups, although the parameter S_{A3} was given the name $\phi_{A3,A4}$ to account for the more general case when the probability of remaining in the San Joaquin River at Paradise Cut, ψ_{A1}, was < 1.

The fifth release group (group 5) was released from June 7 to June 11, and consisted of only 285 tagged steelhead. The small size of the release group combined with the late release dates resulted in sparse detection data through much of the study area, in particular in the San Joaquin River downstream of Stockton, CA, and in the interior Delta. This made it impossible to estimate detailed route entrainment and reach survival probabilities through these regions. Instead, it was necessary to model detections only before and after these areas, as described above (Model III in *Methods: Survival Model*). Overall survival from the downstream Stockton receiver (STN, site A8) and the first Old River receivers (ORE, site B1) to Chipps Island was estimable, as well as survival via the water export salvage facilities (Figure 7). When pooled with the May releases, this limitation of the data did not occur, and it was possible to use all detections from the June release in estimating detailed route entrainment and survival probabilities.

Using only those detections classified as coming from juvenile steelhead and excluding the predator-type detections, the estimates of total survival from Mossdale to the receivers at Chipps Island, S_{total}, ranged from 0.38 (*SE* = 0.05) for the last release group (June) to 0.69 (*SE* = 0.03) for the first release group (March) (Table 19). The overall population estimate for all fish in the tagging study was 0.54 (*SE* = 0.01). Estimates of the probability of remaining in the San Joaquin River at the junction with Old River $\left(\psi_A = \psi_{A2}\right)$ ranged from 0.49 (*SE* = 0.03) for the third release group to 0.53 (*SE* = 0.03) for the fourth release group, with a population estimate of 0.51 (*SE* = 0.02) (Table 19). There was no significant indication of preference for either route for any release group ($P \geq 0.4039$), or over all release groups (P=0.4342). Survival estimates from Mossdale to Chipps Island through the San Joaquin River route $\left(S_A\right)$ ranged from 0.32 (*SE* = 0.06) for the June release group to 0.69 (*SE*= 0.04) for the March release group; the overall population estimate was 0.55 (*SE* = 0.02). In the Old River route, estimates of survival from Mossdale to Chipps Island ranged from 0.44 for both the second and fifth release group (*SE* = 0.04 to 0.07) to 0.68 (*SE* = 0.04) for the first release group, with an overall estimate of 0.52 (*SE* = 0.02) over all release groups (Table 19). Although slightly more tagged steelhead arrived at Chipps Island via the San Joaquin River route (351) than through the Old River route (320) (Table 16), there was a statistically significant (α=0.05) difference in survival to Chipps Island between the two routes only for the 4th release group (released in late May; P=0.0355): $\hat{S}_A = 0.66$ (*SE* = 0.04) for the San Joaquin River route, and $\hat{S}_B = 0.53$ (*SE* = 0.05) for the Old River route for this release group (Table 19). When the 3rd and 4th release groups were pooled, coinciding with the VAMP release groups of Chinook salmon in the 2011 VAMP study (SJRGA 2011), there was a slightly higher estimated probability of reaching Chipps Island from the San Joaquin River route ($\hat{S}_A = 0.56$; *SE* = 0.03) than through the Old River route ($\hat{S}_B = 0.48$;*SE* = 0.03), but it was not significant at the 5% level (P=0.0931). All other release groups showed no indication of a significant survival difference between routes ($P \geq 0.1841$), nor was there a significant difference when pooled over all release groups (P = 0.4540).

Survival was estimated to the Jersey Point/False River junction for fish that did not pass through the holding tanks at the CVP or the SWP. This survival measure $\left(S_{total(MD)}\right)$ was estimated for the first four release groups. Estimates ranged from 0.24 (*SE* = 0.03) for the third release group to 0.68 (*SE* = 0.03) for the first release group, and averaged 0.37 (*SE* = 0.01) over all of the first four release groups. Survival to the Jersey Point/False River junction was considerably higher via the San Joaquin River route than through the Old River route for each of the four release groups ($P \leq 0.0001$ in each case), presumably because so many of the Old River route fish passed through the salvage facilities and thus did not contribute to survival to Jersey Point/False River. Because $S_{total(MD)}$ does not reflect survival to downstream regions via salvage, it is not indicative of overall survival to Chipps Island $\left(S_{total}\right)$, which often had greater estimates than $S_{total(MD)}$ (Table 19). In all, only five tags were observed leaving the San Joaquin River for False River (Table 16, and Table A2 in Appendix A).

Survival was estimated through the South Delta ($S_{A(SD)}$, $S_{B(SD)}$, and $S_{total(SD)}$) for all but the last release group. The "South Delta" region corresponded to the region studied for Chinook salmon survival in the 2009 VAMP study (SJRGA 2010). Estimates of survival in the San Joaquin River from Mossdale to the Shipping Channel Markers (C18/C16) or Turner Cut (TCN/TCS) $\left(S_{A(SD)}\right)$ ranged from 0.74 (*SE* = 0.04) for the third release group to 0.89 (*SE* = 0.03) for the first release group, with a population estimate of 0.83 (*SE* = 0.02) for the first four release groups (Table 7). In the Old River route, estimated survival from Mossdale to the entrances of the water export facilities (CVP, RGU) or the northern Old River and Middle River receivers near Highway 4 (ORN, MRN) $\left(S_{B(SD)}\right)$ ranged from 0.71 (*SE* = 0.04) for the third release group to 0.91 (*SE* = 0.03) for the first release group; the population-level estimate for the first four release groups was 0.78 (*SE* = 0.02) (Table 19). Total estimated survival through the entire South Delta region $\left(S_{total(SD)}\right)$ ranged from 0.72 (*SE* = 0.03) for the third release group to 0.90 (*SE* = 0.02) for the first release group, with a population estimate of 0.81 (*SE* = 0.01) for the first four release groups (Table 19).

Including predator-type detections in the analysis produced little change in the estimates of survival on any of the spatial scales considered, including survival to Chipps Island, survival to the Jersey Point/False River region, and survival through the South Delta (Table 7, Table 20). The largest difference was in estimates of survival through the South Delta region, with South Delta survival estimates through the Old River route increasing from 0.78 (*SE* = 0.02) without the predator-type detections to 0.83 (*SE* = 0.02) with the predator-type detections (Table 19, Table 20). The increase may have been caused by predators moving from Delta waters to the CVP trashracks and radial gates, which typically have high predator densities. Overall survival to Chipps Island increased little when predator-type detections were included, from 0.54 (*SE* = 0.01) to 0.56 (*SE* = 0.01) (Table 20). Survival from Mossdale to the Jersey Point/False River region (without salvaged fish) also increased only slightly when predator-type detections were included, changing from 0.37 (*SE* = 0.01) without the predator-type detections to 0.39 (*SE* = 0.01) with the predator-type detections (Table 7,Table 20).

Travel Time

For tags classified as being in steelhead, average travel time through the system from release at Durham Ferry to Chipps Island was 11.08 days (*SE* = 0.12 days), with no difference among the releases (Table 21). Nevertheless, some tagged steelhead took up to 44 days to get to Chipps Island. There was little difference in overall travel time to Chipps Island between the San

Joaquin River route (average travel time = 10.9 days) and the Old River route (average = 11.2 days). Travel time from release to downstream points in the Old River route (Old River North, Middle River North, CVP trashracks and holding tank, and radial gates) tended to be longer via the San Joaquin River route (average = 11.9 to 13.5 days) than via the Old River route (average = 5.5 to 8.3 days). However, travel time from release to Jersey Point and False River tended to be longer in the Old River route (average = 11.3 to 15.4 days, non-salvaged fish) than in the San Joaquin River route (average = 5.6 to 9.3 days). Including the predator-type detections lengthened the average travel time to the downstream sites, but the general pattern across the routes and release groups remained the same. The average travel time from release to Chipps Island via all routes, including the predator-type detections, was 11.24 days (*SE* = 0.13 days) (Table 21). 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.

Average travel time through reaches of tags classified as being in steelhead ranged from 0.01 days (*SE*< 0.01 days; 189 fish) from the upstream radial gate receivers (RGU) to the downstream radial gate receivers (RGD) to 4.25 days (*SE*= 0.06 days) from Middle River South to the Central Valley Project trashrack (CVP) (Table 22). However, the MRS to CVP transition was observed for only 3 fish. Travel through the large "reach" from Turner Cut to Chipps Island also took a relatively long time, with an average of 4.10 days (*SE* = 0.05 days) (55 fish). Average travel time from Jersey Point to Chipps Island was 0.64 days (*SE* = 0.01 days; 323 fish), while average travel time from the CVP holding tank to Chipps Island (70 fish) was just under a day (0.96 days; *SE* = 0.01 days). Travel time from the entrance to Clifton Court Forebay to Chipps Island tended to be longer, including travel through Clifton Court to the salvage facilities at SWP, and averaging 3.12 days (*SE* = 0.04 days, 150 fish). Including the predator-type detections tended to increase average travel times slightly, but the same patterns observed without the predator-type detections were observed with the predator-type detections (Table 22).

Route Entrainment Analysis

River flow at the San Joaquin River gaging station near Lathrop (station SJL), ranged from 3,829 cfs to 10,510 cfs (average = 5,777 cfs) during the arrival times of the tagged juvenile steelhead in 2011. River flow at Vernalis ranged from 8,930 cfs to 28,800 cfs during the same time period (average = 15,980 cfs). The flow in the San Joaquin River never reversed direction during the 2011 study. River flow at the Old River gaging station near the head of Old River (station OH1) ranged from 4,290 cfs to 11,380 cfs (average = 6,361 cfs) during the same time. There was high correlation between flow in the San Joaquin River and flow in Old River at the time of tag arrival at the river junction (r = 0.88). Water velocities ranged from 1.4 ft/s to 2.5 ft/s (average = 1.9 ft/s) at SJL, and from 1.6 ft/s to 2.6 ft/s (average = 2.1 ft/s) at OH1. Flow and velocity at the SJL station at the time of tag arrival were only slightly correlated (r = 0.17), but flow and velocity at the OH1 station at that time were highly correlated (r = 0.89). The proportion of flow entering the San Joaquin River averaged 0.48, ranged from 0.39 to 0.54, and was moderately negatively correlated with flow into the San Joaquin River (r = -0.25). However, flow proportion entering the San Joaquin River was more strongly negatively correlated with flow into Old River (r = -0.67), reflecting a pattern of more flow entering Old River than the San Joaquin River as total flows increased. Export rates were variable throughout the study, but were generally higher for the final two release groups (late May through June). Export rates at CVP averaged 1,682 cfs for the first three release groups, and 2,547 for the final two release groups. Export rates at SWP averaged 2,214 for the first three release groups, and then increased to 4,412 for the final two release groups. There was very little correlation between total Delta exports and either flow into the San Joaquin River at Lathrop (r = -0.11), flow into Old River (r = -0.16), or flow proportion into the San Joaquin River (r = 0.14). This result is not surprising given the high flows and relatively low exports during the 2011 study.

The single variate analyses found no significant relationship ($\alpha = 0.05$) between the probability of remaining in the San Joaquin River at the head of Old River in 2011 and any of the covariates considered ($P \geq 0.1017$ for each covariate; Table 23). Examination of observed proportions of fish remaining in the San Joaquin River at the head of Old River over 5-day time periods, compared with observations of flow (Figure 14), water velocity (Figure 15), flow proportion into the San Joaquin River (Figure 16), and export rates (Figure 17) confirm that there was little covariation between these measures and the probability of remaining in the San Joaquin River. Throughout the season when fish were present, there was little variation in the proportion of fish remaining in the San Joaquin River, with estimates ranging from 0.44 to 0.58 (average = 0.51) (omitting the 5-day periods when fewer than 10 fish were detected). Thus, there was little opportunity to detect trends with environmental measures. While flow increased considerably in late March and early April, there were few tagged fish present in the system during that time; when fish were present, there was relatively little variation in either flow or the probability of remaining in the San Joaquin River (Figure 14). There was less variation in water velocity than in flow measured at SJL and OH1, and no apparent relationship between velocity and the probability of remaining in the San Joaquin River (Figure 15). Flow proportion into the San Joaquin River remained largely stable in 2011, as did the proportions of fish remaining in the San Joaquin River (Figure 16). It is conceivable that there is a relationship between flow proportion and route entrainment, but there was too little variation in the 2011 data to detect it. While there was some variation in export rates during the tagging study in 2011, there was no apparent relationship between export rates and the probability of remaining in the San Joaquin River at the head of Old River, or, conversely, of entering Old River (Figure 17).

Survival through Facilities

Survival through the water export facilities was estimated as the overall probability of reaching either Chipps Island, Jersey Point, or False River after being last detected in the CVP holding tank (model code E2, for the federal facility) or the interior receivers at the radial gates at the entrance to Clifton Court Forebay (site RGD, code D2, for the 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.

The majority of the steelhead detected at the radial gates receivers in the interior of the Clifton Court Forebay (194 of 233) and in the CVP holding tank (66 of 80) came via the Old River route, but some steelhead arrived via the San Joaquin River route (Table 16). When detections from both routes were combined, the estimated survival from the CVP holding tanks to Chipps Island, Jersey Point, and False River ranged from 0.87 (SE<0.09) for the third release group (mid-May) to 0.98 (SE=0.05) for the fourth release group (late May); the population estimate was 0.92 (SE=0.03) (Table 24). When restricted to only those fish that arrived at the CVP trashracks from the Old River route, the population estimate was 0.94 (SE=0.03). The difference observed by including the San Joaquin River route was not statistically significant ($P \geq 0.4379$). For survival from the radial gates to Chipps Island, Jersey Point, and False River, when fish from both routes were combined, estimated survival ranged from 0.31 (SE=0.13) for the fifth release group (June) to 0.76 (SE=0.06) for the fourth release group (late May); the population estimate was 0.70 (SE=0.03) (Table 24). When restricted to those fish that arrived at the radial gates from the Old River route, the population estimate was 0.73 (SE=0.03). Again, the difference in estimated survival that was observed by including the San Joaquin River route was not statistically significant ($P \geq 0.4205$).

Discussion

Numerous objectives were developed as part of the Six Year Study in its requirements in the 2009 National Marine Fisheries Service Biological Opinion on the Long term Operation of the CVP and SWP, but given the limited sample size from the first year (n=5), these analyses are reserved for consideration until completion of three years of the multi-year study. Management implications will be discussed in subsequent reports.

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Figure 1. Stanislaus River *O. mykiss* timing at Caswell Park and Oakdale screw traps, 1998-2009 (includes only fish rated as smolt index 5). Fish leaving in December constitute 1.1% of migrants and are not shown.

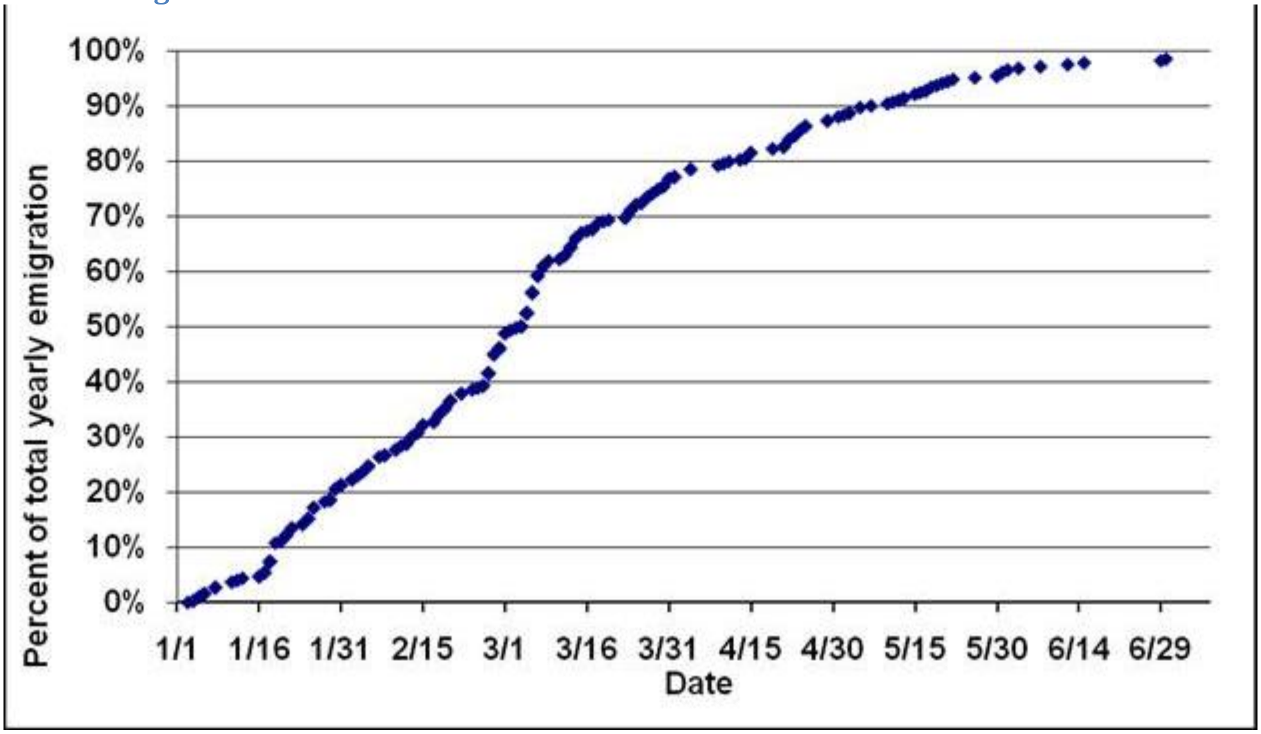

Figure 2. Lower San Joaquin River *O. mykiss* timing at Mossdale., 1998-2010.

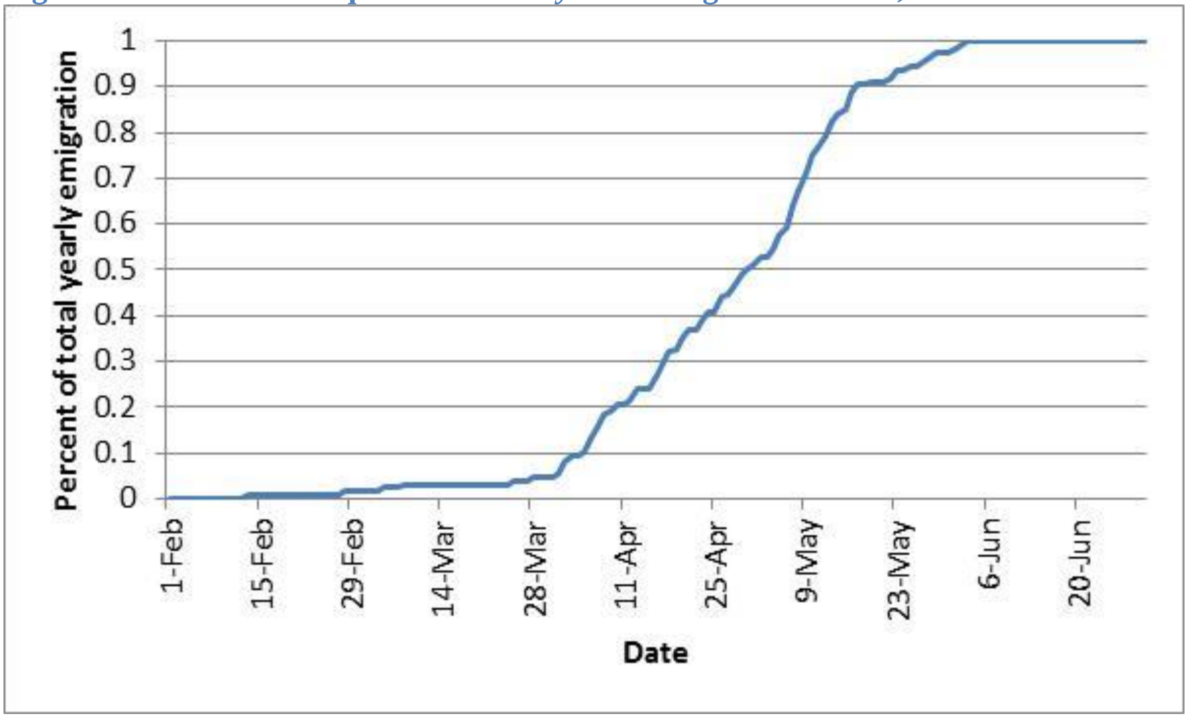

Figure 3. Conceptual model of how Delta water operations, tributary water operations, and habitat control biotic and biotic ecosystem variables influencing survival of steelhead smolts in a reach in the San Joaquin River and south Delta.

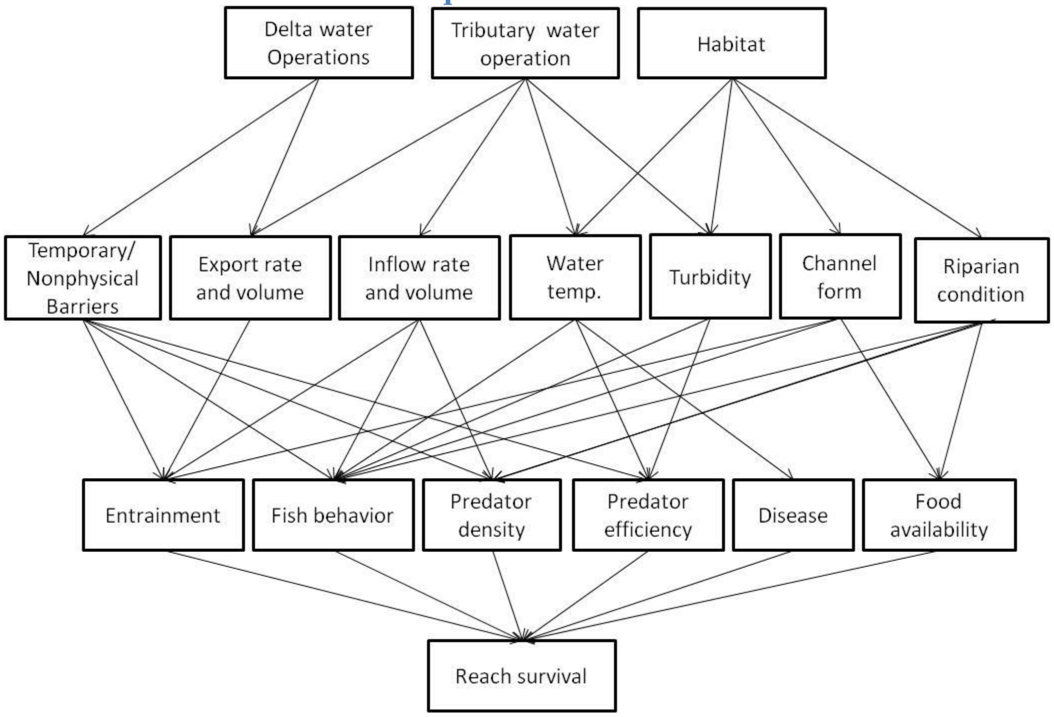

Figure 4. Locations of acoustic receivers and release site used in the 2011 OCAP steelhead study, with site code name (3-letter code) and model code name (letter and number string). Site A1 is the release site at Durham Ferry. Sites T1 (TMN/TMS) and E3 (DMC) were excluded from the survival model.

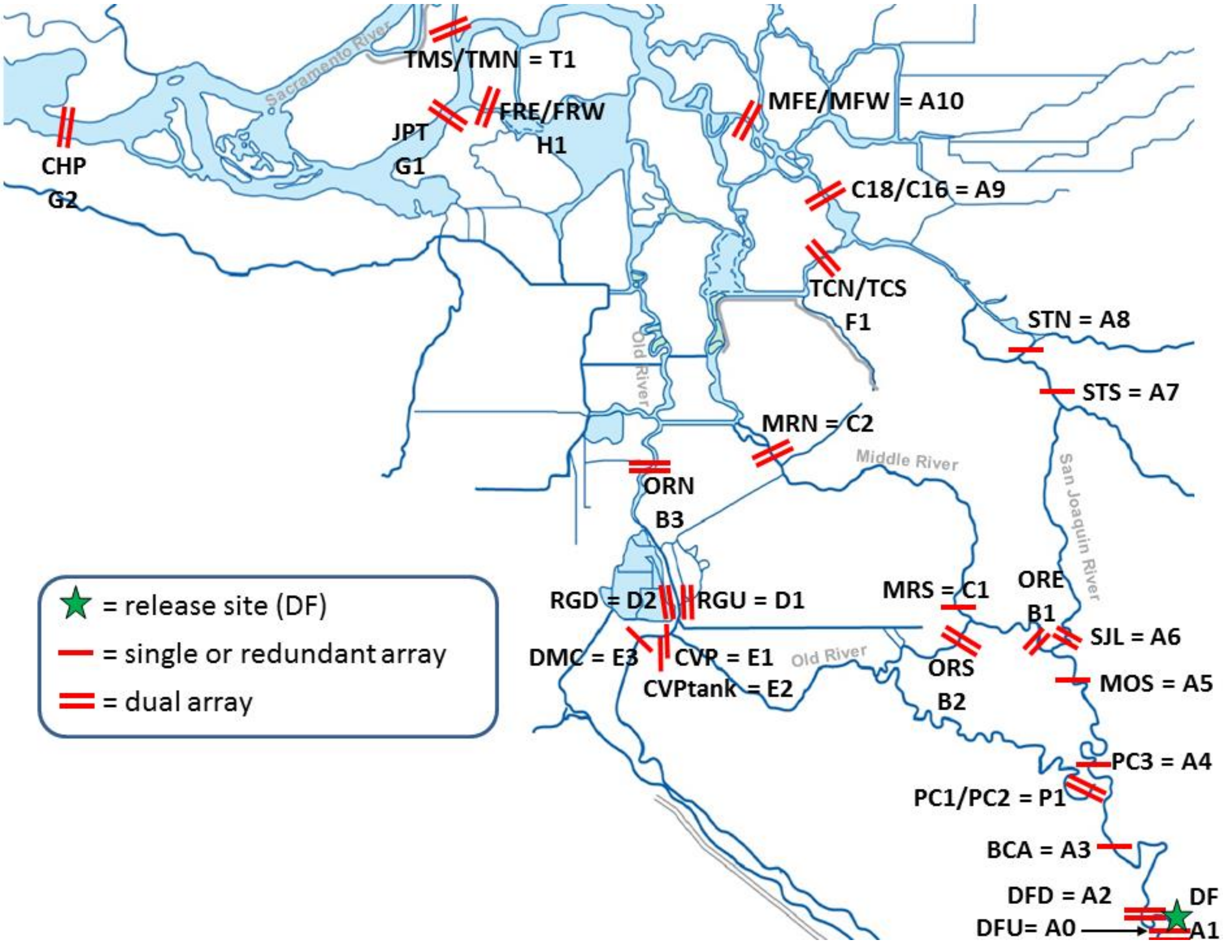

Figure 5. Schematic of 2011 mark-recapture Submodel I with estimable parameters. Single lines denote single-array or redundant dual-line telemetry stations, and double lines denote double-array telemetry stations. Names of telemetry stations correspond to site labels in Figure 4. Parameters $\varphi_{P1,D1}$, $\varphi_{B2,D1}$, $\varphi_{C1,D1}$, and $\varphi_{D1,D2}$ were estimated separately for arrival at D1 when the radial gates were open versus closed. Migration pathways to sites B3 (ORN), C2 (MRN), D1 (RGU), and E1 (CVP) are color-coded by departure site.

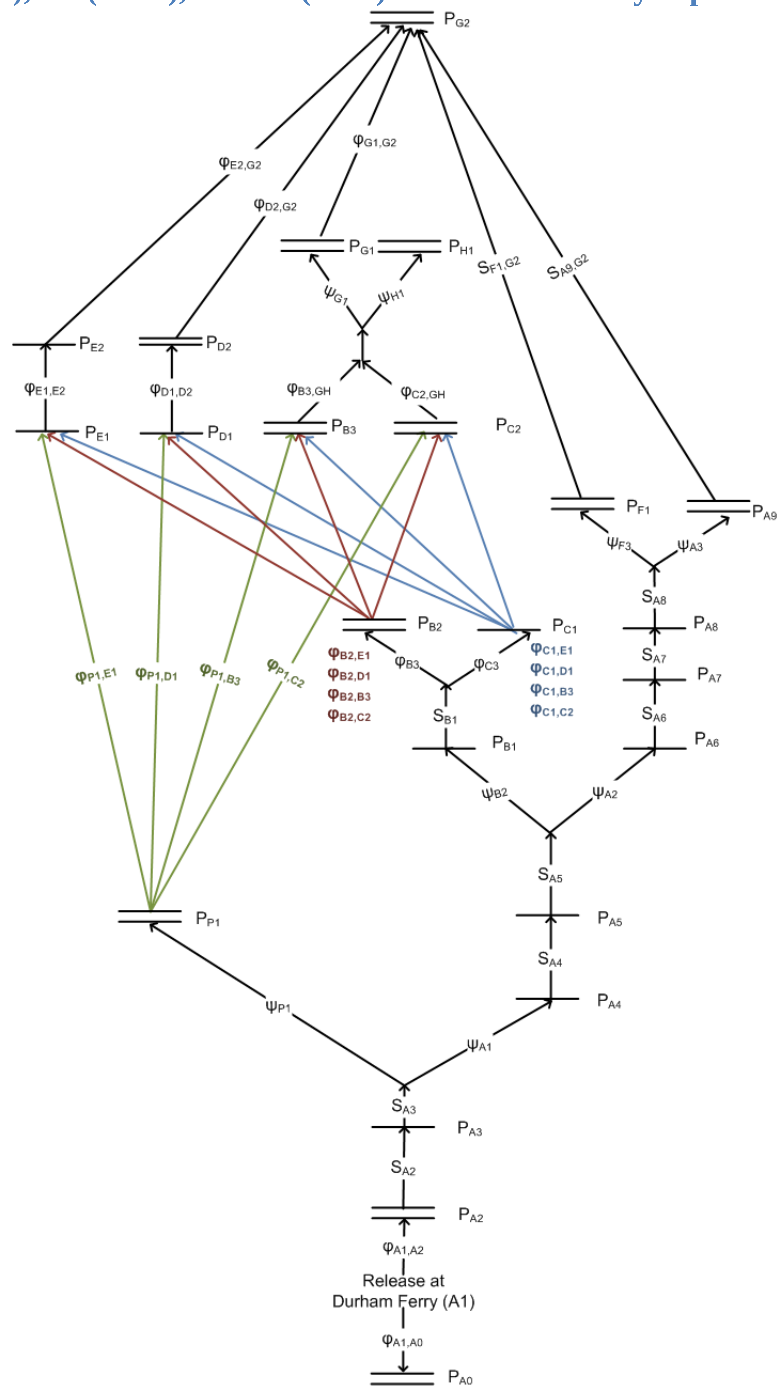

Figure 6. Schematic of 2011 mark-recapture Submodel II with estimable parameters. Single lines denote single-array or redundant dual-line telemetry stations, and double lines denote double-array telemetry stations. Names of telemetry stations correspond to site labels in Figure 4. Parameters $\varphi_{B3,D1}$, $\varphi_{C2,D1}$, and $\varphi_{D1,D2}$ were estimated separately for arrival at D1 when the radial gates were open versus closed. Migration pathways to sites B3 (ORN), C2 (MRN), D1 (RGU), E1 (CVP), G1 (JPT), and H1 (FRE/FRW) are color-coded by departure site.

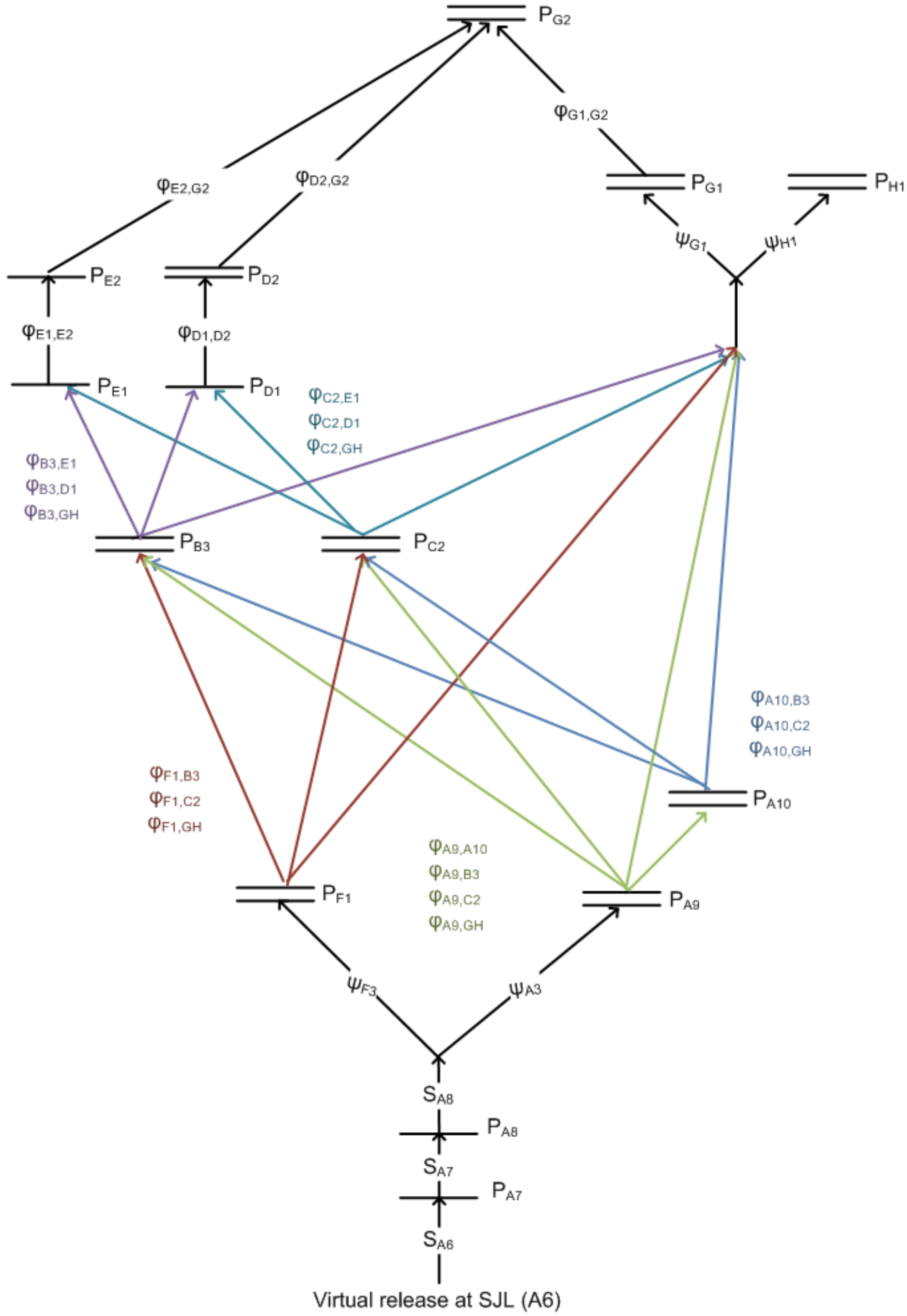

Figure 7. Schematic of 2011 mark-recapture Model III with estimable parameters, used only for release group S5. Single lines denote single-array or redundant dual-line telemetry stations, and double lines denote double-array telemetry stations. Names of telemetry stations correspond to site labels in Figure 4. Parameters $\varphi_{P1,D1}$, $\varphi_{B1,D1}$, $\varphi_{A8,D1}$, and $\varphi_{D1,D2}$ were estimated separately for arrival at D1 when the radial gates were open versus closed. Migration pathways to sites D1 (RGU), E1 (CVP), and G2 (CHP) are color-coded by departure site.

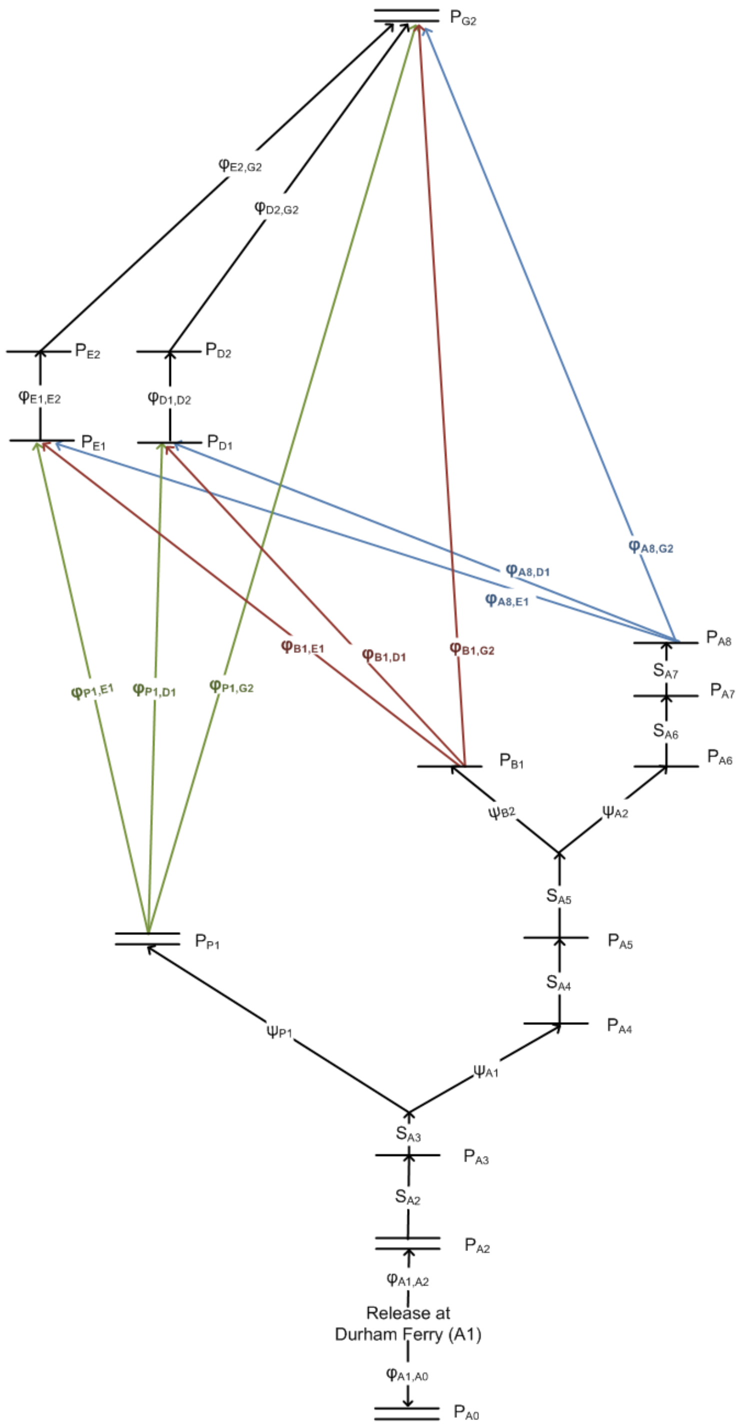

Figure 8. Observed tag failure times from the 2011 tag-life study, color-coded by tag period, and fitted four-parameter vitality curve. Failure times of eight tags were missing.

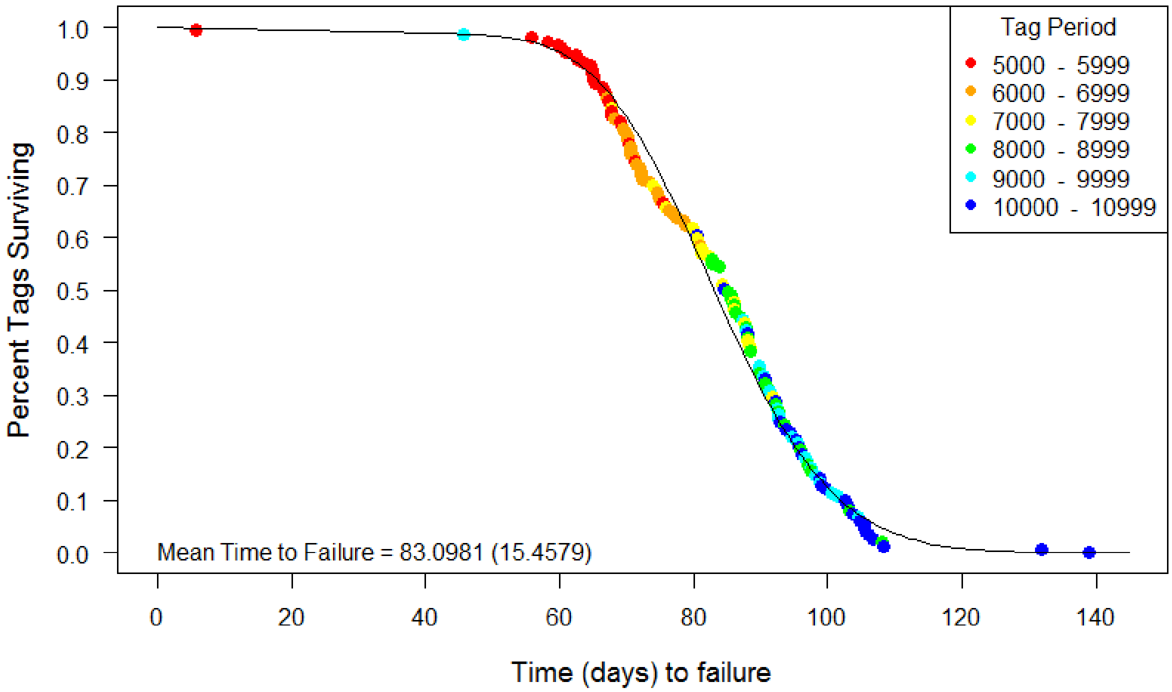

Figure 9. Four-parameter vitality survivorship curve for tag life, and the cumulative arrival timing of acoustic-tagged juvenile steelhead at receivers in the San Joaquin River route to Chipps Island in 2011, including detections classified as predator detections.

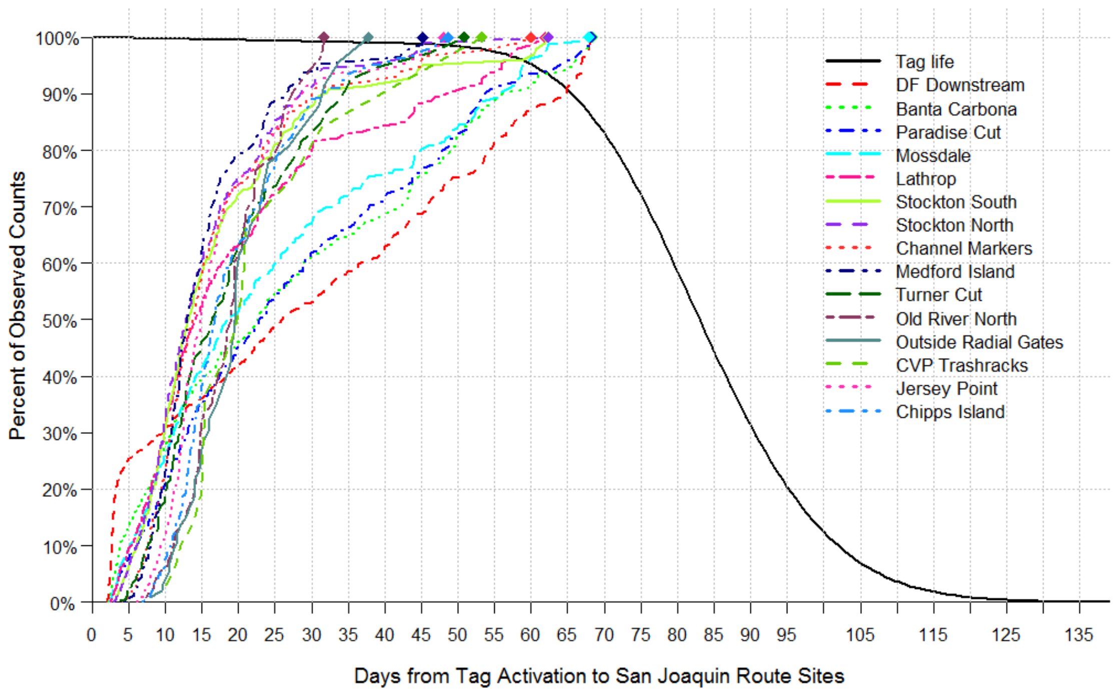

Figure 10. Four-parameter vitality survivorship curve for tag life, and the cumulative arrival timing of acoustic-tagged juvenile steelhead at receivers in the Old River route to Chipps Island in 2011, including detections classified as predator detections.

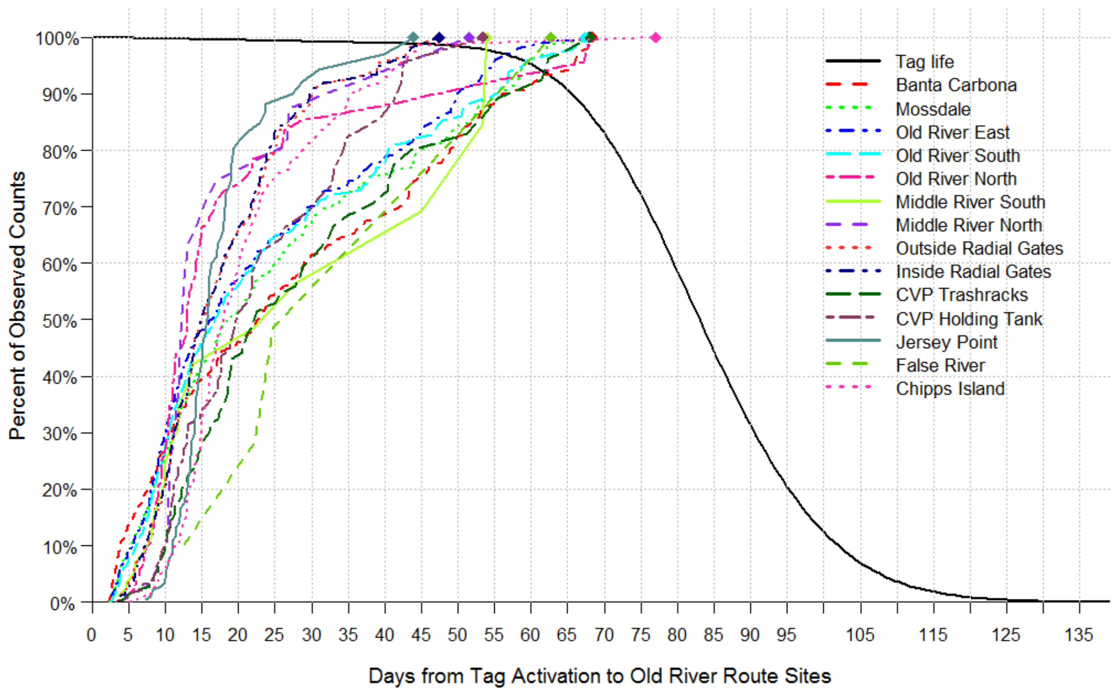

Figure 11. Four-parameter vitality survivorship curve for tag life, and the cumulative arrival timing of acoustic-tagged juvenile steelhead at receivers in the San Joaquin River route to Chipps Island in 2011, excluding detections classified as predator detections.

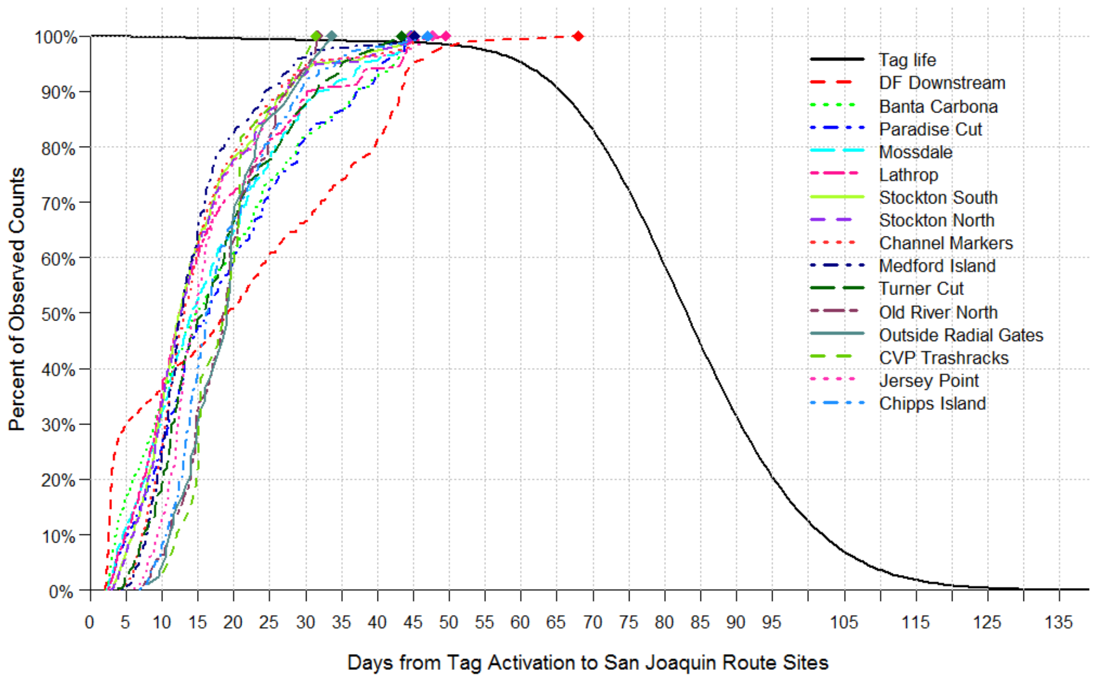

Figure 12. Four-parameter vitality survivorship curve for tag life, and the cumulative arrival timing of acoustic-tagged juvenile steelhead at receivers in the Old River route to Chipps Island in 2011, excluding detections classified as predator detections.

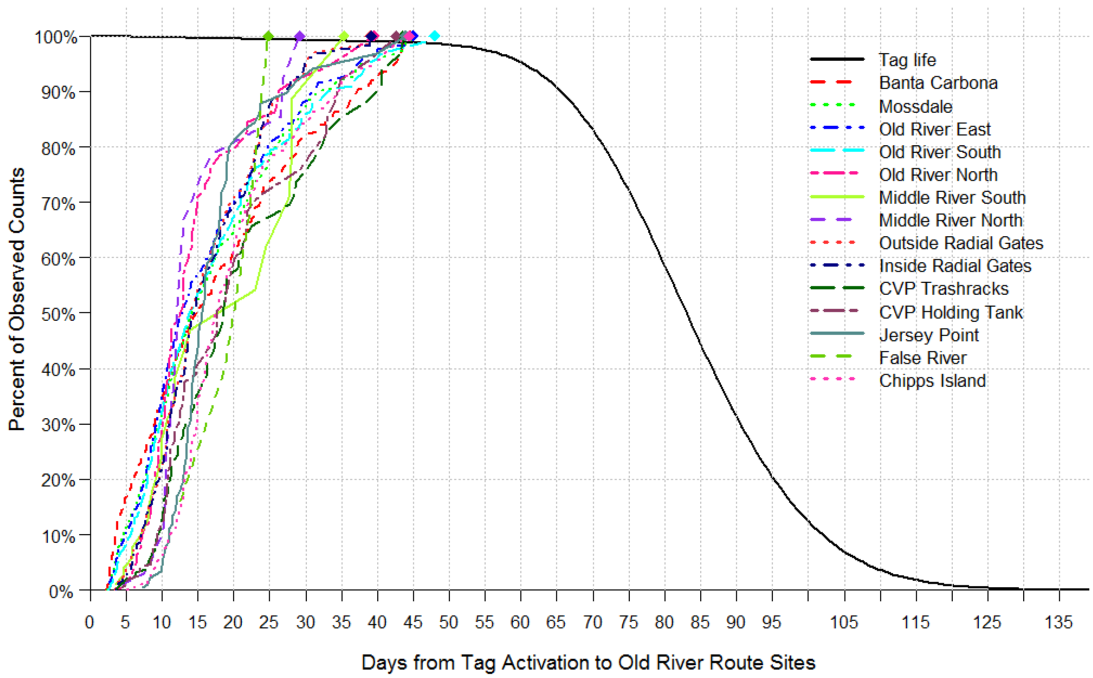

Figure 13. River discharge ("flow") of the San Joaquin River at Vernalis [cfs] in 2011, and dates when Paradise Cut was expected to have been accessible to fish (Vernalis flow > 18,000 cfs). Data from CDEC.

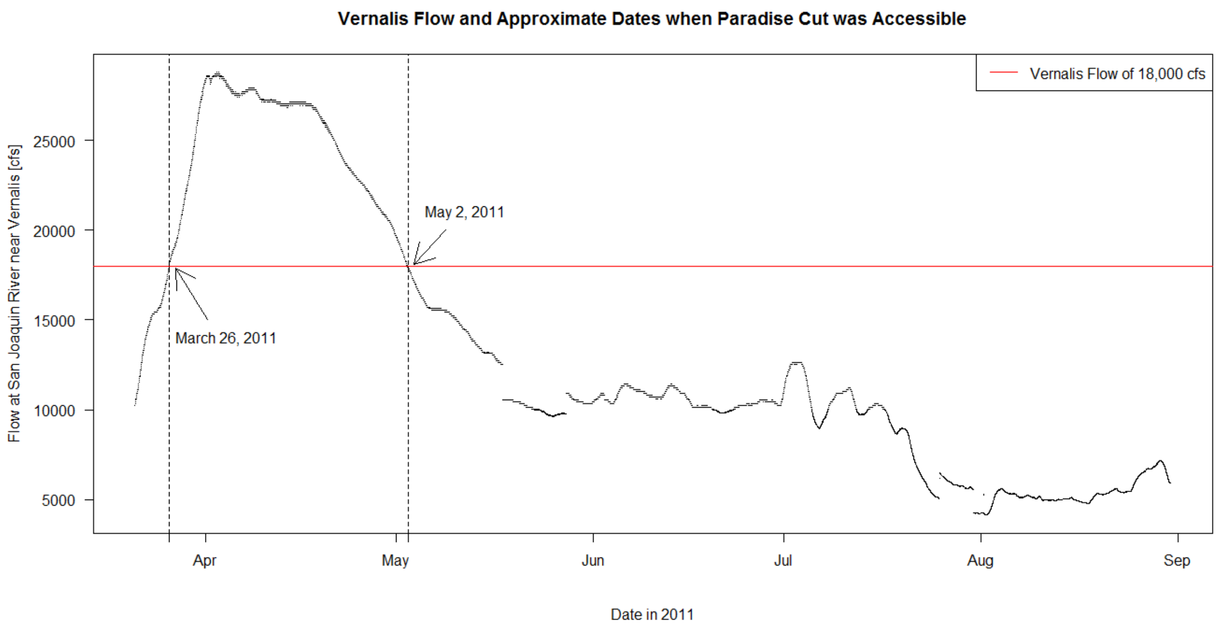

Figure 14. The observed proportion of tagged juvenile steelhead remaining in the San Joaquin River at the Head of Old River during the 2011 tagging study (gray bars, representing 5-day periods), and the average measured flow at the SJL and OH1 gaging stations at the estimated time of fish arrival at the gaging stations. Proportion of fish remaining in the San Joaquin River shown only for time periods with at least 10 fish detected.

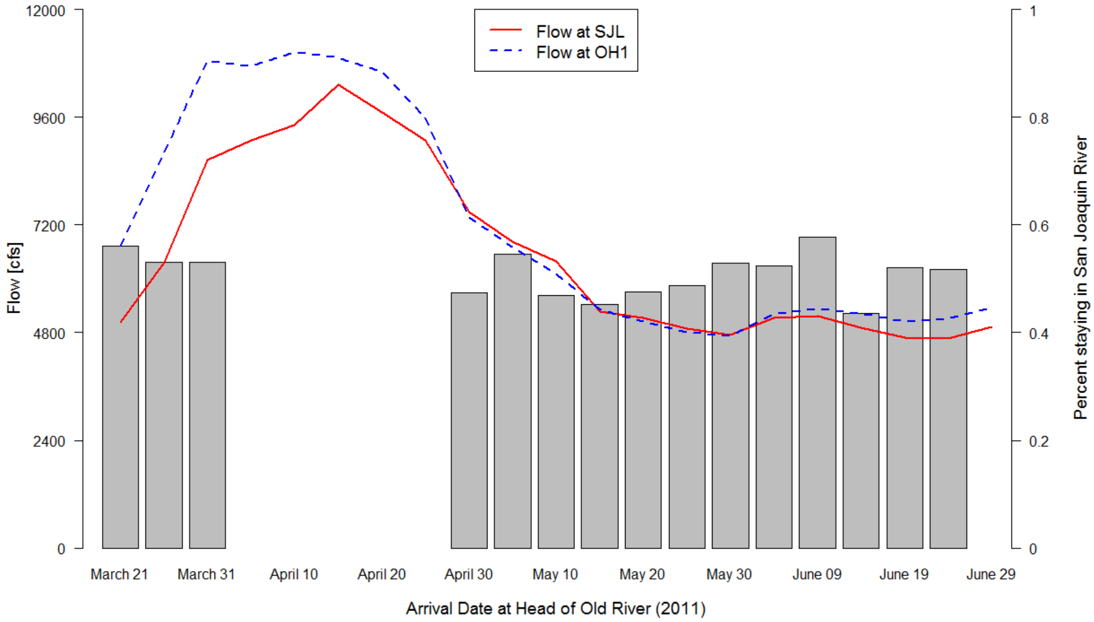

Figure 15. The observed proportion of tagged juvenile steelhead remaining in the San Joaquin River at the Head of Old River during the 2011 tagging study (gray bars, representing 5-day periods), and the average measured water velocity at the SJL and OH1 gaging stations at the estimated time of fish arrival at the gaging stations. Proportion of fish remaining in the San Joaquin River shown only for time periods with at least 10 fish detected.

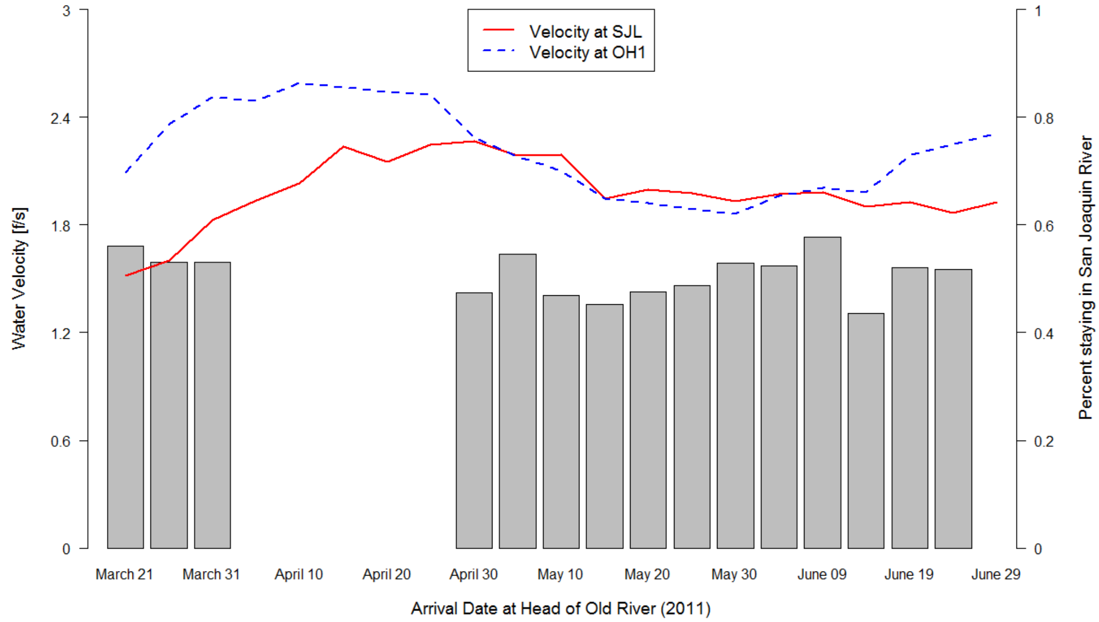

Figure 16. The observed proportion of tagged juvenile steelhead remaining in the San Joaquin River at the Head of Old River during the 2011 tagging study (gray bars, representing 5-day periods), and the average flow proportion into the San Joaquin River at the estimated time of fish arrival at the gaging stations. Proportion of fish remaining in the San Joaquin River shown only for time periods with at least 10 fish detected.

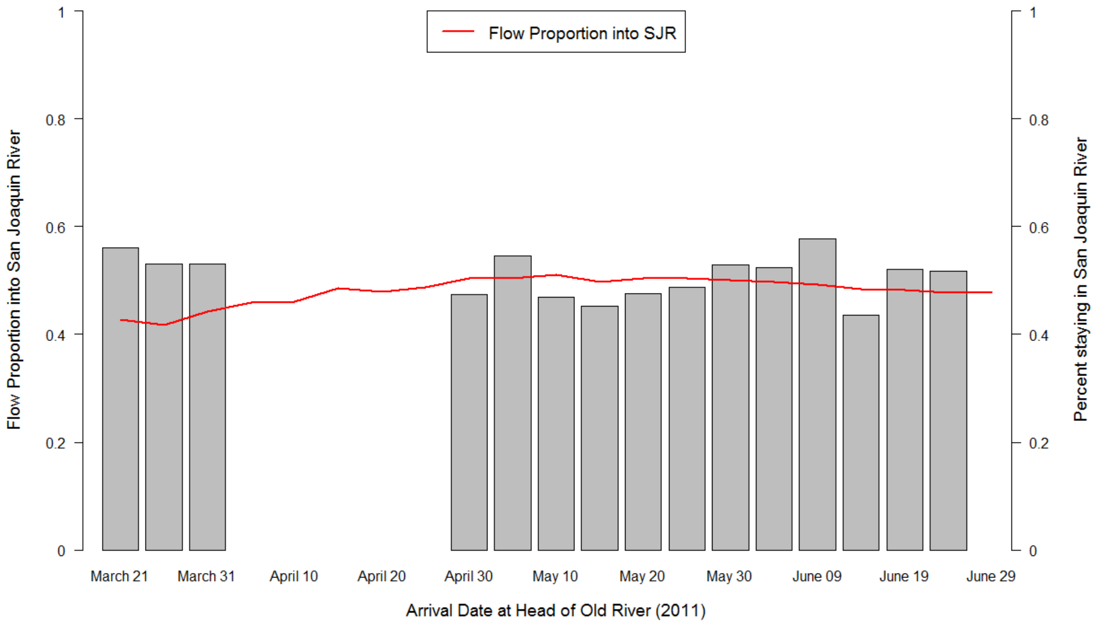

Figure 17. The observed proportion of tagged juvenile steelhead remaining in the San Joaquin River at the Head of Old River during the 2011 tagging study (gray bars, representing 5-day periods), and the average daily export rate at the Central Valley Project (CVP), State Water Project (SWP), and total Delta at the estimated time of fish arrival at the gaging stations. Proportion of fish remaining in the San Joaquin River shown only for time periods with at least 10 fish detected.

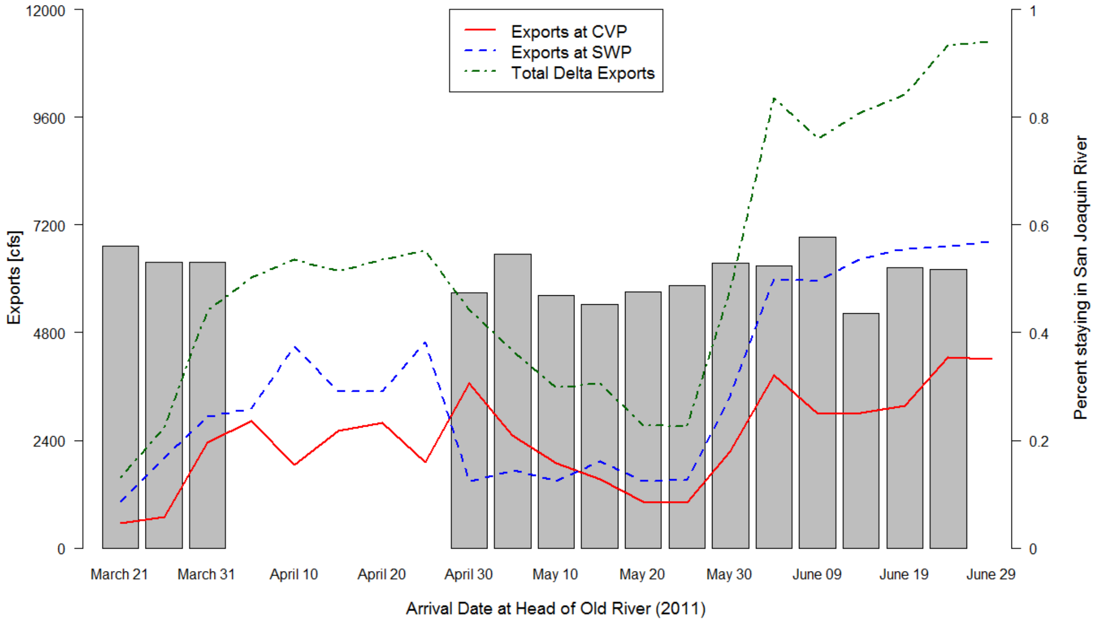

Table 1. River Flow conditions (cfs) from environmental monitoring sites in DAYFLOW (for CVP, SWP, and combined exports); CVO (Old and Middle River); and CDEC databases.

		Release				
Environmental Monitoring Site		1	2	3	4	5
BDT		8936	10765	5138	5058	4899
		445	70	64	47	31
FAL	Mean	9950	6334	1923	1631	-492
	SE	638	245	308	370	215
GLC	Mean	11524	14272	5922	5596	5772
	SE	824	62	102	68	31
HLT	Mean	960	2495	1253	535	-1991
	SE	260	456	133	384	160
MDM	Mean	4883	5136	1595	151	-3169
	SE	292	85	214	595	94
MSD	Mean	17831	22023	9698	9084	8859
	SE	844	388	271	105	40
OH1	Mean	9218	10912	4923	4807	5083
	SE	487	18	79	48	25
OH4	Mean	5607	5624	1911	635	-3019
	SE	262	95	52	573	133
ORI	Mean	9593	11265	4486	3515	1982
	SE	447	134	77	379	177
SJG	Mean	10011	10679	4963	4743	4652
	SE	513	25	50	41	30
SJJ	Mean	56372	35242	15499	12710	6348
	SE	3831	897	1157	992	676
TSL	Mean	-2549	761	-342	-492	-2316
	SE	436	419	200	264	212
VNS	Mean	22873	27334	10113	10246	10092
	SE	1523	97	353	121	51
Old RiverAtHead	Mean	9218	10912	4923	4807	5083
	SE	487	18	79	48	25
TRN	Mean	-547	-656	-471	-442	-538
	SE	20	30	27	37	43
DOMR	Mean	8253	9082	3013	1317	-5050
	SE	618	178	171	826	202
5DOMR	Mean	6100	9332	2675	2359	-4764
	SE	1011	154	171	356	143
14DOMR	Mean	1716	9077	2687	2454	-4236
	SE	816	149	76	84	96
SAC (dayflow)	Mean	78185	62145	36881	34890	39945
	SE	1879	2611	708	328	1240
SJR (dayflow)	Mean	24554	28736	10872	10500	10249
	SE	1669	200	101	70	54
SWP (dayflow)	Mean	2158	3958	1493	2539	6677
	SE	403	229	7	548	6
CVP (dayflow)	Mean	1174	2054	1012	1676	3422
	SE	347	170	6	371	177
EXPORTS (dayflow)	Mean	3337	6082	2709	4422	10361
	SE	613	155	12	917	179

Table 2. Tagging, transport and holding date and times and the number of steelhead released (mortalities in parentheses) as part of the 2011 Six-Year Study and south Delta Temporary Barriers Study. Dummy tagged fish with an asterisk were given to the CA/NV Fish Health Center for the fish health studies (see Appendix B).

				Release A		Release B		Release C		Release D		Fish Health
Tagging Date	Transport Date/ Time	Start Holding time	Total released (A+B+C+D)	Date/Time	Number released	Date/Time	Number released	Date/Time	Number released	Date/time	Number released	Dummy tagged
3/21/11	3/21/11; 1205 - 1300	3/21; 1345	118	3/22; 1500, 1501	29	3/22; 2103, 2104	30					
	3/21/11; 1500 - 1600	3/21; 1645						3/23; 0310, 0311	29	3/23; 0901, 0902	30	6
3/22/11	3/22/11; 1500 - 1600	3/22; 1645	119	3/23; 1800	30	3/24; 0000	30					
	3/22/11; 1900 - 1954	3/22; 2030						3/24; 0554, 0555	30	3/24; 1201, 1202	29	6
3/23/11	3/23/11; 1050 - 1145	3/23; 1224	120	3/24; 1456, 1457	30	3/24; 2156, 2157	30					
	3/23/11; 1338 - 1424	3/23; 1453						3/25; 0300	30	3/25; 0900	30	6
3/24/11	3/24/11; 1505 - 1552	3/25; 1639	120	3/25; 1801, 1802	30	3/25; 2359	30					
	3/24/11; ~1720 - 1750	3/25; 1800						3/26; 0559, 0600	30	3/26; 1200, 1201	30	24*
Total			**477**									
5/2/11	5/2/11; 1515-1610	5/2; 1700	118	5/3; 1800, 1801, 1802	36	5/4; 0000, 0001	24					
	5/2/11; 1730-1827	5/2; 1910						5/4; 0600	24	5/4; 1200, 1201	34 (2)	6
5/3/11	5/3/11; 1440-1536	5/3; 1620	119	5/4; 1800, 1801, 1802	36	5/5; 0000, 0001	23 (1)					
	5/3/11; 1740-1830	5/3; 1903						5/5; 0600	24	5/5; 1200	36	9
5/4/11	5/4/11; 1100-1155	5/4; 1250	119	5/5; 1501, 1502, 1503	36	5/5; 2102, 2104	24					
	5/4/11; 1330-1416	5/4; ~1445						5/6; 0258	23	5/6; 0859, 0900	36	3
5/5/11	5/5/11; 1103-1137	5/5; 1230	118	5/6; 1501, 1502, 1503	36	5/6; 2101, 2103	24					
	5/5/11; 1345-1435	5/5; ~1500						5/7; 0300	24	5/7; 0900	34(2)	6
Total			**474**									
5/16/11	5/16/11; 1600-1650	5/16; 1738	119	5/17; 1800	36	5/17; 0000, 0002	23(1)					
	5/16/11; 1800-1850	5/16; 1938						5/18; 0600, 0600, 0604	36	5/18; 1158	24	6
5/17/11	5/17/11; 1100-1150	5/17; 1220	120	5/18; 1500	36	5/18; 2100	24					
	5/17/11; 1315-1410	5/17; 1444						5/19; 0300, 0302	36	5/19; 0859, 0900	24	24*

				Release A		Release B		Release C		Release D		
Tagging Date	**Transport Date/ Time**	**Start Holding time**	**Total released (A+B+C+D)**	**Date/Time**	**Number released**	**Date/Time**	**Number released**	**Date/Time**	**Number released**	**Date/time**	**Number released**	**Fish Health Dummy tagged**
5/18/11	5/18/11; 1515-1615	5/18; 1646	119	5/19; 1800	36	5/20; 0000	24					
	5/18/11; 1715-1811	5/18; 1843						5/20; 0559, 0600	36	5/20; 1201	23(1)	6
5/19/11	5/19; 1045-1124	5/19; 1200	120	5/20; 1500	36	5/20; 2100	24					
	5/19; 1255-1355	5/19; 1425						5/21; 0301	36	5/21; 0900	24	6
Total			**477[a]**									
5/21/11	Sat 5/21; 1010-1110	5/21; 1153	120	5/22; 1501, 1502	36	5/22; 2058, 2100	24					
	Sat 5/21; 1220-1300	5/21; 1335						5/23; 0259, 0300	36	5/23; 0901, 0902	24	6
5/22/11	5/22/11; 1430-1514	5/22; 1540	120	5/23; 1759, 1800	36	5/23; 2359	24					
	Sun 5/22; 1508-1550	5/22; 1616						5/24; 0559	36	5/24; 1202	24	6
5/23/11	5/23/11; 1015-1108	5/23; 1145	120	5/25; 1501	36	5/24; 2100	24					
	5/23/11; 1200-1245	5/23; 1315						5/25; 0300	36	5/25; 0901, 0902	24	6
5/24/11	5/24/11; ~1400 - 1440	5/24; 1513	120	5/25; 1800	36	5/25; 2358	24					
	5/24/11; ~1600-1635	5/24; 1704						5/26; 0559	36	5/26; 1202, 1204	24	6
Total			**480**									
6/14/11	6/14/11; 1530-1620	6/14; 1700	117	6/15; 1805, 1807, 1811	35(1)	6/16; 0000, 0003	23(1)					
	6/14/11; 1748-11845	6/14; 1935						6/16; 0600	36	6/16; 1200	23	23*
6/15/11	6/15/11; 1045-1140	6/15; 1240	120	6/16; 1501, 1502, 1505	36	6/16; 2101, 2102	24					
	6/15/11; 1230-1310	6/15; 1420						6/17; 0300, 0301	36	6/17; 0900	24	6
6/16/11	6/16/11; 1425-1515	6/16; 1554	48	6/17; 1807, 1811	35(1)	6/18; 0000	13					
												3
Total			**285**									

[a] The number released (477) does not include two fish that had tags that could not be confirmed and thus were not actually released. These tags were initially included in the database due to a data entry error, and have been included in the subsequent analyses. We do not anticipate any significant changes in survival due to including these two fish in survival modeling.

Table 3. Water temperature and dissolved oxygen conditions in the transport tank after loading, prior to transport, after transport, and in the river at Durham Ferry release site just prior to placing fish in holding containers.

Transport		Tank after loading		Tank after transport			River		
Date	Loading time	Temp (˚C)	DO (mg/L)	Temp (˚C)	DO (mg/L)	# morts after transport	Temp (˚C)	DO (mg/L)	Mortalities just prior to release
3/21/2011	930	13.0	10.0	13.3	10.0	0	13.7	9.2	0
3/21/2011	1300	12.9	10.4	13.2	9.6	0	11.2	10.26	0
3/22/2011	1230	12.7	10.1	13.0	11.6	0	-	-	0
3/22/2011	1645	12.7	12.5	12.7	10.4	0	11.5	10.05	0
3/23/2011	900	12.1	10.0	12.0	9.9	0	11.1	9.9	0
3/23/2011	1200	12.2	10.7	12.6	11.8	0	11.2	9.9	0
3/24/2011	1300	12	11.2	11.6	10.6	0	10.8	10.0	0
3/24/2011	1430	11.6	11.4	11.4	11.2	0	10.9	10.0	0
5/2/2011	1245	18.1	10.4	18.7	10.0	0	16.1	9.3	0
5/2/2011	1545	18.4	9.7	18.9	12.6	0	16.2	9.7	2
5/3/2011	1200	16.8	10.6	16.9	12.1	0	16.7	9.4	1
5/3/2011	1515	16.5	9.5	16.9	12.5	0	16.8	9.5	0
5/4/2011	900	16.3	10.5	16.5	11.5	0	16.8	9.0	0
5/4/2011	~1300	16.7	11.3	17.5	10.8	0	17.2	9.7	0
5/5/2011	915	17.0	9.4	17.5	11.7	0	17.4	8.6	0
5/5/2011	1145	17.5*	11.1	18.4	11.5	0	17.9	8.8	2
5/16/2011	1330	16.9	9.0	15.9	12.6	0	15.0	9.4	1
5/16/2011	1615	15.6	14.7	15.6	10.2	0	14.9	9.45	0
5/17/2011	930	14.8	9.4	14.4	9.4	0	14.1	9.42	0
5/17/2011	1130	14.9	9.0	14.4	10.9	0	14.2	9.46	0
5/18/2011	1330	16.0	8.1	16.3	9.5	0	14.8	9.31	0
5/18/2011	1530	17.6	9.4	15.6	10.4	0	14.7	9.36	1
5/19/2011	930	16.5	10.5	16.6	9.1	0	14.9	9.1	0
5/19/2011	1115	16.3	9.1	17.8	9.7	0	15.4	9.23	0
5/21/2011	845	15.5	9.4	16.0	9.0	0	16.6	9.12	0
5/21/2011	1040	16.3	11.4	17.1	8.2	0	16.9	9.25	0
5/22/2011	1215	16.4	9.6	17.3	8.4	0	17.2	9.4	0
5/22/2011	1430	16.6	11.8	16.9	9.2	0	17.3	9.34	0
5/23/2011	915	15.6	7.9	15.7	10.6	0	16.7	9.2	0
5/23/2011	1030	16.6	8.9	17.1	9.1	0	16.9	9.2	0
5/24/2011	1230	16	11.2	16.7	9.7	0	16.9	9.4	0
5/24/2011	1415	15.8	10.4	16.7	9.6	0	16.9	9.4	0
6/14/2011	1330	18.5	8.3	20.2	9.3	1	17.9	9.9	1
6/14/2011	1600	20.5	9.3	21.2	9.9	0	18.2	9.8	0
6/15/2011	930	19.9	11.4	20.4	14.3	0	17.5	9.5	0
6/15/2011	1130	20.0	9.2	20.5	12.6	0	17.5	9.7	0
6/16/2011	1250	19.5	8.2	19.7	16.4	0	18.1	9.8	1

* 40 lbs of ice was added after loading and prior to taking temperature

Table 4. Characteristics assessed for steelhead health condition and short term survival.

Character	Normal	C
Percent Scale Loss	Lower relative numbers based on 0-100%	Higher relative numbers based on 0-100%
Body Color	High contrast dark dorsal surfaces and light sides	Low contrast dorsal surfaces and coppery colored sides
Fin Hemorrhaging	No bleeding at base of fins	Blood present at base of fins
Eyes	Normally shaped	Bulging or with hemorrhaging
Gill Color	Dark beet red to cherry red colored gill filaments	Grey to light red colored gill filaments
Vigor	Active swimming (prior to anesthesia)	Lethargic or motionless (prior to anesthesia)

Table 5. Results of dummy tagged steelhead evaluated after being held for 48 hours at the release site during the 6 Year and South Delta Temporary Barrier studies.

Holding Site	Examination Date, Time	Mean (sd) Forklength (mm)	Mortality	Mean (sd) scale loss %	Normal Body Color	No Fin Hemorrhaging	Normal Eye Quality	Normal Gill Color
Durham Ferry	3/23/11, 0915	273.8 (9.7)	0/6	5.7 (2.7)	6/6	6/6	6/6	6/6
Durham Ferry	3/24/11, 1220	251.8 (19.0)	0/6		6/6	6/6	6/6	6/6
Durham Ferry	3/25/11, 0900	247.8 (19.2)	0/6	4.3 (1.6)	6/6	6/6	6/6	6/6
Durham Ferry	3/26/11, 1201		0/24[2]					
Durham Ferry	5/4/11, 1210	287.8 (17.3)	0/6	43.4 (21.9)	5/6	6/6	5/6	6/6
Durham Ferry	5/5/11, 1216	267.5 (15.9)	1/9[1]	25.6 (16.1)	9/9	8/9	8/9	6/9
Durham Ferry	5/6/11, 0910	274.7 (16.6)	0/3[1]	4.3 (1.2)	3/3	3/3	3/3	3/3
Durham Ferry	5/7/11, 0910	282.8 (18.8)	0/6	6.3 (2.9)	6/6	6/6	6/6	6/6
Durham Ferry	5/18/11, 1204	270.7 (18.9)	0/6	12.2 (5.5)	6/6	6/6	6/6	6/6
Durham Ferry	5/19/11, 0900		0/24[2]					
Durham Ferry	5/20/11, 1212	269.3 (26.1)	0/6	15.0 (7.1)	6/6	6/6	6/6	6/6
Durham Ferry	5/21/11, 0906	278.5 (27.2)	0/6	27.5 (6.9)	6/6	6/6	6/6	6/6
Durham Ferry	5/23/11, 0910	289.7 (15.5)	0/6	20 (10.5)	6/6	6/6	6/6	6/6
Durham Ferry	5/24/11, 1210	287 (31.2)	0/6	19.2 (2)	6/6	6/6	6/6	6/6
Durham Ferry	5/25/11, 0910	294.2 (19.2)	0/6	16.7 (5.2)	6/6	6/6	6/6	6/6
Durham Ferry	5/26/11, 1215	288 (15.7)	0/6	9.2 (3.8)	6/6	6/6	6/6	6/6
Durham Ferry	6/16/11, 1204		0/23[2]					
Durham Ferry	6/17/11, 1206[3]	282.7 (27)	1/6	33.3 (29.6)	3/6	6/6	6/6	5/6
Durham Ferry	6/18/11, 1200	269 (17.8)	0/6	3.3 (1.5)	6/6	6/6	6/6	6/6

1 Only three fish were sampled on 5/6/11 due to three additional fish sampled on 5/5/11
2 Fish given to CA/NV Fish Health Center for further evaluation
3 Assessed 3 hours late

Table 6. Names and descriptions of acoustic receivers and hydrophones used in the 2011 steelhead tagging study, with receiver codes used in Figure 4, the survival model (Figure 10-Figure 12), and in data processing at the Columbia River Research Lab (CRRL) of the United States Geological Survey (USGS) in Cook, Washington.

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 node	37.685333	121.256389	DFU1	A0a	901
San Joaquin River near Durham Ferry upstream of the release site, downstream node	37.687617	121.258150	DFU2	A0b	902
San Joaquin River near Durham Ferry; release site (no acoustic hydrophone located here)	37.686991	121.268258	DF	A1	
San Joaquin River near Durham Ferry downstream of the release site, upstream node	37.687550	121.271117	DFD1	A2a	903
San Joaquin River near Durham Ferry downstream of the release site, downstream node	37.688950	121.275667	DFD2	A2b	904
San Joaquin River near Banta Carbona	37.728183	121.298550	BCA	A3	905
San Joaquin River downstream of Paradise Cut	37.761650	121.309300	PCO	A4	937
San Joaquin River near Mossdale Bridge	37.794000	121.310900	MOS	A5	906
San Joaquin River near Lathrop, upstream	37.811167	121.319283	SJLU	A6a	909
San Joaquin River near Lathrop, downstream	37.811650	121.318683	SJLD	A6b	910
San Joaquin River at Stockton USGS gauge	37.933367	121.328667	STS	A7	911
San Joaquin River at Stockton Navy Drive Bridge	37.946550	121.339633	STN	A8	912
San Joaquin River at Shipping Channel Marker 18	38.021933	121.465983	C18	A9a	915
San Joaquin River at Shipping Channel Marker 16	38.026083	121.470817	C16	A9b	916
San Joaquin River near Medford Island, east	38.052767	121.510917	MFE	A10a	917
San Joaquin River near Medford Island, west	38.053200	121.513517	MFW	A10b	918
Old River East, near junction with San Joaquin, upstream	37.812217	121.335467	OREU	B1a	907
Old River East, near junction with San Joaquin, downstream	37.812600	121.335450	ORED	B1b	908
Old River South, upstream	37.819709	121.379215	ORSU	B2a	802
Old River South, downstream	37.818843	121.379814	ORSD	B2b	803
Old River North, upstream	37.889961	121.572875	ORNU	B3a	814
Old River North, downstream	37.892072	121.567887	ORND	B3b	815
Middle River South	37.824913	121.380829	MRS	C1	801
Middle River North, upstream	37.890200	121.489479	MRNU	C2a	816
Middle River North, downstream	37.892264	121.490199	MRND	C2b	817

Table 6. (Continued)

Individual Receiver Name and Description	Hydrophone Location		Receiver Code	Survival Model Code	Data Processing Code
	Latitude (°N)	Longitude (°W)			
Radial Gate at Clifton Court Forebay, upstream (in entrance channel to forebay), array 1	37.829600	121.556949	RGU1	D1a	810
Radial Gate at Clifton Court Forebay, upstream, array 2	37.829591	121.556949	RGU2	D1b	811
Radial Gate at Clifton Court Forebay, downstream (inside forebay), array 1 in dual array	37.829852	121.557694	RGD1	D2a	812
Radial Gate at Clifton Court Forebay, downstream, array 2 in dual array	37.829906	121.557670	RGD2	D2b	813
Central Valley Project trashracks	37.816658[a]	121.558690[a]	CVP	E1	701–713
Central Valley Project holding tank (all holding tanks pooled)	37.815910[a]	121.559090[a]	CVPtank	E2	715/716
Delta Mendota Canal[b]	37.816240	121.560367	DMC	E3	714
Turner Cut, north (closer to San Joaquin)	37.991383	121.455200	TCN	F1a	914
Turner Cut, south (farther from San Joaquin)	37.989850	121.460017	TCS	F1b	913
San Joaquin River at Jersey Point, east (upstream)	38.056085[a]	121.686341[a]	JPTE	G1a	600
San Joaquin River at Jersey Point, west (downstream)	38.050615[a]	121.692585[a]	JPTW	G1b	610
False River, west (closer to San Joaquin)	38.056217	121.668150	FRW	H1a	922
False River, east (farther from San Joaquin)	38.056100	121.661467	FRE	H1b	921
Chipps Island, east (upstream)	38.047540[a]	121.890599[a]	CHPE	G2a	500/517
Chipps Island, west (downstream)	38.046090[a]	121.896439[a]	CHPW	G2b	510/516
Chipps Island, north (near Spoonbill Creek)[b]	38.052640	121.889735	CHPN		515
Paradise Cut inside, east (upstream)	37.760061	121.310481	PCIE	P1a	935
Paradise Cut inside, west (downstream)	37.760897	121.315811	PCIW	P1b	936
Threemile Slough, south[b]	38.097333	121.685200	TMS	T1a	920
Threemile Slough, north[b]	38.111133	121.683067	TMN	T1b	919

a = Average latitude and longitude given for sites with multiple hydrophones

b = Not used in survival model

Table 7. Environmental monitoring sites used in predator decision rule.

Environmental Monitoring Site				Data Available				
Site Name	Latitude (°N)	Longitude (°W)	Detection Site	River Flow	Water Velocity	River Stage	Pumping	Reservoir Inflow
CLC	37.8298	121.5574	RGU, RGD	No	No	No	No	Yes
FAL	38.0555	121.6672	FRE/FRW	Yes	Yes	Yes	No	No
GLC	37.8201	121.4497	ORS	Yes	Yes	Yes	No	No
HLT	38.0031	121.5108	C18/C16, MFE/MFW	Yes	Yes	No	No	No
MAL	38.0428	121.9201	CHP	No	No	Yes	No	No
MDM	37.9425	121.5340	MRN	Yes	Yes	Yes	No	No
MSD	37.7860	121.3060	BCA, PCO, MOS	Yes	Yes	Yes	No	No
ODM	37.8101	121.5419	CVP, DMC	Yes	Yes	Yes	No	No
OH1	37.8080	121.3290	ORE	Yes	Yes	Yes	No	No
OH4	37.8900	121.5697	ORN	Yes	Yes	Yes	No	No
ORI	37.8280	121.5526	RGU, RGD	Yes	Yes	No	No	No
SJG	37.9351	121.3295	STS, STN	Yes	Yes	Yes	No	No
SJJ	38.0520	121.6891	JPT	Yes	Yes	Yes	No	No
SJL	37.8100	121.3230	SJL	Yes	Yes	Yes	No	No
TRN	37.9927	121.4541	TCN/TCS	Yes	Yes	Yes	No	No
TRP	37.8165	121.5596	CVP, DMC	No	No	No	Yes	No
TSL	38.1004	121.6866	TMS/TMN	Yes	Yes	Yes	No	No
VNI	38.0500	121.4960	C18/C16	No	No	Yes	No	No
VNS	37.6670	121.2670	DFU, DFD, BCA	Yes	No	Yes	No	No

Table 8. Cutoff values of migration metrics used in predator filter. Observed values past cutoff indicate a predator. See Table 9 for extra conditions and comments. Footnotes refer to both this table and Table 9.

		Residence Time[a] (hr)		Migration Rate[b, c] (km/hr)		BLPS (Absolute value)	No. of Visits	No. of Prior Upstream Forays
		Near Field	Mid-Field					
Detection Site	Previous Site	Maximum	Maximum	Minimum	Maximum	Maximum	Maximum	Maximum
DFU	DF	500	1,000	0	4		1	0
	DFU, DFD, BCA	500	1,000	0	4		3	2
DFD	DF	500	1,000	0	4		1	0
	DFU, DFD	500	1,000	0	4		10	2
	BCA	500	1,000	0.2	4		3	2
BCA	DF	5	10	0	4	4	1	0
	DFU, DFD	20	40	0.1	4	4	3	0
	BCA	30	320				8	1
	PCO, MOS	1	2	0.1	4	4	4 (2 from MOS)	2
PCO	DFU, DFD	25	50	0.1	4	4	3	0
	BCA	25	50	0	4	4	3	0
	PCO	20	130				3	2
	MOS	2	4	0.2	4	4	2	2
MOS	DFU	50 (100[f])	100 (200[f])	0.1	5.5	4.5	2 (1[f])	0
	DFD	50 (100[f])	100 (200[f])	0.1	5.5	4.5	1	0
	BCA, POS	50 (100[f])	100 (200[f])	0	5.5	4.5	1	0
	MOS	20	250				3	1
	SJL	10	20	0.2	5.5	4.5	2	1
	ORE	10	20	0.4	5.5	4.5	2	1

a = Near-field residence time includes up to 12 hours missing between detections, while mid-field residence time includes entire time lag between first and last detections without intervening detections elsewhere

b = Approximate migration rate calculated on most direct pathway

c = Missing values for transitions to and from single site (or between CVP and DMC): travel times must be 12 to 24 hours

f = See comments for alternative criteria.

Table 8. (Continued)

		Residence Time[a] (hr)						
		Near Field	Mid-Field	Migration Rate[b, c] (km/hr)		BLPS (Absolute value)	No. of Visits	No. of Prior Upstream Forays
Detection Site	Previous Site	Maximum	Maximum	Minimum	Maximum	Maximum	Maximum	Maximum
SJL	DF, DFD	24	48	0.1	5.5	4.5	2	0
	BCA, PCO, MOS	24	48	0.1	5.5	4.5	2	0
	SJL	2	236 (86[f])				3	1
	ORE	1	2	0.5	5.5		1	1
	STS	1	10	1.5	4	4.5	2	0
STS	DFD – MOS, SJL, ORE	12 (6[f])	24 (12[f])	0.2 (0.1[f])	5.5	4.5	1	0
	STS	3	49				5	1
	STN	3	6	0.2	4	4.5	2	3
STN	MOS, SJL	10 (2.5[f])	20 (5[f])	0.1 (0.2[f])	5.5	4	1	0
	STS	10 (2.5[f])	20 (5[f])	0.03 (0.1[f])	5.5	4	1	0
	STN	4	84				2	4
	ORE	3	5	1.3	5.5		1	0
	C18/C16	4	8	1.3 (1.1[f])	4	4	2	4
C18/C16	DFD, BCA, SJL	30	60	0.5	5.5	4	1	0
	STS	30 (15[f])	60 (30[f])	0.1 (0.5[f])	5.5	4	1	0
	STN	30 (15[f])	60 (30[f])	0.1 (0.4[f])	5.5	4	1	0
	C18/C16	30 (15[f])	500				3	4
	MFE/MFW	15 (3[f])	30 (6[f])	0.4	4	4	3	2
	TCN/TCS	15	6	0.1	4		3	1
	MRN	15	30	0.1	4		1	1

a = Near-field residence time includes up to 12 hours missing between detections, while mid-field residence time includes entire time lag between first and last detections without intervening detections elsewhere

b = Approximate migration rate calculated on most direct pathway

c = Missing values for transitions to and from single site (or between CVP and DMC): travel times must be 12 to 24 hours

f = See comments for alternative criteria

Table 8. (Continued)

		Residence Time[a] (hr)						
		Near Field	Mid-Field	Migration Rate[b, c] (km/hr)		BLPS (Absolute value)	No. of Visits	No. of Prior Upstream Forays
Detection Site	Previous Site	Maximum	Maximum	Minimum	Maximum	Maximum	Maximum	Maximum
MFE/MFW	SJL, STN	24	48	0.3	4	4	1	0
	C18/C16	24	48	0.1	4	4	2	0
	TCN/TCS	24	48	0.1	4	4	1	0
	MFE/MFW	10	128				2	4
	MRN	24	48	0.1	4		1	1
TCN/TCS	BCA	20	40	0.3	4	4	1	0
	STS, STN	20	40	0.1	4	4	1	0
	TCN/TCS	15	165				3	4
	C18/C16	10	20	0.2	4		1	4
	MFE/MFW	3	6	0.8	4	4	1	4
	MRN	10	20	0.2	4		1	4
TMN/TMS	C18/C16, MFE/MFW	20	20 (100[f])	0.2	4	3	1	0
	ORN, MRN	20	100	0.2	4	3	1	0
	RGU/RGD	20	100	0.02	1	4	1	0
	CVPtank	20	100	0.2	3	4	1	0
	JPT, FRE/FRW	20	100	0.2	4	4	1	4
	TMN/TMS	10	64				2	0
ORE	DF, DFU, DFD	1	2	0.03	5.5	4.5	1	0
	BCA	1	2	0.1	5.5	4.5	1	0
	PCO	1 (3[f])	2 (6[f])	0.02	5.5	4.5	1	0
	MOS	1 (3[f])	2 (6[f])	0.03	5.5	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

b = Approximate migration rate calculated on most direct pathway

c = Missing values for transitions to and from single site (or between CVP and DMC): travel times must be 12 to 24 hours

f = See comments for alternative criteria

Table 8. (Continued)

Detection Site	Previous Site	Residence Time[a] (hr) Near Field Maximum	Mid-Field Maximum	Migration Rate[b, c] (km/hr) Minimum	Maximum	BLPS (Absolute value) Maximum	No. of Visits Maximum	No. of Prior Upstream Forays Maximum
ORE (cont.)	ORE	3	76				3	1
	SJL	1	2	0.5	5.5		1	1
	ORS, MRS	3	6	0.3	4	4.5	2	3
ORS	DF/DFU/DFD - MOS	80	160	0.05	5.5	4.5	1	0
	SJL	80	160	0.1	5.5		1	0
	ORE	80	160	0.04 (0.1[f])	5.5	4.5	1	0
	ORS	20	220				8	1
	MRS	20	40	0.3	5.5		1	0
	ORN, MRN	20	40	0.3	4	4	2	1
	RGU	20	40	0.3	4	4	2	1
	CVP	20	40	0.3	4	4	2	2
MRS	BCA	10	20	0.3	5.5		1	0
	ORE	10	20	0.04	5.5		1	0
	ORS	1	2	0.3	5.5		1	1
MRN	ORE	15	30	0.6	4	3	1	0
	ORS, MRS	15	30	0.1	4	3	1	0
	ORN	15	30	0.1	4		1	0
	MRN	10	75				2	0
	RGU	15	30	0.1	4		1	0
	CVP	15	30	0.1	4		1	0
	C18/C16, MFE/MFW	15	30	0.1	4		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

b = Approximate migration rate calculated on most direct pathway

c = Missing values for transitions to and from single site (or between CVP and DMC): travel times must be 12 to 24 hours

f = See comments for alternative criteria

Table 8. (Continued)

Detection Site	Previous Site	Residence Time[a] (hr) Near Field		Migration Rate[b, c] (km/hr)		BLPS (Absolute value)	No. of Visits	No. of Prior Upstream Forays
		Near Field	Mid-Field					
		Maximum	Maximum	Minimum	Maximum	Maximum	Maximum	Maximum
MRN (cont.)	TCN/TCS	15	30	0.1	4		1	0
CVP	rel, DFD, BCA	500	800	0.1	5.5		1	0
	MOS, ORS	500	800	0.2	4	2	1	0
	CVP	100	1,000				4	3
	CVPtank	100	1,000	0	1		5	3
	RGU	500	800	0	4	3	10	9
	ORN	300 (500[f])	600 (800[f])	0	4	3	10 (8)	9
	MRN	500	800	0	4		1	0
CVPtank, DMC	CVP	20	150	0	NA		2	9
ORN	BCA	100	200	0.3	4	3	1	0
	ORE	100	200	0.2	4	3	1	0
	ORS	100	200	0.2	4	3	2	1
	RGU	100	200	0	4	3	15	4
	CVP	100	200	0	4	3	15	4
	ORN	100	700				15	4
	MRN	100	200	0.1	4		4	4
	C18/C16, MFE/MFW, TCN/TCS	100	200	0.1	4		1	4
	JPT	20	40	0.1	4	3	15	4
RGU/RGD	ORE, ORS	80 (336[h])	80 (336[h])	0.08	4.1	3	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

b = Approximate migration rate calculated on most direct pathway

c = Missing values for transitions to and from single site (or between CVP and DMC): travel times must be 12 to 24 hours

f = See comments for alternative criteria

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

Table 8. (Continued)

		Residence Time[a] (hr)						No. of Prior
		Near Field	Mid-Field	Migration Rate[b, c] (km/hr)		BLPS (Absolute value)	No. of Visits	Upstream Forays
Detection Site	Previous Site	Maximum	Maximum	Minimum	Maximum	Maximum	Maximum	Maximum
RGU/RGD	CVP	80 (336[h])	80 (336[h])	0.02	4.5	3	2	0
(cont.)	ORN	80 (336[h])	80 (336[h])	0	4	3	2	2
	MRN	10 (336[h])	10 (336[h])	0	4		1	0
JPT	MOS	40	200	0.2	4	3	1	0
	C18/C16, MFE/MFW, TCN/TCS	40	200 (40[f])	0.2	4	3	1	0
	TMN/TMS	40	200	0.2	4	3	2	4
	ORS	40	200	0.1	4	3	1	0
	ORN, MRN	40	200	0.2	4	3	1	0
	RGU	40	200	0.03	0.7	4.5	1	0
	JPT	30	150				3	0
	FRE/FRW	30	150	0.1	7		3	4
	CHP	10	50	0.5	4	2	2	4
FRE/FRW	STN	30	150	0.2	4	3	1	0
	C18/C16, MFE/MFW, TCN/TCS	30	150 (30[f])	0.1	4	3	1	0
	TMN/TMS	30	150	0.2	4	3	1	0
	ORS	30	150	0.2	4	3	1	0
	ORN, MRN	30	150	0.1	4	3	1	0
	CVPtank	30	150	0.1	4	3	1	0
	RGU/RGD	30	150	0.1	1	3	1	0
	JPT	30	94	0.1	NA		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

b = Approximate migration rate calculated on most direct pathway

c = Missing values for transitions to and from single site (or between CVP and DMC): travel times must be 12 to 24 hours

f = See comments for alternative criteria.

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

Table 8. (Continued)

		Residence Time[a] (hr)						
		Near Field	Mid-Field	Migration Rate[b, c] (km/hr)		BLPS (Absolute value)	No. of Visits	No. of Prior Upstream Forays
Detection Site	Previous Site	Maximum	Maximum	Minimum	Maximum	Maximum	Maximum	Maximum
FRE/FRW	FRE/FRW	10	94				3	0
(cont.)	CHP	10	50	0.2	4	3	2	4
CHP	DFD, MOS, ORS	40	200	0.3	4		1	0
	C18/C16, MFE/MFW, TCN/TCS	40	200	0.2	7		1	0
	TMN/TMS	40	200	0.2	7		2	0
	ORN, MRN	40	200	0.2	7		1	0
	CVPtank	40	200	0.2	3		1	0
	RGU/RGD	40	200	0	1		1	0
	JPT, FRE/FRW	40	40	0.2	7		2	0
	CHP	40	160				3	0

a = Near-field residence time includes up to 12 hours missing between detections, while mid-field residence time includes entire time lag between first and last detections without intervening detections elsewhere

b = Approximate migration rate calculated on most direct pathway

c = Missing values for transitions to and from single site (or between CVP and DMC): travel times must be 12 to 24 hours

Table 9. Flow and water velocity conditions used in predator filter. Unmet conditions indicate a predator. Footnotes, “Extra conditions” and “Comment” refers to both this table and Table 8.

		Flow[d] (cfs)		Water Velocity[d] (ft/sec)				
Detection Site	Previous Site	At arrival	At departure[e]	At arrival	At departure[e]	Average during transition	Extra Conditions	Comment
DFU	DF							
	DFU, DFD, BCA							
DFD	DF						Transition from PCO not allowed	
	DFU, DFD						Allow 15 visits coming from DFD	
	BCA							
BCA	DF	<12000						
	DFU, DFD		<5000 (from MOS)				Maximum residence time 1000 hrs if next transition is downstream	
	BCA						Maximum residence time 1000 hrs if next transition is downstream; allowed only 3 visits if arrival flow > 12000 cfs	
	PCO, MOS							
PCO	DFU, DFD							
	BCA		<5000					
	PCO						Maximum mid-field residence time is 190 hours if next transition is downstream	
	MOS	>11000						
MOS	DFU	>11000						Alternate values if next transition is downstream

d = Flow or velocity condition, if any, must be violated for predator classification

e = Condition at departure from previous site

Table 9. (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
MOS (cont.)	DFD	<14000				<2.7	Allow 2 visits if arrival flow < 11,000 cfs	Alternate values if next transition is downstream
	BCA, POS	<14000				<3	Allow 2 visits if arrival flow < 11,000 cfs	Alternate values if next transition is downstream
	MOS	<14000				<3		
	SJL					<1.9		
	ORE							
SJL	DF, DFD					<1.9	Minimum migration rate from DFD is 0.2 if average transition water velocity > 1.9	
	BCA, PCO, MOS						Minimum migration rate from MOS is 0.2	
	SJL					<1		Alternate values if average transition water velocity outside range
	ORE			<0.5				
	STS	<-300 (>-300)[g]	>-300 (<-300)[g]	<-0.5 (>-0.5)[g]	>-0.5 (<-0.5)[g]	<0.2		Not allowed
STS	DFD – MOS, SJL, ORE	<1700	<4000	<0.5	<1	<0.5		Alternate values if arrival water velocity out of range and do not arrive at beginning of flood tide
	STS	<8000 (>8000)	<2.5 (>2.5)					
	STN	<8000 (>8000)	<2.5 (>2.5)					
STN	MOS, SJL	<4000	<1					Alternate values for alternate flow conditions

d = Flow or velocity condition, if any, must be violated for predator classification

e = Condition at departure from previous site

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

Table 9. (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		
STN (cont.)	STS							Alternate values for alternate flow conditions
	STN							
	ORE							
	C18/C16					-0.01 to 0.4		
C18/C16	DFD, BCA, SJL					-0.01 to 0.4		
	STS					<0.1		Alternate values if average transition water velocity outside range
	STN			<-0.8				Alternate values if average transition water velocity outside range
	C18/C16							Alternate values if average transition water velocity outside range
	MFE/MFW							Alternate values if arrival water velocity outside range
	TCN/TCS							
	MRN							
MFE/MFW	SJL, STN						Transition from RGU/RGD is not allowed	
	C18/C16							
	TCN/TCS		>-0.01					
	MFE/MFW			<0.1				
	MRN			<0.1				
TCN/TCS	BCA						Transition from FRE/FRW is not allowed.	Flow/velocity < 0 is directed into Turner Cut from San Joaquin River
	STS, STN					<0.1		

d = Flow or velocity condition, if any, must be violated for predator classification

e = Condition at departure from previous site

Table 9. (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
TCN/TCS (cont.)	TCN/TCS		<2000	<0	<0			
	C18/C16			<0.1	>-0.01			
	MFE/MFW		<-50000		<-1			
	MRN		>0		>0			
TMN/TMS	C18/C16, MFE/MFW							Alternate value for transitions from C18/C16
	ORN, MRN							
	RGU/RGD							
	CVPtank	<0 (>0)[g]	>0 (<0)[g]	<0 (>0)[g]	>0 (<0)[g]			
	JPT, FRE/FRW							
	TMN/TMS							
ORE	DF, DFU, DFD			<2		1.9–2.3	Minimum migration rate is 0.1 from DFD, 0.04 from DFU	
	BCA			<2		1.9–2.3		
	PCO							Alternate value if arrival water velocity > 2; Migration rate > 0.03 if average transition water velocity is outside range
	MOS	>3000						Alternate value if arrival water velocity > 2; Migration rate > 0.03 if average transition water velocity is outside range
	ORE	<3000						
	SJL							
	ORS, MRS							
ORS	DF/DFU/DFD - MOS					<1.8		

d = Flow or velocity condition, if any, must be violated for predator classification

e = Condition at departure from previous site

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

Table 9. (Continued)

		Flow[d] (cfs)		Water Velocity[d] (ft/sec)				
Detection Site	Previous Site	At arrival	At departure[e]	At arrival	At departure[e]	Average during transition	Extra Conditions	Comment
ORS (cont.)	SJL							
	ORE							Alternate value if average transition water velocity outside range
	ORS					<1.5		
ORS (cont.)	MRS					<1.5		
	ORN, MRN					<1.5		
	RGU							
	CVP							
MRS	BCA							Return visits not allowed
	ORE							
	ORS							
MRN	ORE	<0		<0				
	ORS, MRS	<-5500 (>-6000)[g]	>-6000 (-5500)[g]	<-0.5 (>-0.5)[g]	>-0.5 (<-0.5)[g]			
	ORN							
	MRN							
	RGU			0.15			CCFB inflow < 3000 cfs on departure[e]	
	CVP			<0.15	<0.1		CVP pumping < 4000 cfs on departure[e]	
	C18/C16, MFE/MFW							
	TCN/TCS							
CVP	rel, DFD, BCA							Allow only for first release group
	MOS, ORS							

d = Flow or velocity condition, if any, must be violated for predator classification

e = Condition at departure from previous site

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

Table 9. (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
CVP (cont.)	CVP	<3000		<1.5			CVP pumping > 1500 cfs on arrival[e]	
	CVPtank	<3000	<2000	<1.5	<0.8			
	RGU							Do not allow if came from lower San Joaquin River
	ORN						CVP pumping > 1500 cfs on arrival[e]	Alternate values if came from lower San Joaquin River
CVP (cont.)	MRN	>-700		>-0.3				
CVPtank, DMC	CVP	>-700		>-0.3				
ORN	BCA	>-700		>-0.3				
	ORE	>-700		>-0.3				
	ORS	>-700	>-1000	>-0.3	>-0.6			
	RGU	<-900 or >1000		<-0.2 or >0.3			CCFB inflow < 3000 cfs on departure[e]	
	CVP						CVP pumping < 1500 cfs on departure[e]	
	ORN	<500		<0.3				
	MRN	<500		<0.3				
	C18/C16, MFE/MFW, TCN/TCS							
	JPT		>-1000		>-0.6			
RGU/RGD	ORE, ORS		<2000		<0.8			Maximum residence time is 800 hours if at gates < 80 hours, or if present at RGU < 80% of total residence time before returning to Old River

d = Flow or velocity condition, if any, must be violated for predator classification
e = Condition at departure from previous site

Table 9. (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 (cont.)	CVP and ORN						CVP pumping < 4000 cfs at departure	Maximum residence time is 800 hours if at gates < 80 hours, or if present at RGU < 80% of total residence time before returning to Old River
	MRN							Maximum residence time is 100 hours if at gates < 10 hours, or 800 hours if present at RGU < 80% of total residence time before returning to Old River
	MOS							
JPT	C18/C16, MFE/MFW, TCN/TCS							Alternate value for transitions from MFE/MFW
	TMN/TMS							
	ORS							
	ORN, MRN							
	CVP, CVPtank	<0 (>0)[g]	>0 (<0)[g]	<0 (>0)[g]	>0 (<0)[g]		Maximum migration rate is 3 from CVPtank	Trucking release sites are downstream of JPT
	RGU							Trucking release sites are downstream of JPT
	JPT							
	FRE/FRW							
	CHP							
	CHP							

d = Flow or velocity condition, if any, must be violated for predator classification
e = Condition at departure from previous site

Table 9. (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
FRE/FRW	STN							
	C18/C16, MFE/MFW, TCN/TCS							Alternate value for transitions from MFE/MFW
	TMN/TMS							
	ORS							
	ORN, MRN							
	CVPtank							Trucking release sites are downstream of JPT
	RGU/RGD							Trucking release sites are downstream of JPT
	JPT							
	FRE/FRW							
	CHP							
CHP	DFD, MOS, ORS							
	C18/C16, MFE/MFW, TCN/TCS							
	TMN/TMS							
	ORN, MRN							
	CVPtank							
	RGU/RGD							
	JPT, FRE/FRW							
	CHP							

d = Flow or velocity condition, if any, must be violated for predator classification

e = Condition at departure from previous site

Table 10. Number of tags from each release group that were detected after release in 2011, including predator-type detections and detections omitted from the survival analysis.

Release Group	1	2	3	4	5	Total
Number Released	479	474	478	480	285	2,196
Number Detected	469	464	471	474	281	2,159
Number Detected Downstream	464	446	438	439	239	2,026
Number Detected Upstream of Study Area	461	463	471	474	281	2,150
Number Detected in Study Area	346	265	266	262	103	1,242
Number Detected in San Joaquin River Route	176	137	132	139	57	641
Number Detected in Old River Route	166	129	140	126	49	610
Number Assigned to San Joaquin River Route	173	123	113	133	51	593
Number Assigned to Old River Route	167	114	121	116	42	560

Table 11. Number of tags observed from each release group at each detection site in 2011, 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 across 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	Release Group 4	Release Group 5	Total
Release site at Durham Ferry			479	474	478	480	285	2,196
Durham Ferry Upstream	DFU	A0	53	107	108	137	99	504
Durham Ferry Downstream	DFD	A2	439	444	436	435	237	1,991
Banta Carbona	BCA	A3	269	301	298	297	126	1,291
Paradise Cut (Outside)	PCO	A4	8	120	147	141	72	488
Mossdale	MOS	A5	122	209	238	228	91	888
Lathrop	SJL	A6	165	127	126	135	56	609
Stockton USGS Gauge	STS	A7	158	114	113	121	43	549
Stockton Navy Drive Bridge	STN	A8	144	117	107	117	37	522
Shipping Channel Marker 18	C18	A9a	147	87	82	91	16	423
Shipping Channel Marker 16	C16	A9b	144	82	78	89	15	408
Shipping Channel Markers (Pooled)	C18/C16	A9	149	89	82	92	16	428
Medford Island East	MFE	A10a	112	62	49	53	11	287
Medford Island West	MFW	A10b	119	61	53	55	12	300
Medford Island (Pooled)	MFE/MFW	A10	122	67	54	59	12	314
Turner Cut North	TCN	F1a	18	41	32	42	18	151
Turner Cut South	TCS	F1b	16	42	31	41	18	148
Turner Cut (Pooled)	TCN/TCS	F1	18	42	32	42	18	152
Old River East	ORE	B1	144	126	138	124	49	581
Old River South Upstream	ORSU	B2a	131	108	114	105	43	501
Old River South Downstream	ORSD	B2b	119	109	120	106	43	497
Old River South (Pooled)	ORS	B2	144	113	121	109	43	530
Old River North Upstream	ORNU	B3a	80	59	58	39	5	241
Old River North Downstream	ORND	B3b	77	53	58	38	5	231
Old River North: SJR Route	ORN	B3	2	20	17	15	5	59
Old River North: OR Route	ORN	B3	80	39	42	26	0	187
Old River North (Pooled)	ORN	B3	82	59	59	41	5	246
Middle River South	MRS	C1	11	9	8	4	3	35
Middle River North Upstream	MRNU	C2a	30	22	12	23	7	94
Middle River North Downstream	MRND	C2b	31	20	12	22	6	91
Middle River North: SJR Route	MRN	C2	1	16	7	19	5	48
Middle River North: OR Route	MRN	C2	30	6	5	4	2	47
Middle River North (Pooled)	MRN	C2	31	22	13	23	7	96
Radial Gates Upstream (gate open)	RGU	D1O	44	61	65	60	21	251
Radial Gates Upstream (gate closed)	RGU	D1C	6	26	11	10	1	54

Table 11. (Continued)

Detection Site	Site Code	Survival Model Code	Release Group 1	2	3	4	5	Total
Radial Gates Upstream: SJR Route	RGU	D1	0	17	12	14	8	51
Radial Gates Upstream: OR Route	RGU	D1	50	62	63	54	13	242
Radial Gates Downstream #1	RGD1	D2a	43	67	62	51	14	237
Radial Gates Downstream #2	RGD2	D2b	39	62	47	38	13	199
Radial Gates Downstream: SJR Route	RGD	D2	0	14	9	16	5	44
Radial Gates Downstream: OR Route	RGD	D2	43	56	57	38	8	202
Radial Gates Downstream (Pooled)	RGD	D2	43	70	67	55	14	249
Central Valley Project Trashrack	CVP	E1	10	72	46	43	19	190
CVP Trashrack: SJR Route	CVP	E1	0	14	9	6	0	29
CVP Trashrack: OR Route	CVP	E1	10	57	33	37	19	156
Central Valley Project Holding Tank	CVPtank	E2	6	26	18	23	14	87
CVP tank: SJR Route	CVPtank	E2	0	5	5	5	0	15
CVP tank: OR Route	CVPtank	E2	6	21	13	18	14	72
Delta Mendota Canal	DMC	E3	0	1	4	4	1	10
Threemile Slough South	TMS	T1a	26	14	16	15	0	71
Threemile Slough North	TMN	T1b	21	10	15	12	1	59
Threemile Slough (Pooled)	TMS/TMN	T1	26	14	16	16	1	73
Jersey Point East	JPTE	G1a	192	77	71	86	12	438
Jersey Point West	JPTW	G1b	187	69	68	86	12	422
Jersey Point: SJR Route	JPT	G1	128	60	46	68	10	312
Jersey Point: OR Route	JPT	G1	86	22	31	26	2	167
Jersey Point (Pooled)	JPT	G1	214	82	78	94	12	480
False River East	FRE	H1a	108	28	24	24	8	192
False River West	FRW	H1b	122	33	22	25	10	212
False River: SJR Route	FRE/FRW	H1	51	26	15	21	9	122
False River: OR Route	FRE/FRW	H1	77	9	10	8	1	105
False River (Pooled)	FRE/FRW	H1	128	35	26	29	10	228
Chipps Island East	CHPE	G2a	221	132	116	148	37	654
Chipps Island West	CHPW	G2b	183	121	108	119	31	562
Chipps Island: SJR Route	CHP	G2	122	77	59	91	15	364
Chipps Island: OR Route	CHP	G2	117	63	59	65	23	327
Chipps Island (Pooled)	CHP	G2	240	141	118	156	38	693

Table 12. Number of tags observed from each release group at each detection site in 2011 and used in the survival analysis, including predator-type detections. 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	Release Group 4	Release Group 5	Total
Release site at Durham Ferry			479	474	478	480	285	2,196
Durham Ferry Upstream	DFU	A0	31	74	75	97	87	364
Durham Ferry Downstream	DFD	A2	413	388	394	373	192	1,760
Banta Carbona	BCA	A3	263	280	281	279	116	1,219
Paradise Cut (Outside)	PCO	A4	4[a]	94	124	128	61	411
Mossdale	MOS	A5	119	192	226	220	84	841
Lathrop	SJL	A6	165	114	107	129	50	565
Stockton USGS Gauge	STS	A7	158	109	103	121	39	530
Stockton Navy Drive Bridge	STN	A8	142	113	100	117	36	508
Shipping Channel Marker 18	C18	A9a	143	74	70	78	16	381
Shipping Channel Marker 16	C16	A9b	143	74	71	77	15	380
Shipping Channel Markers (Pooled)	C18/C16	A9	146	78	74	79	16[a]	393
Medford Island East	MFE	A10a	106	57	41	49	11[a]	264
Medford Island West	MFW	A10b	112	59	40	51	11[a]	277
Medford Island (Pooled)	MFE/MFW	A10	115	62	45	55	11[a]	288
Turner Cut North	TCN	F1a	13	35	22	38	18[a]	126
Turner Cut South	TCS	F1b	12	37	21	36	18[a]	124
Turner Cut (Pooled)	TCN/TCS	F1	13	37	22	38	18[a]	128
Old River East	ORE	B1	141	109	118	115	41	524
Old River South Upstream	ORSU	B2a	127	97	99	99	36[a]	458
Old River South Downstream	ORSD	B2b	117	100	108	101	36[a]	462
Old River South (Pooled)	ORS	B2	142	105	109	104	36[a]	496
Old River North Upstream	ORNU	B3a	77	32	33	23	5[a]	170
Old River North Downstream	ORND	B3b	74	23	33	23	4[a]	157
Old River North: SJR Route	ORN	B3	1	18	16	15	5[a]	55
Old River North: OR Route	ORN	B3	79	14	18	10	0[a]	121
Old River North (Pooled)	ORN	B3	83	32	34	25	5[a]	176
Middle River South	MRS	C1	10	4	4	2	2[a]	22
Middle River North Upstream	MRNU	C2a	25	9	5	17	7[a]	63
Middle River North Downstream	MRND	C2b	26	9	6	16	6[a]	63
Middle River North: SJR Route	MRN	C2	0	8	5	17	5[a]	35
Middle River North: OR Route	MRN	C2	26	1	1	0	2[a]	30
Middle River North (Pooled)	MRN	C2	26	9	6	17	7[a]	65

Table 12. (Continued)

Detection Site	Site Code	Survival Model Code	Release Group					Total
			1	2	3	4	5	
Radial Gates Upstream (gate open)	RGU	D1O	41	57	63	56	21	238
Radial Gates Upstream (gate closed)	RGU	D1C	2	16	6	8	0	32
Radial Gates Upstream: SJR Route	RGU	D1	0	16	9	14	8	47
Radial Gates Upstream: OR Route	RGU	D1	43	57	60	50	13	223
Radial Gates Downstream #1	RGD1	D2a	42	65	59	50	13[a]	229
Radial Gates Downstream #2	RGD2	D2b	39	61	44	37	12[a]	193
Radial Gates Downstream: SJR Route	RGD	D2	0	13	7	16	5	41
Radial Gates Downstream: OR Route	RGD	D2	42	55	57	38	8	200
Radial Gates Downstream (Pooled)	RGD	D2	42	68	64	54	13	241
Central Valley Project Trashrack	CVP	E1	6	31	24	30	17	109
CVP Trashrack: SJR Route	CVP	E1	0	5	6	6	0	17
CVP Trashrack: OR Route	CVP	E1	6	27	18	24	17	92
Central Valley Project Holding Tank	CVPtank	E2	6	26	17	23	14	86
CVP tank: SJR Route	CVPtank	E2	0	5	4	5	0	14
CVP tank: OR Route	CVPtank	E2	6	21	13	18	14	72
Jersey Point East	JPTE	G1a	173	54	44	56	12[a]	339
Jersey Point West	JPTW	G1b	166	44	40	54	11[a]	315
Jersey Point: SJR Route	JPT	G1	120	53	42	57	10[a]	282
Jersey Point: OR Route	JPT	G1	72	5	8	5	2[a]	92
Jersey Point (Pooled)	JPT	G1	192	58	50	62	12[a]	374
False River East	FRE	H1a	2	2	2	0	0[a]	6
False River West	FRW	H1b	5	2	0	0	0[a]	7
False River: SJR Route	FRE/FRW	H1	3	1	1	0	0[a]	5
False River: OR Route	FRE/FRW	H1	2	1	1	0	0[a]	4
False River (Pooled)	FRE/FRW	H1	5	2	2	0	0[a]	9
Chipps Island East	CHPE	G2a	217	131	113	148	37	646
Chipps Island West	CHPW	G2b	180	120	106	117	31	554
Chipps Island: SJR Route	CHP	G2	122	77	59	91	15	364
Chipps Island: OR Route	CHP	G2	116	63	59	65	23	326
Chipps Island (Pooled)	CHP	G2	239	141	118	156	38	692

a = not used in survival model.

Table 13. Number of tags in 2011 from each release group that were first classified as in a predator at the detection sites, based on the predator filter.

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	Model Code	1	2	3	4	5	Total	1	2	3	4	5	Total
Durham Ferry Upstream	DFU	A0	12	16	8	12	0	48	2	2	0	2	0	6
Durham Ferry Downstream	DFD	A2	21	19	17	17	0	74	4	1	1	1	0	7
Banta Carbona	BCA	A3	7	17	16	14	3	57	1	6	4	4	2	17
Paradise Cut (Outside)	PCO	A4	1	12	10	4	6	33	0	0	1	2	0	3
Mossdale	MOS	A5	1	7	11	5	2	26	0	4	5	2	2	13
Lathrop	SJL	A6	1	1	5	2	2	11	0	1	1	1	0	3
Stockton USGS Gauge	STS	A7	1	1	1	1	1	5	0	2	1	1	0	4
Stockton Navy Drive Bridge	STN	A8	2	2	2	2	0	8	0	1	1	0	0	2
Shipping Channel Markers	C18/C16	A9	0	1	2	0	0	3	2	0	0	0	0	2
Medford Island	MFE/MFW	A10	2	0	0	1	0	3	0	0	0	0	0	0
Old River East	ORE	B1	1	5	11	10	6	33	1	4	3	5	2	15
Old River South	ORS	B2	1	5	9	6	2	23	1	2	0	0	0	3
Old River North	ORN	B3	2	0	0	0	0	2	0	0	0	1	0	1
Middle River South	MRS	C1	0	1	1	0	1	3	0	1	0	0	0	1
Middle River North	MRN	C2	0	0	0	0	0	0	0	1	0	0	0	1
Radial Gates Upstream	RGU	D1	0	0	1	0	0	1	1	0	1	1	0	3
Radial Gates Downstream	RGD	D2	0	0	0	0	0	0	0	0	0	1	0	1
Central Valley Project Trashrack	CVP	E1	0	2	2	0	0	4	0	3	0	3	0	6
Central Valley Project Holding Tank	CVPtank	E2	0	0	0	0	0	0	0	0	0	0	0	0
Turner Cut	TCN/TCS	F1	0	1	0	1	0	2	0	0	1	0	0	1
Jersey Point	JPT	G1	0	2	2	0	0	4	0	0	0	0	0	0
Chipps Island	CHP	G2	0	1	1	0	0	2	0	0	0	0	0	0
Chipps Island North, near Spoonbill Creek	CHPn		0	0	0	0	0	0	0	0	0	0	0	0
False River	FRE/FRW	H1	1	0	1	0	0	2	0	0	1	0	0	1
Threemile Slough	TMS/TMN	T1	0	0	0	0	1	1	0	0	0	0	0	0
Total Tags			53	93	100	75	24	345	12	28	20	24	6	90

Table 14. Number of tags from each release group that were detected after release in 2011, excluding predator-type detections, and including detections omitted from the survival analysis.

Release Group	1	2	3	4	5	Total
Number Released	479	474	478	480	285	2,196
Total Number Detected	469	461	471	474	281	2,156
Total Number Detected Downstream	460	442	437	437	239	2,015
Total Number Detected Upstream of Study Area	461	460	471	474	281	2,147
Total Number Detected in Study Area	343	260	256	257	102	1,218
Number Detected in San Joaquin River Route	175	129	114	132	52	602
Number Detected in Old River Route	162	124	119	117	48	570
Number Assigned to San Joaquin River Route	173	125	113	130	50	591
Number Assigned to Old River Route	165	123	116	117	48	569

Table 15. Number of tags observed from each release group at each detection site in 2011, excluding predator-type tags. 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 across all routes. Route could not be identified for some tags.

			Release Group					
Detection Site	Site Code	Survival Model Code	1	2	3	4	5	Total
Release site at Durham Ferry			479	474	478	480	285	2,196
Durham Ferry Upstream	DFU	A0	43	90	97	126	96	452
Durham Ferry Downstream	DFD	A2	435	439	435	433	237	1,979
Banta Carbona	BCA	A3	260	291	291	292	126	1,260
Paradise Cut (Outside)	PCO	A4	4	101	140	138	70	453
Mossdale	MOS	A5	119	198	226	223	90	856
Lathrop	SJL	A6	165	119	109	128	51	572
Stockton USGS Gauge	STS	A7	158	108	100	120	40	526
Stockton Navy Drive Bridge	STN	A8	143	112	99	116	37	507
Shipping Channel Marker 18	C18	A9a	146	80	78	90	16	410
Shipping Channel Marker 16	C16	A9b	143	77	74	88	15	397
Shipping Channel Markers (Pooled)	C18/C16	A9	148	82	78	91	16	415
Medford Island East	MFE	A10a	110	58	45	51	11	275
Medford Island West	MFW	A10b	117	57	48	53	12	287
Medford Island (Pooled)	MFE/MFW	A10	119	63	49	57	12	300
Turner Cut North	TCN	F1a	18	37	28	40	18	141
Turner Cut South	TCS	F1b	16	38	27	39	18	138
Turner Cut (Pooled)	TCN/TCS	F1	18	38	28	40	18	142
Old River East	ORE	B1	140	120	118	116	48	542
Old River South Upstream	ORSU	B2a	127	102	98	99	40	466
Old River South Downstream	ORSD	B2b	116	103	103	101	40	463
Old River South (Pooled)	ORS	B2	140	107	104	103	40	494
Old River North Upstream	ORNU	B3a	78	56	56	38	5	233
Old River North Downstream	ORND	B3b	75	50	56	37	5	223
Old River North: SJR Route	ORN	B3	2	19	17	15	5	58
Old River North: OR Route	ORN	B3	79	40	41	26	0	186
Old River North (Pooled)	ORN	B3	80	56	57	40	5	238
Middle River South	MRS	C1	10	6	4	3	2	25
Middle River North Upstream	MRNU	C2a	30	21	10	23	7	91
Middle River North Downstream	MRND	C2b	31	19	10	22	6	88
Middle River North: SJR Route	MRN	C2	1	15	8	19	5	48
Middle River North: OR Route	MRN	C2	30	7	5	4	2	48
Middle River North (Pooled)	MRN	C2	31	21	11	23	7	93
Radial Gates Upstream (gate open)	RGU	D1O	43	58	59	59	21	240
Radial Gates Upstream (gate closed)	RGU	D1C	6	23	11	10	0	50
Radial Gates Upstream: SJR Route	RGU	D1	0	16	13	14	8	51

Table 15. (Continued)

Detection Site	Site Code	Survival Model Code	Release Group 1	2	3	4	5	Total
Radial Gates Upstream: OR Route	RGU	D1	50	63	59	55	14	241
Radial Gates Downstream #1	RGD1	D2a	42	64	58	50	13	227
Radial Gates Downstream #2	RGD2	D2b	38	58	43	37	12	188
Radial Gates Downstream: SJR Route	RGD	D2	0	13	10	16	5	44
Radial Gates Downstream: OR Route	RGD	D2	43	57	55	39	9	203
Radial Gates Downstream (Pooled)	RGD	D2	42	66	63	54	13	238
Central Valley Project Trashrack	CVP	E1	10	68	39	42	18	177
CVP Trashrack: SJR Route	CVP	E1	0	13	9	6	0	28
CVP Trashrack: OR Route	CVP	E1	10	58	34	36	19	157
Central Valley Project Holding Tank	CVPtank	E2	6	24	16	22	13	81
CVP tank: SJR Route	CVPtank	E2	0	5	5	5	0	15
CVP tank: OR Route	CVPtank	E2	6	20	13	17	14	70
Delta Mendota Canal	DMC	E3	0	1	4	4	1	10
Threemile Slough South	TMS	T1a	26	14	15	15	0	70
Threemile Slough North	TMN	T1b	21	10	14	12	0	57
Threemile Slough (Pooled)	TMS/TMN	T1	26	14	15	16	0	71
Jersey Point East	JPTE	G1a	189	71	67	84	12	423
Jersey Point West	JPTW	G1b	185	64	64	84	12	409
Jersey Point: SJR Route	JPT	G1	128	59	46	67	10	310
Jersey Point: OR Route	JPT	G1	86	22	32	27	2	169
Jersey Point (Pooled)	JPT	G1	211	76	73	91	12	463
False River East	FRE	H1a	106	26	22	23	8	185
False River West	FRW	H1b	119	29	20	24	10	202
False River: SJR Route	FRE/FRW	H1	51	25	15	21	9	121
False River: OR Route	FRE/FRW	H1	77	10	11	8	1	107
False River (Pooled)	FRE/FRW	H1	125	31	24	28	10	218
Chipps Island East	CHPE	G2a	216	125	112	144	37	634
Chipps Island West	CHPW	G2b	180	115	104	116	31	546
Chipps Island: SJR Route	CHP	G2	122	74	59	90	15	360
Chipps Island: OR Route	CHP	G2	117	64	59	65	23	328
Chipps Island (Pooled)	CHP	G2	235	134	114	152	38	673

Table 16. Number of tags observed from each release group at each detection site in 2011 and used in survival analysis, excluding predator-type detections. 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	2	3	4	5	Total
Release site at Durham Ferry			479	474	478	480	285	2,196
Durham Ferry Upstream	DFU	A0	30	56	66	87	82	321
Durham Ferry Downstream	DFD	A2	414	402	403	383	197	1,799
Banta Carbona	BCA	A3	258	287	283	286	123	1,237
Paradise Cut (Outside)	PCO	A4	3[a]	94	128	131	67	423
Mossdale	MOS	A5	118	198	224	222	90	852
Lathrop	SJL	A6	165	115	108	126	49	563
Stockton USGS Gauge	STS	A7	158	108	100	120	40	526
Stockton Navy Drive Bridge	STN	A8	143	112	99	116	37	507
Shipping Channel Marker 18	C18	A9a	143	71	68	77	16	375
Shipping Channel Marker 16	C16	A9b	142	71	68	77	15	373
Shipping Channel Markers (Pooled)	C18/C16	A9	145	75	71	79	16[a]	386
Medford Island East	MFE	A10a	105	54	39	48	11[a]	257
Medford Island West	MFW	A10b	110	55	41	50	11[a]	267
Medford Island (Pooled)	MFE/MFW	A10	113	59	42	54	11[a]	279
Turner Cut North	TCN	F1a	14	33	23	37	18[a]	125
Turner Cut South	TCS	F1b	13	35	22	35	18[a]	123
Turner Cut (Pooled)	TCN/TCS	F1	14	35	23	37	18[a]	127
Old River East	ORE	B1	139	117	115	116	47	534
Old River South Upstream	ORSU	B2a	125	99	94	98	39[a]	455
Old River South Downstream	ORSD	B2b	116	101	103	100	40[a]	460
Old River South (Pooled)	ORS	B2	140	106	104	103	40[a]	493
Old River North Upstream	ORNU	B3a	76	30	32	22	5[a]	165
Old River North Downstream	ORND	B3b	74	22	32	22	4[a]	154
Old River North: SJR Route	ORN	B3	2	16	16	15	5[a]	54
Old River North: OR Route	ORN	B3	77	14	17	9	0[a]	117
Old River North (Pooled)	ORN	B3	79	30	33	24	5[a]	171
Middle River South	MRS	C1	9	6	3	3	2[a]	23
Middle River North Upstream	MRNU	C2a	26	9	4	17	7[a]	63
Middle River North Downstream	MRND	C2b	27	9	5	16	6[a]	63
Middle River North: SJR Route	MRN	C2	0	8	5	17	5[a]	35
Middle River North: OR Route	MRN	C2	27	1	0	0	2[a]	30
Middle River North (Pooled)	MRN	C2	27	9	5	17	7[a]	65

a = not used in survival model.

Table 16. (Continued)

Detection Site	Site Code	Survival Model Code	Release Group 1	2	3	4	5	Total
Radial Gates Upstream (gate open)	RGU	D1O	40	54	57	56	21	228
Radial Gates Upstream (gate closed)	RGU	D1C	2	14	6	8	0	30
Radial Gates Upstream: SJR Route	RGU	D1	0	13	9	14	8	44
Radial Gates Upstream: OR Route	RGU	D1	42	55	54	50	13	214
Radial Gates Downstream #1	RGD1	D2a	41	62	56	50	13[a]	222
Radial Gates Downstream #2	RGD2	D2b	38	57	41	37	12[a]	185
Radial Gates Downstream: SJR Route	RGD	D2	0	11	7	16	5	39
Radial Gates Downstream: OR Route	RGD	D2	41	53	54	38	8	194
Radial Gates Downstream (Pooled)	RGD	D2	41	64	61	54	13	233
Central Valley Project Trashrack	CVP	E1	6	53	22	29	16	105
CVP Trashrack: SJR Route	CVP	E1	0	6	6	6	0	18
CVP Trashrack: OR Route	CVP	E1	6	26	16	23	16	87
Central Valley Project Holding Tank	CVPtank	E2	6	24	15	22	13	80
CVP tank: SJR Route	CVPtank	E2	0	5	4	5	0	14
CVP tank: OR Route	CVPtank	E2	6	19	11	17	13	66
Jersey Point East	JPTE	G1a	171	51	42	54	12[a]	330
Jersey Point West	JPTW	G1b	164	41	38	52	11[a]	306
Jersey Point: SJR Route	JPT	G1	119	49	40	54	10[a]	272
Jersey Point: OR Route	JPT	G1	71	5	7	5	2[a]	90
Jersey Point (Pooled)	JPT	G1	190	54	47	59	12[a]	362
False River East	FRE	H1a	2	1	2	0	1[a]	6
False River West	FRW	H1b	5	1	0	0	1[a]	7
False River: SJR Route	FRE/FRW	H1	3	0	1	0	1[a]	5
False River: OR Route	FRE/FRW	H1	2	1	1	0	0[a]	4
False River (Pooled)	FRE/FRW	H1	5	1	2	0	1[a]	9
Chipps Island East	CHPE	G2a	212	125	110	144	37	628
Chipps Island West	CHPW	G2b	177	114	102	114	31	538
Chipps Island: SJR Route	CHP	G2	120	71	57	88	15	351
Chipps Island: OR Route	CHP	G2	114	62	57	64	23	320
Chipps Island (Pooled)	CHP	G2	234	134	114	152	38	672

a = not used in survival model.

Table 17. Number of juvenile steelhead tagged by each tagger in each release group during the 2011 tagging study.

Tagger	Release Group					Total Tags
	1	2	3	4	5	
A	120	149	119	120	72	580
B	119	147	120	120	70	576
C	120	29	119	120	70	458
D	120	149	120	120	73	582
Total Tags	479	474	478	480	285	2196

Table 18. Release size and counts of tag detections at key detection sites by tagger, excluding predator-type detections.

Detection Site	Tagger			
	A	B	C	D
Release at Durham Ferry	580	576	458	582
Mossdale (MOS)	220	237	185	210
Lathrop (SJL)	151	155	112	145
Shipping Channel Markers (C18/C16)	114	103	79	90
Turner Cut (TCN/TCS)	31	36	23	37
Medford Island (MFE/MFW)	81	70	60	68
Old River East (ORE)	132	140	124	138
Old River South (ORS)	117	133	110	133
Old River North (ORN)	44	42	36	49
Middle River North (MRN)	20	17	14	14
Clifton Court Forebay Interior (RGD)	57	65	55	56
Central Valley Project Holding Tank (CVPtank)	24	13	12	31
Jersey Point (JPT)	102	95	87	78
Chipps Island (CHP)	189	175	136	172

Table 19. Performance metric estimates (standard error in parentheses) for tagged juvenile steelhead released in the 2011 tagging study, excluding predator-type detections. South Delta ("SD") survival extended to the Shipping Channel Markers and Turner Cut in Route A, and the Central Valley Project Trash Rack, exterior radial gate receiver at Clifton Court Forebay, and Old River North and Middle River North receivers in Route B. (Population-level estimates were estimated as weighted averages of the release-specific estimates, using weights proportional to release size.)

	Release Group(s)							
Parameter	1	2	3	4	5[a]	2 - 5	3 - 4	Population Estimate
ψ_{AA}	0.47 (0.03)	0.35 (0.03)	0.37 (0.03)	0.36 (0.03)		0.35 (0.02)	0.36 (0.02)	0.39 (0.02)
ψ_{AF}	0.05 (0.01)	0.16 (0.02)	0.12 (0.02)	0.17 (0.02)		0.16 (0.01)	0.15 (0.02)	0.12 (0.01)
ψ_{BB}	0.44 (0.03)	0.46 (0.03)	0.49 (0.03)	0.45 (0.03)		0.46 (0.02)	0.47 (0.02)	0.46 (0.02)
ψ_{BC}	0.04 (0.01)	0.03 (0.01)	0.01 (0.01)	0.03 (0.02)		0.03 (0.01)	0.02 (0.01)	0.03 (0.01)
S_{AA}	0.72 (0.04)	0.68 (0.05)	0.51 (0.05)	0.69 (0.05)		0.60 (0.03)	0.60 (0.03)	0.65 (0.02)
S_{AF}	0.33 (0.12)	0.27 (0.07)	0.26 (0.07)	0.59 (0.07)		0.35 (0.04)	0.44 (0.05)	0.36 (0.04)
S_{BB}	0.68 (0.04)	0.50 (0.05)	0.44 (0.04)	0.55 (0.05)		0.49 (0.02)	0.49 (0.03)	0.54 (0.02)
S_{BC}	0.67 (0.08)	0.30 (0.13)	0.48 (0.06)	0.22 (0.17)		0.32 (0.08)	0.38 (0.11)	0.42 (0.06)
ψ_{A}	0.52 (0.03)	0.51 (0.03)	0.49 (0.03)	0.53 (0.03)	0.52 (0.05)	0.51 (0.02)	0.51 (0.02)	0.51 (0.02)
ψ_{B}	0.48 (0.03)	0.49 (0.03)	0.51 (0.03)	0.47 (0.03)	0.48 (0.05)	0.49 (0.02)	0.49 (0.02)	0.49 (0.02)
S_{A}	0.69 (0.04)	0.55 (0.04)	0.45 (0.04)	0.66[b] (0.04)	0.32 (0.06)	0.52 (0.02)	0.56 (0.03)	0.55 (0.02)
S_{B}	0.68 (0.04)	0.48 (0.04)	0.44 (0.04)	0.53[b] (0.05)	0.44 (0.07)	0.48 (0.02)	0.48 (0.03)	0.52 (0.02)
S_{Total}	0.69 (0.03)	0.52 (0.03)	0.44 (0.03)	0.60 (0.03)	0.38 (0.05)	0.50 (0.02)	0.52 (0.02)	0.54 (0.01)
$S_{A(MD)}$	0.82[b] (0.03)	0.50[b] (0.04)	0.39[b] (0.04)	0.52[b] (0.04)		0.45[b] (0.02)	0.46[b] (0.03)	0.56[b] (0.02)
$S_{B(MD)}$	0.53[b] (0.04)	0.05[b] (0.02)	0.09[b] (0.03)	0.06[b] (0.02)		0.06[b] (0.01)	0.08[b] (0.02)	0.18[b] (0.01)
$S_{Total(MD)}$	0.68 (0.03)	0.28 (0.03)	0.24 (0.03)	0.30 (0.03)		0.26 (0.02)	0.27 (0.02)	0.37 (0.01)
$S_{A(SD)}$	0.89 (0.03)	0.83 (0.03)	0.74 (0.04)	0.85 (0.03)		0.79 (0.02)	0.80 (0.02)	0.83 (0.02)
$S_{B(SD)}$	0.91 (0.03)	0.75 (0.04)	0.71 (0.04)	0.77 (0.04)		0.73 (0.02)	0.73 (0.03)	0.78 (0.02)
$S_{Total(SD)}$	0.90 (0.02)	0.79 (0.03)	0.72 (0.03)	0.81 (0.03)		0.76 (0.01)	0.77 (0.02)	0.81 (0.01)
ϕ_{A1A5}	0.73 (0.02)	0.56 (0.02)	0.54 (0.02)	0.54 (0.02)	0.36 (0.03)	0.52 (0.01)	0.54 (0.02)	0.56 (0.01)

a = a reduced model was fit to release group 5, and only the largest-scale performance metrics were estimable.

b = significant difference between route A and route B estimate (α =0.05) (tested only for Delta survival and Mid-Delta survival)

Table 20. Performance metric estimates (standard error in parentheses) for tagged juvenile steelhead released in the 2011 tagging study, including predator-type detections. South Delta ("SD") survival extended to the Shipping Channel Markers and Turner Cut in Route A, and the Central Valley Project Trash Rack, exterior radial gate receiver at Clifton Court Forebay, and Old River North and Middle River North receivers in Route B. (Population-level estimates were estimated as weighted averages of the release-specific estimates, using weights proportional to release size.)

	Release Group(s)							
Parameter	1	2	3	4	5[a]	2 - 5	3 - 4	Population Estimate
ψ_{AA}	0.47 (0.03)	0.36 (0.03)	0.37 (0.03)	0.36 (0.03)		0.35 (0.02)	0.37 (0.02)	0.39 (0.02)
ψ_{AF}	0.04 (0.01)	0.17 (0.02)	0.11 (0.02)	0.17 (0.03)		0.16 (0.01)	0.14 (0.02)	0.12 (0.01)
ψ_{BB}	0.44 (0.03)	0.46 (0.03)	0.49 (0.03)	0.45 (0.03)		0.46 (0.02)	0.47 (0.02)	0.46 (0.02)
ψ_{BC}	0.05 (0.01)	0.02 (0.01)	0.03 (0.01)	0.02 (0.01)		0.03 (0.01)	0.02 (0.01)	0.03 (0.01)
S_{AA}	0.74 (0.04)	0.74 (0.04)	0.53 (0.05)	0.73 (0.04)		0.63 (0.03)	0.63 (0.03)	0.68 (0.02)
S_{AF}	0.36 (0.13)	0.32 (0.07)	0.28 (0.08)	0.57 (0.07)		0.37 (0.04)	0.45 (0.05)	0.38 (0.05)
S_{BB}	0.71 (0.04)	0.53 (0.05)	0.45 (0.04)	0.56 (0.05)		0.52 (0.03)	0.50 (0.03)	0.56 (0.02)
S_{BC}	0.64 (0.09)	0.48 (0.15)	0.32 (0.13)	0.33 (0.23)		0.37 (0.08)	0.35 (0.12)	0.44 (0.08)
ψ_{A}	0.51 (0.03)	0.52 (0.03)	0.48 (0.03)	0.53 (0.03)	0.55 (0.05)	0.52 (0.02)	0.51 (0.02)	0.52 (0.02)
ψ_{B}	0.49 (0.03)	0.48 (0.03)	0.53 (0.03)	0.47 (0.03)	0.45 (0.05)	0.48 (0.02)	0.49 (0.02)	0.48 (0.02)
S_{A}	0.71 (0.04)	0.60 (0.04)	0.47 (0.04)	0.68[b] (0.04)	0.31[b] (0.06)	0.55 (0.02)	0.58 (0.03)	0.58 (0.02)
S_{B}	0.70 (0.04)	0.53 (0.05)	0.44 (0.04)	0.55[b] (0.05)	0.49[b] (0.07)	0.51 (0.02)	0.49 (0.03)	0.55 (0.02)
S_{Total}	0.71 (0.03)	0.57 (0.03)	0.46 (0.03)	0.62 (0.03)	0.39 (0.05)	0.53 (0.02)	0.54 (0.02)	0.56 (0.01)
$S_{A(MD)}$	0.85[b] (0.03)	0.56[b] (0.04)	0.41[b] (0.04)	0.53[b] (0.04)		0.47[b] (0.02)	0.48[b] (0.03)	0.59[b] (0.02)
$S_{B(MD)}$	0.55[b] (0.04)	0.05[b] (0.02)	0.10[b] (0.03)	0.06[b] (0.02)		0.07[b] (0.01)	0.08[b] (0.02)	0.19[b] (0.01)
$S_{Total(MD)}$	0.70 (0.03)	0.31 (0.03)	0.25 (0.03)	0.31 (0.03)		0.27 (0.02)	0.28 (0.02)	0.39 (0.01)
$S_{A(SD)}$	0.90 (0.02)	0.89 (0.03)	0.76 (0.03)	0.86 (0.03)		0.81 (0.02)	0.81 (0.02)	0.85 (0.01)
$S_{B(SD)}$	0.93 (0.02)	0.84 (0.03)	0.75 (0.04)	0.80 (0.04)		0.79 (0.02)	0.78 (0.03)	0.83 (0.02)
$S_{Total(SD)}$	0.92 (0.02)	0.86 (0.02)	0.76 (0.03)	0.83 (0.02)		0.80 (0.01)	0.79 (0.02)	0.84 (0.01)
ϕ_{A1A5}	0.72 (0.02)	0.53 (0.02)	0.55 (0.02)	0.53 (0.02)	0.34 (0.03)	0.51 (0.01)	0.54 (0.02)	0.55 (0.01)

a = a reduced model was fit to release group 5, and only the largest-scale performance metrics were estimable.
b = significant difference between route A and route B estimate (α=0.05) (tested only for Delta survival and Mid-Delta survival)

Table 21. Average travel time in days (harmonic mean) of acoustic-tagged juvenile steelhead from release at Durham Ferry during the 2011 tagging study. Standard error (SE) of "0" indicates SE < 0.01.

Detection Site and Route	Without Predator-Type Detections									With Predator-Type Detections								
	All Releases			Release S1			Releases S2 – S5			All Releases			Release S1			Releases S2 – S5		
	N	Travel Time	SE	N	Travel Time	SE	N	Travel Time	SE	N	Travel Time	SE	N	Travel Time	SE	N	Travel Time	SE
DFU	321	0.91	0.06	30	3.92	0.37	291	0.84	0.06	364	1.10	0.08	31	4.20	0.42	333	1.03	0.08
DFD	1,799	0.05	0	414	0.03	0	1,385	0.07	0	1,760	0.05	0	413	0.04	0	1,347	0.07	0
BCA	1,237	0.73	0.02	258	0.49	0.03	979	0.84	0.03	1,219	0.73	0.02	263	0.50	0.03	956	0.84	0.03
PCO	423	1.67	0.06	3	35.45	0.39	420	1.66	0.06	411	1.68	0.06	4	43.80	0.86	407	1.67	0.06
MOS	852	1.59	0.05	118	0.83	0.04	734	1.87	0.07	841	1.60	0.05	119	0.84	0.04	722	1.88	0.07
SJL	563	1.99	0.06	165	1.71	0.11	398	2.13	0.07	565	2.02	0.06	165	1.73	0.11	400	2.16	0.08
STS	526	3.72	0.09	158	4.02	0.18	368	3.61	0.10	530	3.77	0.09	158	4.04	0.18	372	3.67	0.11
STN	507	3.92	0.09	143	4.08	0.17	364	6.86	0.11	508	3.97	0.09	142	4.12	0.18	366	3.91	0.11
C18/C16	386	6.68	0.09	145	6.70	0.18	241	6.67	0.11	393	6.83	0.10	146	6.73	0.18	247	6.88	0.12
TCN/TCS	127	6.69	0.11	14	6.65	0.24	113	6.69	0.13	128	6.74	0.12	13	6.54	0.24	115	6.76	0.13
MFE/MFW	279	7.18	0.09	113	7.53	0.15	166	6.95	0.11	288	7.31	0.09	115	7.58	0.15	173	7.13	0.11
ORE	534	1.91	0.06	139	1.64	0.10	395	2.02	0.07	524	1.91	0.06	141	1.67	0.10	383	2.01	0.07
ORS	493	2.49	0.07	140	2.19	0.13	353	2.64	0.08	496	2.53	0.07	142	2.19	0.13	354	2.70	0.09
ORN via SJR	54	11.94	0.12	2	7.83	0.33	52	12.19	0.13	55	12.03	0.12	1	4.76	NA	54	12.38	0.14
ORN via OR	117	6.54	0.09	77	6.65	0.19	40	6.35	0.10	121	6.60	0.09	79	6.73	0.20	42	6.38	0.10
MRS	23	5.32	0.11	9	4.38	0.19	14	6.18	0.15	22	5.20	0.11	10	4.82	0.23	12	5.56	0.13
MRN via SJR	35	11.97	0.09	0	NA	NA	35	11.97	0.10	35	12.23	0.10	0	NA	NA	35	12.23	0.11
MRN via OR	30	8.27	0.11	27	7.98	0.22	3	12.25	0.13	30	8.31	0.11	26	7.78	0.21	4	15.08	0.23
RGU via SJR	44	12.56	0.11	0	NA	NA	44	12.56	0.12	47	13.00	0.12	0	NA	NA	47	13.00	0.13
RGU via OR	214	5.54	0.11	42	5.80	0.17	172	5.48	0.13	223	5.64	0.11	43	5.55	0.17	180	5.67	0.14
RGD via SJR	39	13.61	0.11	0	NA	NA	39	13.61	0.13	41	14.01	0.12	0	NA	NA	41	14.01	0.14
RGD via OR	194	5.81	0.11	41	5.58	0.15	153	5.87	0.14	200	5.86	0.11	42	5.36	0.15	158	6.01	0.14
CVP via SJR	18	13.71	0.10	0	NA	NA	18	13.71	0.11	17	13.98	0.12	0	NA	NA	17	13.98	0.13
CVP via OR	87	7.27	0.18	6	7.32	0.11	81	7.26	0.21	92	8.09	0.21	6	7.32	0.11	86	8.15	0.25
CVPtank via SJR	14	14.54	0.13	0	NA	NA	14	14.54	0.15	14	14.54	0.13	0	NA	NA	14	14.54	0.15

Table 21. (Continued)

Detection Site and Route	Without Predator-Type Detections									With Predator-Type Detections								
	All Releases			Release 1			Releases 2 – 5			All Releases			Release 1			Releases 2 – 5		
	N	Travel Time	SE	N	Travel Time	SE	N	Travel Time	SE	N	Travel Time	SE	N	Travel Time	SE	N	Travel Time	SE
CVPtank via OR	66	8.19	0.15	6	7.77	0.10	60	8.24	0.18	72	8.69	0.17	6	7.77	0.10	66	8.79	0.20
JPT via SJR	272	9.32	0.09	119	9.40	0.16	153	9.26	0.12	282	9.45	0.10	120	9.39	0.15	162	9.50	0.13
JPT via OR	90	11.33	0.09	71	11.36	0.18	19	11.21	0.12	92	11.37	0.09	72	11.38	0.18	20	11.31	0.11
FRE/FRW via SJR	5	5.55	0.08	3	6.07	0.15	2	4.81	0.12	5	8.82	0.16	3	6.70	0.15	2	27.58	0.52
FRE/FRW via OR	4	15.44	0.13	2	13.23	0.28	2	18.54	0.12	4	18.86	0.26	2	13.23	0.28	2	32.84	0.50
CHP	672	11.08	0.12	234	11.03	0.17	438	11.11	0.16	692	11.24	0.13	239	11.14	0.18	453	11.30	0.16
CHP via SJR	351	10.93	0.10	120	10.33	0.15	231	11.27	0.14	364	11.10	0.11	122	10.37	0.16	242	11.51	0.14
CHP via OR	320	11.23	0.14	114	11.87	0.18	206	10.90	0.17	326	11.35	0.14	116	11.97	0.19	210	11.03	0.18

Table 22. Average travel time in days (harmonic mean) of acoustic-tagged juvenile steelhead through the San Joaquin River Delta during the 2011 tagging study. Standard error (SE) of "0" indicates SE < 0.01.

Reach		Without Predator-Type Detections									With Predator-Type Detections								
		All Releases			Release S1			Releases S2 – S5			All Releases			Release S1			Releases S2 – S5		
Upstream Boundary	Downstream Boundary	N	Travel Time	SE	N	Travel Time	SE	N	Travel Time	SE	N	Travel Time	SE	N	Travel Time	SE	N	Travel Time	SE
DF Release Site	BCA	1,237	0.73	0.02	258	0.49	0.03	979	0.84	0.03	1,219	0.73	0.02	263	0.50	0.03	956	0.84	0.03
BCA	MOS	766	0.41	0.01	102	0.27	0.01	674	0.45	0.01	765	0.42	0.01	102	0.28	0.01	663	0.45	0.01
MOS	SJL	399	0.10	0	58	0.09	0.00	341	0.11	0	400	0.10	0	59	0.09	0	341	0.11	0
	ORE	374	0.10	0	54	0.07	0.00	320	0.10	0	369	0.10	0	56	0.07	0	313	0.10	0
SJL	STS	503	0.53	0.01	151	0.45	0.02	352	0.58	0.01	506	0.54	0.01	151	0.45	0.02	355	0.59	0.01
STS	STN	487	0.06	0	137	0.04	0.00	350	0.06	0	488	0.06	0	136	0.05	0	352	0.06	0
STN	C18/C16	357	1.02	0.01	125	1.01	0.02	232	1.02	0.02	363	1.01	0.01	126	1.02	0.02	237	1.00	0.02
	TCN/TCS	123	1.12	0.02	11	1.11	0.03	113	1.12	0.02	123	1.11	0.02	10	1.04	0.03	113	1.12	0.02
C18/C16	MFE/MFW	277	0.18	0	112	0.02	0.01	165	0.17	0	286	0.17	0	114	0.19	0.01	172	0.16	0
	ORN	17	2.61	0.04	0	NA	NA	17	2.61	0.05	17	2.61	0.04	0	NA	NA	17	2.61	0.05
	MRN	10	1.97	0.03	0	NA	NA	10	1.97	0.03	10	1.97	0.03	0	NA	NA	10	1.97	0.03
MFE/MFW	JPT/FRE/FRW	208	1.15	0.01	99	1.22	0.03	109	1.09	0.02	215	1.14	0.01	100	1.21	0.03	115	1.08	0.02
	ORN	7	2.77	0.04	0	NA	NA	7	2.77	0.04	7	2.77	0.04	0	NA	NA	7	2.77	0.04
	MRN	5	2.81	0.02	0	NA	NA	5	2.81	0.03	5	2.81	0.02	0	NA	NA	5	2.81	0.03
TCN/TCS	JPT/FRE/FRW	23	2.42	0.04	7	3.61	0.06	16	2.11	0.04	24	2.81	0.04	7	3.61	0.06	17	2.57	0.05
	ORN	29	2.10	0.03	1	1.83	NA	28	2.11	0.03	24	2.28	0.03	1	1.83	NA	23	2.31	0.04
	MRN	16	1.33	0.02	0	NA	NA	16	1.33	0.02	15	1.24	0.02	0	NA	NA	15	1.24	0.02
ORE	ORS	466	0.17	0	119	0.12	0.00	347	0.21	0	468	0.17	0	121	0.12	0	348	0.20	0
	MRS	22	0.36	0.01	8	0.22	0.01	14	0.59	0.02	21	0.33	0.01	9	0.24	0.01	12	0.46	0.01
ORS	ORN	111	1.44	0.03	72	1.22	0.04	39	2.15	0.06	115	1.43	0.03	74	1.23	0.04	41	2.02	0.05
	MRN	14	2.24	0.03	13	2.16	0.07	1	4.28	NA	13	2.48	0.03	12	2.40	0.07	1	4.28	NA
	RGU	209	1.00	0.02	41	0.62	0.02	168	1.17	0.02	218	1.01	0.02	42	0.62	0.02	176	1.19	0.02
	CVP	81	0.86	0.02	4	0.62	0.03	77	0.88	0.02	85	0.84	0.02	4	0.62	0.03	81	0.86	0.02
ORN via OR	JPT/FRE/FRW	69	2.61	0.03	56	2.64	0.06	13	2.48	0.04	70	2.64	0.03	56	2.64	0.06	14	2.63	0.04
ORN via SJR	JPT/FRE/FRW	3	0.16	0.01	0	NA	NA	3	1.59	0.01	3	1.59	0.01	0	NA	NA	3	1.59	0.01
	RGU	28	0.40	0.01	0	NA	NA	28	0.40	0.01	30	0.42	0.01	0	NA	NA	30	0.42	0.01
	CVP	11	0.38	0.01	0	NA	NA	11	0.38	0.01	10	0.36	0.01	0	NA	NA	10	0.36	0.01

Table 22. (Continued)

Reach		Without Predator-Type Detections									With Predator-Type Detections								
		All Releases			Release 1			Releases 2 – 5			All Releases			Release 1			Releases 2 – 5		
Upstream Boundary	Downstream Boundary	N	Travel Time	SE	N	Travel Time	SE	N	Travel Time	SE	N	Travel Time	SE	N	Travel Time	SE	N	Travel Time	SE
MRS	ORN	1	2.89	NA	0	NA	NA	1	2.89	NA	1	2.89	NA	0	NA	NA	1	2.89	NA
	MRN	10	0.94	0.02	9	0.93	0.04	1	1.09	NA	10	0.94	0.02	9	0.93	0.04	1	1.09	NA
	RGU	3	2.41	0.05	0	NA	NA	3	2.41	0.06	3	2.41	0.05	0	NA	NA	3	2.41	0.06
	CVP	3	4.25	0.06	0	NA	NA	3	4.25	0.05	3	4.25	0.06	0	NA	NA	3	4.25	0.07
MRN via OR	JPT/FRE/FRW	18	3.09	0.04	16	3.28	0.09	2	2.12	0.03	18	3.09	0.04	16	3.28	0.09	2	2.12	0.03
MRN via SJR	JPT/FRE/FRW	0	NA	NA	0	NA	NA	0	NA	NA	0	NA	NA	0	NA	NA	0	NA	NA
	RGU	16	0.36	0.01	0	NA	NA	16	0.36	0.01	17	0.38	0.01	0	NA	NA	17	0.38	0.01
	CVP	7	0.36	0	0	NA	NA	7	0.36	0	7	0.36	0	0	NA	NA	7	0.36	0
RGU via OR (gates open)	RGD	159	0.01	0	37	0.01	0.00	122	0.01	0	165	0.01	0	38	0.01	0	127	0.01	0
RGU via OR (gates closed)	RGD	22	0.02	0	2	0.38	0.02	20	0.02	0	23	0.02	0	2	0.38	0.02	21	0.02	0
RGU via SJR (gates open)	RGD	30	0.01	0	0	NA	NA	30	0.01	0	31	0.01	0	0	NA	NA	31	0.01	0
RGU via SJR (gates closed)	RGD	3	0.14	0	0	NA	NA	3	0.14	0	4	0.17	0	0	NA	NA	4	0.17	0
CVP via OR	CVPtank	66	0.09	0.01	6	0.12	0.00	60	0.09	0.01	72	0.09	0.01	6	0.12	0	66	0.09	0.01
CVP via SJR	CVPtank	14	0.16	0.01	0	NA	NA	14	0.16	0.01	14	0.16	0.01	0	NA	NA	14	0.16	0.01
JPT	CHP	323	0.64	0.01	160	0.64	0.02	163	0.63	0.01	335	0.63	0.01	162	0.63	0.02	173	0.64	0.01
MFW/MFW		229	2.06	0.02	94	2.11	0.04	135	2.02	0.02	238	2.04	0.02	96	2.09	0.04	142	2.01	0.02
TCN/TCS		55	4.10	0.05	5	3.87	0.03	50	4.12	0.06	57	4.08	0.05	5	3.87	0.03	52	4.11	0.05
ORN		80	3.37	0.03	60	3.50	0.06	20	3.03	0.04	82	3.39	0.03	61	3.53	0.06	21	3.02	0.04
MRN		22	3.32	0.04	1	3.69	0.08	4	2.27	0.03	22	3.32	0.04	18	3.69	0.08	4	2.27	0.03
RGD		150	3.12	0.04	27	3.51	0.08	123	3.04	0.04	151	3.11	0.04	27	3.51	0.08	124	3.03	0.04
CVPtank		70	0.96	0.01	5	0.89	0.03	65	0.97	0.02	73	0.98	0.01	5	0.89	0.03	68	0.98	0.02

Table 23. Results of single-variate regression analyses of route entrainment at the head of Old River, ordered by P-value. The values df1 and df2 are the degrees of freedom for the F-test.

	F-test			
Covariate	F	df1	df2	*P*
Fork Length	2.6827	1	1,089	0.1017
Change in flow at OH1	1.2233	1	1,089	0.2690
Change in velocity at OH1	0.9912	1	1,089	0.3197
Flow proportion into San Joaquin	0.6291	1	1,089	0.4279
Velocity at SJL	0.4796	1	1,089	0.4888
Flow at OH1	0.2461	1	1,089	0.6200
Change in flow at SJL	0.2444	1	501	0.6212
Change in velocity at SJL	0.2257	1	501	0.6349
Change in flow proportion into San Joaquin	0.1781	1	498	0.6732
Velocity at OH1	0.1639	1	1,089	0.6857
Exports at SWP	0.0661	1	1,089	0.7971
Flow at SJL	0.0364	1	1,089	0.8486
Release Group	0.3137	4	1,086	0.8689
Exports at CVP	0.0187	1	1,089	0.8914
Combined Exports	0.0078	1	1,089	0.9297

Table 24. Estimates of survival in 2011 from the CVP holding tank or interior radial gates receiver to Chipps Island, Jersey Point, and False River for tagged steelhead that arrived at CVP or radial gates via only the Old River route, or via either the Old River route or the San Joaquin River route. Standard errors are in parentheses. Predator-type detections were excluded.

	From CVP holding tank		From Radial Gates (Interior)	
Release Group	OR Route	OR and SJR Route	OR Route	OR and SJR Route
1[a]	0.88 (0.16)	0.88 (0.16)	0.72 (0.08)	0.72 (0.88)
2	0.90 (0.07)	0.88 (0.07)	0.74 (0.06)	0.70 (0.06)
3	0.91 (0.09)	0.87 (0.09)	0.73 (0.06)	0.71 (0.06)
4	1 (0) (n=22)	0.98 (0.05)	0.79 (0.08)	0.76 (0.06)
5	0.93 (0.07)	0.93 (0.07)	0.38 (0.17)	0.31 (0.13)
2-5	0.95 (0.03)	0.92 (0.03)	0.73 (0.04)	0.69 (0.03)
3-4	0.98 (0.04)	0.93 (0.05)	0.76 (0.05)	0.73 (0.04)
Pooled	0.94 (0.03)	0.92 (0.03)	0.73 (0.03)	0.70 (0.03)

a = No tagged steelhead from this release group were detected at the CVP holding tank or the radial gates coming from the San Joaquin River route.

Appendix A

Table A1. Definitions of parameters used in the release-recapture survival model. Parameters used only in particular submodels are noted.

Parameter	Definition
S_{A2}	Probability of survival from Durham Ferry Downstream (DFD) to Banta Carbona (BCA)
S_{A3}	Probability of survival from Banta Carbona (BCA) to Paradise Cut (PCO); not estimated separately from ψ_{A1} ($_{A3A4}$ estimated instead)
S_{A4}	Probability of survival from Paradise Cut to Mossdale (MOS)
S_{A5}	Probability of survival from Mossdale (MOS) to Lathrop (SJL) or Old River East (ORE)
S_{A6}	Probability of survival from Lathrop (SJL) to Stockton USGS Gauge (STS)
S_{A7}	Probability of survival from Stockton USGS Gauge (STS) to Stockton Navy Drive Bridge (STN)
S_{A8}	Probability of survival from Stockton Navy Drive Bridge (STN) to Shipping Channel Markers (C18/C16) or Turner Cut (TCN/TCS)
S_{B1}	Probability of survival from Old River East (ORE) to Old River South (ORS)
$S_{A8,G2}$	Overall survival from Stockton Navy Drive Bridge (STN) to Chipps Island (CHPE/CHPW)
$S_{A9,G2}$	Overall survival from C18/C16 to Chipps Island (CHPE/CHPW) (Submodel I)
$S_{B2,G2}$	Overall survival from ORS to Chipps Island (CHPE/CHPW)
$S_{C1,G2}$	Overall survival from MRS to Chipps Island (CHPE/CHPW)
$S_{F1,G2}$	Overall survival from TCN/TCS to Chipps Island (CHPE/CHPW) (Submodel I)
ψ_{A1}	Probability of remaining in the San Joaquin River at the junction with Paradise Cut; = 1 - ψ_{P1}; assumed = 1
ψ_{A2}	Probability of remaining in the San Joaquin River at the head of Old River; = 1 - ψ_{B2}
ψ_{A3}	Probability of remaining in the San Joaquin River at the junction with Turner Cut; = 1 - ψ_{F3}
ψ_{B2}	Probability of entering Old River at the head of Old River; = 1 - ψ_{A2}
ψ_{B3}	Probability of remaining in Old River at the head of Middle River; = 1 - ψ_{C3}
ψ_{C3}	Probability of entering Middle River at the head of Middle River; = 1 - ψ_{B3}
ψ_{F3}	Probability of entering Turner Cut at the junction with the San Joaquin River; = 1 - ψ_{A3}
ψ_{G1}	Probability of moving downriver in the San Joaquin River at the Jersey Point/False River junction; = 1 - ψ_{H1}
ψ_{H1}	Probability of entering False River at the Jersey Point/False River junction; = 1 - ψ_{G1}
ψ_{P1}	Probability of entering Paradise Cut at its junction with the San Joaquin River; = 1 - ψ_{A1}; assumed = 0
$\phi_{A1,A0}$	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
$\phi_{A3,A4}$	Joint probability of moving from BCA toward PCO, and surviving from BCA to PCO
$\phi_{A3,A5}$	Joint probability of moving from BCA toward MOS, and surviving from BCA to PCO
$\phi_{A3,B3}$	Joint probability of moving from BCA toward ORN via Paradise Cut, and surviving from BCA to ORN
$\phi_{A3,C2}$	Joint probability of moving from BCA toward MRN via Paradise Cut, and surviving from BCA to MRN
$\phi_{A3,D1O}$	Joint probability of moving from BCA toward RGU via Paradise Cut, surviving from BCA to RGU, and arriving there when the radial gates were open
$\phi_{A3,D1C}$	Joint probability of moving from BCA toward RGU via Paradise Cut, surviving from BCA to RGU, and arriving there when the radial gates were closed
$\phi_{A3,E1}$	Joint probability of moving from BCA toward CVP via Paradise Cut, and surviving from BCA to CVP

Table A1. (Continued)

Parameter	Definition
$\phi_{A3,G2}$	Joint probability of moving from BCA toward CHP via Paradise Cut, and surviving from BCA to CHP (Model III)
$\phi_{A8,D1O}$	Joint probability of moving from STN toward RGU, surviving to RGU, and arriving there when the radial gates were open (Model III)
$\phi_{A8,D1C}$	Joint probability of moving from STN toward RGU, surviving to RGU, and arriving there when the radial gates were closed (Model III)
$\phi_{A8,E1}$	Joint probability of moving from STN toward CVP and surviving to CVP (Model III)
$\phi_{A8,G2}$	Joint probability of moving from STN toward Chipps Island (CHPE/CHPW) and surviving to CHPE/CHPW (Model III)
$\phi_{A9,A10}$	Joint probability of moving from C18/C16 toward MFE/MFW, and surviving to MFE/MFW (Submodel II)
$\phi_{A9,B3}$	Joint probability of moving from C18/C16 toward ORN, and surviving from C18/C16 to ORN (Submodel II)
$\phi_{A9,C2}$	Joint probability of moving from C18/C16 toward MRN, and surviving from C18/C16 to MRN (Submodel II)
$\phi_{A9,GH}$	Joint probability of moving from C18/C16 toward Jersey Point (JPTE/JPTW) or False River (FRE/FRW), and surviving PTE/JPTW or FRE/FRW (Submodel II)
$\phi_{A10,B3}$	Joint probability of moving from MFE/MFW toward ORN, and surviving to ORN (Submodel II)
$\phi_{A10,C2}$	Joint probability of moving from MFE/MFW toward MRN, and surviving from MFE/MFW to MRN (Submodel II)
$\phi_{A10,GH}$	Joint probability of moving from MFE/MFW toward Jersey Point (JPTE/JPTW) or False River (FRE/FRW), and surviving to JPTE/JPTW or FRE/FRW (Submodel II)
$\phi_{B1,D1O}$	Joint probability of moving from ORE toward RGU, surviving to RGU, and arriving there when the radial gates were open (Model III)
$\phi_{B1,D1C}$	Joint probability of moving from ORE toward RGU, surviving to RGU, and arriving there when the radial gates were closed (Model III)
$\phi_{B1,E1}$	Joint probability of moving from ORE toward CVP and surviving to CVP (Model III)
$\phi_{B1,G2}$	Joint probability of moving from ORE toward Chipps Island (CHPE/CHPW) and surviving to CHPE/CHPW (Model III)
$\phi_{B2,B3}$	Joint probability of moving from ORS toward ORN, and surviving from ORS to ORN
$\phi_{B2,C2}$	Joint probability of moving from ORS toward MRN, and surviving from ORS to MRN
$\phi_{B2,D1O}$	Joint probability of moving from ORS toward RGU, and surviving from ORS to RGU, and arriving when the radial gates are open
$\phi_{B2,D1C}$	Joint probability of moving from ORS toward RGU, and surviving from ORS to RGU, and arriving when the radial gates are closed
$\phi_{B2,E1}$	Joint probability of moving from ORS toward CVP, and surviving from ORS to CVP
$\phi_{B3,D1O}$	Joint probability of moving from ORN toward RGU, surviving from ORN to RGU, and arriving when the radial gates are open, conditional on coming from lower San Joaquin River (Submodel II)
$\phi_{B3,D1C}$	Joint probability of moving from ORN toward RGU, surviving from ORN to RGU, and arriving when the radial gates are closed, conditional on coming from lower San Joaquin River (Submodel II)
$\phi_{B3,D1}$	Overall joint probability of moving from ORN toward RGU and surviving from ORN to RGU conditional on coming from lower San Joaquin River (Submodel II)
$\phi_{B3,E1}$	Joint probability of moving from ORN toward CVP, and surviving from ORN to CVP, conditional on coming from lower San Joaquin River (Submodel II)
$\phi_{B3,GH(A)}$	Joint probability of moving from ORN toward Jersey Point (JPTE/JPTW) or False River (FRE/FRW), and surviving from ORN to JPTE/JPTW or FRE/FRW (Submodel II [route A])
$\phi_{B3,GH(B)}$	Joint probability of moving from ORN toward Jersey Point (JPTE/JPTW) or False River (FRE/FRW), and surviving from ORN to JPTE/JPTW or FRE/FRW (Submodel I [route B])
$\phi_{C1,B3}$	Joint probability of moving from MRS toward ORN, and surviving from MRS to ORN
$\phi_{C1,C2}$	Joint probability of moving from MRS toward MRN, and surviving from MRS to MRN

Table A1. (Continued)

Parameter	Definition
$\phi_{C1,D1O}$	Joint probability of moving from MRS toward RGU, and surviving from MRS to RGU, and arriving when the radial gates are open
$\phi_{C1,D1C}$	Joint probability of moving from MRS toward RGU, and surviving from MRS to RGU, and arriving when the radial gates are closed
$\phi_{C1,E1}$	Joint probability of moving from MRS toward CVP, and surviving from MRS to CVP
$\phi_{C2,D1O}$	Joint probability of moving from MRN toward RGU, surviving from MRN to RGU, and arriving when the radial gates are open, conditional on coming from lower San Joaquin River (Submodel II)
$\phi_{C2,D1C}$	Joint probability of moving from MRN toward RGU, surviving from MRN to RGU, and arriving when the radial gates are closed, conditional on coming from lower San Joaquin River (Submodel II)
$\phi_{C2,E1}$	Joint probability of moving from MRN toward CVP, and surviving from MRN to CVP, conditional on coming from lower San Joaquin River (Submodel II)
$\phi_{C2,GH(A)}$	Joint probability of moving from MRN toward Jersey Point (JPTE/JPTW) or False River (FRE/FRW), and surviving from MRN to JPTE/JPTW or FRE/FRW (Submodel II [route A])
$\phi_{C2,GH(B)}$	Joint probability of moving from MRN toward Jersey Point (JPTE/JPTW) or False River (FRE/FRW), and surviving from MRN to JPTE/JPTW or FRE/FRW (Submodel I [route B])
$\phi_{D1O,D2(A)}$	Joint probability of moving from RGU toward RGD, and surviving from RGU to RGD, conditional on arrival at RGU when the gates are open (Submodel II [route A])
$\phi_{D1O,D2(B)}$	Joint probability of moving from RGU toward RGD, and surviving from RGU to RGD, conditional on arrival at RGU when the gates are open (Submodel I [route 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 gates are open (Model III [either route])
$\phi_{D1C,D2(A)}$	Joint probability of moving from RGU toward RGD, and surviving from RGU to RGD, conditional on arrival at RGU when the gates are closed (Submodel II [route A])
$\phi_{D1C,D2(B)}$	Joint probability of moving from RGU toward RGD, and surviving from RGU to RGD, conditional on arrival at RGU when the gates are closed (Submodel I [route B])
$\phi_{D1C,D2}$	Joint probability of moving from RGU toward RGD, and surviving from RGU to RGD, conditional on arrival at RGU when the gates are closed (Model III [either route]) (inestimable in 2011)
$\phi_{D2,G2(A)}$	Joint probability of moving from RGD toward Chipps Island (CHPE/CHPW) and surviving from RGU to CHPE/CHPW (Submodel II [route A])
$\phi_{D2,G2(B)}$	Joint probability of moving from RGD toward Chipps Island (CHPE/CHPW) and surviving from RGU to CHPE/CHPW (Submodel I [route B])
$\phi_{D2,G2}$	Joint probability of moving from RGD toward Chipps Island (CHPE/CHPW) and surviving from RGU to CHPE/CHPW (Model III [either route])
$\phi_{E1,E2(A)}$	Joint probability of moving from CVP toward CVPtank, and surviving from CVP to CVPtank (Submodel II [route A])
$\phi_{E1,E2(B)}$	Joint probability of moving from CVP toward CVPtank, and surviving from CVP to CVPtank (Submodel I [route B])
$\phi_{E1,E2}$	Joint probability of moving from CVP toward CVPtank, and surviving CVPtank (Model III [either route])
$\phi_{E2,G2(A)}$	Joint probability of moving from CVPtank toward Chipps Island (CHPE/CHPW) and surviving from CVPtank to CHPE/CHPW (Submodel II [route A])
$\phi_{E2,G2(B)}$	Joint probability of moving from CVPtank toward Chipps Island (CHPE/CHPW) and surviving from CVPtank to CHPE/CHPW (Submodel I [route B])
$\phi_{E2,G2}$	Joint probability of moving from CVPtank toward Chipps Island (CHPE/CHPW) and surviving from CVPtank to CHPE/CHPW (Model III [either route])
$\phi_{F1,B3}$	Joint probability of moving from TCN/TCS toward ORN, and surviving from TCN/TCS to ORN (Submodel II)
$\phi_{F1,C2}$	Joint probability of moving from TCN/TCS toward MRN, and surviving from TCN/TCS to MRN (Submodel II)
$\phi_{F1,GH}$	Joint probability of moving from TCN/TCS toward Jersey Point (JPTE/JPTW) or False River (FRE/FRW), and surviving to JPTE/JPTW or FRE/FRW (Submodel II)

Table A1. (Continued)

Parameter	Definition
$\phi_{G1,G2(A)}$	Joint probability of moving from JPE/JPW toward Chipps Island (CHPE/CHPW), and surviving to CHPE/CHPW (Submodel II [route A])
$\phi_{G1,G2(B)}$	Joint probability of moving from JPE/JPW toward Chipps Island (CHPE/CHPW), and surviving to CHPE/CHPW (Submodel I [route B])
$\phi_{P1,B3}$	Joint probability of moving from Paradise Cut Interior receivers (PCI) toward ORN, and surviving from PCI to ORN (inestimable in 2011)
$\phi_{P1,C2}$	Joint probability of moving from PCI toward MRN, and surviving from PCI to MRN (inestimable in 2011)
$\phi_{P1,D1O}$	Joint probability of moving from PCI toward RGU, and surviving from PCI to RGU, and arriving when the radial gates are open (inestimable in 2011)
$\phi_{P1,D1C}$	Joint probability of moving from PCI toward RGU, and surviving from PCI to RGU, and arriving when the radial gates are closed (inestimable in 2011)
$\phi_{P1,D1}$	Overall joint probability of moving from PCI toward RGU, and surviving from PCI to RGU (inestimable in 2011)
$\phi_{P1,E1}$	Joint probability of moving from PCI toward CVP, and surviving from PCI to CVP (inestimable in 2011)
$\phi_{P1,G2}$	Joint probability of moving from PCI toward Chipps Island (CHPE/CHPW), and surviving from PCI to CHPE/CHPW (Model III) (inestimable in 2011)
P_{A0a}	Conditional probability of detection at DFU1
P_{A0b}	Conditional probability of detection at DFU2
P_{A2a}	Conditional probability of detection at DFD1
P_{A2b}	Conditional probability of detection at DFD2
P_{A2}	Conditional probability of detection at DFD (either DFD1 or DFD2)
P_{A3}	Conditional probability of detection at BCA
P_{A4}	Conditional probability of detection at PCO
P_{A5}	Conditional probability of detection at MOS
P_{A6}	Conditional probability of detection at SJL (either SJLU or SJLD)
P_{A7}	Conditional probability of detection at STS
P_{A8}	Conditional probability of detection at STN
P_{A9a}	Conditional probability of detection at C18
P_{A9b}	Conditional probability of detection at C16
P_{A10a}	Conditional probability of detection at MFE
P_{A10b}	Conditional probability of detection at MFW
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_{B3a}	Conditional probability of detection at ORNU
P_{B3b}	Conditional probability of detection at ORND
P_{C1}	Conditional probability of detection at MRS
P_{C2a}	Conditional probability of detection at MRNU
P_{C2b}	Conditional probability of detection at MRND
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

Table A1. (Continued)

Parameter	Definition
P_{D2}	Conditional probability of detection at RGD (either RGD1 or RGD2) (Model III)
P_{E1}	Conditional probability of detection at CVP
P_{E2}	Conditional probability of detection at CVPtank
P_{F1a}	Conditional probability of detection at TCN
P_{F1b}	Conditional probability of detection at TCS
P_{G1a}	Conditional probability of detection at JPTE
P_{G1b}	Conditional probability of detection at JPTW
P_{G2a}	Conditional probability of detection at CHPE
P_{G2b}	Conditional probability of detection at CHPW
P_{H1a}	Conditional probability of detection at FRW
P_{H1b}	Conditional probability of detection at FRE

Table A2. Parameter estimates (standard errors in parentheses) for tagged juvenile steelhead released in 2011, excluding predator-type detections. Parameters without standard errors were estimated at fixed values in the model. Population-level estimates were estimated from the pooled release groups. Some parameters were not estimable because of sparse data.

	Release Group(s)							Population
Parameter	1	2	3	4	5[a]	2 - 5	3 - 4	Estimate
S_{A2}	0.82 (0.02)	0.77 (0.02)	0.76 (0.02)	0.78 (0.02)	0.72 (0.03)	0.76 (0.01)	0.77 (0.02)	0.77 (0.01)
S_{A4}		0.84 (0.04)	0.90 (0.03)	0.91 (0.03)	0.72 (0.06)	0.86 (0.02)	0.91 (0.02)	0.86 (0.02)
S_{A5}	0.96 (0.02)	0.95 (0.02)	0.89 (0.02)	0.96 (0.01)	0.96 (0.02)	0.93 (0.01)	0.92 (0.01)	0.94 (0.01)
S_{A6}	0.96 (0.01)	0.93 (0.02)	0.91 (0.03)	0.95 (0.02)	0.82 (0.05)	0.92 (0.01)	0.93 (0.02)	0.92 (0.01)
S_{A7}	1.00 (0.01)	0.98 (0.01)	0.97 (0.02)	0.98 (0.01)	1.00 (0.05)	0.97 (0.01)	0.97 (0.01)	0.98 (0.01)
S_{A8}	0.96 (0.02)	0.96 (0.02)	0.94 (0.02)	0.97 (0.02)		0.95 (0.01)	0.95 (0.01)	0.96 (0.01)
S_{B1}	0.98 (0.01)	0.93 (0.03)	0.92 (0.03)	0.93 (0.04)		0.93 (0.02)	0.92 (0.02)	0.94 (0.01)
$S_{A8,G2}$	0.74 (0.04)	0.63 (0.05)	0.57 (0.05)	0.75 (0.04)	0.41 (0.08)	0.62 (0.03)	0.67 (0.03)	0.64 (0.02)
$S_{A9,G2}$	0.82 (0.04)	0.81 (0.05)	0.69 (0.06)	0.81 (0.05)		0.76 (0.03)	0.76 (0.04)	0.78 (0.02)
$S_{B2,G2}$	0.73 (0.04)	0.56 (0.05)	0.53 (0.05)	0.61 (0.05)		0.57 (0.03)	0.57 (0.03)	0.61 (0.02)
$S_{C1,G2}$	0.71 (0.08)	0.34 (0.14)	0.58 (0.07)	0.24 (0.20)		0.37 (0.09)	0.45 (0.13)	0.47 (0.07)
$S_{F1,G2}$	0.37 (0.13)	0.32 (0.08)	0.35 (0.10)	0.69 (0.08)		0.45 (0.05)	0.56 (0.07)	0.43 (0.05)
ψ_{A2}	0.52 (0.03)	0.51 (0.03)	0.49 (0.03)	0.53 (0.03)	0.52 (0.05)	0.51 (0.02)	0.51 (0.02)	0.51 (0.02)
ψ_{A3}	0.91 (0.02)	0.68 (0.04)	0.76 (0.04)	0.68 (0.04)		0.68 (0.02)	0.71 (0.03)	0.76 (0.02)
ψ_{B2}	0.48 (0.03)	0.49 (0.03)	0.51 (0.03)	0.47 (0.03)	0.48 (0.05)	0.49 (0.02)	0.49 (0.02)	0.49 (0.02)
ψ_{B3}	0.91 (0.02)	0.93 (0.03)	0.97 (0.02)	0.95 (0.04)		0.94 (0.01)	0.97 (0.01)	0.94 (0.01)
ψ_{C3}	0.09 (0.02)	0.07 (0.03)	0.03 (0.02)	0.05 (0.04)		0.06 (0.01)	0.03 (0.01)	0.06 (0.01)
ψ_{F3}	0.09 (0.02)	0.32 (0.04)	0.24 (0.04)	0.32 (0.04)		0.32 (0.02)	0.29 (0.03)	0.24 (0.02)
ψ_{G1}	0.98 (0.02)	0.84 (0.15)	0.92 (0.08)	1.00 (0.00)		0.93 (0.05)	0.95 (0.05)	0.93 (0.04)
ψ_{H1}	0.02 (0.02)	0.16 (0.15)	0.08 (0.08)	0.00 (0.00)		0.07 (0.05)	0.05 (0.05)	0.07 (0.04)
$\phi_{A1,A0}$	0.07 (0.01)	0.13 (0.02)	0.14 (0.02)	0.19 (0.02)	0.29 (0.03)	0.17 (0.01)	0.16 (0.01)	0.15 (0.01)
$\phi_{A1,A2}$	0.93 (0.01)	0.86 (0.02)	0.85 (0.02)	0.81 (0.02)	0.70 (0.03)	0.82 (0.01)	0.83 (0.01)	0.84 (0.01)
$\phi_{A3,A4}$		1.00 (0.04)	0.92 (0.03)	0.93 (0.02)	0.98 (0.06)	0.95 (0.02)	0.93 (0.02)	0.96 (0.02)
$\phi_{A3,A5}$	0.95 (0.02)							0.95 (0.02)
$\phi_{A3,B3}$	0.01 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)		0.00 (0.00)	0.00 (0.00)	0.00 (0.00)

a = a reduced model was fit to release group 5

Table A2. (Continued)

Parameter	Release Group(s) 1	2	3	4	5[a]	2 - 5	3 - 4	Population Estimate
$\phi_{A3,C2}$	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)		0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
$\phi_{A3,D1O}$	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
$\phi_{A3,D1C}$	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
$\phi_{A3,E1}$	0.01 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
$\phi_{A3,G2}$					0.00 (0.00)			0.00 (0.00)
$\phi_{A8,D1O}$					0.20 (0.07)			0.20 (0.07)
$\phi_{A8,D1C}$					0.00 (0.00)			0.00 (0.00)
$\phi_{A8,E1}$					0.00 (0.00)			0.00 (0.00)
$\phi_{A8,G2}$					0.29 (0.07)			0.29 (0.07)
$\phi_{A9,A10}$	0.81 (0.03)	0.84 (0.04)	0.62 (0.06)	0.71 (0.05)		0.72 (0.03)	0.67 (0.04)	0.74 (0.02)
$\phi_{A9,B3}$	0.00 (0.00)	0.04 (0.02)	0.04 (0.02)	0.04 (0.02)		0.04 (0.01)	0.04 (0.02)	0.03 (0.01)
$\phi_{A9,C2}$	0.00 (0.00)	0.03 (0.02)	0.00 (0.00)	0.04 (0.02)		0.02 (0.01)	0.02 (0.01)	0.02 (0.01)
$\phi_{A9,GH}$	0.14 (0.03)	0.05 (0.03)	0.21 (0.05)	0.16 (0.04)		0.14 (0.02)	0.18 (0.03)	0.14 (0.02)
$\phi_{A10,B3}$	0.00 (0.00)	0.03 (0.02)	0.10 (0.05)	0.02 (0.02)		0.04 (0.02)	0.05 (0.02)	0.04 (0.01)
$\phi_{A10,C2}$	0.00 (0.00)	0.00 (0.00)	0.07 (0.04)	0.02 (0.02)		0.03 (0.01)	0.04 (0.02)	0.02 (0.01)
$\phi_{A10,GH}$	0.99 (0.01)	0.91 (0.04)	0.67 (0.07)	0.87 (0.05)		0.82 (0.03)	0.78 (0.04)	0.86 (0.02)
$\phi_{B1,D1O}$					0.31 (0.07)			0.31 (0.07)
$\phi_{B1,D1C}$					0.00 (0.00)			0.00 (0.00)
$\phi_{B1,E1}$					0.34 (0.07)			0.34 (0.07)
$\phi_{B1,G2}$					0.02 (0.02)			0.02 (0.02)
$\phi_{B2,B3}$	0.53 (0.04)	0.14 (0.03)	0.17 (0.04)	0.12 (0.03)		0.13 (0.02)	0.15 (0.02)	0.24 (0.02)
$\phi_{B2,C2}$	0.09 (0.02)	0.01 (0.01)	0.00 (0.00)	0.00 (0.00)		0.00 (0.00)	0.00 (0.00)	0.03 (0.01)
$\phi_{B2,D1O}$	0.29 (0.04)	0.41 (0.05)	0.48 (0.05)	0.46 (0.05)		0.44 (0.03)	0.47 (0.04)	0.41 (0.02)
$\phi_{B2,D1C}$	0.01 (0.01)	0.10 (0.03)	0.06 (0.02)	0.09 (0.03)		0.08 (0.01)	0.08 (0.02)	0.07 (0.01)
$\phi_{B2,E1}$	0.03 (0.01)	0.22 (0.04)	0.14 (0.03)	0.22 (0.04)		0.22 (0.02)	0.18 (0.03)	0.15 (0.02)
$\phi_{B3,D1O}$	0.00 (0.00)	0.50 (0.13)	0.57 (0.12)	0.58 (0.13)		0.54 (0.07)	0.56 (0.09)	0.41 (0.06)

a = a reduced model was fit to release group 5

Table A2. (Continued)

Parameter	Release Group(s)							Population Estimate
	1	2	3	4	5[a]	2 - 5	3 - 4	
$\phi_{B3,D1C}$	0.00 (0.00)	0.12 (0.08)	0.00 (0.00)	0.00 (0.00)		0.04 (0.03)	0.00 (0.00)	0.03 (0.02)
$\phi_{B3,E1}$	0.00 (0.00)	0.25 (0.11)	0.25 (0.11)	0.20 (0.10)		0.21 (0.06)	0.23 (0.07)	0.17 (0.05)
$\phi_{B3,GH(A)}$	0.00 (0.00)	0.06 (0.06)	0.06 (0.06)	0.09 (0.08)		0.07 (0.04)	0.08 (0.05)	0.05 (0.03)
$\phi_{B3,GH(B)}$	0.89 (0.04)	0.41 (0.13)	0.63 (0.11)	0.57 (0.14)		0.54 (0.07)	0.61 (0.09)	0.63 (0.06)
$\phi_{C1,B3}$	0.00 (0.00)	0.00 (0.00)	0.33 (0.27)	0.00 (0.00)		0.09 (0.07)	0.14 (0.13)	0.08 (0.07)
$\phi_{C1,C2}$	1.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)		0.10 (0.07)	0.00 (0.00)	0.25 (0.00)
$\phi_{C1,D1O}$	0.00 (0.00)	0.13 (0.13)	0.33 (0.27)	0.34 (0.28)		0.21 (0.09)	0.39 (0.19)	0.20 (0.10)
$\phi_{C1,D1C}$	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)		0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
$\phi_{C1,E1}$	0.00 (0.00)	0.37 (0.19)	0.33 (0.27)	0.00 (0.00)		0.18 (0.09)	0.14 (0.13)	0.17 (0.08)
$\phi_{C2,D1O}$		0.25 (0.15)	0.20 (0.18)	0.77 (0.10)		0.57 (0.09)	0.64 (0.10)	0.41 (0.09)
$\phi_{C2,D1C}$		0.12 (0.12)	0.00 (0.00)	0.00 (0.00)		0.04 (0.04)	0.00 (0.00)	0.04 (0.04)
$\phi_{C2,E1}$		0.25 (0.15)	0.40 (0.22)	0.18 (0.09)		0.20 (0.07)	0.23 (0.09)	0.28 (0.09)
$\phi_{C2,GH(A)}$		0.00 (0.00)	0.00 (0.00)	0.00 (0.00)		0.03 (0.04)	0.00 (0.00)	0.00 (0.00)
$\phi_{C2,GH(B)}$	0.78 (0.08)	0.00 (0.00)				0.68 (0.27)		0.39 (0.04)
$\phi_{D1O,D2(A)}$		0.91 (0.10)	0.91 (0.10)	1.00 (0.00)		0.99 (0.03)	1.00 (0.04)	0.94 (0.05)
$\phi_{D1O,D2(B)}$	0.98 (0.02)	1.00 (0.00)	1.00 (0.02)	0.97 (0.05)		1.00 (0.01)	0.99 (0.03)	0.99 (0.01)
$\phi_{D1O,D2}$					1.00 (0.00)			
$\phi_{D1C,D2(A)}$		1.00 (0.00)				1.00 (0.00)		1.00 (0.00)
$\phi_{D1C,D2(B)}$	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	0.64 (0.18)		0.90 (0.07)	0.81 (0.12)	0.91 (0.05)
$\phi_{D1C,D2}$								
$\phi_{D2,G2(A)}$		0.50 (0.15)	0.66 (0.16)	0.72 (0.10)		0.60 (0.07)	0.68 (0.09)	0.63 (0.08)
$\phi_{D2,G2(B)}$	0.70 (0.07)	0.74 (0.06)	0.67 (0.06)	0.74 (0.07)		0.71 (0.04)	0.70 (0.05)	0.70 (0.03)
$\phi_{D2,G2}$					0.59 (0.11)			
$\phi_{E1,E2(A)}$		0.83 (0.15)	0.67 (0.19)	0.84 (0.15)		0.78 (0.10)	0.76 (0.13)	0.78 (0.10)
$\phi_{E1,E2(B)}$	1.00 (0.00)	0.73 (0.09)	0.69 (0.12)	0.78 (0.09)		0.75 (0.05)	0.75 (0.07)	0.80 (0.04)
$\phi_{E1,E2}$					0.81 (0.10)			

a = a reduced model was fit to release group 5

Table A2. (Continued)

Parameter	Release Group(s) 1	2	3	4	5[a]	2 - 5	3 - 4	Population Estimate
$\phi_{E2,G2(A)}$		0.81 (0.18)	0.75 (0.22)	0.80 (0.19)		0.79 (0.11)	0.78 (0.14)	0.79 (0.11)
$\phi_{E2,G2(B)}$	0.86 (0.16)	0.91 (0.07)	0.73 (0.13)	1.00 (0.00)		0.91 (0.04)	0.90 (0.06)	0.88 (0.05)
$\phi_{E2,G2}$					0.93 (0.07)			
$\phi_{F1,B3}$	0.15 (0.10)	0.36 (0.09)	0.43 (0.11)	0.31 (0.08)		0.33 (0.05)	0.35 (0.06)	0.31 (0.05)
$\phi_{F1,C2}$	0.00 (0.00)	0.19 (0.07)	0.10 (0.06)	0.36 (0.08)		0.24 (0.04)	0.26 (0.06)	0.16 (0.03)
$\phi_{F1,GH}$	0.62 (0.14)	0.13 (0.06)	0.19 (0.09)	0.19 (0.07)		0.17 (0.04)	0.19 (0.05)	0.28 (0.05)
$\phi_{G1,G2(A)}$	0.85 (0.03)	0.92 (0.04)	0.98 (0.02)	0.98 (0.02)		0.96 (0.02)	0.98 (0.02)	0.93 (0.02)
$\phi_{G1,G2(B)}$	0.92 (0.04)	0.79 (0.19)	1.00 (0.00)	1.00 (0.00)		0.97 (0.04)	1.00 (0.00)	0.93 (0.05)
P_{A0a}	0.83 (0.08)	0.70 (0.07)	0.89 (0.04)	0.85 (0.04)	0.93 (0.03)	0.85 (0.02)	0.87 (0.03)	0.83 (0.03)
P_{A0b}	0.73 (0.09)	0.76 (0.07)	0.83 (0.05)	0.88 (0.04)	0.83 (0.04)	0.83 (0.02)	0.86 (0.03)	0.81 (0.03)
P_{A2a}	0.80 (0.02)	0.73 (0.02)	0.76 (0.02)	0.79 (0.02)	0.70 (0.03)	0.75 (0.01)	0.78 (0.01)	0.76 (0.01)
P_{A2b}	0.62 (0.02)	0.86 (0.02)	0.94 (0.01)	0.93 (0.01)	0.92 (0.02)	0.91 (0.01)	0.93 (0.01)	0.85 (0.01)
P_{A2}	0.92 (0.01)	0.96 (0.01)	0.98 (0.00)	0.99 (0.00)	0.98 (0.01)	0.98 (0.00)	0.99 (0.00)	0.97 (0.00)
P_{A3}	0.71 (0.02)	0.92 (0.02)	0.91 (0.02)	0.94 (0.01)	0.86 (0.03)	0.91 (0.01)	0.93 (0.01)	0.87 (0.01)
P_{A4}		0.30 (0.03)	0.45 (0.03)	0.46 (0.03)	0.48 (0.05)	0.41 (0.02)	0.46 (0.02)	0.42 (0.02)
P_{A5}	0.34 (0.03)	0.75 (0.03)	0.87 (0.02)	0.86 (0.02)	0.89 (0.03)	0.83 (0.01)	0.86 (0.02)	0.73 (0.01)
P_{A6}	0.95 (0.02)	0.91 (0.03)	0.95 (0.02)	0.97 (0.02)	1.00 (0.00)	0.95 (0.01)	0.96 (0.01)	0.95 (0.01)
P_{A7}	0.95 (0.02)	0.91 (0.03)	0.97 (0.02)	0.98 (0.01)	0.97 (0.03)	0.96 (0.01)	0.97 (0.01)	0.95 (0.01)
P_{A8}	0.86 (0.03)	0.96 (0.02)	0.99 (0.01)	0.97 (0.02)	0.90 (0.07)	0.97 (0.01)	0.98 (0.01)	0.94 (0.01)
P_{A9a}	0.98 (0.01)	0.93 (0.03)	0.96 (0.02)	0.97 (0.02)		0.96 (0.01)	0.97 (0.01)	0.96 (0.01)
P_{A9b}	0.97 (0.01)	0.93 (0.03)	0.96 (0.02)	0.97 (0.02)		0.95 (0.01)	0.97 (0.01)	0.96 (0.01)
P_{A10a}	0.93 (0.02)	0.91 (0.04)	0.93 (0.04)	0.88 (0.05)		0.91 (0.02)	0.90 (0.03)	0.91 (0.02)
P_{A10b}	0.97 (0.02)	0.93 (0.04)	0.97 (0.03)	0.92 (0.04)		0.94 (0.02)	0.94 (0.02)	0.95 (0.02)
P_{B1}	0.86 (0.03)	0.95 (0.02)	0.99 (0.01)	0.99 (0.01)	1.00 (0.00)	0.97 (0.01)	0.99 (0.01)	0.95 (0.01)
P_{B2a}	0.86 (0.03)	0.92 (0.03)	0.90 (0.03)	0.95 (0.02)		0.93 (0.01)	0.93 (0.02)	0.91 (0.01)
P_{B2b}	0.80 (0.03)	0.94 (0.02)	0.99 (0.01)	0.97 (0.02)		0.97 (0.01)	0.98 (0.01)	0.93 (0.01)

a = a reduced model was fit to release group 5

Table A2. (Continued)

Parameter	Release Group(s)							Population Estimate
	1	2	3	4	5[a]	2 - 5	3 - 4	
P_{B3a}	0.94 (0.03)	0.96 (0.04)	0.91 (0.05)	0.80 (0.08)		0.90 (0.03)	0.87 (0.04)	0.90 (0.03)
P_{B3b}	0.92 (0.03)	0.71 (0.08)	0.91 (0.05)	0.80 (0.08)		0.81 (0.04)	0.87 (0.04)	0.84 (0.03)
P_{C1}	0.66 (0.13)	0.77 (0.23)	1.00 (0.00)	0.52 (0.37)		0.64 (0.14)	0.84 (0.19)	0.74 (0.11)
P_{C2a}	0.96 (0.04)	1.00 (0.00)	0.80 (0.18)	1.00 (0.00)		0.97 (0.03)	0.95 (0.04)	0.94 (0.05)
P_{C2b}	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	0.94 (0.06)		0.94 (0.04)	0.95 (0.04)	0.99 (0.01)
P_{D1}	0.95 (0.04)	0.98 (0.02)	0.94 (0.03)	0.80 (0.05)	0.92 (0.07)	0.91 (0.02)	0.87 (0.03)	0.92 (0.02)
P_{D2a}	0.94 (0.04)	0.91 (0.03)	0.85 (0.05)	0.66 (0.06)		0.78 (0.03)	0.74 (0.04)	0.84 (0.02)
P_{D2b}	0.87 (0.05)	0.84 (0.05)	0.62 (0.06)	0.49 (0.06)		0.63 (0.03)	0.55 (0.04)	0.71 (0.03)
P_{D2}					0.57 (0.11)			
P_{E1}	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)
P_{E2}	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	0.95 (0.05)	1.00 (0.00)	0.98 (0.02)	0.97 (0.03)	0.99 (0.01)
P_{F1a}	1.00 (0.00)	0.94 (0.04)	1.00 (0.00)	1.00 (0.00)		0.98 (0.01)	1.00 (0.00)	0.99 (0.01)
P_{F1b}	0.93 (0.07)	1.00 (0.00)	0.96 (0.04)	0.95 (0.04)		0.97 (0.02)	0.95 (0.03)	0.96 (0.02)
P_{G1a}	0.75 (0.03)	0.75 (0.05)	0.73 (0.06)	0.71 (0.05)		0.74 (0.03)	0.72 (0.04)	0.74 (0.02)
P_{G1b}	0.72 (0.03)	0.61 (0.06)	0.66 (0.06)	0.69 (0.05)		0.66 (0.03)	0.68 (0.04)	0.67 (0.03)
P_{G2a}	0.88 (0.02)	0.92 (0.03)	0.96 (0.02)	0.93 (0.02)	0.97 (0.03)	0.94 (0.01)	0.95 (0.02)	0.93 (0.01)
P_{G2b}	0.73 (0.03)	0.84 (0.03)	0.89 (0.03)	0.74 (0.04)	0.81 (0.06)	0.81 (0.02)	0.80 (0.02)	0.80 (0.02)
P_{H1a}	0.40 (0.22)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)		1.00 (0.00)	1.00 (0.00)	0.85 (0.05)
P_{H1b}	1.00 (0.00)	1.00 (0.00)	0.00 (0.00)	1.00 (0.00)		0.50 (0.25)	0.00 (0.00)	0.75 (0.00)

a = a reduced model was fit to release group 5

Table A3. Parameter estimates (standard errors in parentheses) for tagged juvenile steelhead released in 2011, including predator-type detections. Parameters without standard errors were estimated at fixed values in the model. Population-level estimates were estimated from the pooled release groups. Some parameters were not estimable because of sparse data.

	Release Group(s)							
Parameter	1	2	3	4	5[a]	2 - 5	3 - 4	Population Estimate
S_{A2}	0.84 (0.02)	0.77 (0.02)	0.77 (0.02)	0.79 (0.02)	0.71 (0.04)	0.77 (0.01)	0.78 (0.02)	0.78 (0.01)
S_{A4}		0.87 (0.04)	0.92 (0.03)	0.93 (0.02)	0.73 (0.06)	0.88 (0.02)	0.93 (0.02)	0.88 (0.02)
S_{A5}	0.98 (0.01)	0.95 (0.02)	0.90 (0.02)	0.97 (0.01)	0.94 (0.03)	0.94 (0.01)	0.94 (0.01)	0.95 (0.01)
S_{A6}	0.96 (0.01)	0.96 (0.02)	0.94 (0.02)	0.93 (0.02)	0.78 (0.06)	0.92 (0.01)	0.93 (0.02)	0.93 (0.01)
S_{A7}	0.99 (0.01)	1.00 (0.00)	0.95 (0.02)	0.98 (0.01)	1.00 (0.05)	0.97 (0.01)	0.96 (0.01)	0.98 (0.01)
S_{A8}	0.97 (0.02)	0.98 (0.01)	0.95 (0.02)	0.97 (0.02)		0.96 (0.01)	0.96 (0.01)	0.96 (0.01)
S_{B1}	0.99 (0.01)	0.98 (0.02)	0.96 (0.02)	0.93 (0.03)		0.95 (0.01)	0.94 (0.02)	0.96 (0.01)
$S_{A8,G2}$	0.76 (0.04)	0.67 (0.04)	0.59 (0.05)	0.77 (0.04)	0.42 (0.08)	0.65 (0.03)	0.68 (0.03)	0.66 (0.02)
$S_{A9,G2}$	0.82 (0.04)	0.83 (0.04)	0.69 (0.05)	0.85 (0.04)		0.78 (0.03)	0.77 (0.03)	0.80 (0.02)
$S_{B2,G2}$	0.73 (0.04)	0.57 (0.05)	0.52 (0.05)	0.62 (0.05)		0.58 (0.03)	0.57 (0.03)	0.61 (0.02)
$S_{C1,G2}$	0.67 (0.10)	0.51 (0.16)	0.37 (0.15)	0.36 (0.26)		0.41 (0.09)	0.39 (0.14)	0.48 (0.09)
$S_{F1,G2}$	0.40 (0.14)	0.36 (0.08)	0.37 (0.10)	0.67 (0.08)		0.46 (0.05)	0.56 (0.07)	0.45 (0.05)
ψ_{A2}	0.51 (0.03)	0.52 (0.03)	0.48 (0.03)	0.53 (0.03)	0.55 (0.05)	0.52 (0.02)	0.51 (0.02)	0.52 (0.02)
ψ_{A3}	0.92 (0.02)	0.68 (0.04)	0.77 (0.04)	0.67 (0.04)		0.68 (0.02)	0.72 (0.03)	0.76 (0.02)
ψ_{B2}	0.49 (0.03)	0.48 (0.03)	0.52 (0.03)	0.47 (0.03)	0.45 (0.05)	0.48 (0.02)	0.49 (0.02)	0.48 (0.02)
ψ_{B3}	0.91 (0.02)	0.95 (0.02)	0.94 (0.03)	0.96 (0.03)		0.94 (0.01)	0.95 (0.02)	0.94 (0.01)
ψ_{C3}	0.09 (0.02)	0.05 (0.02)	0.06 (0.03)	0.04 (0.03)		0.06 (0.01)	0.05 (0.02)	0.06 (0.01)
ψ_{F3}	0.08 (0.02)	0.32 (0.04)	0.23 (0.04)	0.33 (0.04)		0.32 (0.02)	0.28 (0.03)	0.24 (0.02)
ψ_{G1}	0.98 (0.01)	0.84 (0.15)	0.92 (0.08)	1.00 (0.00)		0.93 (0.05)	0.95 (0.05)	0.93 (0.04)
ψ_{H1}	0.02 (0.01)	0.16 (0.15)	0.08 (0.08)	0.00 (0.00)		0.07 (0.05)	0.05 (0.05)	0.07 (0.04)
$\phi_{A1,A0}$	0.07 (0.01)	0.17 (0.02)	0.16 (0.02)	0.21 (0.02)	0.31 (0.03)	0.20 (0.01)	0.18 (0.01)	0.17 (0.01)
$\phi_{A1,A2}$	0.93 (0.01)	0.83 (0.02)	0.83 (0.02)	0.79 (0.02)	0.69 (0.03)	0.79 (0.01)	0.81 (0.01)	0.83 (0.01)
$\phi_{A3,A4}$		0.95 (0.04)	0.93 (0.03)	0.92 (0.02)	0.97 (0.06)	0.94 (0.02)	0.92 (0.02)	0.94 (0.02)
$\phi_{A3,A5}$	0.92 (0.02)							0.92 (0.02)
$\phi_{A3,B3}$	0.01 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)		0.00 (0.00)	0.00 (0.00)	0.00 (0.00)

a = a reduced model was fit to release group 5

Table A3. (Continued)

Parameter	Release Group(s) 1	2	3	4	5[a]	2 - 5	3 - 4	Population Estimate
$\phi_{A3,C2}$	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)		0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
$\phi_{A3,D1O}$	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
$\phi_{A3,D1C}$	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
$\phi_{A3,E1}$	0.01 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
$\phi_{A3,G2}$					0.00 (0.00)			0.00 (0.00)
$\phi_{A8,D1O}$					0.21 (0.07)			0.21 (0.07)
$\phi_{A8,D1C}$					0.00 (0.00)			0.00 (0.00)
$\phi_{A8,E1}$					0.00 (0.00)			0.00 (0.00)
$\phi_{A8,G2}$					0.30 (0.08)			0.30 (0.08)
$\phi_{A9,A10}$	0.82 (0.03)	0.83 (0.04)	0.63 (0.06)	0.71 (0.05)		0.72 (0.03)	0.67 (0.04)	0.75 (0.02)
$\phi_{A9,B3}$	0.00 (0.00)	0.04 (0.02)	0.04 (0.02)	0.04 (0.02)		0.04 (0.01)	0.04 (0.02)	0.03 (0.01)
$\phi_{A9,C2}$	0.00 (0.00)	0.03 (0.02)	0.00 (0.00)	0.04 (0.02)		0.02 (0.01)	0.02 (0.01)	0.02 (0.01)
$\phi_{A9,GH}$	0.14 (0.03)	0.06 (0.03)	0.20 (0.05)	0.17 (0.04)		0.14 (0.02)	0.19 (0.03)	0.14 (0.02)
$\phi_{A10,B3}$	0.00 (0.00)	0.03 (0.02)	0.09 (0.04)	0.02 (0.02)		0.04 (0.02)	0.05 (0.02)	0.03 (0.01)
$\phi_{A10,C2}$	0.00 (0.00)	0.00 (0.00)	0.07 (0.04)	0.02 (0.02)		0.03 (0.01)	0.04 (0.02)	0.02 (0.01)
$\phi_{A10,GH}$	0.99 (0.01)	0.91 (0.04)	0.67 (0.07)	0.89 (0.04)		0.82 (0.03)	0.79 (0.04)	0.87 (0.02)
$\phi_{B1,D1O}$					0.35 (0.08)			0.35 (0.08)
$\phi_{B1,D1C}$					0.00 (0.00)			0.00 (0.00)
$\phi_{B1,E1}$					0.41 (0.08)			0.41 (0.08)
$\phi_{B1,G2}$					0.02 (0.03)			0.02 (0.03)
$\phi_{B2,B3}$	0.55 (0.04)	0.14 (0.03)	0.17 (0.04)	0.13 (0.03)		0.13 (0.02)	0.15 (0.02)	0.25 (0.02)
$\phi_{B2,C2}$	0.08 (0.02)	0.01 (0.01)	0.01 (0.01)	0.00 (0.00)		0.00 (0.00)	0.00 (0.00)	0.03 (0.01)
$\phi_{B2,D1O}$	0.29 (0.04)	0.42 (0.05)	0.50 (0.05)	0.45 (0.05)		0.45 (0.03)	0.48 (0.03)	0.42 (0.02)
$\phi_{B2,D1C}$	0.01 (0.01)	0.11 (0.03)	0.06 (0.02)	0.09 (0.03)		0.08 (0.01)	0.07 (0.02)	0.07 (0.01)
$\phi_{B2,E1}$	0.03 (0.01)	0.23 (0.04)	0.15 (0.03)	0.23 (0.04)		0.23 (0.02)	0.19 (0.03)	0.16 (0.02)
$\phi_{B3,D1O}$	0.00 (0.00)	0.50 (0.12)	0.56 (0.12)	0.58 (0.13)		0.54 (0.07)	0.56 (0.09)	0.41 (0.05)

a = a reduced model was fit to release group 5

Table A3. (Continued)

Parameter	Release Group(s)							Population Estimate
	1	2	3	4	5[a]	2 - 5	3 - 4	
$\phi_{B3,D1C}$	0.00 (0.00)	0.17 (0.09)	0.00 (0.00)	0.00 (0.00)		0.06 (0.03)	0.00 (0.00)	0.04 (0.02)
$\phi_{B3,E1}$	0.00 (0.00)	0.17 (0.09)	0.25 (0.11)	0.20 (0.10)		0.18 (0.05)	0.23 (0.08)	0.15 (0.04)
$\phi_{B3,GH(A)}$	0.00 (0.00)	0.06 (0.05)	0.06 (0.06)	0.09 (0.08)		0.07 (0.04)	0.09 (0.05)	0.05 (0.03)
$\phi_{B3,GH(B)}$	0.88 (0.04)	0.41 (0.13)	0.65 (0.11)	0.53 (0.14)		0.54 (0.07)	0.61 (0.09)	0.62 (0.06)
$\phi_{C1,B3}$	0.00 (0.00)	0.00 (0.00)	0.17 (0.16)	0.00 (0.00)		0.09 (0.07)	0.10 (0.10)	0.04 (0.04)
$\phi_{C1,C2}$	0.90 (0.09)	0.00 (0.00)	0.01 (0.01)	0.00 (0.00)		0.14 (0.08)	0.00 (0.00)	0.23 (0.02)
$\phi_{C1,D1O}$	0.00 (0.00)	0.20 (0.18)	0.17 (0.16)	0.51 (0.36)		0.21 (0.09)	0.30 (0.17)	0.22 (0.11)
$\phi_{C1,D1C}$	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)		0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
$\phi_{C1,E1}$	0.00 (0.00)	0.55 (0.23)	0.33 (0.21)	0.00 (0.00)		0.22 (0.10)	0.20 (0.14)	0.22 (0.08)
$\phi_{C2,D1O}$		0.38 (0.17)	0.20 (0.18)	0.77 (0.10)		0.59 (0.09)	0.61 (0.12)	0.45 (0.09)
$\phi_{C2,D1C}$		0.12 (0.12)	0.00 (0.00)	0.00 (0.00)		0.04 (0.04)	0.00 (0.00)	0.04 (0.04)
$\phi_{C2,E1}$		0.25 (0.15)	0.40 (0.22)	0.18 (0.09)		0.20 (0.07)	0.23 (0.09)	0.28 (0.09)
$\phi_{C2,GH(A)}$		0.00 (0.00)	0.00 (0.00)	0.00 (0.00)		0.03 (0.04)	0.03 (0.07)	0.00 (0.00)
$\phi_{C2,GH(B)}$	0.81 (0.08)	0.00 (0.00)	0.00 (0.00)			0.52 (0.25)	0.00 (0.00)	0.27 (0.03)
$\phi_{D1O,D2(A)}$		0.84 (0.11)	0.91 (0.10)	1.00 (0.00)		0.97 (0.04)	1.00 (0.04)	0.92 (0.05)
$\phi_{D1O,D2(B)}$	0.98 (0.02)	1.00 (0.00)	0.96 (0.03)	0.97 (0.05)		0.99 (0.02)	0.97 (0.03)	0.98 (0.01)
$\phi_{D1O,D2}$					1.00 (0.00)			
$\phi_{D1C,D2(A)}$		1.00 (0.00)				1.00 (0.00)		1.00 (0.00)
$\phi_{D1C,D2(B)}$	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	0.64 (0.18)		0.91 (0.07)	0.81 (0.12)	0.91 (0.05)
$\phi_{D1C,D2}$								
$\phi_{D2,G2(A)}$		0.50 (0.14)	0.66 (0.16)	0.72 (0.10)		0.60 (0.07)	0.68 (0.09)	0.63 (0.08)
$\phi_{D2,G2(B)}$	0.68 (0.07)	0.72 (0.06)	0.64 (0.06)	0.74 (0.07)		0.69 (0.04)	0.68 (0.05)	0.68 (0.03)
$\phi_{D2,G2}$					0.59 (0.11)			
$\phi_{E1,E2(A)}$		1.00 (0.00)	0.67 (0.19)	0.84 (0.15)		0.83 (0.09)	0.75 (0.13)	0.83 (0.08)
$\phi_{E1,E2(B)}$	1.00 (0.00)	0.77 (0.08)	0.72 (0.11)	0.79 (0.08)		0.78 (0.04)	0.76 (0.07)	0.82 (0.04)
$\phi_{E1,E2}$					0.82 (0.09)			

a = a reduced model was fit to release group 5

Table A3. (Continued)

Parameter	Release Group(s)							Population Estimate
	1	2	3	4	5[a]	2 - 5	3 - 4	
$\phi_{E2,G2(A)}$		0.81 (0.18)	0.75 (0.22)	0.80 (0.19)		0.79 (0.11)	0.78 (0.14)	0.79 (0.11)
$\phi_{E2,G2(B)}$	0.86 (0.16)	0.87 (0.08)	0.69 (0.13)	1.00 (0.00)		0.87 (0.04)	0.88 (0.06)	0.86 (0.05)
$\phi_{E2,G2}$					0.86 (0.09)			
$\phi_{F1,B3}$	0.08 (0.08)	0.40 (0.09)	0.45 (0.11)	0.31 (0.08)		0.35 (0.05)	0.36 (0.06)	0.31 (0.04)
$\phi_{F1,C2}$	0.00 (0.00)	0.18 (0.07)	0.10 (0.07)	0.36 (0.08)		0.23 (0.04)	0.27 (0.06)	0.16 (0.03)
$\phi_{F1,GH}$	0.67 (0.14)	0.18 (0.07)	0.20 (0.09)	0.19 (0.07)		0.18 (0.04)	0.20 (0.05)	0.31 (0.05)
$\phi_{G1,G2(A)}$	0.86 (0.03)	0.93 (0.04)	0.98 (0.02)	0.98 (0.02)		0.97 (0.02)	0.98 (0.02)	0.94 (0.01)
$\phi_{G1,G2(B)}$	0.93 (0.04)	0.79 (0.19)	1.00 (0.00)	1.00 (0.00)		0.97 (0.04)	1.00 (0.00)	0.93 (0.05)
P_{A0a}	0.80 (0.08)	0.79 (0.05)	0.92 (0.03)	0.86 (0.04)	0.93 (0.03)	0.88 (0.02)	0.89 (0.03)	0.86 (0.02)
P_{A0b}	0.77 (0.08)	0.82 (0.05)	0.84 (0.04)	0.86 (0.04)	0.84 (0.04)	0.84 (0.02)	0.85 (0.03)	0.83 (0.02)
P_{A2a}	0.80 (0.02)	0.74 (0.02)	0.76 (0.02)	0.80 (0.02)	0.71 (0.03)			0.76 (0.01)
P_{A2b}	0.64 (0.02)	0.87 (0.02)	0.93 (0.01)	0.91 (0.01)	0.92 (0.02)			0.85 (0.01)
P_{A2}	0.93 (0.01)	0.97 (0.01)	0.98 (0.00)	0.98 (0.00)	0.98 (0.01)	0.99 (0.00)	0.99 (0.00)	0.97 (0.00)
P_{A3}	0.70 (0.02)	0.92 (0.02)	0.92 (0.02)	0.94 (0.01)	0.83 (0.03)	0.91 (0.01)	0.93 (0.01)	0.87 (0.01)
P_{A4}		0.33 (0.03)	0.44 (0.03)	0.47 (0.03)	0.45 (0.05)	0.42 (0.02)	0.45 (0.02)	0.42 (0.02)
P_{A5}	0.34 (0.03)	0.76 (0.03)	0.87 (0.02)	0.86 (0.02)	0.86 (0.04)	0.83 (0.01)	0.87 (0.02)	0.73 (0.01)
P_{A6}	0.95 (0.02)	0.92 (0.03)	0.94 (0.02)	0.97 (0.02)	1.00 (0.00)	0.95 (0.01)	0.96 (0.01)	0.95 (0.01)
P_{A7}	0.95 (0.02)	0.92 (0.03)	0.97 (0.02)	0.98 (0.01)	0.97 (0.03)	0.96 (0.01)	0.97 (0.01)	0.95 (0.01)
P_{A8}	0.86 (0.03)	0.95 (0.02)	0.99 (0.01)	0.97 (0.02)	0.90 (0.07)	0.97 (0.01)	0.98 (0.01)	0.94 (0.01)
P_{A9a}	0.97 (0.01)	0.94 (0.03)	0.95 (0.03)	0.99 (0.01)		0.96 (0.01)	0.97 (0.01)	0.96 (0.01)
P_{A9b}	0.97 (0.01)	0.94 (0.03)	0.96 (0.02)	0.97 (0.02)		0.96 (0.01)	0.97 (0.01)	0.96 (0.01)
P_{A10a}	0.92 (0.03)	0.92 (0.04)	0.91 (0.04)	0.88 (0.05)		0.91 (0.02)	0.89 (0.03)	0.91 (0.02)
P_{A10b}	0.97 (0.02)	0.95 (0.03)	0.98 (0.02)	0.92 (0.04)		0.95 (0.02)	0.94 (0.02)	0.95 (0.01)
P_{B1}	0.86 (0.03)	0.95 (0.02)	0.97 (0.01)	0.99 (0.01)	1.00 (0.00)	0.97 (0.01)	0.98 (0.01)	0.95 (0.01)
P_{B2a}	0.87 (0.03)	0.91 (0.03)	0.91 (0.03)	0.95 (0.02)		0.93 (0.01)	0.93 (0.02)	0.91 (0.01)
P_{B2b}	0.80 (0.03)	0.94 (0.02)	0.99 (0.01)	0.97 (0.02)		0.97 (0.01)	0.98 (0.01)	0.92 (0.01)

a = a reduced model was fit to release group 5

Table A3. (Continued)

Parameter	Release Group(s) 1	2	3	4	5[a]	2 - 5	3 - 4	Population Estimate
P_{B3a}	0.92 (0.03)	0.97 (0.03)	0.91 (0.05)	0.81 (0.08)		0.91 (0.03)	0.87 (0.04)	0.90 (0.03)
P_{B3b}	0.88 (0.04)	0.69 (0.08)	0.91 (0.05)	0.81 (0.08)		0.81 (0.04)	0.87 (0.04)	0.83 (0.03)
P_{C1}	0.66 (0.13)	0.78 (0.23)	0.58 (0.24)	0.52 (0.37)		0.55 (0.13)	0.57 (0.20)	0.63 (0.13)
P_{C2a}	0.96 (0.04)	1.00 (0.00)	0.83 (0.15)	1.00 (0.00)		0.97 (0.03)	0.96 (0.04)	0.95 (0.04)
P_{C2b}	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	0.94 (0.06)		0.95 (0.04)	0.96 (0.04)	0.99 (0.01)
P_{D1}	0.95 (0.03)	0.99 (0.01)	0.96 (0.02)	0.80 (0.05)	0.92 (0.07)	0.92 (0.02)	0.88 (0.03)	0.92 (0.02)
P_{D2a}	0.95 (0.04)	0.90 (0.04)	0.85 (0.05)	0.66 (0.06)		0.78 (0.03)	0.75 (0.04)	0.84 (0.02)
P_{D2b}	0.88 (0.05)	0.85 (0.04)	0.64 (0.06)	0.49 (0.06)		0.64 (0.03)	0.56 (0.04)	0.71 (0.03)
P_{D2}					0.57 (0.11)			
P_{E1}	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)
P_{E2}	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	0.96 (0.04)	1.00 (0.00)	0.99 (0.01)	0.97 (0.03)	0.99 (0.01)
P_{F1a}	1.00 (0.00)	0.95 (0.04)	1.00 (0.00)	1.00 (0.00)		0.98 (0.01)	1.00 (0.00)	0.99 (0.01)
P_{F1b}	0.92 (0.07)	1.00 (0.00)	0.95 (0.04)	0.95 (0.04)		0.97 (0.02)	0.95 (0.03)	0.96 (0.02)
P_{G1a}	0.75 (0.03)	0.74 (0.05)	0.73 (0.06)	0.71 (0.05)		0.74 (0.03)	0.72 (0.04)	0.73 (0.02)
P_{G1b}	0.72 (0.03)	0.61 (0.06)	0.66 (0.06)	0.69 (0.05)		0.66 (0.03)	0.67 (0.04)	0.67 (0.03)
P_{G2a}	0.88 (0.02)	0.92 (0.03)	0.95 (0.02)	0.94 (0.02)	0.97 (0.03)	0.94 (0.01)	0.94 (0.02)	0.93 (0.01)
P_{G2b}	0.73 (0.03)	0.84 (0.03)	0.89 (0.03)	0.74 (0.04)	0.81 (0.06)	0.82 (0.02)	0.81 (0.02)	0.80 (0.02)
P_{H1a}	0.40 (0.22)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)		1.00 (0.00)	1.00 (0.00)	0.85 (0.05)
P_{H1b}	1.00 (0.00)	1.00 (0.00)	0.00 (0.00)	1.00 (0.00)		0.50 (0.25)	0.00 (0.00)	0.75 (0.00)

a = a reduced model was fit to release group 5

APPENDIX B. SUMMARY OF 2011 STEELHEAD HEALTH AND PHYSIOLOGY SAMPLING

California-Nevada Fish Health Center

TECHNICAL MEMORANDUM

TO: Josh Israel, USBR

FROM: Ken Nichols

DATE: November 30, 2011

SUBJECT: Summary of 2011 Steelhead Health and Physiology Sampling

This technical memorandum summarizes the results of pathology and physiology monitoring in support of the six year acoustic telemetry study (Action IV.2.2) of the NMFS BiOp on the Coordinated Long-term operation of the Central Valley Project and State Water Project. Sampled fish were dummy-tagged control groups which shadowed treatment and handling of acoustic tagged fish used in the study. These control fish were sampled after holding for 48 (±12 hrs.) in the San Joaquin River at Durham Ferry (release site for the acoustic tagged cohorts). Sampling was conducted at 3 time points in the study period (26 Mar, 19 May and 16 Jun 2011). Fish were euthanized at the release site, examined for external or internal abnormalities, and tissue samples were collected. Assays and tissues collected are summarized in Table 1.

Pathogen screening results (Table 2): No virus was detected in the 24 pooled kidney samples (71 total fish) tested. No bacterial pathogens were detected by culture (71 samples) or DFAT (64 samples).

Histopathology results: No significant abnormality or infections were observed in tissues from any of the 36 fish examined.

Table 1. Number of fish sampled by assay and tissues at each time point.

Assay	Tissue	March	May	June	Total
Virology	kidney and spleen	24	24	23	71
Bacteriology	kidney	24	24	23	71
DFAT	kidney	20	21	23	64
Histology	gill, liver, kidney and intestine	12	12	12	36
Gill ATPase	Gill	12	12	8	32

Table 2. Summary of pathology assay results.

Assay	March	May	June	Total
Virology (pooled samples)	0/8	0/8	0/8	0/24
Bacteriology	0/24	0/24	0/23	0/71
Rs-DFAT	0/20	0/21	0/23	0/64
Histology	0/12	0/12	0/12	0/36

Gill Na^+/K^+-ATPase activity: Activity levels observed in these fish ranged from 0.2 to 8.7 (µmol ADP·mg $protein^{-1}·hr^{-1}$) with a mean of 2.6 (Figure 1). Activity levels were highest in the first (March) release group (P=0.008, Kruskal-Wallis rank sum test). Gill ATPase activity in salmonids typically increases and peaks near the time of most active migratory behavior (Duston, Saunders and Knox 1991; Ewing, Ewing and Satterthwaite 2001; Wedemeyer 1996). Decreases in ATPase activity can also occur due to increases in water temperature (Duston et al. 1991). Smolting Chinook salmon typically demonstrate activity levels of greater than 6.7 (CA-NV Fish Health Center unpublished assay calibration data). The majority of fish in all release groups were below this Chinook smolt cutoff. In Chinook salmon, the difference observed between time points in this study would not be biologically significant. In our experience activity levels measured in juvenile steelhead can be highly plastic and may increase markedly in a few days. It will be of interest to compare the observed levels with migration behavior in the acoustic tagged cohorts to see if the relatively small difference was meaningful.

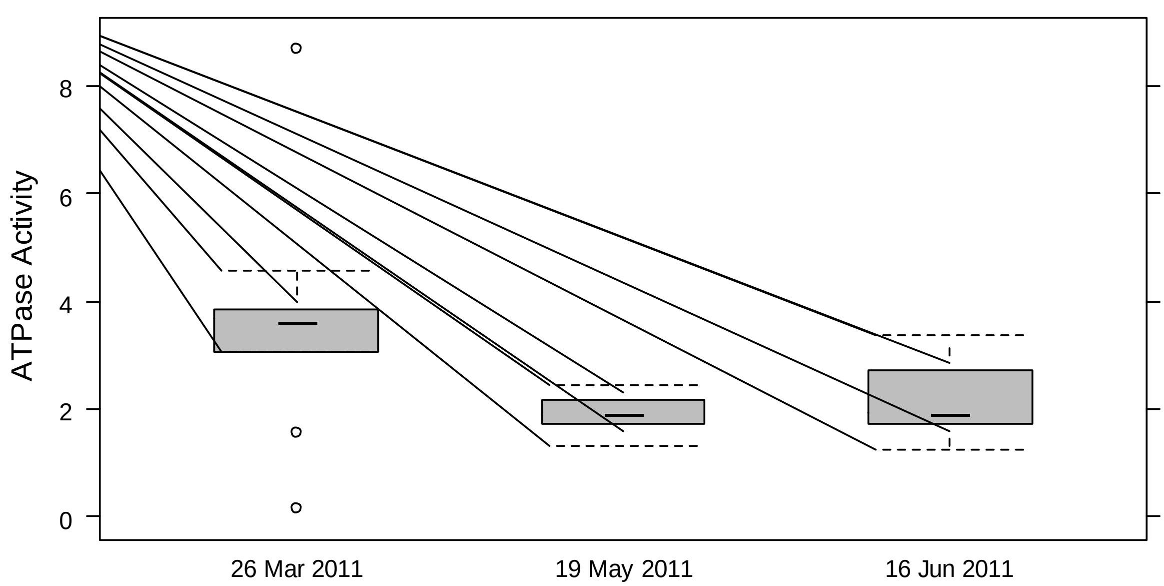

Figure 1. Boxplot of gill ATPase activity (µmol ADP·mg $protein^{-1}·hr^{-1}$) in steelhead.

References

Duston J, RL Saunders and DE Knox. 1991. Effects of increases in freshwater temperature on loss of smolt characteristics in Atlantic salmon (Salmo salar). Canadian Journal of Aquatic Animal Sciences 48: 164-169.

Ewing RD, GS Ewing and TD Satterthwaite. 2001. Changes in gill Na+, K+-ATPase specific activity during seaward migration of wild juvenile Chinook salmon. Journal of Fish Biology 58: 1414-1426.

Wedemeyer GA. 1996. Physiology of Fish in Intensive Culture Systems. Chapman & Hall, New York.

Appendix C. Photos for 2011 Six Year Steelhead Telemetry Study

Photo credits: FishBio

Image 1. Acoustic tag activation and preparation

Image 2. Tag preparation

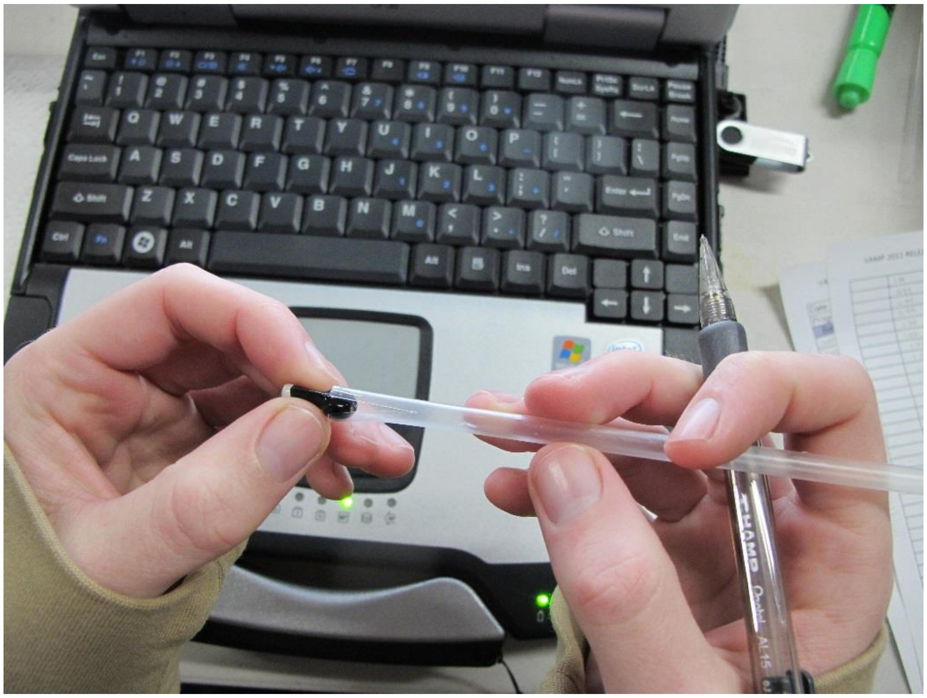

Image 3. Tag preparation

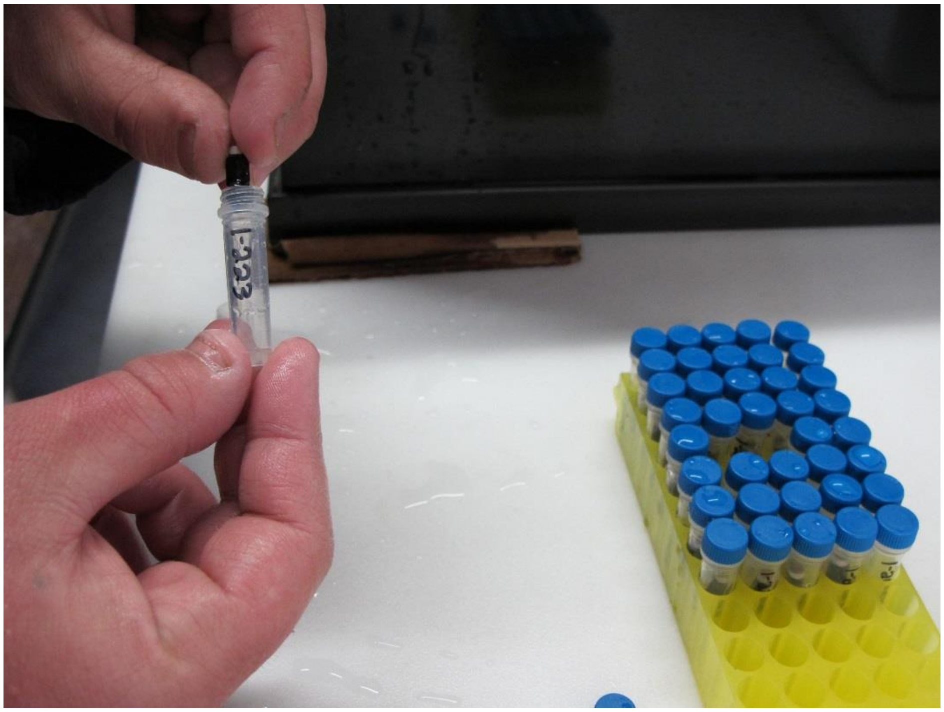

Image 4. Steelhead aesthesis in preparation for surgical implantation of acoustic tag

Image 5. Measuring Steelhead length

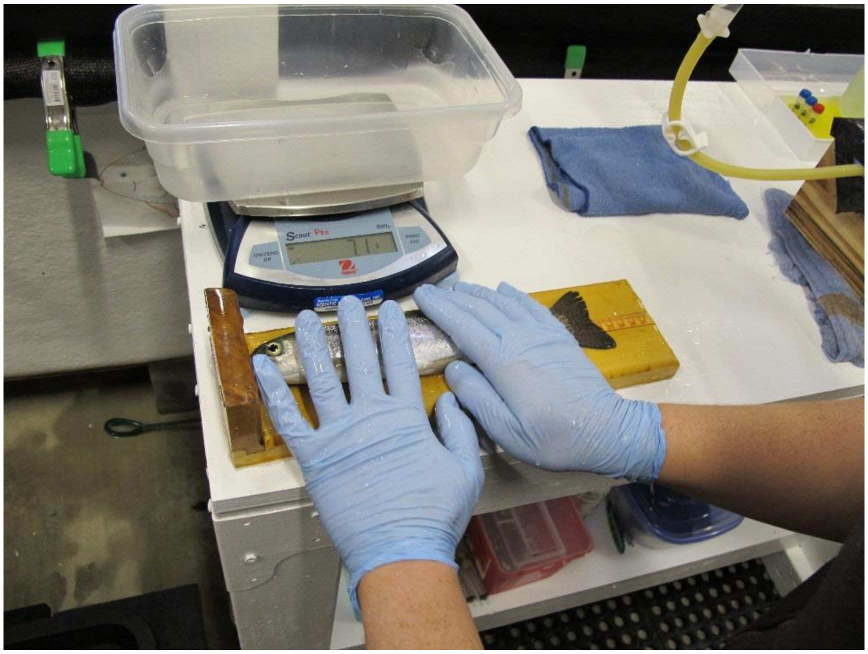

Image 6. Surgery set up

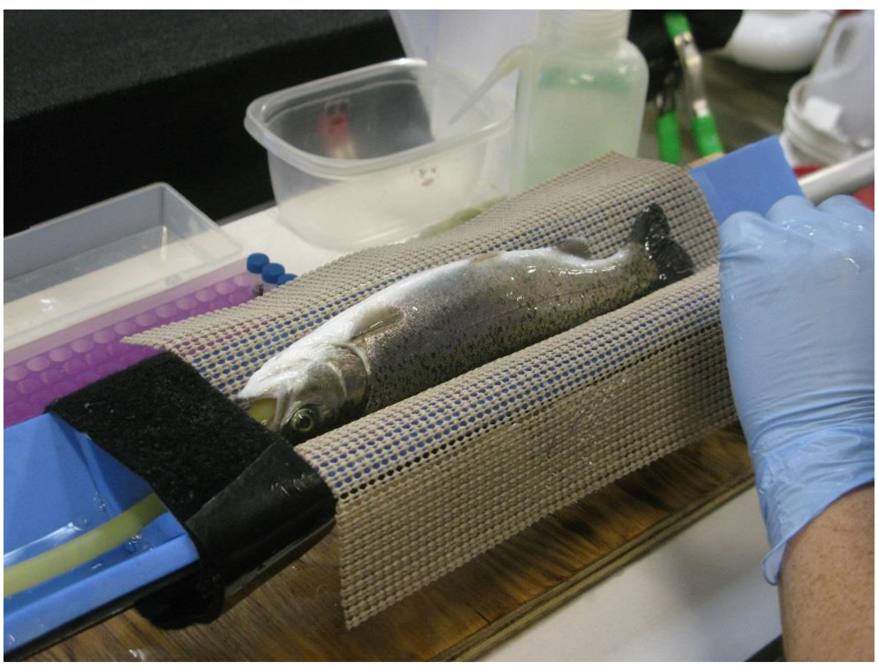

Image 7. Surgery set up

Image 8. Oxygen tank to maintain dissolved oxygen levels during transport and release operations.

Image 9. Holding and release operations

Image 10 (left). Measuring water quality during transportation, holding, and release operations.

Image 11 (right). Transferring Steelhead to holding container placed in river while it recovers from surgery.

Image 12. Steelhead holding operation

Image 13. Steelhead holding operation

Image 14. Acoustic telemetry receiver set up

Image 15. Acoustic telemetry receiver station

Image 16. USFWS Delta Acoustic Telemetry Receiver Station

Image 17. USFWS Delta Acoustic Telemetry Receiver Station

Image 18. Fish health assessment

Image 19. Steelhead with normal gill coloration

Image 20. Fish health assessment operations removal of dummy tag

Image 21. Dummy tag removal of steelhead.

Image 22. Abnormal coloration of scales on ventral surface of Steelhead.