RECLAMATION

Managing Water in the West

NMFS Biological Opinion RPA IV.2.2: 2013 Six-Year Acoustic Telemetry Steelhead Study

U.S. Department of the Interior
Bureau of Reclamation
Mid-Pacific Region
Bay-Delta Office

June 2018

NMFS Biological Opinion RPA IV.2.2: 2013 Six-Year Acoustic Telemetry Steelhead Study

June 2018

Contributions by
Rebecca Buchanan[2]; Pat Brandes[3], and Joshua Israel[1]

Compiled and Edited by
Elissa Buttermore[1] and Pat Brandes[3]

[1] U.S Department of the Interior
U.S. Bureau of Reclamation
801 I Street, Suite 100
Sacramento, CA 95626

[2]University of Washington
Columbia Basin Research
1325 Fourth Street, Suite 1820
Seattle WA 98101-2509

[3]U.S Department of the Interior
U.S. Fish and Wildlife Service
Lodi Fish and Wildlife Office
850 Guild Ave, Suite 105
Lodi, CA 95240

[4] Previously with California Department of Water Resources
1416 Ninth Street, Rm 115
Sacramento, CA 94326-001

[5] Presently with ESA | Environmental Science Associates
2600 Capitol Ave Suite 200
Sacramento, CA 95816

MISSION STATEMENTS

The U.S. Department of the Interior protects America's natural resources and heritage, honors our cultures and tribal communities, and supplies the energy to power our future.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

SUGGESTED CITATION:

U.S. Bureau of Reclamation (USBR). 2018. NMFS Biological Opinion RPA IV.2.2: 2013 Six-Year Acoustic Telemetry Steelhead Study. Contributions by: R. Buchanan, P. Brandes, J. Israel, and E. Buttermore. U.S. Bureau of Reclamation. Bay-Delta Office, Mid-Pacific Region, Sacramento, CA. FINAL REPORT. June 2018, 213 pp.

Bay-Delta Office

David Mooney, Manager

Josh Israel, Science Division Chief

DISCLAIMER

Acknowledgments

The U.S. Bureau of Reclamation funded this project. Several individuals from a variety of agencies made this project possible. Those agencies and individuals who participated in the tagging and release components of the project were—USFWS: Denise Barnard, Crystal Castle, Lori Chumney, Dustin Dinh, David Dominguez, Kevin Estramaria, Kyle Fronte, Garrett Gianneta, Gary Gonzalez, Carlie Jackson, Joseph Kirsch, David LaPlante, Jerrica Lewis, Duane Linander, Tim Matt, Louanne McMartin, Greg Nelson, Jacob Osborne, Mike Marshall, Ronald Smith, Jonathan Thompson, Caroline Walls, Jack Ingram, Ken Nichols, Kristin Towne, and Rob Wilson; USBR: Raymond Bark; Environmental Science Associates: Bryce Kozak. USGS provided training for the surgeons (Theresa [Marty] Liedtke), assisted in study design and deployed and maintained the receivers (Chris Vallee, Jon Burau, and Norbert VandenBranden), and preprocessed the tag observation data (Mike Simpson).

Table of Contents

Introduction

The NOAA National Marine Fisheries Service's (NMFS) Biological Opinion (BO) on Long-term Coordinated Operation of the Central Valley Project (CVP) and State Water Project (SWP) includes a Reasonable and Prudent Alternative (RPA) action to undertake experiments utilizing acoustic-tagged salmonids to identify 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 (NMFS 2009a). This study is to coincide with different periods of operations and focus on clipped hatchery steelhead (*Oncorhynchus mykiss*), but may include fall run Chinook (*O. tshawytscha*) as surrogate fish or wild steelhead smolts from tributaries for comparative purposes, when appropriate and permitted.

The study period of interest is between March 1 and June 15, which coincides with a majority of *O. mykiss* outmigration from the Stanislaus River (USBR 2018a) and recoveries of steelhead smolts in the Mossdale fish monitoring efforts (USBR 2018a). This period also includes changes in CVP/SWP operations including reductions in exports, reductions in reverse flows in Old and Middle rivers (OMR), and San Joaquin River pulse outflows.

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 for juvenile steelhead outmigration on the San Joaquin River include habitat availability, changes in hydrology, water temperature, reverse flow conditions, contaminants, habitat degradation, and entrainment (NMFS 2014). It is possible that reduced survival of emigrating smolts may be the greatest management concern to preserving anadromy in *O. mykiss* (Satterthwaite et al. 2010). The impacts of these stressors can be studied using acoustic telemetry, and an updated conceptual model, developed by the South Delta Salmonid Research Collaborative (SDSRC), demonstrates how experimental variables of interest to the Six-Year Study (i.e. Delta water operations, tributary water operations, and habitat) are influential in survival and behavior of emigrating smolts (Figure 1). This conceptual model has guided specific hypotheses and investigations of the Six-Year study.

Recent advances in acoustic technology have allowed investigators to evaluate the influence of behavior, species interactions, and physiology on reach-specific survival of salmonids in the Sacramento-San Joaquin river basins (Perry et al. 2010, Vogel 2010). Water operations for fish protection in the San Joaquin River include increasing river flows for salmonid emigration, reducing export diversions and reverse flows, and directing fish away from the south delta water project facilities via nonphysical or physical barriers. NMFS (2009a) identified flow at Vernalis, export volume, and the ratio of Vernalis flow-to-export as variables to test during this study as priority variables. Separating the effects of these covariates is difficult because the variables are likely to be correlated.

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 the winter and spring high flows, and use the lower San Joaquin River and delta for rearing and migration. On the Sacramento River, acoustic-tagged juvenile hatchery steelhead smolts can take days to over a month to emigrate from the upper Sacramento River through the delta. 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 (Garza and Pearse 2009). Because naturally emigrating *O. mykiss* are rare, this study used the closest hatchery stock of steelhead, found at the Mokelumne River Fish Hatchery. Recent review panels have suggested that Chinook salmon are a poor surrogate for steelhead (DSP 2009), thus simultaneous survival studies of juvenile Chinook salmon and steelhead smolts occurred in 2011 and 2012. In 2013, alternating releases of these two species were used throughout the spring: steelhead March 6-9, April 3-6, and May 8-11 and Chinook salmon, May 1-5 and May 15-19.

The NMFS Biological Opinion includes two actions that influence CVP/SWP export and discharges through the San Joaquin River and Old and Middle River corridor during the study period. Action IV.2.1 identifies targeted levels of export dependent on San Joaquin inflow at Vernalis, which may increase with higher Delta inflow from the San Joaquin River during wetter periods (i.e. inflow to export (I/E) ratio) (NMFS 2009a). This action is calendar based and occurs between April 1 and May 31. The action hypothesizes 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 flow through the Old and Middle River corridor (NMFS 2009a). Similar to Action IV.2.1, this action attempts to increase survival of emigrating Sacramento and San Joaquin origin ESA-listed 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 -3,500 cfs and -2,500 cfs.

In 2011, the Six-Year Study was coordinated with the VAMP and South Delta Temporary Barriers fish monitoring studies to simultaneously release juvenile steelhead and fall-run Chinook salmon to examine questions concerning surrogacy and species-specific route selection and survival estimates. In 2012, the Six-Year Study funded the deployment of the receiver array throughout the Delta which detected tagged fish from other studies, such as Reclamation's San Joaquin Flow Modification Project (SJFMP) and the U.S. Fish and Wildlife Service's Chinook salmon survival Study. In 2012, the Six-Year Study changed tag technology to support the integrated fish survival and behavioral studies funded by Reclamation and USFWS for the San Joaquin River Restoration Program, and the salmonid survival studies being undertaken by East Bay Municipal Utility District. Finally, in 2012, the acoustic telemetry study implemented as part of the "Joint Stipulation Regarding CVP and SWP Operations in 2012" was also coordinated with the Six-Year Study. In combination with the Six-Year Study steelhead releases, that study attempted to provide finer-scale information on steelhead route entrainment and survival in the Old and Middle River (OMR) corridor and adaptive management of OMR flows, to test hypotheses about fish distribution and the ability to manage residence times to reduce exposure to, degraded habitat, and direct take at the export facilities (Delaney et al 2014). The 2013 Six-Year Study used the same receiver array deployment, tagging and release SOPs as in the 2012 Six-Year Study (USBR 2018b), and included three releases between March 6 and May 9. The 2013 study also coordinated with juvenile Chinook releases for the CVPIA Chinook salmon survival study, and other local steelhead survival studies evaluating similar variables in the conceptual model (Figure 1).

Project Objectives

It is unknown what increased level of steelhead survival would be targeted by the various operational conditions required by the RPA; this question is one objective of the study. In addition, relevant fish management objectives identified in NMFS Opinion Action IV.2.2 include:

a) Determine survival of emigrating smolts from the tributaries into the mainstem of the San Joaquin River.
b) Determine survival of emigrating smolts through the mainstem San Joaquin River downstream into the Delta.
c) Determine survival of emigrating smolts through the Delta to Chipps Island.
d) Assess the role and influence of flow and exports on survival in these migratory reaches.
e) Identify reach-specific mortality and/or export loss of tagged fish.
f) Assess the influence of flows and exports on route entrainment and selections by tagged fish.

g) Test effectiveness of experimental technologies on route entrainment and selection by tagged fish.

Uncertainties and assumptions

O. mykiss residency

One complexity of working with *O. mykiss* is their residency in San Joaquin Basin tributaries. It is unknown what proportion of *O. mykiss* may remain as a resident or residualize following tagging. It is anticipated that after the first three years of the study (2011-2013), movement data will be available to quantify residency and develop a survival model that includes residency as a parameter influencing the accuracy of observations.

Surrogacy of fall-run Chinook

Given the rarity of *O. mykiss* smolts originating from San Joaquin basin tributaries, this study used fall run Chinook salmon as a surrogate in 2010 to evaluate relevant issues concerning tributary survival of steelhead smolts. As noted by the 2010 VAMP Review Panel, life history differences between Chinook salmon and steelhead are striking and it is likely that Chinook salmon surrogates do not provide a reliable basis for inference concerning flows and steelhead survival. The differences between the targeted study species, juvenile steelhead, and surrogate species, juvenile Chinook salmon, can be evaluated by comparing the influence of measured environmental parameters (e.g. flow, exports, and temperature) on survival of both species.

Use of hatchery clipped steelhead

The 2010 VAMP Review Panel suggested that hatchery steelhead are a reasonable source, although complementary studies with juvenile Chinook salmon were recommended to be paired with investigations using hatchery steelhead to examine the issues of inference between species. While using hatchery steelhead provides a critical benefit, it includes the potential risk of straying of hatchery steelhead back into the San Joaquin River tributaries. The genetic threat of straying is likely very low, based on recent genetics studies (Garza and Pearse 2009) that characterized populations of naturally spawning *O. mykiss* below tributary dams with non-native hatchery broodstocks (i.e. Nimbus hatchery). These studies suggest that all below-barrier *O. mykiss* have introgressed across the Central Valley and thus, it may be assumed straying impacts from this study would be minimal because no below-barrier native populations exist on the San Joaquin River tributaries. Additionally, expected survival rates were considered in an integrated demographic risk evaluation of potential straying by individual steelhead used in this study; it was determined that with the proposed sample sizes during 2013 (n = 1,500; comparable sample size in 2012), very high ocean survival would be necessary for fish surviving through the Delta and Bay in order for them to return as adults and impact San Joaquin River tributary populations.

Methods

A total of 1,425 acoustic-tagged steelhead were released into the San Joaquin River at Durham Ferry in March, April, and May of 2013: 476 in early March, 477 in early April, and 472 in early May. Acoustic tags were detectable on hydrophones located at 27 stations throughout the lower San Joaquin River and Delta to Chipps Island (i.e., Mallard Slough). Detection data were also available from 30 acoustic tags implanted into several species of predatory fish released in the Delta in March–May 2013: 25 striped bass, 4 largemouth bass, and 1 channel catfish. No barrier was installed at the head of Old River in 2013. Personnel from the Stockton Fish and Wildlife Office were tasked with the tagging, transport, holding and release components of the Six Year Survival study, while receiver deployment and maintenance were tasks of the U.S. Geological Survey. Rebecca Buchanan of University of Washington conducted the survival analysis. This report was jointly developed.

Sample Size Analysis

Modeling of juvenile salmon survival in the San Joaquin River for the 2011 VAMP study (SJRGA 2013) was used to determine the minimum number of fish released at Durham Ferry for the 2011-2013 releases (Buchanan 2010). Buchanan (2010) derived release size estimates for two overall survival values while leaving route selection proportions at Head of Old River constant with 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 was low (0.05). Additionally, if survival between Durham Ferry and Chipps Island was higher (0.15) and survival between Durham Ferry and the Old River junction was 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 release group of 475 at Durham Ferry was expected to provide accurate information about route entrainment and survival for examining biotic and abiotic factors influencing juvenile steelhead survival.

A second power analysis (Appendix A) was completed in 2013 to support development of an experiment as part of the South Delta Salmonid Research Collaborative. This power analysis derived release size recommendations based on Delta survival comparable to the average survival estimate from the five steelhead releases undertaken in 2011 (i.e., survival = 0.55; USBR 2018a). The analysis recommended a sample size of approximately 500 steelhead to achieve 80% power to detect a 20% increase in survival from Mossdale to Chipps Island (Appendix A). A sample size of 500 would also be sufficient to achieve one of the aims of this project, which was to detect differences in survival of more than 10% that resulted from distinct flow and export conditions within a single study season. While the 2011 average total survival was 0.54, the estimates from the individual release groups ranged from 0.38 to 0.69, suggesting a wide range of variability in survival could be detected with the samples sizes used in 2011 (474–480 and one release of 285, OCAP 2014) and the recommended sample size of 475 in 2013. To balance individual surgeon contribution to each release, the number of steelhead in each release group in 2013 was increased to 480.

Tagging, Transport, Release, and Fish Health Methods

Study Fish

A total of 1,924 juvenile steelhead trout (*O. mykiss*) from the Mokelumne River Hatchery (MRH) were requested for use from the California Department of Fish and Game for the 2013 Six-Year Study. Fish were used for the acoustic telemetry releases, tag life study, tag retention study, dummy tag studies, and fish health studies.

The fish were tagged at the MRH with support from CDFW and EBMUD. Fish weight averaged 94.9 grams (SD = 27.1 g) and ranged between 29.6 and 267.0 g. Fish fork length averaged 212.2 mm (SD = 20.7 mm) and ranged between 115 and 300 mm. A maximum length of 300 mm was applied during the tagging process, and fish greater than 300 mm were not tagged.

Tags

VEMCO V6-180 khz tags were used for tagging. The manufacturer reported that tags weighed 1.0 g in air. Of the 24 tags that were weighed, the average tag weight was 0.98 g. The tag burden averaged 1.0% and ranged from 0.3 to 3.3% of body weight for the steelhead used in the 2013 study. To make sure the tag burden was not greater than 5%, no steelhead smaller than 20 g were tagged with V6 tags. Tags were custom programmed with two separate coding schemes (three codes): a traditional Pulse Position Modulation (PPM) style coding along with a hybrid PPM/High Residence (HR) coding. The HR component of the coding allowed for detection at high residence receivers. High residence receivers were placed in locations where high densities of tags and tag signal collisions (i.e. many tags emitting signals at the same time to the same receiver) were anticipated (CVP, Clifton Court Forebay). The transmission of the PPM identification code was followed by a 25-35 second delay, followed by the PPM/HR code, followed by a 25-35 second delay, and then back to the PPM code, etc. The PPM code consisted of 8 pings approximately every 1.2 to 1.5 seconds. This sequence of 8 pings was transmitted every 50 to 70 seconds. The PPM/HR code also consisted of 8 pings transmitted within 1.2 to 1.5 seconds every 50-70 seconds. Each of the 8 pings of the PPM/HR transmission also contained an HR code that was the same for each transmitter. The PPM and PPM/HR transmissions were alternated such that a tag transmitted on average every 30 seconds.

Tags were soaked in saline water for at least 24 hours prior to tag activation. Tags were activated using a VEMCO tag activator (Figure 2) approximately 24 hours prior to tag implantation. Tag activation was identified to the nearest minute. Twelve tags were deactivated after activation and reactivated within a day or so later. This information was entered into the database and was considered when estimating tag life (see later section).

Surgeon training

A 5-day surgery training session was held at MRH between February 25 and March 1, 2013, one week prior to the initiation of the steelhead tagging. Training of tagging staff was conducted by the US Geological Survey's (USGS) Columbia River Research Lab (CRRL) following methods similar to past years (2011 and 2012) and incorporated into a Standard Operating Procedure (SOP) (Appendix B). Returning surgeons (two) received a refresher course during which they were required to tag a minimum of 35 fish. New surgeons (two) received more thorough training on surgical techniques and were required to tag a minimum of 75 fish during training. Training included sessions on knot tying, tagging bananas, tagging dead fish and finally tagging live fish, holding them overnight and necropsying them to evaluate techniques and provide feedback. Although four surgeons participated in the training, only three were used in the tagging for the study. The fourth surgeon was trained as a back-up, in case one was needed. Two of the returning surgeons and one new surgeon were used to tag the experimental fish. The back-up tagger was not needed during the study. Lastly, a mock tagging session was held on March 1 to practice logistical procedures, identify potential problems, and discuss solutions.

Tagging

Tagging was done using standard operating procedures (SOP) developed by the CRRL (Liedtke et al. 2012), and tailored to the Six-Year Study in 2012 (Appendix B). Methods were refined during the training week. The steelhead smolts were tagged by surgical insertion of V6 tag into the fish's peritoneal cavity (Figure 3). Visual inspection prior to tagging ensured that fish used for tagging were free of injuries, were less than 20% descaled, and had no other abnormalities. Two simple interrupted stitches tied with square knots on non-absorbable sutures were used to close the incision. All surgeons were USFWS employees. Each surgeon had an assistant, and three additional individuals (runners) helped to move fish into and out of the tagging operation. A fish tagging trailer placed near the raceway was used for the tagging operation at MRH in 2013. A total of 11 people were used for the tagging: three surgeons, three assistants, three runners, a tag validator, and a tagging coordinator. Three tagging shifts were completed each day. Because tagging occurred at MRH and fish were transported to Durham Ferry on the San Joaquin River, there were concerns about biosecurity regarding disease and invasive species transport between the tagging and release locations. A Biosecurity Awareness and Procedure Form was used to ensure that all participants in the Six-Year Study and associated Chinook salmon study were aware of and complied with prescribed steps to minimize these hazards (Appendix C).

Surgeries (air time) ranged from 1 minute and 33 seconds to 8 minutes and 32 seconds. Only two fish had air time of more than 5 minutes. The tagging coordinator completed compliance checklists to confirm standard operating procedures were followed (Appendix B).

Transmitter Validation

After the surgical implantation of tags, fish were placed into 19 liter (L) (5 gal) buckets with high dissolved oxygen concentrations (130-150%) at a density of 1 or 2 fish per bucket, and allowed to recover from anesthesia for 10 minutes. During this time, tag codes were verified using a 180 kHz hydrophone connected to a VR100 receiver. Two VR100s were used to facilitate verification of multiple tags concurrently and to accelerate the validation process (Figure 4). Tags that could not be verified using the VR100 were replaced with a new tag in a new fish.

Transport to Release Site

After validation, pairs of buckets containing one or two fish each were combined into a perforated 68 L (18 gallon) tote within a 68 L non-perforated tote (sleeve) (Figure 5), for a total of three fish in each tote. A lid was placed on the tote and then it was moved into a transport tank on a large 8 m (26 foot) flat-bed truck. Immediately prior to loading, all fish were visually inspected for mortality or signs of poor recovery from tagging (e.g. erratic swimming behavior). Fish that died or were not recovering from surgery were replaced with a new tagged fish.

In order to minimize the stress associated with moving fish and for tracking small groups of individually tagged fish, three specially designed transport tanks were used to move steelhead from the MRH, where the tagging occurred, to the release site at Durham Ferry. The transport tanks for steelhead were designed to securely hold 24 68-L perforated totes (Figure 6). The transport tanks had an internal frame that held 24 totes in individual compartments to minimize contact between buckets and to prevent tipping (Figure 7). Water levels in the transport tanks were 3 to 4 inches below the top of the totes, to allow the fish access to air for reestablishing neutral buoyancy after the handling during the tagging process (Liedtke et al 2012). Totes were covered in the transport tanks with stretched cargo nets to ensure totes did not tip over and lids did not come off.

Each transport tank was outfitted with an oxygen system (Figure 8) that allowed dissolved oxygen (DO) levels to be regulated, for maintaining fish health. The oxygen system consisted of two oxygen tanks mounted to a metal frame. A Weldmark (Model # RC250-80-540) medium-duty regulator was used to regulate pressure from the tank to a Victor (Model # 1000-0189) 7LPM flow meter. The oxygen flow rate was maintained at 2 LPM during transport. If DO levels were above 10 mg/L (100% saturated), the oxygen flow rate was reduced by 0.5 mg/L. A YSI Pro DO meter was used to measure DO and temperature.

Water temperature and DO in the transport tanks were recorded after loading totes into transport tanks and before leaving the MRH, and at the release site after transport. Water temperatures were continuously monitored in the transport tanks during transport using an Onset TidbiT v2 temperature logger. Transport time from the MRH to Durham Ferry took approximately 75 minutes. Temperature loggers were downloaded at the end of each transport period, with the exception of the first week. Three separate trips to the release site were made each tagging day.

Transfer to Holding Containers

Once the transport truck reached the holding site, temperature and dissolved oxygen (DO) were measured and recorded. If the difference between the temperature of the transport tank water and the river was greater than 5˚C, the fish required tempering. Tempering consisted of adding river water to the 68-L tote in approximately 11.3 L (3 gallon) increments. Once the water was added, the fish were allowed to acclimate for a period of 15 minutes, at which time the temperature was taken. If the difference in temperature between tote water and river water was less than 5˚C, the fish were ready to be placed into the holding containers. If additional tempering was required, the process of adding river water to the tote was repeated. Tempering was required only once during the study (on 4/4/2013).

Once totes were ready to be transferred to the holding containers, each perforated tote, which typically contained three steelhead, was moved from the transport tank to the river using a pick-up truck. Non-perforated totes (sleeves) were filled 1/2 to 2/3 full of river water, placed into the bed of a pick-up truck and driven up the levee, and parked next to the transport truck. Perforated totes were then lifted out of the transport tank by the transport truck driver and usually another crew member, handed to crew in the back of the pick-up, and placed into the partially filled tote sleeves (Figure 9). Once the pick-up truck was filled with approximately 8 totes, the pick-up truck was driven a short distance to the river's edge. Perforated totes were then unloaded from their sleeves in the pick-up truck and given to crew on the ground for carrying to the river's edge and to perforated holding cans anchored in the river. Perforated totes were submerged into the river while being moved to the holding containers which were anchored one to two meters from shore (Figure 10). Multiple trips were made with the pick-up truck until all perforated totes were unloaded from the transport tank. Water temperature and DO were measured in the river prior to placing the steelhead into the holding containers in the river.

Steelhead were loaded into 166-L (44-gallon) perforated holding cans (Rubbermaid, Commercial Brute Plastic Vented Utility Container, round, 61 cm [24"] diameter x 80 cm [31.5"] height). These holding containers were held in the river, attached to a tether line (Figure 10). Holding containers had perforated-hole sizes of 1.24 cm in diameter. Four totes containing three fish each were emptied into each holding container. Twelve steelhead were moved into each of 13 166-L holding cans, with one additional can only having six fish each day. Once 12 fish were placed into a holding container, the lid was secured using four bolts and wingnuts. Each tote and holding can was labeled to track the specific tag codes and ensure fish were transferred to the correct holding can for later release at the correct time. Tagged steelhead were held in the perforated holding cans for approximately 24 hours prior to release. There were fourteen perforated holding cans of live tagged fish and 1 holding can of dummy tagged fish used each day at the holding site.

A total of 156 to 162 steelhead were transported to the holding site every other day during the tagging period (Table 1). Three transport trips were required daily to transport all tagged steelhead to the holding site. Each transport tank accommodated 56 steelhead at a time. The use of sterile waders or hip boots was required on the flatbed of the transport truck. This was required as part of the bio-contaminant protocol (Appendix C). Three transport trucks were used to transport the fish from the MRH to the holding site at Durham Ferry.

After transfer to the 166-L holding containers, the 68-L totes were collected and placed on a clean tarp (4.3 m [14'] square) and allowed to dry. Once dry, any foreign material observed was brushed off using a clean whisk broom. At the end of the day, all 68-L totes were transported back to the Stockton Fish and Wildlife Office. These totes were then transported to the MRH where they were placed into a -20˚C freezer for a period of 24 hours prior to reuse. All fish were held in-river for a period of at least 24 hours prior to release.

Fish Releases

The juvenile steelhead, held in perforated holding cans, were transported downstream by boat to the release location, which was in the middle of the channel downstream of the holding location. The fish were released downstream of the holding site to reduce potential predation of tagged fish immediately after release, under the assumption that predators may congregate near the holding location. Releases were made every 4 hours after the 24 hour holding period, at approximately 1500, 1900, 2300 (the day after tagging), and 0300, 0700, and 1100 hours (2 days after tagging) (Table 1). Fish releases were made at these 4-hour increments throughout the 24-hour period to spread the fish out and to better represent naturally produced fish that may migrate downstream throughout the 24 hour period.

A STFWO research vessel (16 ft. aluminum boat with 25 hp Honda outboard motor, tiller steer) was used to transport the holding containers to the specified release site. During each release, two to three holding containers were unclipped from the tether line and clipped to the gunnel of the research vessel. These holding containers were then transported to the specified release site, located mid-channel approximately 150 meters downstream of the holding location.

Immediately prior to release, each holding container was checked for any dead or impaired fish. At the release time, the lid was removed and the holding container was rotated to look for mortalities. The container was then inverted to allow the fish to be released into the river. After the holding container was inverted, the time was recorded. As the holding containers were flipped back over, they were inspected to make sure that none of the released fish had swum back into the container. A Global Positioning System (GPS) reading was taken for each release which was then converted into a latitude and longitude point estimate. The holding container was then brought into the vessel to be returned to the tether line.

Once the release was completed, the information on any dead fish was recorded and the tags removed. The tags were bagged and labeled and returned to the office for tag code identification. A total of 1,430 juvenile steelhead were released with VEMCO V6 acoustic tags into the San Joaquin River at Durham Ferry on March 6 to 9 (477), April 3 to 6 (480), and May 8 to 11 (473) (Table 1). Ten fish died between transport and release and one was culled because it was not recovering from surgery (Table 1).

Dummy-tagged fish

In order to evaluate the effects of tagging and transport on the survival of the tagged fish, several groups of steelhead were implanted with inactive ("dummy") transmitters. Dummy tags in 2013 were systematically interspersed into the tagging order for each release group. For each day of tagging and transport, at least 12 fish were implanted with dummy transmitters and included in the tagging process (Table 1). 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 fish were kept separately from live tagged juvenile steelhead while being held in the river, but at the same density (12 fish per 166-L holding container). Dummy-tagged fish were evaluated for condition and mortality after being held at the release site for approximately 48 hours, or used to assess fish health (see next section).

At the time of assessment, field crew moved the holding container, filled with dummy tagged steelhead, to the shore so it would dewater to half full of water. The lid of the holding container was then removed to observe if there were any dead or dying fish. After a majority of the water had drained from the holding container, crew poured the fish and remaining water into a 19-L bucket containing a lethal concentration of MS-222. After being euthanized, fish were assessed qualitatively for percent scale loss, body color, fin hemorrhaging, eye quality, and gill coloration (Table 2). All tags were returned to the Stockton Fish and Wildlife Office, for reuse in the following tagging session.

Fish Health Assessment

As a part of the 2013 Six-Year Steelhead Survival Study, the U.S. Fish and Wildlife Service's CA-NV Fish Health Center (CNFHC) conducted a general pathogen screening and smolt physiological assessment on three groups of 24 dummy-tagged fish held at the release site for 48 hours (Table 1). One group of dummy tagged fish was assessed for fish health per tagging week. A sample was taken to assess gill parasites, viruses, and bacteria for an assessment of pathogens (Appendix F). These dummy tagged fish were assessed to determine if study fish health condition was compromised prior to release.

Tag life tests

The first of the two tag-life studies began on March 14, 2013, and the final detection was observed on June 5, 2013. The second tag-life study began on May 17, 2013, and its final detection was observed on August 4, 2013. For each study, three tanks were used with 16–17 tags per tank. A total of 50 V6 tags were used in each tag-life study. The tag life test was conducted by USBR at the Tracy Fish Facility in Byron, CA.

Tag retention

Thirty steelhead were tagged on March 1 and transported to the State Water Project's Collection, Handling, Transport and Release (CHTR) facility for an assessment of tag retention and mortality effects of surgical implantation of acoustic tags. The 30 steelhead were implanted with a dummy V6 acoustic tag and a PIT tag; two simple interrupted sutures were used to close the incision. PIT tags were used to identify individuals past 60 days. The steelhead were euthanized on May 10, 2013, and a 70-day tag retention assessment necropsy was performed by DWR personnel. The steelhead were assessed on a variety of criteria including the presence of sutures (both anterior and posterior), the intactness of the suture pattern, incision apposition, presence of fungus, organ inclusion in the suturing process, and signs of tag expulsion (Table 3).

Statistical Methods

Data Processing for Survival Analysis

The University of Washington received the database of tagging and release data from the U.S. Fish and Wildlife Service. The tagging database included the date and time of tag activation and tagging surgery for each tagged steelhead released in 2013, as well as the name of the surgeon (i.e., tagger), and the date and time of release of the tagged fish to the river. Fish size (length and weight), tag size, and any notes about fish condition were included, as well as the survival status of the fish at the time of release. Tag serial number and three unique tagging codes were provided for each tag, representing codes for various types of signal coding. Tagging data were summarized according to release group and tagger, and were cross-checked with Pat Brandes (USFWS) and Josh Israel (USBR) for quality control. Some tags had been deactivated after initial activation, and then reactivated before being implanted in a steelhead and released to the river. For these tags, a "virtual activation date" was computed that accounted for the entire time the tag was actively sending a signal before the fish implanted with the tag was released. The virtual activation date was used as the basis for tag-life adjustments to fish survival estimates (see "Analysis of Tag Failure" section).

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

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

The information for each tag in the database included the date and time of the beginning and end of each detection event when a tag was detected. Unique detection events were distinguished by detection on a separate hydrophone or by a time delay of 30 minutes between repeated hits on the same receiver. Separate events were also distinguished by the three unique tag codes assigned to each tag. The cleaned detection event data were converted to detections denoting the beginning and end of receiver "visits," with consecutive visits to a receiver 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, as were detections using different tag coding schemes.

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

Distinguishing between Detections of Steelhead and Predators

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

The predator filter used for analysis of the 2013 data was based on the predator filter designed and used in the analysis of the 2011 and 2012 data (USBR 2018a; USBR 2018b). The 2011 predator filter was based on predator analyses presented by Vogel (2010, 2011), as well as conversations with fisheries biologists familiar with the San Joaquin River and Delta regions. The 2013 filter used detections of acoustic-tagged predatory fish to characterize detection patterns indicative of predators. The filter was applied to all detections of all tags implanted in steelhead. Two datasets were then constructed: the full steelhead-tag dataset of all detections, including those classified as coming from predators (i.e., “predator-type”), and the reduced dataset, restricted to those detections classified as coming from live juvenile steelhead (i.e., “steelhead-type”). The survival model was fit to both datasets separately. The results from the analysis of the reduced “steelhead-type” dataset are presented as the final results of the 2013 Six-Year Study. Results from analysis of the full dataset including “predator-type” detections were used to indicate the degree of uncertainty in survival estimates arising from the predator decision process.

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

Even with these flexible criteria for steelhead, it was impossible to perfectly distinguish between a residualizing or extended rearing steelhead and a resident predator. A truly residualizing steelhead that is classified as a predator should not bias the overall estimate of successfully leaving the Delta at Chipps Island, because a residualizing steelhead would not be detected at Chipps Island. However, the case of a steelhead exhibiting extended rearing or delayed migration before finally outmigrating past Chipps

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

The predator filter was based on assumed behavioral differences between actively migrating steelhead smolts and predators such as striped bass and channel catfish. Detections from 30 acoustic-tagged predatory fish (25 striped bass, 4 largemouth bass, and 1 channel catfish) were used to characterize the range of predator behavior. For each steelhead tag, all detections were considered when implementing the filter, including detections from acoustic receivers that were not otherwise used in the survival model. As part of the decision process, environmental data including river flow, river stage, and water velocity were examined from several points throughout the Delta (Table 5), as available, downloaded from the California Data Exchange Center website (http://cdec.water.ca.gov/selectQuery.html) and the California Water Data Library (www.water.ca.gov/waterdatalibrary/) on 27 September 2013. Environmental data were reviewed for quality, and obvious errors were omitted.

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

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, under the assumption that such tags must have been in steelhead smolts rather than in steelhead predators. 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 detection sites in the western portion of the study area. This method mirrors that used for the 2011 and 2012 predator filters (USBR 2018a; USBR 2018b).

Acoustic receivers were stationed inside the holding tanks at CVP, and tags that were observed in the holding tanks and then next observed at either Chipps Island (i.e., Mallard Island), Jersey Point, or False River were assumed to have been transported. Acoustic receivers were not placed in the holding tanks at SWP, and so fish transported from SWP were identified with less certainty. It was assumed that tags were transported from SWP if they were detected either inside or outside the radial gates at the entrance to the Clifton Court Forebay (CCFB; the final receivers encountered before the SWP holding tank) and next detected at 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, evading detection at the multiple Old River and Middle River receivers north of the CCFB. While this pathway was possible, it was deemed less likely than the SWP transport pathway for fish with no detections between CCFB and the downstream sites (Jersey Point, etc.). Although 5 of the 9 tags implanted into predatory fish were detected at Chipps Island, Jersey Point, or False River after previous detections at the CCFB radial gates or the CVP trash racks, none were observed moving directly from the radial gates or CVP trash racks to Chipps Island, Jersey Point, or False River without intervening detections on receivers in channels in the Delta.

The predator filter used various criteria that addressed several spatial and temporal scales and fit under several categories (see USBR 2018a for more details): fish speed, residence time, upstream transitions, other unexpected transitions, travel time since release, and movements against flow. The criteria used in the 2011 and 2012 studies were updated to reflect river conditions and observed tag detection patterns in 2013 (Table 6). There were two new receiver sites installed in 2013 that were added to the predator filter: RRI (R1) = Rough and Ready Island, and SJS = San Joaquin River Shipping Channel at the junction with Turner Cut (A8) (Figure 11). One of the main differences between 2012 conditions and conditions during the 2013 study was the absence of the physical barrier blocking most access to the head of Old River, which was present in 2012. The absence of the barrier made some transitions acceptable for steelhead in 2013 even though they were assumed to indicate predation in 2012. Several new criteria were developed, including the maximum total visit length at a site (combined over multiple visits), time between visits to the same site, and large-scale movements from different regions of the study area. Unless otherwise specified, the maximum total visit length at a site was limited to 500 hours (approximately 21 days). The other criteria are specified below and in Table 6.

The predator scoring and classification method used for the 2011 and 2012 studies were used again for the 2013 study, resulting in tags being classified as in either a predator or a smolt upon arrival at and departure from a given receiver site and visit; for more details, see USBR 2018a. All detections of a tag subsequent to its first predator designation were classified as coming from a predator, as well.

The criteria used in the predator filter were spatially explicit, with different limits defined for different receivers and transitions (Table 6). The overall approach to various regions and some additional criteria are 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, maximum total visit length = 1000 hours.

BCA, MOS, and HOR = Banta Carbona (A3), Mossdale (A4), and Head of Old River (B0): allow longer residence time if next transition is directed downstream; may have extra visits at A3 or lower travel times to A4 and B0 if arrival flow is low. Allow limited transitions to B0 from the Lathrop receiver in the San Joaquin River (A5) and the Old River East receiver (B1). Maximum total visit length to any of these sites = 1000 hours.

SJL = San Joaquin River near Lathrop (A5): allow longer between repeat visits if low flow during transition; upstream transitions from Stockton sites are not allowed; limited transitions from Old River East (B1) were allowed. Maximum total visit length = 328 hours.

ORE = Old River East (B1): allow limited transitions from the San Joaquin River receiver near Lathrop (A5); no previous detections in lower San Joaquin River (near Stockton or farther downstream). Maximum total visit length = 370 hours.

SJG = San Joaquin River at Garwood Bridge (A6): repeat visits or transitions from upstream require arrival flow/velocity to be opposite direction from flow/velocity on previous departure. Maximum total visit length = 45 hours.

SJNB and RRI = San Joaquin River at Navy Bridge Drive (A7) and Rough and Ready Island (R1): fast transitions moving downstream require positive water velocity. Maximum total visit length = 45 hours.

SJS and MAC = San Joaquin River Shipping Channel (A8) and MacDonald Island (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. Maximum total visit length = 45 hours (SJS) or 60 hours (MAC).

MFE/MFW = Medford Island (A10): 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; transitions from interior Delta sites (B3, B4, C2, C3) must have departed interior Delta sites with very low or positive flow/velocity; transitions from Jersey Point (G1) not allowed.

TCE/TCW = Turner Cut (F1): should not move against flow.

ORS = Old River South (B2): allow longer transition times from ORE if mean water velocity during transition was low; no previous detections in lower San Joaquin River (near Stockton or farther downstream).

MRH = Middle River Head (C1): shorter residence times than ORS; repeat visits are not allowed; no previous detections in lower San Joaquin River (near Stockton or farther downstream).

MR4 = Middle River at Highway 4 (C2): should not move against flow or high water velocity; should not arrive from San Joaquin River (Stockton) via water export facilities (D, E1).

MRE = Middle River at Empire Cut (C3): should not move against flow; should not arrive from Turner Cut after being in western (B3, E1, D) or northern (G1, G2, H1, T1) Delta.

CVP = Central Valley Project (E1): allow multiple visits; transitions from downstream Old River should not have departed Old River site against flow or arrived during low pumping.

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

OR4 = Old River at Highway 4 (B3): allow many visits; should not arrive against flow or water velocity; should not arrive from water facilities after previous detections in San Joaquin River near or downstream of Stockton or Turner Cut.

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

- Assume juvenile steelhead can move from D2 back to D1
- 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 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 residence time appear to have spent long time inside CCFB before returning to Old River, look like predators;

  - otherwise maximum combined residence time = 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.

- Maximum total visit length (summed over visits that were separated by detections elsewhere) = 800 hours.

JPE/JPW and FRE/FRW = Jersey Point (G1) and False River (H1): no flow/velocity restrictions; allowed for transition from Threemile Slough (TMS/TMN). Maximum total visit length = 80 hours.

TMS/TMN = Threemile Slough (T1): should not move against flow on departing from interior Delta or San Joaquin River sites. Maximum total visit length = 20 hours.

MAE/MAW = Chipps Island (G2): should not arrive against strong negative water velocity/flow. Maximum total visit length = 50 hours.

Detections in the San Joaquin River or near the heads of Old and Middle Rivers (B1, B2, C1) after previous entry to the Interior Delta (e.g., Old and Middle River sites or export facilities) from Stockton or sites farther downstream in the San Joaquin River were generally not allowed. The exceptions were at MacDonald Island (A9), Turner Cut (F1), and Medford Island (A10). Detections at sites other than CVP (E1), the radial gates (D1/D2), Jersey Point (G1), False River (H1), Chipps Island (G2), and Threemile Slough (T1) after arriving at either CVP or the radial gates from the lower San Joaquin River were not allowed. These restrictions were based on the assumption that juvenile steelhead that leave the lower San Joaquin River for the Interior Delta are not expected to return to the San Joaquin River, and those that leave the lower San Joaquin River for the water export facilities are not expected to subsequently leave the facilities other than through salvage and transport. Maximum travel times were imposed on transitions in the Interior Delta and at the facilities for steelhead observed leaving the lower San Joaquin River for these regions. Transitions from the northern Delta sites (G1, G2, H1, T1) or western Delta sites (B2, B3, C1, C2, D, E1, E2) back to the regions of the San Joaquin River near Stockton and farther upstream were not allowed. Finally, transitions to the interior Delta or Old River from the San Joaquin River near Stockton or farther downstream (including Turner Cut) were not expected to come via the head of Old River for steelhead.

Constructing Detection Histories

For each tag, the detection data summarized on the "visit" scale were converted to a detection history (i.e., capture history) that indicated the chronological sequence of detections on the fixed site receivers throughout the study area. In cases in which a tag was observed passing a particular receiver or river junction multiple times, the detection history represented the final route of the tagged fish past the receiver or river junction. In particular, if a fish was observed even far downstream in one route but then returned to the river junction and finally selected the other route, then survival and detection in the later route were modeled. This is a small change from previous years, in which receivers located far downstream from the junction were given precedence over receivers near the junction in determining the "final route"; in particular, in previous years, fish detected far downstream in the first route were assigned to that route, even if they were later detected at the river junction again[1]. Detections from the receivers comprising certain dual arrays were pooled, thereby converting the dual arrays to redundant arrays: the San Joaquin River near Mossdale Bridge (A4), Lathrop (A5), and Garwood Bridge (A6); Old River East near the head of Old River (B1); the Central Valley Project trash racks (E1); and the radial gates just outside of Clifton Court Forebay (D1). For some release groups, a better model fit was found by pooling detections from dual arrays into redundant arrays at the Durham Ferry Downstream site (D2), MacDonald Island (A9), Old River South (B2), and/or Jersey Point (G1). The status of the radial gates (opened or closed) upon detection at the receivers just outside the radial gates (D1) was included in the detection history. Detections on receivers at the Head of Old River site (B0) and in the San Joaquin River Shipping Channel (A8) were used in determining the detection history, but were later omitted from the survival model.

Survival Model

A two-part multi-state statistical release-recapture model was developed and used to estimate perceived juvenile steelhead survival and migration route parameters throughout the study area. The release-recapture model is a slightly simplified version of the models used in the 2011 and 2012 steelhead analyses (USBR 2018a; USBR 2018b), and similar to the model developed by Perry et al. (2010) and the model developed for the 2009–2011 VAMP studies (SJRGA 2010, 2011, 2013). Figure 11 shows the layout of the receivers using both descriptive labels for site names and the code names used in the

[1] The 2011 and 2012 data were assessed using the revised route assignment protocol. There was no change for the 2011 data (USBR 2018a). For the 2012 data (USBR 2018b), two tags that were assigned to route A using the old protocol would have been reassigned to route B using the new protocol, but only if predator-type detections were included.

survival model (Table 4). The survival model represents movement and perceived survival throughout the study area to the primary exit point at Chipps Island (i.e., Mallard Island) (Figure 12, Figure 13). Individual receivers comprising dual arrays were identified separately, using "a" and "b" to represent the upstream and downstream receivers, respectively. Most sites used in 2013 were also used in 2012, although some site names changed (Figure 11, Table 4).As in 2012, the Paradise Cut sites used in 2011 were not used in 2013 because flows were too low for fish to enter Paradise Cut. Additional receivers were installed in 2013 in the San Joaquin River Shipping Channel just upstream of Turner Cut (SJS = A8), and in Burns Cutoff around Rough and Ready Island near Stockton (RRI = R1), but were not used in the survival model. Receivers just upstream of the head of Old River (HOR = B0), in Middle River north of Highway 4 (MRE = C3), and in Threemile Slough (TMS/TMN = T1) were also omitted from the survival model. All sites were used in the predator filter.

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, A4), then the multi-state statistical release-recapture model estimated perceived survival rather than true survival, where perceived survival is the joint probability of migrating and surviving. The complement of perceived survival includes both the probability of mortality and the probability of halting migration to rear or residualize. Unless otherwise specified, references to "survival" below should be interpreted to mean "perceived survival."

Fish moving through the Delta toward Chipps Island may have used any of several routes. The two primary routes modeled were the San Joaquin River route (Route A) and the Old River route (Route B). Route A followed the San Joaquin River past the distributary point with Old River near the town of Lathrop and past the city of Stockton. Downstream of Stockton, fish in the San Joaquin River route (route A) may have remained in the San Joaquin River past its confluence with the Sacramento River and on to Chipps Island. Alternatively, fish in Route A may have exited the San Joaquin River for the interior Delta at any of several places downstream of Stockton, including Turner Cut, Columbia Cut (just upstream of Medford Island), and the confluence of the San Joaquin River with either Old River or Middle River, at Mandeville Island. 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 just 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), there were several pathways available to Chipps Island. These fish may have migrated to Chipps Island either by moving northward in either the Old or Middle rivers through the interior Delta, or they may have moved to the state or federal water export facilities to be salvaged and trucked. The Middle River route (subroute C) was monitored and contained within Route B. Passage through the State Water Project via Clifton Court Forebay was monitored at the entrance to the forebay and assigned a route (subroute D). Likewise, passage through the federal Central Valley Project was monitored at the entrance trashracks and in the facility holding tank and assigned a route (subroute E). Subroutes D and E were both contained in subroutes C (Middle River) and F (Turner Cut), as well as in primary routes A (San Joaquin River) and B (Old River). All routes and subroutes included multiple unmonitored pathways for passing through the Delta to Chipps Island.

Several exit points from the San Joaquin River were monitored and given route names for convenience, although they did not determine unique routes to Chipps Island. The first exit point encountered was False River, located off the San Joaquin River just upstream of Jersey Point. Fish entering False River from the San Joaquin River entered the interior Delta at that point, and would not be expected to reach Chipps Island without subsequent detection in another route. Thus, False River was considered an exit point of the study area, rather than a waypoint on the route to Chipps Island. It was given a route name (H) for convenience. Likewise, Jersey Point and Chipps Island were not included in unique routes. Jersey Point was included in many of the previously named routes (in particular, routes A and B, and subroutes C and F), whereas Chipps Island (the final exit point) was included in all previously named routes and subroutes except route H. Thus, Jersey Point and Chipps Island were given their own route name (G). Four additional sets of receivers located in the San Joaquin River (Route A), Burns Cutoff on the San Joaquin River near Stockton (Subroute R of Route A), Middle River (Subroute C) north of Highway 4, and in Threemile Slough (Route T) 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

R = Rough and Ready Island: not used in survival model

T = Threemile Slough: not used in survival model

The release-recapture model used parameters that denote the probability of detection (P_{hi}), route selection ("route entrainment", ψ_{hl}), perceived steelhead survival (the joint probability of migrating and surviving; S_{hi}), and transition probabilities equivalent to the joint probability of directed movement and survival ($\phi_{kj,hi}$) (Figure 12, Figure 13, Table G1). For each dual array, unique detection probabilities were estimated for the individual receivers in the array: P_{hia} represented the detection probability of the upstream array at station i in route h, and P_{hib} represented 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), 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, the parameters $\phi_{kj,D1O}$ and $\phi_{D1O,D2}$ represent transition to and from site D1 when the gates are open, and parameters $\phi_{kj,D1C}$ and $\phi_{D1C,D2}$ represent transition to and from D1 when the gates are closed. It was not possible to estimate unique detection probabilities at site D1 for open and closed gates, so a common probability of detection, P_{D1}, was assumed at that site regardless of gate status upon arrival. This assumption was reasonable in light of high detection probabilities at this site for most release groups ($\hat{P}_{D1}$ = 1 for all release groups) (Tables G1, G2, G3 [Appendix G. Survival Model Parameters]).

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 11). This river junction marks the distinction between routes G and H, so transition probabilities to this junction are named $\phi_{kj,GH}$ for the joint probability of surviving and moving from station j in route k to the False River junction. Fish may arrive at the junction either from the San Joaquin River or from the interior Delta. The complex tidal forces present in this region prevent distinguishing between smolts using False River as an exit from the San Joaquin and smolts using False River as an entrance to the San Joaquin from Frank's Tract. Regardless of which approach the fish used to reach this junction, the $\phi_{kj,GH}$ parameter (e.g. $\phi_{A9,GH}$ 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 $\psi_{H1} = 1 \quad \psi_{G1}$ is the probability of exiting (or re-exiting) the San Joaquin River to False River from the junction (Figure 12, Figure 13).

Although the full survival model provides separate estimates for the transition probabilities to the Jersey Point/False River junction ($\phi_{kj,GH}$) and the route entrainment probability at that junction $\left(\psi_{G1}\right)$, it was not possible to estimate these two parameter separately in 2013. Of the 32 steelhead tags observed on the False River receivers, all of them were later detected at either Jersey Point, Chipps Island, or Threemile Slough, or had been detected at False River after salvage and release from the CVP, for which route False River is not a modeled way point or exit. Thus, no detections at False River appeared in the modeled detection histories. In this case, it was not possible to separately estimate the survival transition parameters $\phi_{kj,GH}$ from the route entrainment probability ψ_{G1}, for transitions from station j in route k. Instead, only their product was estimable: $\phi_{kj,G1} = \phi_{kj,GH}\psi_{G1}$. Under the assumption that no fish passed the H1 receivers without detection after subsequent detection at G1 or elsewhere, then the route entrainment parameter ψ_{G1} =1 and the estimable parameter $\phi_{kj,G1}$ is equal to $\phi_{kj,GH}$. However, there was no way to test that assumption.

The survival models used in the 2011 and 2012 analyses included transitions from the San Joaquin River route sites near and in Turner Cut (A9, A10, and F1) to the interior Delta sites in Old and Middle rivers north of Highway 4 (B3 and C2), and transitions from sites B3 and C2 to the water export facilities. In 2013, there were no detections at B3 of tags that had previously been detected in the San Joaquin River route, so it was not possible to model transitions to and from B3 for this route. There were only three tags detected at C2 after previous detections in the San Joaquin River route, and one of the three tags was detected at C2 only using the predator-type detections; there were too few detections at C2 from the San Joaquin River route tags to model transitions to and from C2 for this route. Thus, both sites B3 and C2 were omitted from the model of the San Joaquin River route to Chipps Island (Figure 13). Only two tags from the San Joaquin River route were detected at either of the water export facilities; these detections were pooled with detections from Old River route tags at those sites to model transitions within the facilities (i.e., $\phi_{D1,D2}$ and $\phi_{E1,E2}$), and from the facilities to Chipps Island (i.e., $\phi_{D2,G2}$ and $\phi_{E2,G2}$).

One of the receivers placed just upstream of the release site at Durham Ferry (DFU1, model code A0a) was stolen between 6 May 2013, the date of the first data retrieval from that site, and 5 September 2013, the date of the final data retrieval. There were no detections from the DFU1 receiver after 19 April 2013, which was approximately 2 weeks after the second release group was released. This meant that the A0 site could not be used in the survival model for the second and third release groups, because it was not possible to estimate the detection probability at that site.

For fish that reached the interior receivers at the State Water Project (D2) or the Central Valley Project (E2), the parameters $\phi_{D2,G2}$ and $\phi_{E2,G2}$, respectively, represent the joint probability of migrating and surviving to Chipps Island, including survival during and after collection and transport (Figure 12). Some salvaged and transported smolts were released in the San Joaquin River between Jersey Point and Chipps Island, and others were released in the Sacramento River upstream of the confluence with the San Joaquin River. Because salvaged fish were not required to pass Jersey Point and the False River junction, it was not possible to estimate the transition probability to Chipps Island via Jersey Point for salvaged fish. Thus, only the overall probability of making the transition to Chipps Island was estimated for fish passing through the water export facilities.

Because of the complexity of routing in the vicinity of MacDonald Island (referred to as “Channel Markers” in previous reports [USBR 2018a, SJRGA 2010, 2011, 2013]) 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, as in the 2011 and 2012 analyses (USBR 2018a; USBR 2018b). Submodel I modeled the overall migration from release at Durham Ferry to arrival at Chipps Island without modeling the specific routing from the lower San Joaquin River (i.e., from the Turner Cut Junction) through the interior Delta to Chipps Island, although it included detailed subroutes in route B for fish that entered Old River at its upstream junction with the San Joaquin River (Figure 12). In Submodel I, transitions from MacDonald Island (A9) and Turner Cut (F1) to Chipps Island were interpreted as survival probabilities ($S_{A9,G2}$ and $S_{F1,G2}$) because they represented all possible pathways from these sites to Chipps Island. Submodel II, on the other hand, focused entirely on Route A, and used a virtual release of tagged fish detected at the San Joaquin River receiver array near Lathrop (A5, SJL) to model the detailed routing from the lower San Joaquin River near MacDonald Island and Turner Cut through or around the interior Delta to Jersey Point and Chipps Island (Figure 13). Submodel II included the Medford Island detection site (A10), which was omitted from Submodel I because of complex routing in that region. Unlike in 2011 and 2012, Submodel II omitted sites B3 (OR4) and C2 (MR4) in the 2013 analysis.

The two submodels I and II were fit concurrently using common detection probabilities at certain shared receivers: D1 (RGU), D2 (RGD), E1 (CVP), E2 (CVP holding tank), G1 (JPE/JPW), and H1 (FRE/FRW). While submodels I and II both modeled detections at these receivers, actual detections modeled at these receivers came from different tagged fish in the two submodels: detections from

Route B fish were used in Submodel I, and detections from Route A fish were used in Submodel II. Detections at all other sites included in Submodel II either included the same fish as in Submodel I (i.e., sites SJG [A6], SJNB [A7], MAC [A9], TCE/TCW [F1], and MAE/MAW [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 and II to avoid "double-counting" tags used in both submodels. In the 2011 study (USBR 2018a), unique transition parameters through the water export facility sites (i.e., $\phi_{D1,D2}$, $\phi_{D2,G2}$, $\phi_{E1,E2}$, and $\phi_{E2,G2}$) were estimated for Submodels I and II, under the assumption that fish that arrive outside the CVP or the Clifton Court Forebay coming from the head of Old River might have a different likelihood of reaching the interior receivers than fish that came from the lower San Joaquin River. In 2013, however, only two tags were observed at Clifton Court Forebay or the CVP that came from the lower San Joaquin River; there were too few Route-A detections at these sites to fit the models using unique transition parameters in the two submodels, so the submodels were fit using common facility transition parameters.

There were very few tagged steelhead detected in the San Joaquin River route (Route A) from the first release group, and it was not possible to estimate the majority of the transition parameters within that route. Thus, a simplified model was used for Route A fish that directly estimated survival from SJG (site A6) to Chipps Island (MAE/MAW, site G2) in Submodel I, or to Jersey Point (JPT, site G1) and then on to Chipps Island in Submodel II. Transition probabilities from Turner Cut, MacDonald Island, and Medford Island were not available from this model or for this release group, nor was the route selection probability at the Turner Cut junction (ψ_{A2}). The survival probabilities estimated from A6 to either G1 in Submodel II ($S_{A6,G1}$) or directly to G2 in Submodel I ($S_{A6,G2}$) represent total survival from A6 to these sites, and include all possible routes between A6 and these sites.

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

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

$\psi_{AF} = \psi_{A1}\psi_{F2}$: probability of remaining in the San Joaquin River past the head of Old River, and exiting to the interior Delta at Turner Cut,

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

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

where $\psi_{B1} = 1 \quad \psi_{A1}$, $\psi_{F2} = 1 \quad \psi_{A2}$, and $\psi_{C2} = 1 \quad \psi_{B2}$. In cases where there were too few detections in the Route A to model detections downstream of site A6 (i.e., for the first release group), route selection probabilities were not available for the subroutes within route A, and only $\psi_A = \psi_{A1}$ was estimated for route A.

The probability of surviving from the entrance of the Delta near Mossdale Bridge (site A4, MOS) through an entire migration pathway to Chipps Island was estimated as the product of survival probabilities that trace that pathway:

$S_{AA} = S_{A4}S_{A5}S_{A6}S_{A7}S_{A9,G2}$: Delta survival for fish that remained in the San Joaquin River past the head of Old River and Turner Cut,

$S_{AF} = S_{A4}S_{A5}S_{A6}S_{A7}S_{F1,G2}$: Delta survival for fish that entered Turner Cut from the San Joaquin River,

$S_{BB} = S_{A4}S_{B1}S_{B2,G2}$: Delta survival for fish that entered Old River at its head, and remained in Old River past the head of Middle River,

$S_{BC} = S_{A4} S_{B1} S_{C1,G2}$: Delta survival for fish that entered Old River at its head, and entered Middle River at its head.

In cases where detections downstream of site A6 could not be modeled (i.e., first release group), Delta survival could not be estimated for the individual subroutes within route A; in this case, Delta survival was estimated on the primary route scale for route A: $S_A = S_{A4} S_{A5} S_{A6,G2}$.

The parameters $S_{A9,G2}$ and $S_{F1,G2}$ represent the probability of getting to Chipps Island (i.e., Mallard Island, site MAE/MAW) from sites A9 and F1, respectively. Both parameters represent multiple pathways around or through the Delta to Chipps Island (Figure 12). Fish that were detected at the A9 receivers (MacDonald Island) may have remained in the San Joaquin River all the way to Chipps Island, or they may have entered the interior Delta downstream of Turner Cut. Fish that entered the interior Delta either at Turner Cut or farther downstream may have migrated through the interior Delta to Chipps Island via Frank's Tract or Fisherman's Cut, False River, and Jersey Point; returned to the San Joaquin River via its downstream confluence with either Old or Middle River at Mandeville Island; or gone through salvage and trucking from the water export facilities. All such routes are represented in the $S_{A9,G2}$ and $S_{F1,G2}$ parameters, which were estimated directly using Submodel I.

Survival probabilities $S_{B2,G2}$ and $S_{C1,G2}$ represent survival to Chipps Island of fish that remained in the Old River at B2 (ORS), or entered the Middle River at C1 (MRH), respectively. Fish in both these routes may have subsequently been salvaged and trucked from the water export facilities, or have migrated through the interior Delta to Jersey Point and on to Chipps Island (Figure 12). Because there were many unmonitored river junctions within the "reach" between sites B2 or C1 and Chipps Island, it was impossible to separate the probability of taking a specific pathway from the probability of survival along that pathway. Thus, only the joint probability of movement and survival could be estimated to the next receivers along a route (i.e., the $\phi_{kj,hi}$ parameters defined above and in Figure 12). However, the overall survival probability from B2 ($S_{B2,G2}$) or C1 ($S_{C1,G2}$) to Chipps Island was defined by summing products of the $\phi_{kj,hi}$ 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 River.

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

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

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

The probability of surviving from the entrance of the Delta (site A4, MOS) through an entire large-scale migration pathway to Chipps Island was defined as a function of the finer-scale route-specific survival probabilities and route selection probabilities:

$S_A = \psi_{A2} S_{AA} + \psi_{F2} S_{AF}$: Delta survival (from Mossdale to Chipps Island) for fish that remained in the San Joaquin River at the head of Old River, and

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

Using the estimated migration route probabilities and route-specific survival for these two primary routes (A and B), survival of the population from A4 (Mossdale) to Chipps Island was estimated as:

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

Survival was also estimated from Mossdale to the Jersey Point/False River junction, both by route and overall. Survival through this region ("Mid-Delta" or MD) was estimated only for fish that migrated entirely inriver, without being trucked from either of the water export facilities, because trucked fish were not required to pass the Jersey Point/False River junction in order to reach Chipps Island. The route-specific Mid-Delta survival for the large-scale San Joaquin River and Old River routes was defined as follows:

$S_{A(MD)} = \psi_{A2} S_{AA(MD)} \quad \psi_{F2} S_{AF(MD)}$: Mid-Delta survival for fish that remained in the San Joaquin River past the head of Old River, and

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

$$S_{AA(MD)} = S_{A4} S_{A5} S_{A6} S_{A7} \left[\phi_{A9,GH} + \phi_{A9,A10} \phi_{A10,GH} \right],$$

$$S_{AF(MD)} = S_{A4} S_{A5} S_{A6} S_{A7} \phi_{F1,GH},$$

$$S_{BB(MD)} = S_{A4} S_{B1} \left(\phi_{B2,B3} \phi_{B3,GH} + \phi_{B2,C2} \phi_{C2,GH} \right), \text{ and}$$

$$S_{BC(MD)} = S_{A4} S_{B1} \left(\phi_{C1,B3} \phi_{B3,GH} + \phi_{C1,C2} \phi_{C2,GH} \right).$$

In cases where detections downstream of A6 could not be modeled (i.e., for the first release group), the Mid-Delta survival probabilities for the subroutes in route A could not be estimated. Instead, only the total Mid-Delta survival probability for route A could be estimated: $S_{A(MD)} = S_{A4} S_{A5} S_{A6} S_{A6,GH}$.

Total Mid-Delta survival (i.e., from Mossdale to the Jersey Point/False River junction) was defined as $S_{Total(MD)} = \psi_{A} S_{A(MD)} \quad \psi_{B} S_{B(MD)}$. 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), both within each primary route and overall:

$$S_{A(SD)} = S_{A4} S_{A5} S_{A6} S_{A7}, \text{ and}$$

$$S_{B(SD)} = S_{A4} S_{B1} \left(\psi_{B2} S_{B2(SD)} + \psi_{C2} S_{C1(SD)} \right),$$

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

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

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

Total survival through the Southern Delta was defined as:

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

The probability of reaching Mossdale from the release point at Durham Ferry, $\phi_{A1,A4}$, was defined as the product of the intervening reach survival probabilities:

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

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

Individual detection histories (i.e., capture histories) were constructed for each tag as described above. More details and examples of detection history construction and model parameterization are available in USBR 2018a. Under the assumptions of common survival, route 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 et al. 2009). Point estimates and standard error estimates 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 in the USER model as appropriate, based on the observed detections. The model was fit separately for each release group. For each release group, the complete dataset that included possible detections from predatory fish was analyzed separately from the reduced dataset restricted to detections classified as steelhead detections. Population-level estimates of parameters and performance measures, representing all three release groups, were estimated as weighted averages of the release-specific estimates, using weights proportional to release size.

The significance of the radial gates status on arrival at the outside receiver (RGU, site D1) was assessed for the each release group separately, using a difference in Akaike Information Criterion (AIC) ≥ = 2 to indicate a significant difference in model fit (Burnham and Anderson 2002). If the effect of the gates was found to be insignificant using this criterion, then a simplified model was used for parameter estimation in which $\phi_{B2,D1O}=\phi_{B2,D1C}$, $\phi_{C1,D1O}=\phi_{C1,D1C}$, and $\phi_{D1O,D2}=\phi_{D1C,D2}$. For each release group, common transition probabilities at the Central Valley Project and the radial gates at the Clifton Court Forebay to Chipps Island (i.e., $\phi_{D1O,D2}$, $\phi_{D1C,D2}$, $\phi_{D2,G2}$, $\phi_{E1,E2}$, and $\phi_{E2,G2}$) were used regardless of the primary route used at the head of Old River (route A or route B) to reach the water export facilities. For each model, goodness-of-fit was assessed visually using Anscombe residuals (McCullagh and Nelder 1989). The sensitivity of parameter and performance metric estimates to inclusion of detection histories with large absolute values of Anscombe residuals was examined for each release group individually.

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

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

where

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

The parameter V was estimated using Program USER. Estimates of survival to Jersey Point and False River (i.e., $S_{A(MD)}$ and $S_{B(MD)}$) were also compared in this way. Also tested was whether tagged steelhead showed a preference for the San Joaquin River route using a one-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 (α = 0.05).

Analysis of Tag Failure

Five tags used in the March tag-life study were originally activated for implantation into steelhead to be released to the river, but were later extracted and temporarily deactivated because the fish either died, was culled, or was rejected for another reason. Three tags in the March study required several activation attempts. Total activation time was used to model tag survival for all tags, including the preliminary activation period preceding deactivation and eventual reactivation for tags moved from the fish-survival study to the tag-life study. The period of deactivation during study transfer was not included in total activation time for such tags. Activating a tag multiple times was not expected to have a measurable effect on total tag life (Dale Webber, VEMCO, personal communication).

Observed tag survival was modeled using the 4-parameter vitality curve (Li and Anderson, 2009). In both tag-life studies, tag failure times were right-censored at day 80 to improve model fit, as in analysis of the 2012 tag survival data (USBR 2018b). Stratifying by tag-life study (March or May) versus pooling across studies was assessed using the Akaike Information Criterion (AIC; Burnham and Anderson 2002).

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

Analysis of Surgeon Effects

Surgeon effects (i.e., “tagger effects”) were analyzed in several ways. The simplest method used contingency tests of independence on the number of tag detections at key detection sites throughout the study area. Specifically, a lack of independence (i.e., heterogeneity) between the detections distribution and surgeon was tested using a chi-squared test ($\alpha = 0.05$; Sokal and Rohlf, 1995). Detections from those downstream sites with sparse data were omitted for this test in order to achieve adequate cell counts.

Lack of independence may be caused by differences in survival, route entrainment, or detection probabilities. A second method visually compared estimates of cumulative survival throughout the study area among surgeons. A third method used Analysis of Variance to test for a surgeon effect on individual reach survival estimates, and an F-test to test for a surgeon effect on cumulative survival throughout each major route (routes A and B). Finally, the nonparametric Kruskal-Wallis rank sum test (Sokal and Rohlf 1995, ch. 13) was used to test for whether one or more surgeons performed consistently poorer than others, based on individual reach survival or transition probabilities through key reaches. In the event that survival was different for a particular surgeon, the model was refit to the pooled release groups without tags from the surgeon in question, and the difference in survival estimates due to the surgeon was tested using a two-sided Z-test on the lognormal scale. The reduced data set (without predator detections), pooled over release groups, was used for these analyses.

Analysis of Travel Time

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

Route Entrainment Analysis

There was no barrier at the head of Old River in 2013, so analysis of the factors affecting route selection (entrainment) at the head of Old River was performed. There were too few detections at the Turner Cut junction to perform a full route entrainment analysis there; instead, simple data descriptions are provided for Turner Cut. Acoustic tag detections used in these analyses were restricted to those detected at the acoustic receiver arrays located just downstream of the junction in question: SJL (model code A5) or ORE (B1) for the head of Old River junction, and MAC (A9) or TCE/TCW (F1) for the Turner Cut junction. Tags were further restricted to those whose final pass of the junction came from either upstream sites or from the opposite leg of the junction; tags whose final pass of the junction came either from downstream sites or from a previous visit to the same receivers (e.g., repeated visits to the SJL receivers for the head of Old River junction) were excluded from this analysis. Tags were restricted in this way to limit the delay between initial arrival at the junction, when hydrologic covariates were measured, and the tagged fish's final route selection at the junction. Predator-type detections were also excluded.

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

Route Entrainment at the Head of Old River

Tags that were estimated to have arrived at the junction more than 2 hours before final route selection, indicated by detection on either SJL or ORE receivers, were excluded from the analysis, to limit the time delay between arrival at the junction and final route selection. This restriction omitted 51 of the 866 (6%) tags observed at the head of Old River junction coming from either upstream or the opposite leg of the junction, leaving 815 tags for the route entrainment analysis. Of these 815 tags, 88 took the San Joaquin River route at the head of Old River, giving a total of 88 degrees of freedom available for the analysis.

Hydrologic conditions were represented in several ways, primarily total river flow (discharge), water velocity, and river stage. These measures were available at 15-minute intervals from the Lathrop (SJL) and Old River (OH1) gaging stations maintained by the California Department of Water Resources (Table 5). Most hydrologic data were downloaded from the California Water Data Library (www.water.ca.gov/waterdatalibrary); river stage data from OH1 were downloaded from CDEC (cdec.water.ca.gov). 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 head of Old River junction. Time of arrival was estimated because no receivers were located at the junction itself. 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 to either SJL or OH1. The gaging stations were located 0.52 km (SJL) and 0.14 km (OH1) downstream of the junction. No effort was made to model hydrologic conditions at the junction itself at the estimated time of fish arrival.

The gaging stations typically recorded flow, velocity, and river stage measurements every 15 minutes. Some observations were missing during the time period when tagged steelhead were passing the junction. Linear interpolation was used to estimate the flow, velocity, and river stage conditions at the time of tag arrival at the gaging station:

$$x_i = w_i x_{t_{1(i)}} \quad (1 + w_i) x_{t_{2(i)}}$$

where $x_{t_{1(i)}}$ and $x_{t_{2(i)}}$ are the two observations of metric x (x = Q [flow], V [velocity], or C [stage]) 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 x_i toward the closest flow, velocity, or stage observation.

In cases with a short time delay between consecutive flow and velocity observations (i.e., $t_{2(i)} - t_{1(i)} \le 60$ minutes), the change in conditions between the two time points was used to represent the tidal stage (Perry 2010):

$$\Delta x_i = x_{t_{2(i)}} \quad x_{t_{1(i)}}$$

for $x = Q, V, \text{ or } C$, and tag i.

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

$$pQ_{iA} = \begin{cases} \dfrac{Q_{iA}}{Q_{iA} + Q_{iB}}, & \text{for } Q_{iA} \geq 0 \\ 0, & \text{for } Q_{iA} < 0 \\ 1, & \text{for } Q_{iB} < 0 \end{cases}$$

into the San Joaquin River, and

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

Flow proportion values of 0 into the San Joaquin River indicated negative flow into the San Joaquin River and positive flow into Old River, while proportion values of 1 into the San Joaquin River indicated positive flow into the San Joaquin River and negative 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 $\Delta pQ_{iA} = pQ_{t_2(i)A} \quad pQ_{t_1(i)A}$.

Flow reversal in either river was represented by the indicator variable U_Q (Perry 2010):

$$U_{iQh} = \begin{cases} 1, & \text{for } Q_{ih} < 0 \\ 0, & \text{for } Q_{ih} \geq 0 \end{cases}.$$

Similar measures for defined for negative velocity (U_V).

Daily export rate for day of arrival of tag i at the head of Old River junction was measured at the Central Valley Project $\left(E_{iCVP}\right)$ and State Water Project $\left(E_{iSWP}\right)$ (data downloaded from DayFlow on June 16, 2014).

All continuous covariates were standardized, i.e.,

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

for the observation x of covariate j from tag i. The indicator variables U, RG, $time$, and $twilight$ were not standardized.

The form of the generalized linear model was

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

where $\tilde{x}_{i1}, \tilde{x}_{i2}, \ldots, \tilde{x}_{ip}$ are the observed values of standardized covariates for tag i (covariates 1, 2, …, p, see below), and ψ_{iA} is the predicted probability that the fish with tag i selected route A (San Joaquin River route), and $\psi_{iB} = 1 - \psi_{iA}$ (B = Old River route). Route choice for tag i was determined based on detection of tag i at either site A5 (route A) or site B1 (route B). Estimated detection probabilities for the three release groups were 1.00 for both sites (Appendix G, Table G2).

Single-variate regression was performed first, and covariates were ranked by P-values from the appropriate F-test (if the model was overdispersed) or χ-square test otherwise (McCullagh and Nelder 1989). Covariates that were significant alone were then analyzed together in a series of multivariate regression models. Because of high correlation between flow and velocity measured from the same site, the covariates flow and velocity were analyzed in separate models. River stage was analyzed both separately from flow, velocity, and flow proportion, and together with flow.

Flow proportion into the San Joaquin River varied only when there was positive flow directed into the San Joaquin River. When flow was directed out of the San Joaquin River, flow proportion was zero. Because there were many instances with negative flow measured at the SJL gage in 2013, the flow proportion model used the flow proportion metric when flow was positive, and the SJL flow measure when flow was negative. This model allowed for a higher probability of selecting the San Joaquin River route when more of the flow entered the San Joaquin River, and lower probability of entering the San Joaquin River when flow was more negative at SJL. All flow proportion models considered included the proportion flow (pQ_A), the indicator of reverse flow (U_{QA}), and the product of the reverse flow indicator and the measure of flow at SJL ($U_{QA} \cdot Q_A$). Thus, four multiple regression models were compared: flow, flow proportion, velocity, and river stage. In each of these models, fork length and release group were included, as well as one measure of exports (CVP, SWP, or total; generally E) and one measure of arrival timing ($time$ or $twilight$, generally $arrival$). Which export and arrival timing measure was included depended on which accounted for the most variability in the route selection in that model. The general forms of the four multivariate models were:

Flow model: $Q_A + Q_B + \Delta Q_A + \Delta Q_B + U_{QA} + U_{QB} + arrival + E \ + L + RG$

Flow proportion model: $pQ_A + U_{QA} + U_{QA} \cdot Q_A + \Delta pQ_A + U_{QB} + E + arrival + L + RG$

Velocity model: $V_A + V_B + \Delta V_A + \Delta V_B + U_{VA} + U_{VB} + E + arrival + L + RG$

Stage model: $C_A + C_B + \Delta C_A + \Delta C_B + U_{QA} + U_{QB} + E + arrival + L + RG.$

Flow + Stage model:

$$Q_A + Q_B + \Delta Q_A + \Delta Q_B + C_A + C_B + \Delta C_A + \Delta C_B + U_{QA} + U_{QB} + E + arrival + L + RG.$$

Backwards selection with F-tests was used to find the most parsimonious model in each category (flow, velocity, and stage) that explained the most variation in the data (McCullagh and Nelder 1989). Main effects were considered using the full model; two-way interaction effects were considered using the reduced model found from backwards selection on the main effects model. The model that resulted from the selection process in each category (flow, flow proportion, velocity, stage, or flow + stage) was compared using an F-test to the full model (or a χ^2-test if the data were not overdispersed from the model) from that category to ensure that all significant main effects were included. AIC was used to select among the flow, flow proportion, velocity, stage, and flow + stage 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).

Route Entrainment at Turner Cut

There were too few tags detected at the Turner Cut junction in 2013 to perform a route entrainment analysis at this junction: 27 tags were detected at the Turner Cut junction, 10 entered Turner Cut, and 17 remained in the San Joaquin River past Turner Cut. Although there were too few tags to perform the full route entrainment analysis, the data were nevertheless formatted using methods adapted from the route entrainment analysis developed for the head of Old River junction, and the data are briefly described in the Results section. As described in the 2012 report, there is no gaging station near the MacDonald Island receivers (model code A9), and so no measures of flow proportion or of conditions in the San Joaquin River near MacDonald Island are available. River flow and water velocity data from the SJG gaging station (18 km upstream of the junction) were used to provide an index of average conditions during the time when the fish was moving from SJG to the Turner Cut junction. In particular, prevailing flow and velocity conditions in the reach from the SJG acoustic receiver to arrival at the Turner Cut junction (indicated by arrival at the SJS receiver, model code A8) were represented by the root mean square (RMS) of the time series of observed conditions measured at the SJG gaging station during the estimated duration of the transition:

$$x_{RMS(i)} = \sqrt{\frac{1}{n_i} \sum_{j=T_{1(i)}}^{T_{2(i)}} x_j^2}$$

where x_j = observed covariate x at time j at the SJG gaging station $(x = Q \text{ or } V)$, $T_{1(i)}$ = closest observation time of covariate x to the final detection of tag i on the SJG acoustic receivers, and $T_{2(i)}$ = closest observation time of covariate x to the time of arrival of tag i at SJS. If the time delay between either $T_{1(i)}$ and final detection of tag i on the SJG acoustic receivers, or $T_{2(i)}$ and arrival time at SJS, was greater than 1 hour, then no measure of covariate x from the SJG gaging station was used for tag i.

Conditions at the TRN gaging station in Turner Cut (flow, velocity, and river stage) were measured at time of departure from the SJS receiver. The TRN gaging station typically recoded flow, velocity, and river stage measurements every 15 minutes; in the case that observations were missing when tagged steelhead were passing the junction, linear interpolation was used to estimate the flow, velocity, and river stage conditions at time of departure from SJS using the same methods as used for the head of Old River junction. Similarly, in cases where the delay between consecutive flow and velocity observations was < 1 hour, the change in conditions between the two time points was used to represent the tidal stage (Perry 2010), as described for the head of Old River analysis. Negative flow at the TRN station was identified, and was interpreted as river flow being directed into the interior Delta, away from the San Joaquin River (Cavallo et al. 2013).

Daily export rates at CVP, SWP, and total throughout the Delta were measured for the day of tag arrival at SJS. Fork length, release group, and time of day of arrival (as described for the head of Old River analysis) were also compiled.

Tags used in this descriptive analysis were restricted to those arriving from upstream sites or the alternate leg of the junction, and to those that did not delay more than 4 hours between departure from SJS and arrival at either MAC or TCE/TCW. This restriction was to reduce the time delay between measures of hydrological covariates and actual route selection. This restriction removed 10 of the 27 tags, leaving 17 tags in the analysis: 6 selected the Turner Cut route, and 11 selected the San Joaquin River route at this junction. This means that were only 6 degrees of freedom available for statistical tests. This was insufficient for even single-variable analyses. Thus, simple graphical comparisons of conditions for the two routes selected were constructed.

Survival through Facilities

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

$$S_{k2(salvage)} = \phi_{k2,GH} \quad \phi_{k2,G2},$$

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 subset of detection histories that included detection at site $k2$ $(k = D, E)$ were used for this analysis; predator-type detections were excluded. Detections from the full data set were used to estimate the detection probability at sites G1, G2, and H1, although only data from tags detected at either D2 or E2 were used to estimate salvage survival. Because there were many tags detected at H1 that were later detected elsewhere and thus were not used in the survival model, all tags ever detected at H1 were used to estimate the detection probability at H1; only detections from the final visit to H1 were used for detection probability estimation. Profile likelihood was used to estimate the 95% confidence intervals for both $S_{D2(salvage)}$ and $S_{E2(salvage)}$.

Results

Transport to release sites

Oxygen flow rates in the transport tanks varied over the course of the study. During transport, an increase in the amount of dissolved oxygen (DO) in each tank was observed; the rate of oxygen pumped into the tank was decreased by 0.5 mg/L for each transport to counteract the increase in DO. Upon arrival at the release location, DO levels varied from a low of 9.02 mg/L to a high of 16.38 mg/L. The DO levels varied among transports. Higher average DO levels occurred during the first transport period (mean = 13.4 mg/L, n=9) than either the second transport (mean = 12.3 mg/L, n=9) or third transport (mean = 11.2 mg/L, n=9). This may be due to both higher air and water temperatures observed during those transports.

Temperature loggers experienced some problems during the study (as noted in Appendix E). During the first set of transports in March, the first transport truck had mechanical difficulties. Because the tank was already full of fish, the fish were removed from the tank and moved to another transport truck. The water temperature of the first transport tank was recorded; however, the temperature logger in the tank that was used had a full memory and did not record any water temperatures (Appendix E). This problem was not identified until after the first transport and release period had been completed.

Of the transport incidents with properly recorded temperature data, water temperatures did not vary more than 3.5°C during any transport period (Appendix E). The difference between the water temperature after loading and the water temperature prior to unloading (i.e. increase during transport) was at most 3.9°C. This occurred on 4/4/13 for the second transport. The difference in water temperature between the transport tank and that in the river was as great as 5.3°C on the same day (4/4/13), where tempering was needed. The second week of releases had higher water temperatures in the river than either the first or the third week of releases (Table 7).

Fish Releases

One impaired steelhead was culled on March 7, 2013, transport 2, prior to transferring fish into the holding containers (Table 1). A replacement fish was tagged and sent to the holding location the same day in transport truck 3. One fish was found dead after transport from the same transport and day (Table 7). In addition, there were a total of ten steelhead mortalities observed prior to release. These fish were collected and processed (Table 7). The majority (70%, n=7) of the mortalities occurred during the May release period. River temperatures during this period were at their highest, possibly contributing to higher mortality numbers. It was noted during tagging that a higher percentage of steelhead appeared to have more scale loss during the May release than at other tagging times during the study. Tagging protocol states that if a fish has a higher than 20% scale loss on one side of the body, that it be rejected for tagging by the surgeon. While these fish did appear to have an acceptable scale loss, it appeared that the percentage of scale loss overall was higher for fish tagged during this tagging period. Observations by field technicians transferring these fish from the transport to holding containers also commented on the appearance of higher than normal scale loss; while performing assessments on the dummy-tagged fish, it was noted that the May groups had relatively high scale loss (Table 8).

Dummy Tag Fish

One dummy tagged fish was observed dead on 5/10/13 after the 48 holding period. Scale loss was high and ranged from an average of 5% to 27% for each of the held groups (Table 8). All remaining fish had normal body and gill color, normal eyes, and no fin hemorrhaging.

Fish Health

For steelhead release groups, survival over the 24 holding period was high. No significant pathogen infections were detected in steelhead used for the 2013 Steelhead study. Gill ATPase activity levels were lower in later release groups of steelhead, suggesting these later groups were beyond the peak of smoltification (See Appendix F for further details on results).

Tag Retention

Seventeen of the 30 fish (57%) evaluated still had at least one suture present at day 70 (Table 9). This was as expected. What we have seen in the past is that the sutures loosen as the fish starts to expel them. The sutures then move around and can irritate the point where the sutures enter the fish as well as the skin surface where the sutures can rub (see the photographs of Fish # 2, 7, 8, 9, 10 and 11; Appendix H). Occasionally the sutures get caught and can rip out of the fish. We saw evidence of this in several fish including #4, 6 and 8 (Appendix H). While this leaves a scar behind, the wound heals without any noticeable negative effects on the fish.

Pattern Intactness refers to whether the pattern of the sutures with relation to the incision and ventral midline of the fish was intact as per the tagging protocols (Appendix B). Eight of the 30 fish (27%) were observed to not have the aforementioned suture pattern (Table 9). The deviations from the pattern that were observed included sutures not bridging the incision (6 fish), sutures extending across the ventral midline (9 fish), and suture/incision located too far dorsally on the fish (1 fish). In the fish where the sutures were observed not to bridge the incision, it appeared that the sutures started or ended inside the incision itself.

We observed that all 30 fish had complete healing of the incision and there was complete closure of the incision (incision apposition) (Table 9). Fungus was present on the sutures of only 2 fish (Table 9). In both cases this occurred when the sutures were still present and irritation was observed around the incision site. Tags were generally located directly over the incision with some tags straying anterior to and posterior to the incision. One fish appeared to be showing signs of tag expulsion (Table 9). No obvious signs of disease were observed on any of the fish.

Organ inclusion (where organs had been caught by the suture and attached to the body wall at the incision) was observed. Ten of the 30 fish (33%) had organ inclusion (Table 9). The organ involved was observed to be the pyloric caeca and the surrounding fatty tissue.

Detections of Acoustic-Tagged Fish

A total of 1,430 tagged juvenile steelhead were released at Durham Ferry in 2013 (Table 1), and 1,425 were used in the survival study (Table 10). Five fish were released early (Table 1) and were not used in the survival analyses. Of the 1,425 released and used in the survival analysis, 1,285 (90%) were detected on one or more receivers either upstream or downstream of the release site (Table 10), including any predator-type detections. A total of 1,239 (87%) were detected at least once downstream of the release site, and 935 (66%) were detected in the study area from Mossdale to Chipps Island (Table 10). One hundred forty-six (146) tags were detected upstream of the release site; 100 of these were also detected downstream of the release site.

Overall, there were 285 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 285 tags, 280 were detected on the receivers near Lathrop, CA; 50 were detected on one or more receivers near Stockton, CA (SJG, SJNB, or RRI); 36 were detected on the receivers near the Turner Cut (SJS, MAC, or TCE/TCW), and 22 were detected at Medford Island (Table 11). A majority of the tags detected in the San Joaquin River downstream of the head of Old River were not assigned to that route for the survival model, because they were subsequently detected in the Old River route or upstream of Old River. Overall, 87 tags were assigned to the San Joaquin River route for the survival model, mostly from the April and May release groups (Table 10). Of these, 12 were observed exiting the San Joaquin River at Turner Cut, 5 were observed at the Middle River receivers near Empire Cut, 4 were observed at the Old or Middle River receivers near Highway 4, and 3 were observed at the water export facilities (including the radial gates at the entrance to the Clifton Court Forebay) (Table 11, Table 12). A total of 16 San Joaquin River route tags were detected at the Jersey Point/False River receivers, including 5 on the False River receivers (Table 11). However, all of the tags detected at False River were later detected either at Jersey Point or Chipps Island, and so none of the San Joaquin River tags were used in the survival model at False River (Table 12). A total of 16 San Joaquin River route tags were eventually detected at Chipps Island, including predator-type detections, all from the April and May release groups (Table 11).

The majority (839) of the tags detected downstream of the head of Old River were detected in the Old River route (Table 10). All 839 tags were detected at the Old River East receivers near the head of Old River; 792 were detected near the head of Middle River, 490 at the receivers at the water export facilities, and 184 at the Old or Middle River receivers near Highway 4 in the interior Delta (Table 11). A total of 37 tags were detected at the Middle River receiver near Empire Cut: 32 tags reached these receivers through the Old River route, and 5 came from the San Joaquin River route (Table 11). One tag was observed at the Empire Cut receivers twice, once after entering Old River at its head, and once after returning to the head of Old River and then moving down the San Joaquin River. The majority of the tags detected at the Old or Middle River receivers in the interior Delta (OR4, MR4, MRE) entered Old River at its head (Table 11).

Some of the 839 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 detections. In all, 822 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 822 tags, 376 were detected at the CVP trash racks, although only 230 of these detections were used in the survival model because some tags were subsequently detected either at the radial gates or farther north in Old or Middle rivers (Table 11, Table 12). Likewise, 240 of the tags assigned to the Old River route were detected at the radial gates, and 172 of those detections were used in the survival model (Table 11, Table 12). A total of 45 of the Old River route tags were detected at either Jersey Point or False River (Table 11); 24 of those tags were detected at the Old River receiver north of the export facilities (OR4) in route to Jersey Point or False River, whereas 21 were presumed to have been salvaged at either the CVP or SWP before detection at Jersey Point or False River. All but 2 of the 27 tags detected at False River from the Old River route were also detected at Jersey Point. Of the 822 tags assigned to the Old River route at the head of Old River, 126 were detected at Chipps Island, including predator-type detections (Table 11, Table 12).

In addition to the Middle River receivers located near Empire Cut, tag detections were recorded at the Threemile Slough receivers but were purposely omitted from the survival model. Twenty-one (21) tags were detected on the Threemile Slough receivers (Table 11): 5 tags came directly from the San Joaquin River receivers (MacDonald and Medford Islands), 19 from the export facilities, Jersey Point, or False River, and 2 from the Middle River receiver near Empire Cut.

The predator filter used to distinguish between detections of juvenile steelhead and detections of predatory fish that had eaten the tagged steelhead classified 206 of the 1,425 tags (14%) released as being detected in a predator at some point during the study (Table 13). Of the 935 tags detected in the study area (i.e., at Mossdale or points downstream), 190 tags (20%) were classified as being in a predator, although some had also been identified as a predator before entering the study area. A total of 185 tags (20%) were first classified as a predator within the study area. Relatively few (27, 2%) of the 1,228 tags detected upstream of Mossdale were classified as in a predator in that region; 6 of those 27 tags were first classified as a predator downstream of Mossdale, and then returned to the upstream region (Table 13).

Within the study area, the detection sites with the largest number of first-time predator-type detections were the head of Old River receivers (B0; 23 of 922, 2%), San Joaquin River at Lathrop (A5, 23 of 280, 8%), Old River East (B1, 18 of 839, 2%), Old River South (B2, 15 of 778, 2%), the Clifton Court Forebay radial gates (D1, 34 of 241, 14%), and the CVP trash racks (E1, 42 of 380, 11%) (Table 13). An equal number (103) of predator classifications were assigned to tags on arrival as on departure at the study area sites, collectively. Predator classifications on arrival were typically due to unexpected travel time or unexpected transitions between detection sites, and were most common around the head of Old River (sites B0 and A5) and at the CVP trash racks (Table 13). Predator classifications on departure were typically due to long residence times, and were most prevalent at the radial gates and the CVP trashracks (Table 13). Only detections classified as from predators on arrival were removed from the survival model, along with any detections subsequent to the first predator-type detection for a given tag.

When the detections classified as coming from predators were removed from the detection data, slightly fewer detections were available for survival analysis (Table 14, Table 15,Table 16). With the predator-type detections removed, 1,236 of the 1,425 (87%) tags released were detected downstream of the release site, and 926 (65% of those released) were detected in the study area from Mossdale to Chipps Island (Table 14). A total of 140 tags were detected upstream of the release site with steelhead-type detections; 92 of these were also detected downstream of the release site.

Many more steelhead were observed using the Old River route at the head of Old River (791) than the San Joaquin River route (110) (Table 14). As observed from the full data set including the predator-type detections, the reduced data set with only steelhead-type detections showed that the majority of the tags detected at the receivers in the western and northern portions of the study area, including the water export facilities, Jersey Point, and Chipps Island, used the Old River route at the head of Old River rather than the San Joaquin River route (Table 15). No tagged steelhead from the San Joaquin River route were detected at the Old River receivers near Highway 4 or the radial gates receivers at the entrance to Clifton Court Forebay (OR4 and RGU/RGD, respectively), although 154 tagged steelhead from the Old River route were detected at OR4 and 220 were detected at RGU/RGD (Table 15). Of the 110 tags that took the San Joaquin River route at the head of Old River, 4 were subsequently detected in the interior Delta, compared to 34 tags that were detected only in the main stem San Joaquin River downstream of the head of Old River; 15 (14%) were subsequently detected at Jersey Point, and an equal number at Chipps Island (Table 15). More tags were detected taking the San Joaquin River route as the season progressed (Table 14). Of the 791 tags assigned to the Old River route at the head of Old River, 351 were detected at the CVP trash racks, 39 at Jersey Point, and 118 (15%) at Chipps Island. Detection counts used in the survival model follow a similar pattern (Table 16).

Tag-Survival Model and Tag-Life Adjustments

In all tanks used in the March tag-life study, a gap in the observed times of final detections was observed around day 70 (May 23, 2013). This gap was not accounted for by hydrophone or receiver performance, or by the tags that had been activated multiple times in the March study. No such gap was observed for the May study.

The Akaike Information Criterion (AIC) indicated that pooling data from both tag-life studies (AIC = 18.2) was preferable to stratifying by study month (AIC = 33.7). Thus, a single tag survival model was fitted and used to adjust fish survival estimates for premature tag failure. The estimated mean time to failure from the pooled data was 69.0 days ($\widehat{SE} = 10.7$ days) (Figure 14).

The complete set of detection data, including any detections that may have come from predators, contained some detections that occurred after the tags began dying (Figure 15, Figure 16). The sites with the latest detections were the Durham Ferry site located just downstream of the release site, Banta Carbona, Mossdale, the San Joaquin River receiver near Lathrop, Old River East (near the head of Old River), Old River South (near the head of Middle River), the CVP trash racks, and the radial gates at Clifton Court Forebay (Figure 15, Figure 16). Some of these late-arriving detections may have come from predators, or from residualizing steelhead. Tag-life corrections were made to survival estimates to account for the premature tag failure observed in the tag-life studies. All estimates of reach survival for the acoustic tags were greater than 0.98 (out of a possible range of 0–1), and cumulative tag survival to Chipps Island was estimated at 0.99 or above with or without predator-type detections. Thus, there was very little effect of either premature tag failure or corrections for tag failure on the estimates of steelhead reach survival.

Surgeon Effects

Fish in the release groups were evenly distributed across surgeons (Table 17). Additionally, for each surgeon, the number tagged was well-distributed across release group. A chi-squared test found no evidence of lack of independence of surgeon across release group (χ^2 = 0.1560, df = 4, P = 0.9971). The distribution of tags detected at various key detection sites was also well-distributed across surgeons and showed no evidence of a surgeon effect on survival, route selection, or detection probabilities at these sites (χ^2 = 12.9689, df = 24, P = 0.9666; Table 18).

Estimates of cumulative survival throughout the San Joaquin River route to Chipps Island showed similar patterns of survival across all surgeons. Although surgeon A had consistently lower point estimates of cumulative survival through the entire San Joaquin River route, there was no significant difference in cumulative survival to any site in the San Joaquin River route (P≥0.1015), and in particular to Chipps Island (P=0.4155; Figure 17). Analysis of variance found no effect of surgeon on reach survival (P=0.1919). There were smaller differences in cumulative survival by surgeon in the Old River route, where most tags were detected; surgeon A had lower point estimates of cumulative survival to the first Old River site (ORE), but there was no difference in cumulative survival to the water export facilities or Highway 4 sites (OR4, MR4; P=0.8851) or to Chipps Island (MAE/MAW; P=0.7292) (Figure 18). Rank tests found no evidence of consistent differences in reach survival for fish from different surgeons either upstream of the Head of Old River (P=1.0000), in the San Joaquin River route (P=0.2189), or in the Old River route (P=0.9439).

Survival and Route Entrainment Probabilities

For the March and April release groups, likelihood ratio tests found that transitions to exterior receivers at Clifton Court Forebay, and into the interior of the Forebay, depended on whether the radial gates were open or closed upon arrival at the exterior receivers (P≤0.0023). Transitions to and into the Clifton Court Forebay did not depend on gate status for the May release group (P≥0.2712, depending on whether predator-type detections were included). Thus, the final models used unique transition probabilities based on gate status for the March and April release groups, but not for the May release groups. Only the May release group had observations of fish at the radial gates or CVP that had come from the San Joaquin River route (i.e., had remained in the San Joaquin River at the head of Old River) (Table 11, Table 16). For this release group, there was no difference in model fit between parameterizing unique transition probabilities through the facilities to Chipps Island based on route taken to the facilities (i.e., route A or route B), and parameterizing common transition probabilities for both routes (P≥0.4029). Thus, the final model for the May release group used common transition probabilities from the entrances of the Clifton Court Forebay or CVP to Chipps Island, regardless of route taken at the head of Old River.

Some parameters were unable to be estimated because of sparse data. In particular, although 32 tags were detected at False River, all of them were either subsequently detected upriver or at Jersey Point or Chipps Island, or had gone through the holding tank at the CVP, and thus no detections at False River were used in the survival model. Parameters $\phi_{x,GH}$ (for transitions from site x), ψ_{G1}, and ψ_{H1} were unable to be estimated; instead, the joint probability of arriving at the junction between the San Joaquin River and False River and the probability of moving downriver toward Jersey Point (i.e., $\phi_{x,G1} = \phi_{x,GH}\psi_{G1}$) was estimated and reported for transitions from sites x = A9, A10, B3, C2, and F1.

As described previously, sparse data in the San Joaquin River route from the March release group prevented fitting the full model for that release group. Rather than estimate survival or transition probabilities in the San Joaquin River from Garwood Bridge (model code A6) to the Navy Drive Bridge, MacDonald Island, and Medford Island, only the overall probability of surviving from Garwood Bridge to Chipps Island was estimated ($S_{A6,G2}$). For this release group, it was also not possible to estimate transition probabilities from Turner Cut, MacDonald Island, or Medford Island to either the water export facilities or Chipps Island. Instead, transition probabilities from Garwood Bridge to these sites were estimated.

There were several fish that apparently passed Jersey Point without detection, although all fish that were detected at Jersey Point were detected on both acoustic receiver lines at that site. For this reason, detections at the dual array at Jersey Point were pooled together from both receiver lines, and a single detection probability for Jersey Point (P_{G1}) was estimated for each release group. Likewise, detections from the lines comprising the dual array at Old River South (model code B2) were pooled for the April release group, as were the detections at the dual array just downstream of the release site at Durham Ferry (model code A2) for the March release group. Because one of the receivers comprising the dual array at the upstream Durham Ferry site (model code A0) was stolen between the second and third release groups, no transition probability or detection probability at this site was estimable for the May release group.

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 0.09 ($\widehat{SE} =$ 0.02) for the April release group to 0.20 ($\widehat{SE} =$ 0.02) for the May release group; the overall population estimate for all fish in the tagging study was 0.15 ($\widehat{SE} =$ 0.01) (Table 19). Estimates of the probability of entering Old River at its head were high, ranging from 0.84 ($\widehat{SE} =$ 0.02) for the May release group to 0.92 ($\widehat{SE} =$ 0.02) for the March release group, and averaging 0.88 ($\widehat{SE} =$ 0.01) overall (Table 19). For each release group, there was a significant preference for the Old River route (route B) (P<0.0001 for each release group). Estimates of survival from Mossdale to Chipps Island via the San Joaquin River route (S_A) ranged from 0 for the March release group to 0.20 ($\widehat{SE} =$ 0.06) for the May release group, and averaged 0.11 ($\widehat{SE} =$ 0.03) overall (Table 19). In the Old River route, estimates of survival from Mossdale to Chipps Island (S_B) ranged from 0.08 ($\widehat{SE} =$ 0.02) for the April release group to 0.20 ($\widehat{SE} =$ 0.20) for the May release group (population average = 0.15, $\widehat{SE} =$ 0.01) (Table 19). The route-specific survival to Chipps Island was significantly higher in the Old River route for the March release group, when none of the 23 fish observed taking the San Joaquin River route were detected at Chipps Island (P<0.0001) (Table 19). There was no significance difference in survival to

Chipps Island between routes for the other two release groups, or for the tagged population overall (P≥0.3008) (Table 19).

Survival was estimated to the Jersey Point/False River junction for routes that did not pass through the holding tanks at the CVP or the SWP. This survival measure ($S_{total(MD)}$) had estimates ranging from 0.01 ($\widehat{SE} = 0.01$) for the March release group to 0.09 ($\widehat{SE} = 0.02$) for the May release group; the population average was 0.04 ($\widehat{SE} = 0.01$) (Table 19). All detections at the Jersey Point/False River junction were at Jersey Point, and the majority of the detections came from the May release group; only 3 tags from the March release group were detected at Jersey Point, and only 7 from the April release group (34 total) (Table 16). Survival to Jersey Point was higher for fish in the Old River route for the first release group, when no San Joaquin River route fish were detected at Jersey Point or False River (P=0.0408), and higher for the San Joaquin River route for the April and May release groups (P≤0.0004) (Table 19). However, many Old River route fish were detected at the radial gates at the entrance to the Clifton Court Forebay or at the CVP trash racks; the survivors of these fish would not have contributed to survival to Jersey Point or False River, because those sites were not on the migration route downstream from the CVP or SWP holding tanks. Because $S_{total(MD)}$ does not reflect survival to downstream regions via salvage, it is not necessarily indicative of overall survival to Chipps Island (S_{total}).

Survival was estimated through the South Delta ($S_{A(SD)}$, $S_{B(SD)}$, and $S_{total(SD)}$) for the April and May release groups; survival through the Old River portion of the South Delta ($S_{B(SD)}$) was estimated for the March release group, as well. 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 MacDonald Island (MAC) or Turner Cut (TCE/TCW) ($S_{A(SD)}$) were 0.23 ($\widehat{SE} = 0.07$) for the April release group, and 0.37 ($\widehat{SE} = 0.07$) for the May release group (Table 19). In the Old River route, estimated survival from Mossdale to the entrances of the water export facilities (CVP, RGU) or the Old River and Middle River receivers near Highway 4 (OR4, MR4) ($S_{B(SD)}$) ranged from 0.53 ($\widehat{SE} = 0.03$) for the March release group to 0.75 ($\widehat{SE} = 0.03$) for the May release group; the population-level estimate was 0.61 ($\widehat{SE} = 0.02$) (Table 19). Total estimated survival through the entire South Delta region ($S_{total(SD)}$) was 0.52 ($\widehat{SE}=$ 0.03) for the April release group, and 0.69 ($\widehat{SE}=$ 0.03) for the May release group (Table 19). No population-level estimate is available because no estimate was available for the San Joaquin River route for the March release group.

Including the predator-type detections in the analysis increased the estimated survival through the South Delta in both routes and for all release groups for which estimates were available (i.e., no estimate was available for the San Joaquin River route for the March release group, even using predator-type detections). Total estimated survival through the South Delta, using predator-type detections, was 0.59 ($\widehat{SE}=$ 0.03) for the March release group, and 0.73 ($\widehat{SE}=$ 0.03) for the May release group (Table 20). The population-level estimate for the Old River route was 0.65 ($\widehat{SE}=$ 0.02) when predator-type detections were used, compared to 0.61 ($\widehat{SE}=$ 0.02) when predator-type detections were omitted. However, there was no detectable difference in total Delta survival estimates whether predator-type detections were included or excluded; in both cases, the population-level estimate of S_{total} was 0.15 ($\widehat{SE}=$ 0.01), and the only release-specific difference was observed for the April release group, for which $\hat{S}_{total}$ was 0.09 without predator-type detections, and 0.10 with predator-type detections (Table 19, Table 20). A similar pattern was observed for survival to the Jersey Point/False River junction (without salvaged fish; $S_{total(MD)}$). The lack of difference in total survival estimates compared to South Delta survival estimates indicates that there was little movement of the successful predators (as identified by the predator filter) between the South Delta boundaries and Chipps Island. Alternatively, the spatial patterns in the survival differences with and without predator-type detections may reflect a reduced ability to distinguish between behavior of steelhead and predators from the available tagging data as fish approach Chipps Island.

Survival estimates in reaches varied throughout the study, depending on the reach. Survival from release to Mossdale, the upstream boundary of the actual study area, varied little: 0.63 ($\widehat{SE}=$ 0.02) for the March release group and 0.66 ($\widehat{SE}=$ 0.02) for both the April and May release groups (Table 19); estimates using the predator-type detections were similar (Table 20). Survival from Mossdale through the head of Old River to the SJL or ORE receivers was estimated to be high (≥ 0.96) for all release groups (Appendix G. Survival Model Parameters; Table G2). However, survival in the San Joaquin River from Lathrop (SJL, model code A5) to Garwood Bridge (A6) varied considerably across the release groups:

0.26 ($\widehat{SE} =$ 0.09) for the March release group to 0.57 ($\widehat{SE} =$0.07) for the May group (Appendix G; Table G2). Survival in Old River from the head (ORE) to the head of Middle River (S_{B1}) was estimated at 0.94–0.95 for all three release groups. The transition probability from Old River South (model code B2) to the Old River receivers near Highway 4 (OR4, code B3) ranged from 0.08 ($\widehat{SE} =$0.02) for the March group to 0.20 ($\widehat{SE} =$0.03) for the May group (Appendix G; Table G2). For fish at OR4, the estimated transition probability to Jersey Point was considerably higher for the May release group (0.31) than for the earlier groups (0.14 in March, and 0.08 in April; $\widehat{SE} \leq$0.08). Transition probabilities through the CVP to Chipps Island were highest for the March release group (0.37 from the CVP trash racks to Chipps Island), while transition probabilities through the exterior receivers at Clifton Court Forebay to Chipps Island were highest for the May release group (0.39) (Appendix G; Table G2). Very few fish from the San Joaquin River route arrived at Chipps Island via Turner Cut; the estimated transition probability to Chipps Island from Turner Cut was 0.25 ($\widehat{SE} =$0.22) for the April release group, 0 for the May release group, and not estimable but probably 0 (no tags were detected at Chipps Island) for the March release group (Appendix G; Table G2). Estimated detection probabilities were high (>0.85) from Mossdale to Chipps Island, when they could be estimated (Appendix G; Table G2). Detection probabilities at Banta Carbona (model code A3) decreased throughout the season (0.72 in March, to 0.30 in May).

Travel Time

For tags classified as being in steelhead, average travel time through the system from release at Durham Ferry to Chipps Island was 11.27 days ($\widehat{SE} =$0.60 days) (Table 21a). Travel time to Chipps Island tended to be shorter for later release groups: the first release group (March) took an average of 20.06 days ($\widehat{SE} =$0.99 days), while the final release group (May) took an average of only 8.22 days ($\widehat{SE} =$0.50 days) (Table 21a). The large majority of tags reaching Chipps Island came via the Old River route; the 15 tags that arrived at Chipps Island via the San Joaquin River route had a similar average travel time overall (11.02 days) as those that used the Old River route (11.30 days). Most tags that were observed at Chipps Island arrived there within 20 days of release at Durham Ferry. However, there were several tags that took longer, and 6 tags took 30–42 days to get to Chipps Island, all via the Old River route and all but one via the Clifton Court Forebay radial gates.

Travel time from release to the Mossdale receivers averaged approximately 5 days for the March release group, and 1–2 days for the April and May release groups (Table 21a). Travel time to the Turner Cut junction (i.e., either Turner Cut receivers or MacDonald Island receivers) averaged 12.8 days (9 tags) for the April release, and 5.6 days (18 tags) for the May release; no tags from the March release were observed at the Turner Cut junction. Travel time from release to the CVP trash racks via the Old River route averaged 7.75 days ($\widehat{SE} = 0.42$ days) over all release groups; average travel time decreased throughout the season (Table 21a). The single tag detected at CVP that remained in the San Joaquin River at the head of Old River took 5.67 days, which was comparable to the average travel time (5.97 days) to CVP for fish that used the Old River route from the same release group (May; Table 21a). Average travel time from release to the receivers just outside the radial gates at Clifton Court Forebay ranged from approximately 14 days for the March release group, to approximately 5 days for the April and May release groups; all were from the Old River route (Table 21a).

Average travel time to the Old River receivers near Highway 4 (OR4) ranged from approximately 21 days for the March release group to about 6–8 days for the April and May release groups; all came from the Old River route (Table 21a). There were fewer detections at the Middle River receivers near Highway 4 (MR4), and the average travel time (5.93 days via the Old River route) was less than to the OR4 site (Table 21a). One of the two tags observed at the MR4 receivers that came via the San Joaquin River route took approximately 5 days, and the other took approximately 44 days (Table 21a). Travel time to Jersey Point averaged 10–11 days regardless of the route; most tags detected at Jersey Point were released in May (Table 21a).

Including detections from tags classified as predators tended to lengthen average travel times slightly, but the general pattern across routes and release groups was the same as without predator-type detections (Table 21b). The average travel time from release to Chipps Island via all routes, including the predator-type detections, was 11.66 days ($\widehat{SE} = 0.62$) (Table 21b). Increases in travel time with the predator-type detections reflect the travel time criteria in the predator filter, which assumes that predatory fish may move more slowly through the study area than migrating steelhead. Travel time increases may also reflect multiple visits to a site by a predator, because the measured travel time reflects time from release to the start of the final visit to the site.

Average travel time through reaches for tags classified as being in steelhead ranged from 0.008–0.014 days (12–21 minutes) from the entrance channel receivers at the Clifton Court Forebay (RGU, gates open) to the interior forebay receivers (RGD), to 4.64 days from RGD to Chipps Island (Table 22a). The "reach" from the exterior to the interior radial gate receivers (RGU to RGD) was the shortest, so it is not surprising that it would have the shortest travel time, as well. Travel times from the San Joaquin River receiver near Lathrop (SJL) to Garwood Bridge (SJG) averaged 2–3 days (~18 rkm). Average travel time per release group from Old River South (ORS) to the Old River receivers near Highway 4 (OR4) (~27 rkm) was approximately 3 days for all release groups. The single tag observed moving from Turner Cut to Chipps Island took over 12 days, while the single tag observed moving from the head of Middle River (MRH) to the Clifton Court Forebay also took 12 days (Table 22a). Although travel time to sites from release tended to be longest for the first release group and shortest for the last release group, that pattern was not consistently observed on the reach scale. Including the predator-type detections had little effect on average travel time through reaches (Table 22b).

Route Entrainment Analysis

Head of Old River

River flow (discharge) at the San Joaquin River gaging station near Lathrop (station SJL) at the time of arrival of the tagged juvenile steelhead at the head of Old River ranged from -1,486 cfs to 1,726 cfs (average = 415 cfs) in 2013. The flow in the San Joaquin River at SJL was negative for 317 of 815 (39%) tags upon their arrival the head of Old River in 2013. River flow at the Old River gaging station near the head of Old River (station OH1) ranged from -49 cfs to 3,230 cfs (average = 1,497 cfs) during the same time; river flow at OH1 was negative for arrival of 4 tags (<1% of 815). There was low correlation between flow in the San Joaquin River and flow in Old River at the time of tag arrival at the river junction (r = -0.27). Flow proportion into the San Joaquin River ranged from 0 (for 317 tags) to 1 (for 4 tags) in 2013, and averaged 0.29; flow proportion was highly correlated with flow into the San Joaquin River (r = 0.91), but not with flow into Old River (r = -0.54). Water velocities ranged from -1.23 ft/s to 1.37 ft/s (average = 0.33 ft/s) at SJL, and from -0.03 ft/s to 2.07 ft/s (average = 1.07 ft/s) at OH1. Flow and velocity at the same gaging station were highly correlated in 2013: r = 0.99 at SJL, and r = 0.94 at OH1. Export rates were variable throughout the study, but were generally higher for the first release group (March). Export rates at CVP averaged 2,235 cfs for the first release group, and 481 cfs for the second and third release groups. Export rates at SWP averaged 2,263 cfs for the first release group, and 1,203 cfs for the second and third release groups. There was little correlation between total Delta exports and either flow into the San Joaquin River (r = -0.13), flow into Old River (r = -0.05), or flow proportion into the San Joaquin River (r = -0.08).

The majority of the fish that arrived at the head of Old River junction in 2013 selected the Old River route, regardless of release group (Table 19), flow (Figure 19), flow proportion (Figure 20), velocity (Figure 21), river stage (Figure 22), or exports (Figure 23). Of the 815 tags used in the head of Old River route entrainment analysis, 727 (89%) selected Old River. This left a maximum of 88 degrees of freedom for the regression models. Covariate data were unavailable for some tags, which further reduced the available degrees of freedom.

The single-variate analyses found significant associations (α = 0.05) between the probability of remaining in the San Joaquin River at the head of Old River and several covariates: flow and velocity at SJL, flow proportion into the San Joaquin River, negative flow and velocity at SJL, and both river stage and the 15-minute change in river stage at both SJL and OH1 (Table 23). Effects of flow and velocity at OH1, the 15-minute change in flow proportion and flow or velocity at both SJL and OH1, all measures of exports and time of day of arrival at the junction (including twilight), release group, and fork length were all non-significant ($P \geq 0.1420$); effects of negative flow and velocity at OH1 were also non-significant ($P=0.7077$), but there were only 4 observations with OH1 flow and velocity < 0.

Several covariates had strong effects based on the single-variate models (Table 23). However, while the single-variate models may suggest possible relationships, confounding among the independent covariates and the possibility of a causal relationship with an unobserved factor both make it impossible to conclude that changes in any of the significant single-variate measures directly produce changes in route selection at the head of Old River. Multiple regression may shed more light on which covariates are worthy of further study, but causal relationships will not be discernable.

Multiple regression found significant effects of flow, velocity, river stage, and 15-minute change in river stage at SJL, as well as negative flow at SJL and the interaction between negative flow and flow at SJL (Table 24). Once measures at SJL were in the model, measures at OH1 were not significant. All four models adequately fit the data ($P>0.28$). The stage model used more observations than the flow, flow proportion, and velocity models because of missing flow and velocity data for two records. Model comparisons using AIC used the same data set for all models. The combined flow and stage model (“flow + stage”) accounted for more variation in route entrainment at the head of Old River than any of the competing models (ΔAIC>17) (Table 24).

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

$$\widehat{\psi}_A = \frac{\exp\left(-6.76 + 0.0012Q_{SJL} + 0.80C_{SJL}\right)}{1 + \exp\left(-6.76 + 0.0012Q_{SJL} + 0.80C_{SJL}\right)},$$

where Q_{SJL} and C_{SJL} represent the river discharge (flow) and river stage at SJL upon tag arrival at the head of Old River junction. Equivalently, the probability of entering Old River was modeled as

$$\widehat{\psi}_B = \left[1 + \exp\left(6.76 - 0.0012Q_{SJL} - 0.80C_{SJL}\right)\right]^{-1}.$$

This model shows an effect of both river flow and river stage on the probability of entering Old River: fish that arrived at the junction with either higher flow or higher river stage were less likely to enter Old River than fish that arrived at lower flows or stages (Figure 24, Figure 25). There was more uncertainty in the effect of river stage at higher river stages than for flow at higher flow levels, because there were relatively few observations at high river stages. In all cases, the predicted probability of entering Old River was 0.5 or higher (Figure 24, Figure 25).

Turner Cut

There were only 17 tags available for analysis at the Turner Cut junction: 6 selected the Turner Cut route, and 11 selected the San Joaquin River route at this junction. Of these 17 tags, 1 arrived at the SJS receivers (used to indicate arrival at the Turner Cut junction) at dawn, 1 arrived at dusk, 13 arrived during the day, and 2 arrived at night. Five of the 6 tagged steelhead that selected the Turner Cut route arrived during the day, and the other arrived at dusk. Five of the 17 tags were from the April release group, and 12 were from the May release group.

Steelhead that entered Turner Cut tended to arrive at the junction (indicated by departure from the SJS receivers) when flow was negative or decreasing at the TRN gaging station (i.e., flow was directed into the Interior Delta) (Figure 26). Flow and velocity at the TRN gaging station in Turner Cut were highly correlated (r=0.999) at times when fish arrived at the junction; thus, no velocity plot is shown. River stage tended to be higher for fish that entered Turner Cut; the 15-minute change in river stage upon arrival at the junction was considerably higher for those few fish that entered Turner Cut than for those that remained in the San Joaquin River (Figure 26). Average magnitude river flow and water velocity between SJG and SJS when fish were transiting that reach tended to be higher for fish that later entered Turner Cut, but there was considerable overlap in the distributions (Figure 26). There was no apparent difference in measures of export rates at either the CVP or the SWP for fish that chose different routes at the Turner Cut junction, and there was considerable overlap in fork length distributions, as well (Figure 26).

The covariate with the largest difference for fish that used the Turner Cut route compared to those that remained in the San Joaquin River route was the 15-minute change in river stage at arrival at the junction (Figure 26). The pattern observed, although based on too few observations to adequately test its significance, is consistent with an incoming tide being associated with entry to Turner Cut. This is also consistent with the 2012 route selection analysis (USBR 2018b).

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 (site E2, for the federal facility) or the interior receivers at the radial gates at the entrance to Clifton Court Forebay (site RGU, code D2, for the receivers closest to 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. Results are reported for the individual release groups (excluding predator-type detections), and also for the full set of data from all three release groups combined (population estimate).

Estimated survival from the CVP holding tank to Chipps Island ranged from 0.77 ($\widehat{SE} = 0.08$) for the May release group, with a 95% profile likelihood interval of (0.61, 0.90), to 1.00 ($\widehat{SE} = 0$) for the April release group (based on only 6 fish). The population estimate, found from pooling across release groups, was 0.82 ($\widehat{SE} = 0.05$; 95% CI = (0.72, 0.90)) (Table 25). For the state facility, estimated survival from the radial gates to Chipps Island, Jersey Point, and False River ranged from 0.30 ($\widehat{SE} = 0.07$; 95% CI = (0.18, 0.43)) for the April release group, to 0.49 ($\widehat{SE} = 0.09$; 95% CI = (0.32, 0.66)) for the May release group. The population estimate for the state facility was 0.40 ($\widehat{SE} = 0.05$; 95% CI = (0.31, 0.49)) (Table 25). For both the federal and state facilities, survival was intermediate between the 2011 estimates and the 2012 estimates (USBR 2018a; USBR 2018b).

Discussion

During the first three years of the study (2011-2013) operational actions were taken based on the BO's RPAs and regulatory requirements (NMFS 2009). The study's assessment of the influence of flow and exports on juvenile steelhead route selection and survival represent observational data regardless of desired experimental tests of export and inflow operational conditions. While there has been variability in the hydrologic and operation conditions achieved in the first three years of the study (Table 26), some I:E, inflow, and export conditions within the range of BO operations have not been reached during the first three years. It is desired to maximize learning about RPAs relevant to operations in the South Delta by focusing the last three years of the study (2014-2016) on achieving inter- and intra-annual variation of hydrologic and operational conditions to achieve RPA export and OMR conditions untested during the first three years.

Over the past three years, Old and Middle River (OMR) flows during the steelhead study period have varied sufficiently to provide observations within five OMR categories identified in the RPAs. Among the 14-day average OMR flow values observed for each of the 11 releases of steelhead during 2011–2013, there were: 3 observations > 0 cfs in 2011, 2 observations from -1,875 to 0 cfs in 2013 (representative of -1,250 cfs); 2 observations from -3,000 cfs to -1,876 cfs in 2012 (representative of -2,500 cfs), and 3 releases of -4,250 to -3,001 cfs (one in each year, representative of -3,500 cfs) (Table 26). The 14-day average OMR flow has been more negative than -4,251 cfs for only one release (June 2011, Table 26).

RPA IV.2.2 identifies increasing survival of juvenile steelhead outmigrating as a performance goal for the study. In order to increase survival of outmigrating steelhead this study aimed to answer the following questions:

1. What is the survival of emigrating steelhead smolts through the Delta from Mossdale to Chipps Island?

2. What is the survival of emigrating steelhead smolts through the San Joaquin River and Old River routes to Chipps Island?

A primary effort of these studies is to evaluate the range of survival estimates for identifying an appropriate survival performance goal for outmigrating steelhead smolts from Mossdale to Chipps Island under conditions targeted for the Delta in the BO. Survival through the Delta was measured by this study from Mossdale to Chipps Island using acoustic tags and a dual array of receivers at Chipps Island. The dual array at Chipps Island allowed the detection probability to be estimated for the receivers at Chipps Island. Thus, estimates of survival through the Delta have been generated in addition to estimates of survival in each of two main routes: the San Joaquin River route and the Old River route. Although tagged steelhead were released at Durham Ferry, estimates of survival started at Mossdale, as it is assumed that any handling mortality due to the tagging and transport occurred before Mossdale.

Survival was low through the Delta (Mossdale to Chipps Island) in 2013 (0.09 to 0.20), and for both routes through the Delta (survival ranged between 0 and 0.20 for the San Joaquin route and between 0.08 and 0.20 for the Old River route; Table 27 and Table 19). With the exception of the first release group, where survival was significantly greater in the Old River route, survival was not significantly different between the two routes in 2013 (Table 19 and Table 27).

The estimates of total survival through the Delta were lower in 2013 than in either 2011 or 2012, both on the scale of the individual release groups and for the overall population-level estimate (Table 27). The exception was for the survival in the Old River route in 2013, where the estimates were comparable to or slightly higher than the estimated survival in the Old River route in 2012 (Table 27). Survival estimates through the Delta were considerably higher in 2011 than in either 2012 or 2013 (Table 27).

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

The 14-day mean of Vernalis flows was correlated to total steelhead survival through the Delta, in the San Joaquin route, and in the Old River route (Table 28), and a linear relationship between Vernalis flow and survival accounted for 69 to 89% of the variation in steelhead survival between 2011 and 2013. As Vernalis flows increased, survival increased (Figure 27). Vernalis flows accounted for more of the variation (i.e. had higher coefficients of determination) in steelhead survival than the other variables: exports, inflow/export ratio, flow at the head of Old River, and OMR flows (Table 28). However, the mean 14-day flow in Old River was highly correlated to flow at Vernalis ($r = 0.9505$; Table 29). Vernalis flows were less correlated to the other flow variables evaluated (I/E ratio and OMR flow), but the relationship between Vernalis flow and both the I/E ratio and OMR was statistically significant ($\alpha = 0.05$; Table 29). The combined export rate was not well-correlated with Vernalis flows ($r = 0.3532$; Table 29) and was also not associated with survival (Table 28).

Exports did not appear to be related to route selection at the head of Old River in 2013. The single-variate analyses did not find significant effects ($\alpha = 0.05$) of any measure of exports on the probability of remaining in the San Joaquin River at the head of Old River. However, a combined flow and stage model demonstrated an effect of both San Joaquin River flow and river stage, measured at Lathrop, on the probability of entering Old River. Fish that arrived at the junction with either higher flow or higher river stage were less likely to enter Old River than fish that arrived at lower flows or stages. The majority of the fish that arrived at the head of Old River junction in 2013 selected the Old River route, regardless of release group, flow, flow proportion, velocity river stage, or exports. In all cases, the predicted probability of entering Old River in 2013 was 0.5 or greater.

Exports also did not appear to have an effect on route selection at Turner Cut in 2013. The covariate with the largest difference for fish that used the Turner Cut route compared to those that remained in the San Joaquin River route was the 15-minute change in river stage at arrival at the junction. The pattern observed, although based on too few observations to adequately test its significance, is consistent with an incoming tide being associated with entry to Turner Cut. This is also consistent with the 2012 route selection analysis (USBR 2018b).

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

Fall run Chinook salmon and steelhead are members of the same family, Salmonidae, and thus the population response to various drivers may be similar between species. The potential for either species to serve as a surrogate for the other species requires an evaluation of the assumptions underlying the expected response of the species. This question was evaluated in Volume 2: Responses to Management Questions, in a recent report on Effects of Water Project Operations on Juvenile Salmonid Migration and Survival in the south Delta (Salmon Scoping Team 2017). That report concluded that determining whether a surrogate species adequately represents a target species is complicated, and depends on the research or management objectives in question, as well as location, timing, habitat, and ecological response to environmental phenomena (SST 2017, Murphy and Weiland 2014). Surrogacy assumptions must be addressed. Some comparisons of migration behavior and survival can be made between the hatchery steelhead from the Mokelumne River used in the Six-Year Study and the hatchery Chinook salmon from the Merced River used in concurrent studies; however, these limited comparisons are neither exhaustive for the hatchery stocks in question, nor representative of naturally produced populations.

In 2013, two of the three weeks of acoustic-tagged steelhead releases occurred four to eight weeks before acoustic-tagged Chinook salmon were released at Durham Ferry; the final steelhead release was timed between two releases of Chinook salmon in May 2013 (Buchanan et al 2016). Steelhead survival in 2013 for this third steelhead release group was greater than that for either of the two Chinook salmon releases in 2013 (0.20 for steelhead and between 0 and 0.03 for the Chinook salmon; Table 30; Buchanan et al 2016). It is expected that steelhead would survive better because the steelhead are much larger than the Chinook salmon and survival is usually higher for larger-sized fish. Both this expectation and the observed comparison between steelhead and Chinook salmon survival limit the direct use of Chinook salmon as surrogates for steelhead.

In 2011 and 2012, steelhead releases were paired with Chinook salmon releases. In 2011, Chinook and steelhead were tagged the same days, with one group tagged in the morning and the other in the afternoon (SJRGA 2013; USBR 2018a). This resulted in both steelhead and salmon being released over a 24-hour period after being held 24 hours, with alternating groups being released every 3 hours throughout the 24-hour period. Survival was much higher for steelhead than salmon in all cases in 2011 (Table 31; SJRGA 2013; USBR2018a). In 2012, the steelhead and salmon were tagged on consecutive days, with releases occurring every 4 hours over 24 hours for each species on alternating days (Buchanan et al 2015, USBR 2018b). Survival was higher in 2012 for steelhead than salmon in almost all cases, with the exception of the Old River route survival for the first salmon release (0.16) compared to the second steelhead release (0.10)) (Table 32; Buchanan et al 2015, USBR 2018b). Survival was low in the Old River route for both the third steelhead release group (0.05) and the second salmon release (0.0) in 2012 (Table 32; Buchanan et al 2015; USBR 2018b). Further evaluation of surrogacy will be done in future reports.

5. Does quantity of predator habitat influence reach specific survival rates of juvenile steelhead?

Predation is assumed to be a major source of mortality during juvenile salmonid outmigration, although its intensity appears to be affected by flow (Cavallo et al 2012). Because the intensity of predation and predator habitat is a critical uncertainty, multiple approaches may be necessary to evaluate its effects on juvenile steelhead outmigration survival. In 2011, we had hoped to approach the question via remote sensing to compare the quantity of submerged aquatic vegetation/floating aquatic vegetation (SAV/FAV) located along reaches as an indicator of predatory fish habitat. However, remote sensing of the Delta was not completed in 2011. Predator classification decision rules were developed for the 2011 study, and these may be used as one measure of predator activity for reaches. This may provide a quantitative way to evaluate a relationship between reach-specific survival and tags appearing to be eaten by predators. However, the predator classification rules are designed to detect only a subset of active predators, in particular those predatory fish that both eat a tagged study fish and then pass one or more acoustic receiver in a manner unlike that expected from an outmigrating steelhead. In 2014, predator monitoring increased in the south Delta. One approach may be to quantify and compare predator densities within previously-identified high and low mortality reaches. These data would be useful for determining if predators densities, assessed with DISDON or split-beam technologies, could be correlated to reach-specific survival.

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

Travel time through the Delta (Mossdale to Chipps Island) averaged approximately 11.3 days in 2013, for both the San Joaquin River route and the Old River route (Table 21). There was considerable variability in travel time for the different release groups, and investigation of the relationship between river discharge and travel time will be performed in a later report. In 2014, we will evaluate discharge in the San Joaquin River and into Old River for when each release group of fish passes Head of Old River to evaluate the mean travel time of fish down the mainstem San Joaquin River and also through the South Delta. Discharge of the San Joaquin River and into Turner Cut will be measured when each release group of fish is passing Turner Cut to estimate the median travel time of steelhead down the mainstem in a river-tidal environment. Finally, discharge in the San Joaquin River and into Old and Middle Rivers will be evaluated to consider the median travel time of steelhead through the Delta. We will compare travel times in these three locations to evaluate which environments contribute to the overall travel time of fish from the lower San Joaquin to Chipps Island.

Complementary Measurements and Outcomes

In the NMFS Opinion, this study was proposed to address the complementary questions below. It is unlikely that these additional study questions will be addressed because the primary objectives of the Six-Year Study were to determine survival and route entrainment through the South Delta. Additional studies with focused on the following questions should be developed in the future.

What is the survival of emigrating steelhead smolts from the tributaries into the mainstem of the San Joaquin River?

A study could be designed to undertake a paired juvenile fall run Chinook salmon release and intensive wild steelhead smolt capture, tag, and release study. By pairing a tributary fall run Chinook survival study with intensive steelhead smolt sampling in the tributary, information concerning the efficacy of using fall run Chinook salmon as a surrogate for steelhead can be used to inform any information derived from this complementary study.

What proportion of juvenile steelhead released during the study residualize?

This question will be difficult to answer, although some information on fish moving upstream is available from the dataset. In 2014-2016, receivers will be left in the water until summer to listen for tags and attempt to relate the detection of live tagged fish with conditions optimal for steelhead residualization.

References

Buchanan, R. A. 2010. Sample Size for VAMP 2011: Preliminary Analysis. Prepared for: Pat Brandes, U.S. Fish and Wildlife Service, Stockton CA. 12 August 2010. Included as Appendix E in SJRGA (2013).

Buchanan, R., P. Brandes, M. Marshall, J. S. Foott, J. Ingram, D. LaPlante, and J. Israel. (2015). 2012 South Delta Chinook Salmon Survival Study. Ed: P. Brandes, U.S. Fish and Wildlife Service. 145 p

Buchanan. R, P. Brandes, M, Marshall, K. Nichols, J. Ingram, D. LaPlante, and J. Israel (2016). 2013 South Delta Chinook Salmon Survival Study. Ed: P. Brandes, U.S. Fish and Wildlife Service 143 pgs.

Burnham, K. P., and D. R. Anderson (2002). Model selection and multimodel inference: A practical information-theoretic approach. 2nd edition. Springer. New York, NY. 488 pp.

Cavallo, B., J. Merz, and J. Setka (2012). Effects of predator and flow manipulation on Chinook salmon (*Oncorhynchus tshawytscha*) survival in an imperiled estuary. Environmental Biology of Fishes.

Cavallo, B., P. Gaskill, and J. Melgo (2013). Investigating the influence of tides, inflows, and exports on sub-daily flow in the Sacramento-San Joaquin Delta. Cramer Fish Sciences Report. 64 pp. Available online at: http://www.fishsciences.net/reports/2013/Cavallo_et_al_Delta_Flow_Report.pdf.

Delaney, D., P. Bergman, B. Cavallo, and J. Melgo (2014). Stipulation Study: Steelhead Movement and Survival in the South Delta with Adaptive Management of Old and Middle River Flows. Prepared under the direction of Kevin Clark, Bay-Delta Office, Biotelemetry and Special Investigations Unit. California Department of Water Resources. 150 pgs.

DSP (Delta Science Program). 2009. The Vernalis Adaptive Management Program (VAMP): report of the 2010 review panel. May 13, 2010. Prepared for the Delta Science Program, 45 p.

Garza, J.C., D.E. Pearse (2009) Population genetic structure of *Oncorhynchus* mykiss in the California Central Valley. Final report for the California Department of Fish and Game Contract #PO485303.

Lady, J. M., and J. R. Skalski (2009). USER 4: User-Specified Estimation Routine. School of Aquatic and Fishery Sciences. University of Washington. Available from http://www.cbr.washington.edu/paramest/user/.

Li, T., and J. J. Anderson (2009). The Vitality model: A Way to understand population survival and demographic heterogeneity. Theoretical Population Biology 76: 118-131.

Liedtke, T.L., J.W. Beeman L.P. Gee (2012). A Standard Operating Procedure for the Surgical Implantation of Transmitters in Juvenile Salmonids. U.S. Geological Survey Open-File Report 2012-1267, 50 p.

McCullagh, P., and J. Nelder (1989). Generalized linear models. 2nd edition. Chapman and Hall, London.

McEwan, D (2001) Central Valley steelhead. In R .L. Brown (editor), Contributions to the Biology of Central Valley Salmonids, Volume 1, pages 1-44. California Department of Fish and Game, Fish Bulletin 179.

Murphy, D. D. and P. S. Weiland. 2014. The use of surrogates in implementation of the federal Endangered Species Act—proposed fixes to a proposed rule. Journal of Environmental Studies and Sciences 4:156-162.

National Marine fisheries Service (NMFS). 2009. Biological Opinion on long-term operations of the Central Valley Project and State Water Project. June 4. NMFS Southwest Region, Long Beach, California. Available from: http://www.westcoast.fisheries.noaa.gov/publications/Central_Valley/Water%20Operations/Operations,%20Criteria%20and%20Plan/nmfs_biological_and_conference_opinion_on_the_long-term_operations_of_the_cvp_and_swp.pdf.

National Marine Fisheries Service (NMFS). 2014. Recovery Plan for the Evolutionarily Significant Units of Sacramento River Winter-run Chinook Salmon and Central Valley Spring-run Chinook Salmon and the distinct Population Segment of Central Valley Steelhead. Sacramento Protected Resources Division. July 2014.

Perry, R. W. (2010). Survival and migration dynamics of juvenile Chinook salmon (Oncorhynchus tshawytscha) in the Sacramento-San Joaquin River Delta. Doctoral Dissertation, University of Washington.

Perry, R. W., J. R. Skalski, P. L. Brandes, P. T. Sandstrom, A. P. Klimley, A. Ammann, and B. MacFarlane (2010). Estimating survival and migration route probabilities of juvenile Chinook salmon in the Sacramento-San Joaquin River Delta. North American Journal of Fisheries Management 30: 142-156.

San Joaquin River Group Authority (2010). 2009 Annual Technical Report: On Implementation and Monitoring of the San Joaquin River Agreement and the Vernalis Adaptive Management Plan (VAMP). Prepared for the California Water Resources Control Board.

San Joaquin River Group Authority (2011). 2010 Annual Technical Report: On Implementation and Monitoring of the San Joaquin River Agreement and the Vernalis Adaptive Management Plan (VAMP). Prepared for the California Water Resources Control Board.

San Joaquin River Group Authority (2013). 2011 Annual Technical Report: On Implementation and Monitoring of the San Joaquin River Agreement and the Vernalis Adaptive Management Plan (VAMP). Prepared for the California Water Resources Control Board.

Seber, G. A. F. (2002). The estimation of animal abundance. Second edition. Blackburn Press, Caldwell, New Jersey.

Sokal, R. R., and Rohlf, F. J. (1995). Biometry, 3rd ed. W.H. Freeman and Co., New York, NY, USA.

Salmon Scoping Team (SST) (2017). Effects of Water Project Operations on Juvenile Salmonid Migration and Survival in the South Delta. Prepared for the Collaborative Adaptive Management Team . January 2017.

Satterthwaite, W.H., M.P. Beakes, E.M. Collins, D.R. Swank, J.E. Merz, R.G. Titus, S.M. Sogard, M. Mangel (2010) State-dependent life history models in a changing (and regulated) environment: steelhead in the California Central Valley. Evolutionary Applications 3: 221-243.

Townsend, R. L., J. R. Skalski, P. Dillingham, and T. W. Steig (2006). Correcting Bias in Survival Estimation Resulting from Tag Failure in Acoustic and Radiotelemetry Studies. Journal of Agricultural, Biological, and Environmental Statistics 11: 183-196.

U. S. Bureau of Reclamation. (USBR). 2018a. NMFS Biological Opinion RPA IV.2.2: 2011 Six-Year Acoustic Telemetry Steelhead Study. Contributions by Buchanan, R., J. Israel, P. Brandes, E. Buttermore. Reclamation Bay-Delta Office, Mid-Pacific Region, Sacramento, CA. FINAL REPORT. May 14, 2018, 144p.

U. S. Bureau of Reclamation. (USBR). 2018b. NMFS Biological Opinion RPA IV.2.2: 2012 Six-Year Acoustic Telemetry Steelhead Study. Contributions by Buchanan, R., P. Brandes, J. Israel, E. Buttermore. Reclamation Bay-Delta Office, Mid-Pacific Region, Sacramento, CA. FINAL REPORT. May 16, 2018, 172p.

Vogel, D. A. (2010). Evaluation of acoustic-tagged juvenile Chinook salmon movements in the Sacramento-San Joaquin delta during the 2009 Vernalis Adaptive Management Program. Technical Report for San Joaquin River Group Authority. 72 p. Available http://www.sjrg.org/technicalreport/ (accessed 13 December 2011).

Vogel, D. A. (2011). Evaluation of acoustic-tagged juvenile Chinook salmon and predatory fish movements in the Sacramento-San Joaquin Delta during the 2010 Vernalis Adaptive Management Program. Technical report for San Joaquin River Group Authority. Available http://www.sjrg.org/technicalreport/ (accessed 13 December 2011).

Zimmerman, C.E., G.W. Edwards, K. Perry (2009). Maternal origin and migratory history of steelhead and rainbow trout captured in rivers of the Central Valley, California. Transactions of the American Fisheries Society 138: 280-291.

Figures

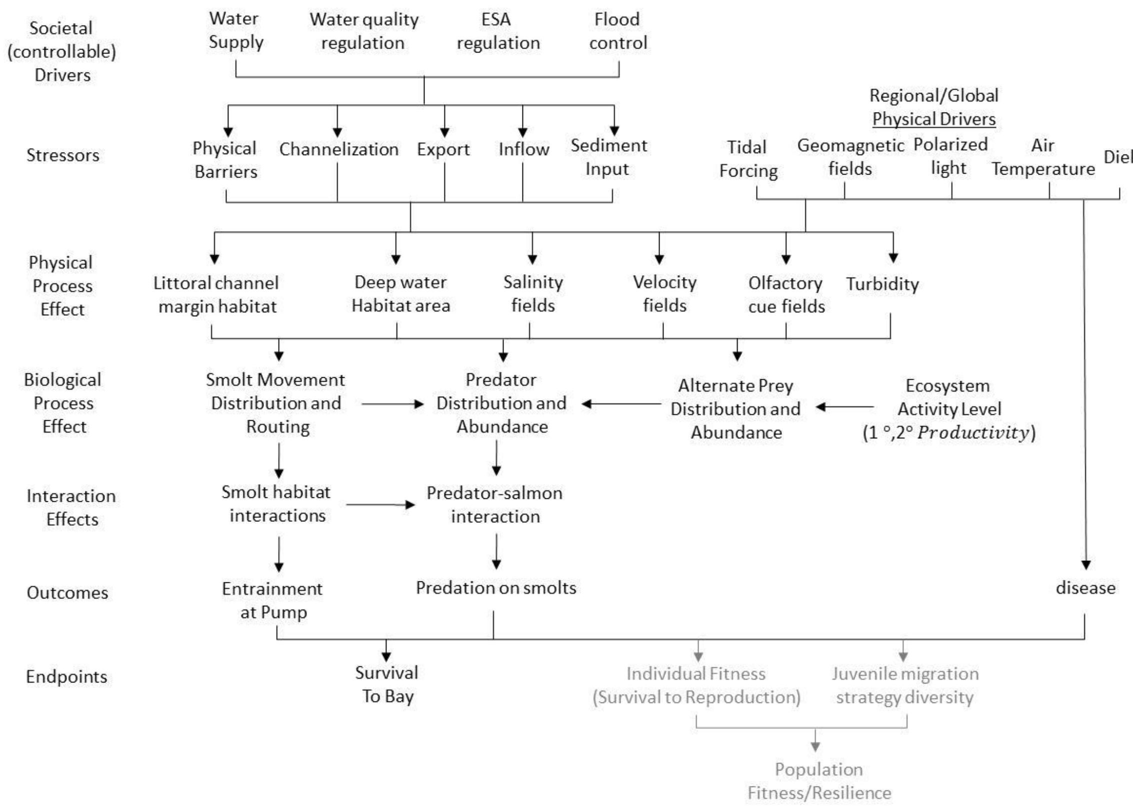


Figure 1. Conceptual model of how Delta water operations, tributary water operations, and habitat control biotic and abiotic ecosystem variables influencing survival of steelhead smolts in a reach along the San Joaquin River and south Delta.

Figure 2. Tag activator for activating tags in the 2013 Six-Year Steelhead Study. Photo credit: Jake Osborne/USFWS

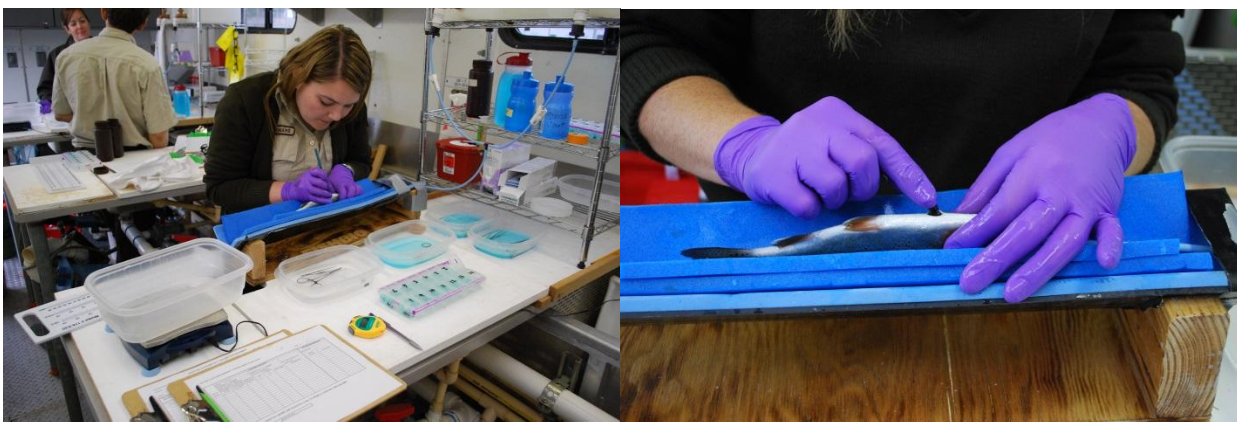


Figure 3. Surgeon making an incision (left) for tag insertion (right) into a steelhead at Mokelumne River Hatchery for the 2013 Six-Year Steelhead Study. Photo Credit: Ron Smith/USFWS

Figure 4. Tagging set-up at the Mokelumne River Hatchery for the 2013 Six-Year Steelhead Study. Photo credit: Ron Smith/USFWS

Figure 5. Moving steelhead from a recovery bucket into a perforated tote, held within a sleeve, while combining fish from multiple buckets into one tote. Photo Credit: Ron Smith/ USFWS.

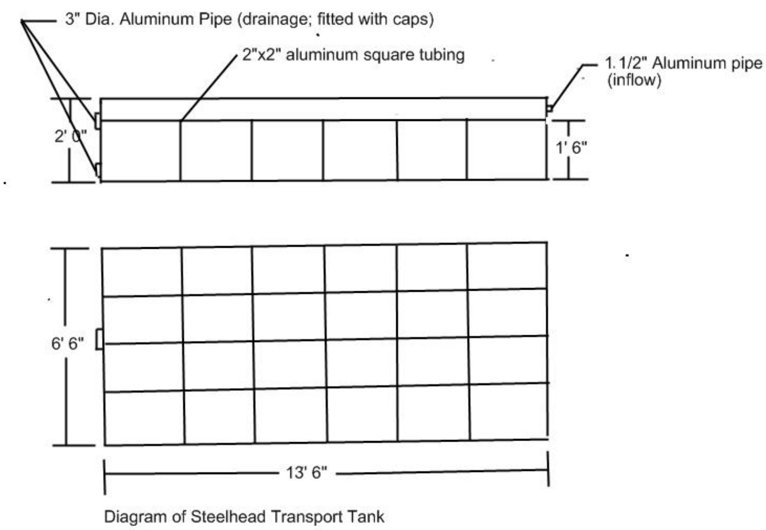


Figure 6. Dimension of the steelhead transport tank, used to transport steelhead from the Mokelumne River Hatchery to the release site at Durham Ferry.

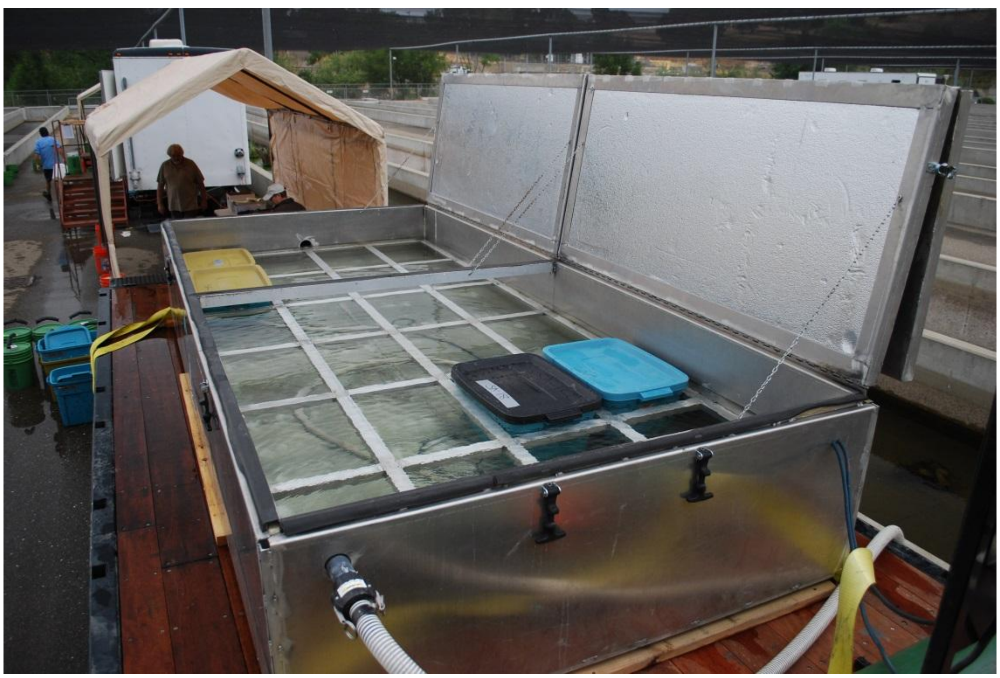


Figure 7. Compartmentalized transport tank with perforated totes for transporting steelhead to Durham Ferry in 2013.

Photo credit: Ron Smith/USFWS

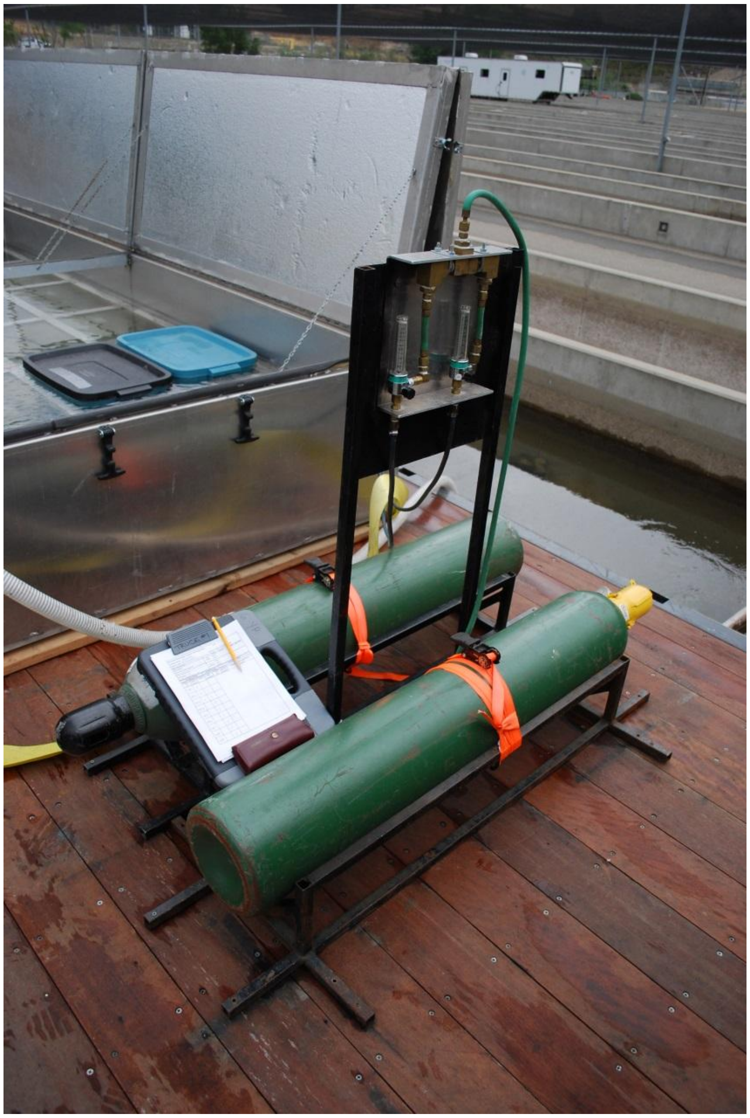


Figure 8. Oxygen tanks set up on 8 meter flat-bed trucks for hauling steelhead as part of the Six-Year Steelhead study in 2013. Photo Credit: Ron Smith/USFWS

Figure 9. Unloading totes from transport tank to pick-up truck at release site (Durham Ferry) for the 2013 Six-Year Steelhead Study. Photo Credit: Ron Smith/ USFWS

Figure 10. Steelhead holding cans anchored in the San Joaquin River near the release site at Durham Ferry. Photo Credit: Josh Israel

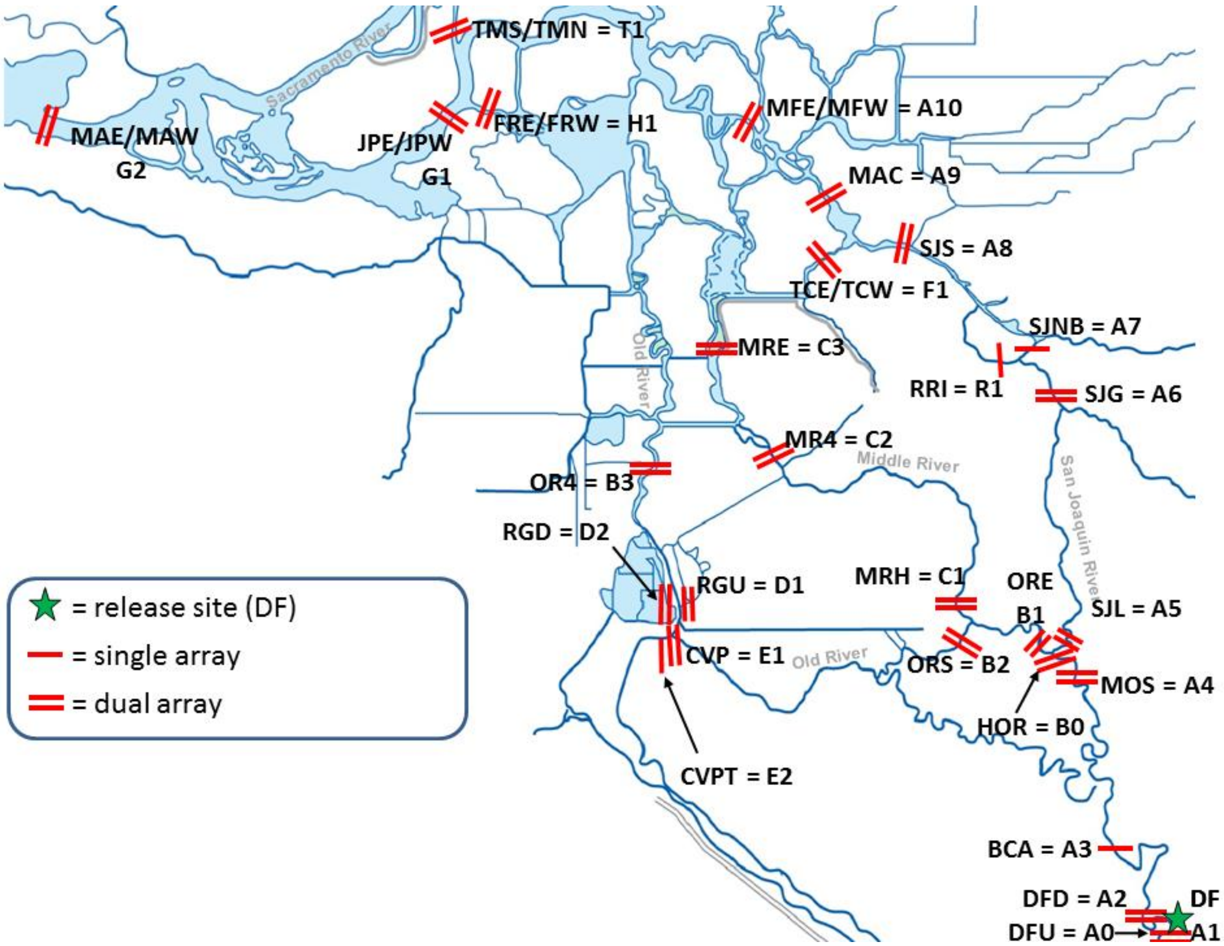


Figure 11. Locations of acoustic receivers and release site used in the 2013 steelhead study, with site code names (3- or 4-letter code) and model code (letter and number string). Site A1 is the release site at Durham Ferry. Sites A8, B0, C3, R1, and T1 were excluded from the survival model.

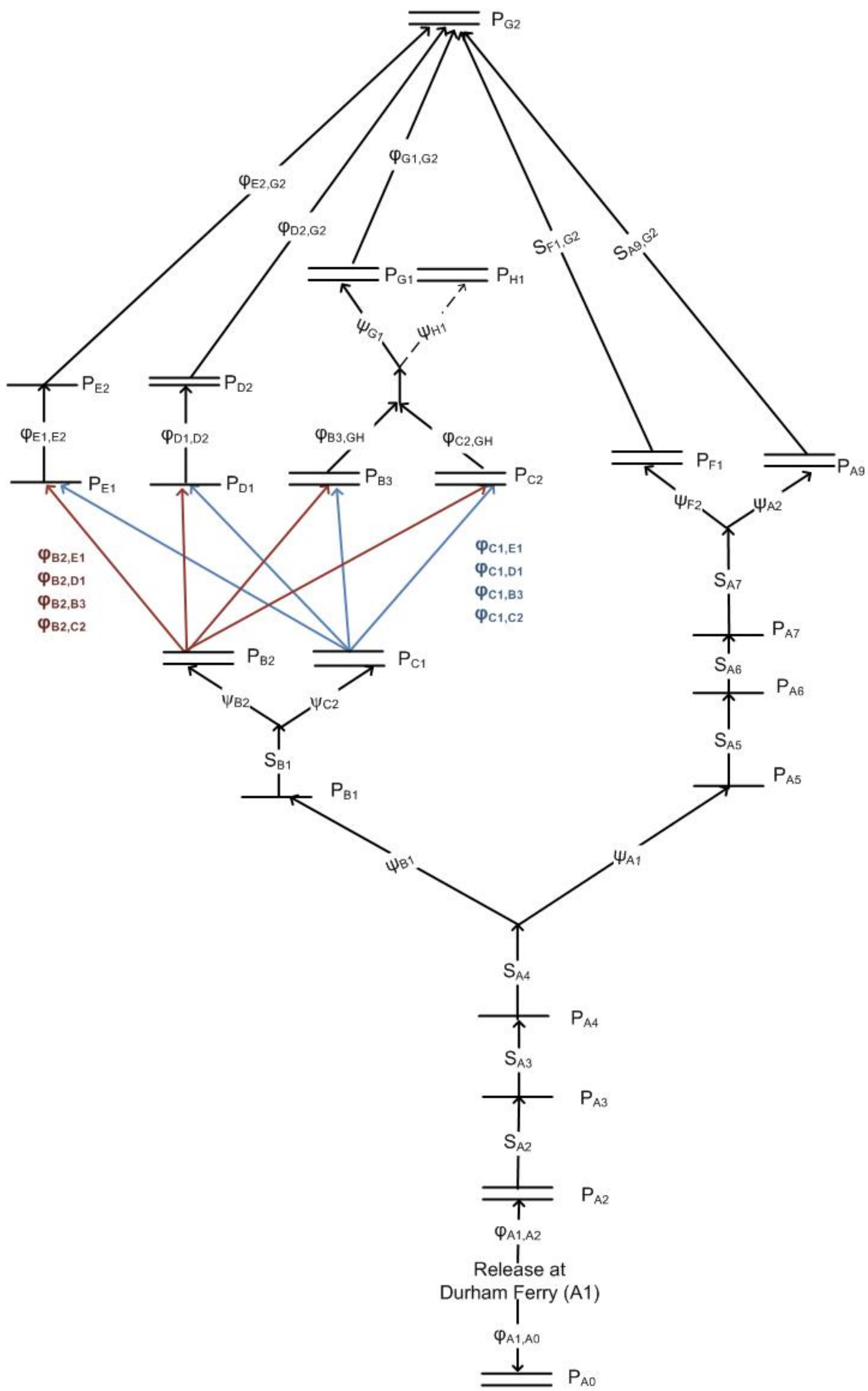


Figure 12. Schematic of 2013 mark-recapture Submodel I with estimable parameters. Single lines denote single-array or redundant double-line telemetry stations, and double lines denote dual-array telemetry stations. Names of telemetry stations correspond to site labels in Figure 13. Parameters $\phi_{B2,D1}$, $\phi_{C1,D1}$, and $\phi_{D1,D2}$ were estimated separately for arrival at D1 when the radial gates were open versus closed. Migration pathways to sites B3 (OR4), C2 (MR4), D1 (RGU), and E1 (CVP) are color-coded by departure site. No detections at H1 were actually used in the survival model.

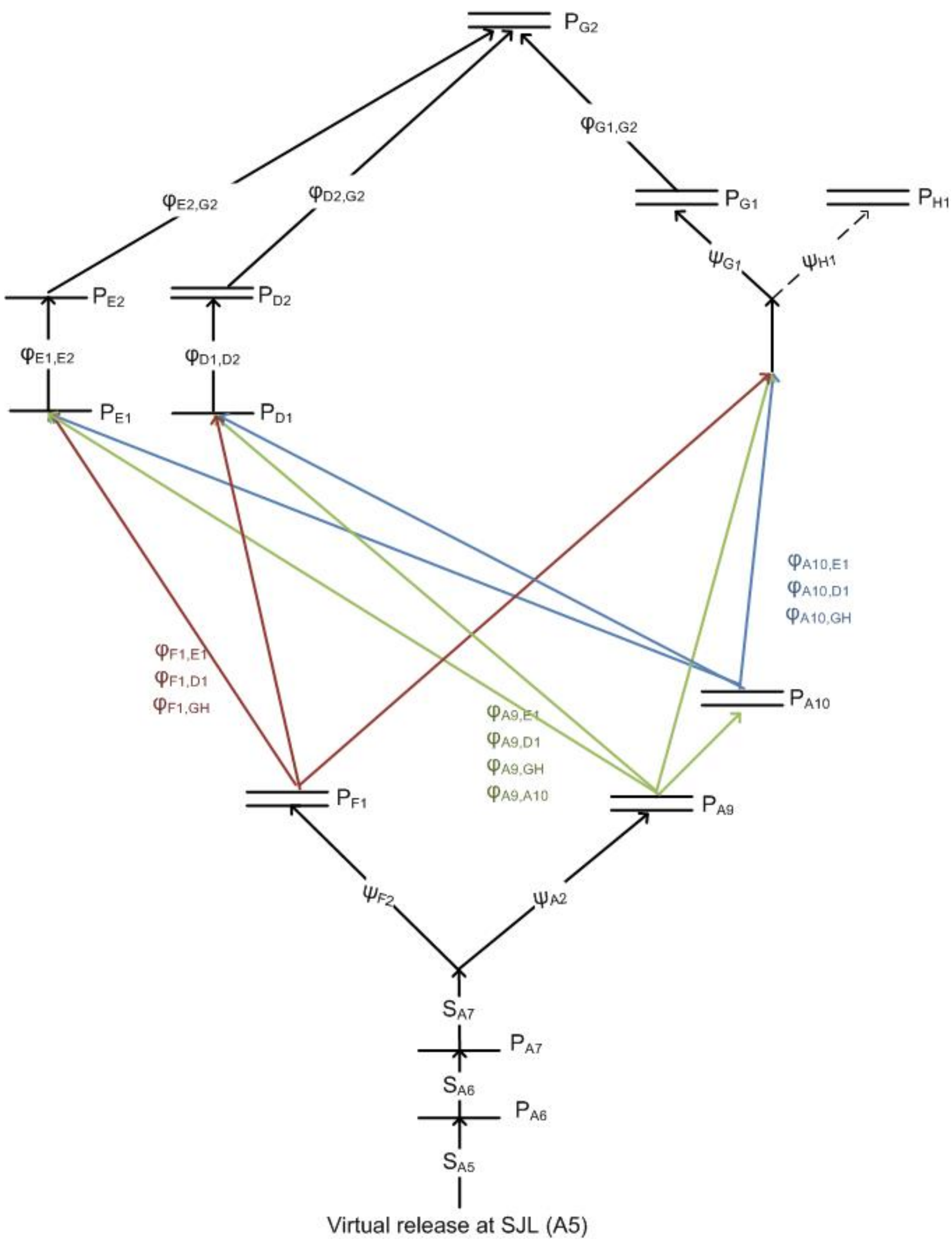


Figure 13. Schematic of 2013 mark-recapture Submodel II with estimable parameters. Single lines denote single-array or redundant double-line telemetry stations, and double lines denote dual-array telemetry stations. Names of telemetry stations correspond to site labels in Figure 13. Parameters $\phi_{A9,D1}$, $\phi_{A10,D1}$, $\phi_{F1,D1}$, and $\phi_{D1,D2}$ were estimated separately for arrival at D1 when the radial gates were open versus closed. Migration pathways to sites D1 (RGU), E1 (CVP), and Jersey Point/False River (JPE/JPW/FRE/FRW) are color-coded by departure site. No detections at H1 were actually used in the survival model.

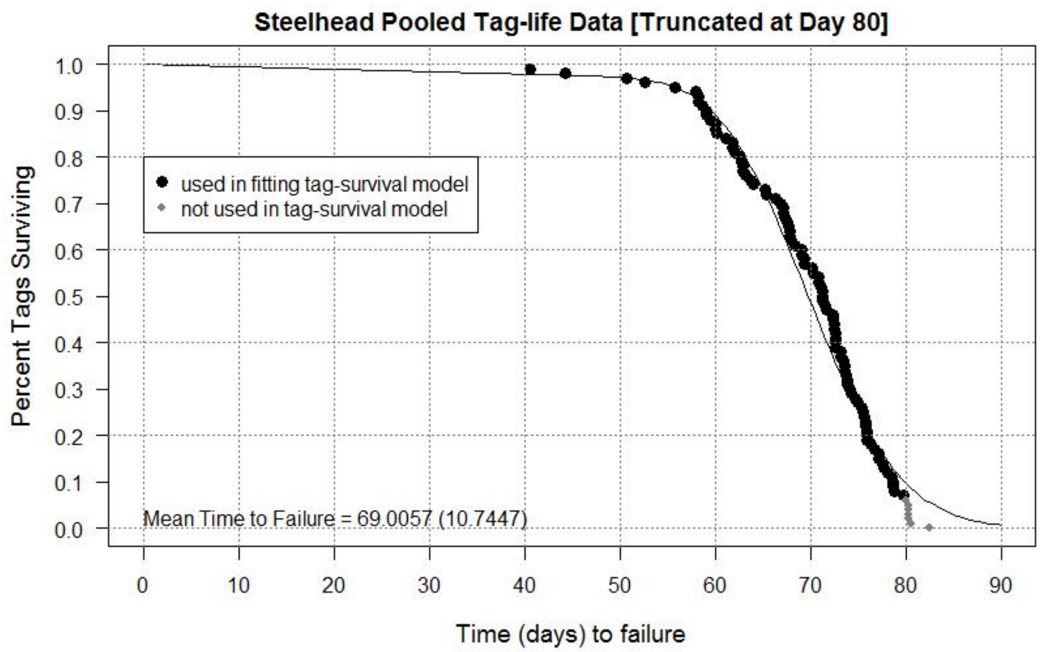


Figure 14. Observed tag failure times from the 2013 tag-life studies, pooled over the March and May studies, and fitted four-parameter vitality curve. Failure times were censored at day 80 to improve fit of the model.

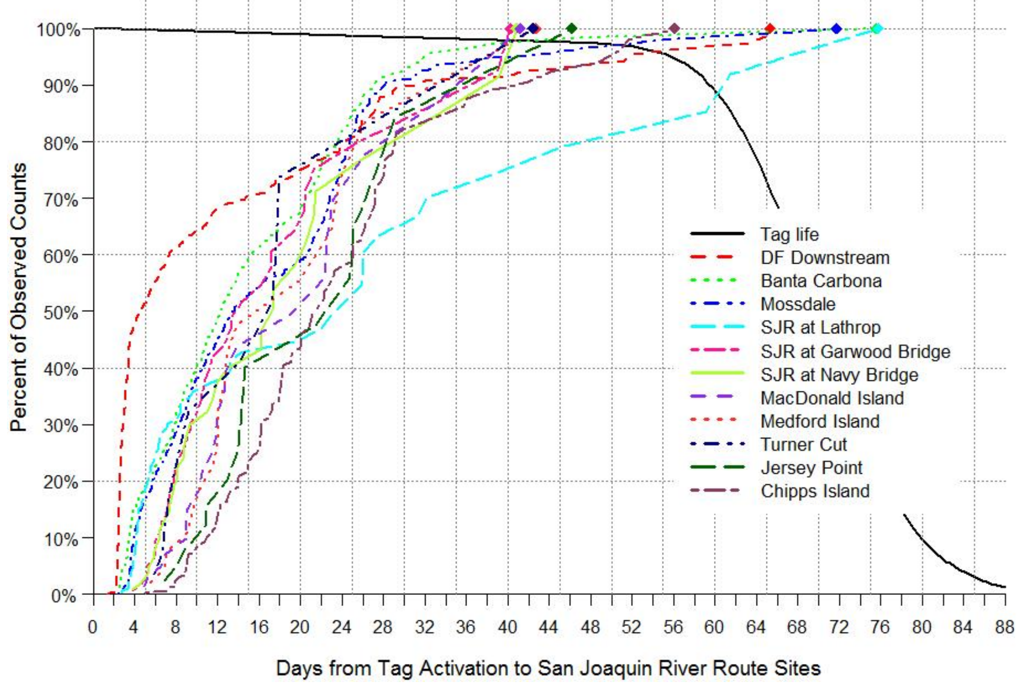


Figure 15. Four-parameter vitality survivorship curve for tag life, and the cumulative arrival timing of acoustic-tagged juvenile steelhead at receivers in the San Joaquin River route to Chipps Island in 2013, including detections that may have come from predators.

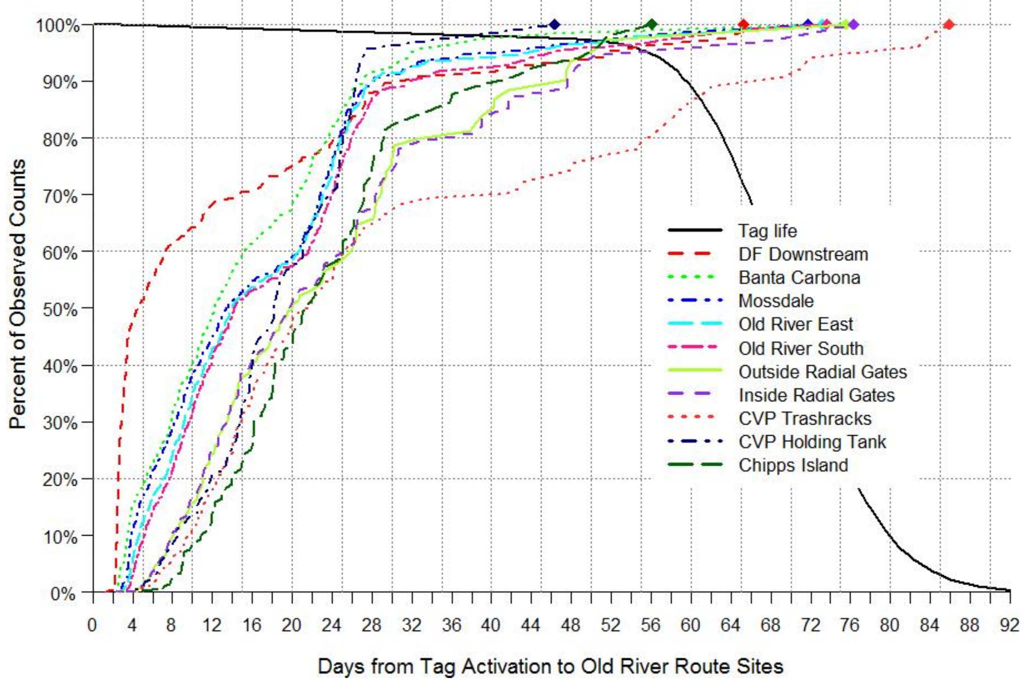


Figure 16. Four-parameter vitality survivorship curve for tag life, and the cumulative arrival timing of acoustic-tagged juvenile steelhead at receivers in the Old River route to Chipps Island in 2013, including detections that may have come from predators.

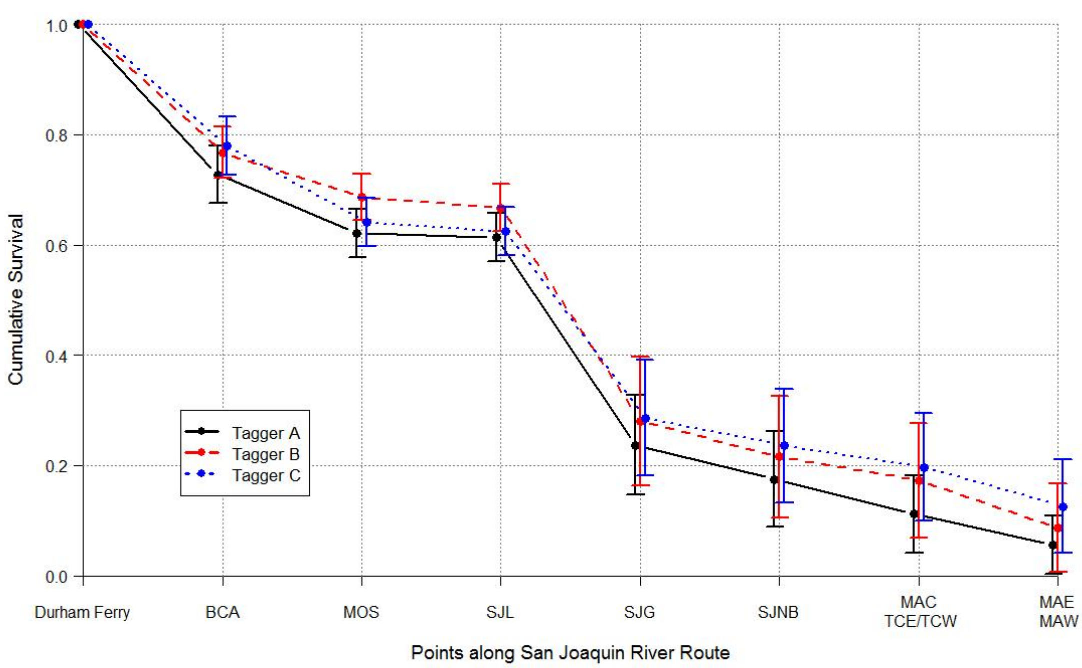


Figure 17. Cumulative survival from release at Durham Ferry to various points along the San Joaquin River route to Chipps Island, by surgeon (i.e., tagger). Error bars are 95% confidence intervals.

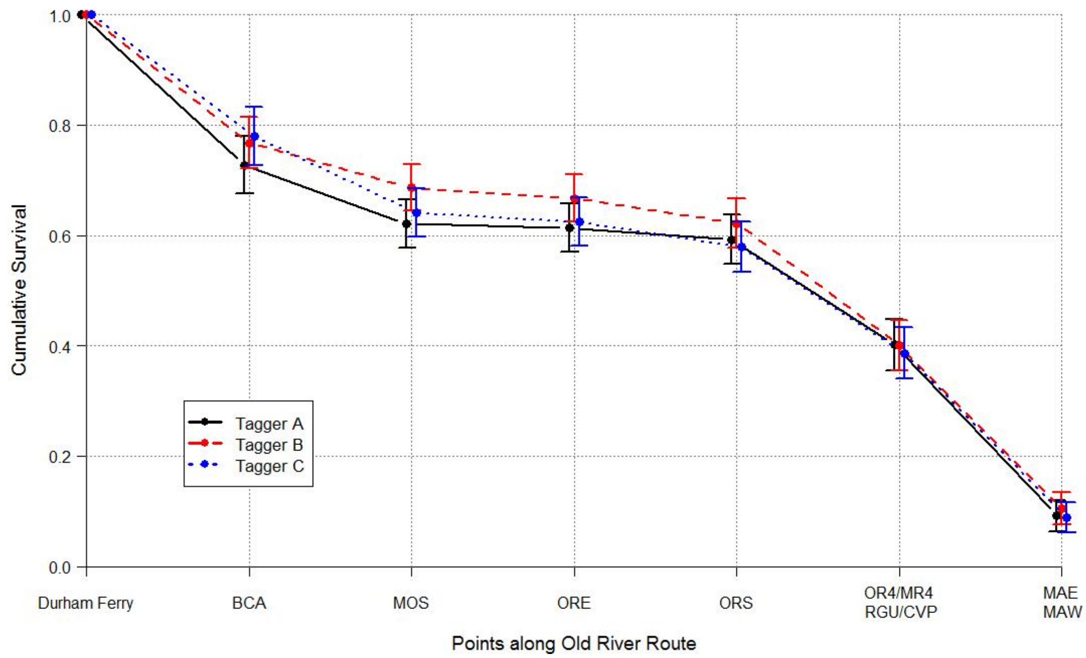


Figure 18. Cumulative survival from release at Durham Ferry to various points along the Old River route to Chipps Island, by surgeon (i.e., tagger). Error bars are 95% confidence intervals.

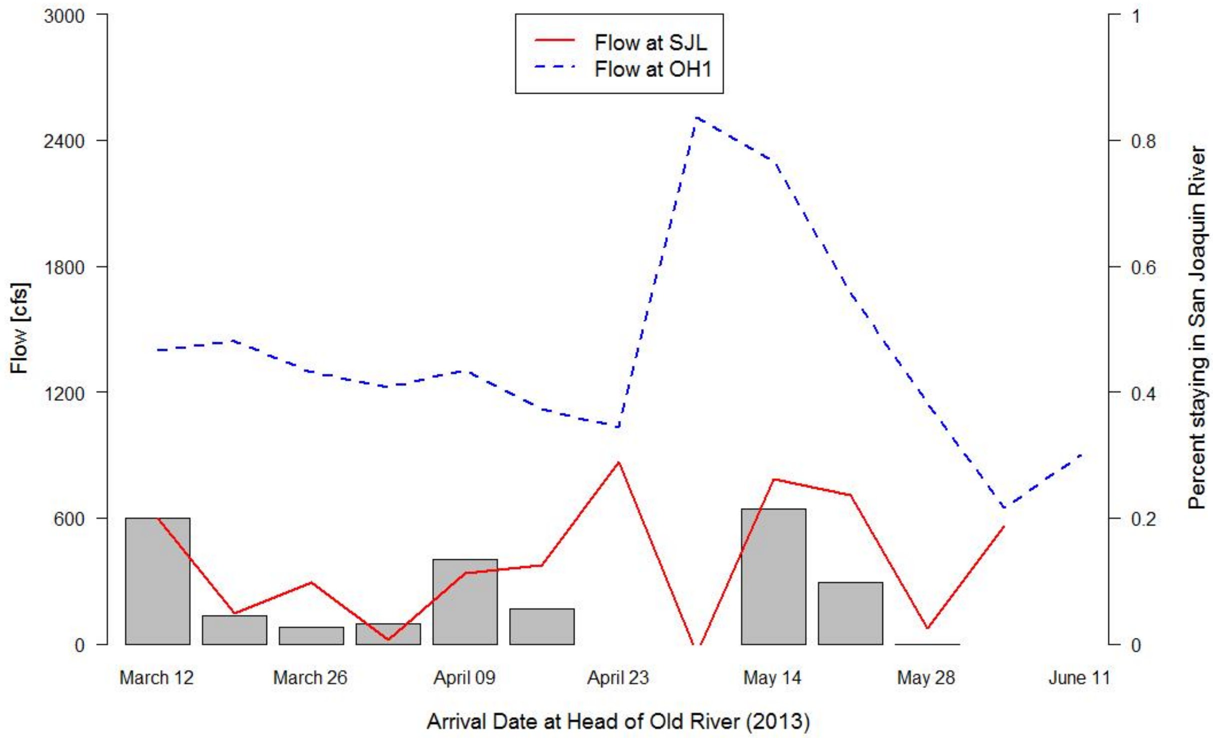


Figure 19. The observed proportion of tagged juvenile steelhead that remained in the San Joaquin River at the head of Old River during the 2013 tagging study (gray bars, representing weekly periods), and the measured flow at the SJL and OH1 gaging stations at the estimated time of fish arrival at the junction, averaged over fish. Proportion of fish remaining in the San Joaquin River is shown only for time periods with at least 10 fish detected. The week from April 29 – May 5 is not included because no fish were observed at the head of Old River junction during that week.

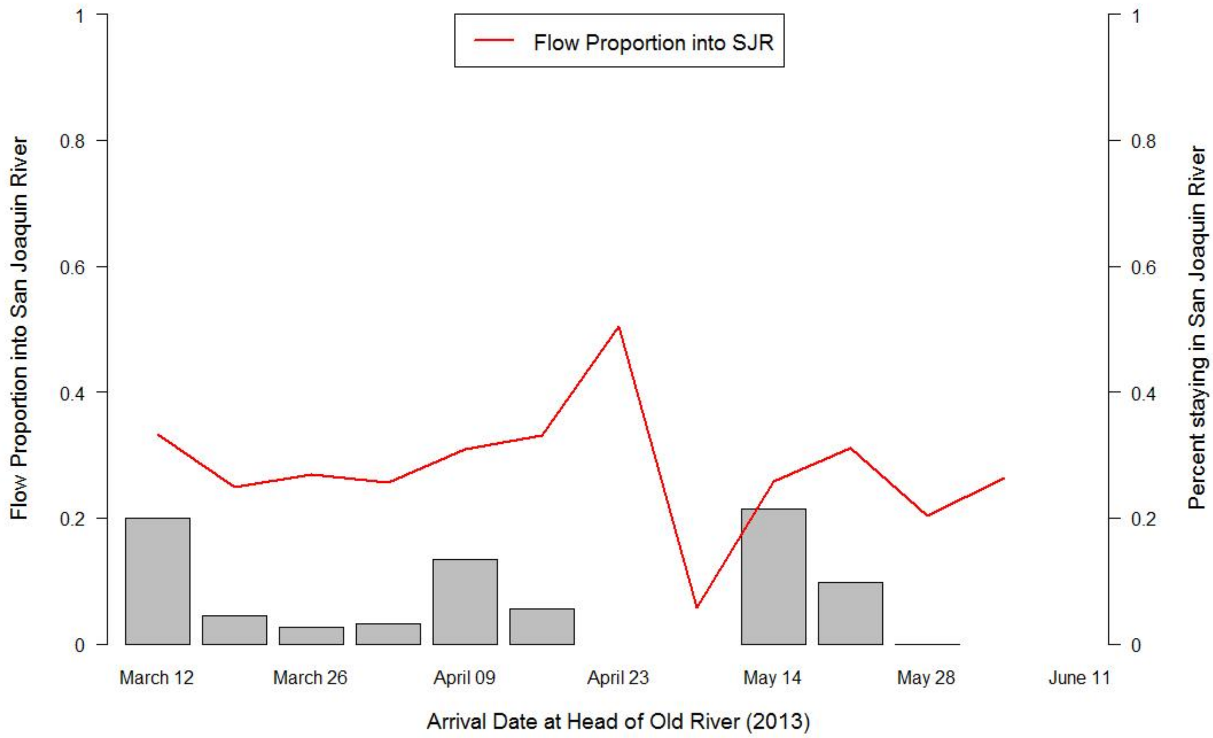


Figure 20. The observed proportion of tagged juvenile steelhead that remained in the San Joaquin River at the head of Old River during the 2013 tagging study (gray bars, representing weekly periods), and the measured flow proportion entering the San Joaquin River at the estimated time of fish arrival at the junction, averaged over fish. Proportion of fish remaining in the San Joaquin River is shown only for time periods with at least 10 fish detected. The week from April 29 – May 5 is not included because no fish were observed at the head of Old River junction during that week.

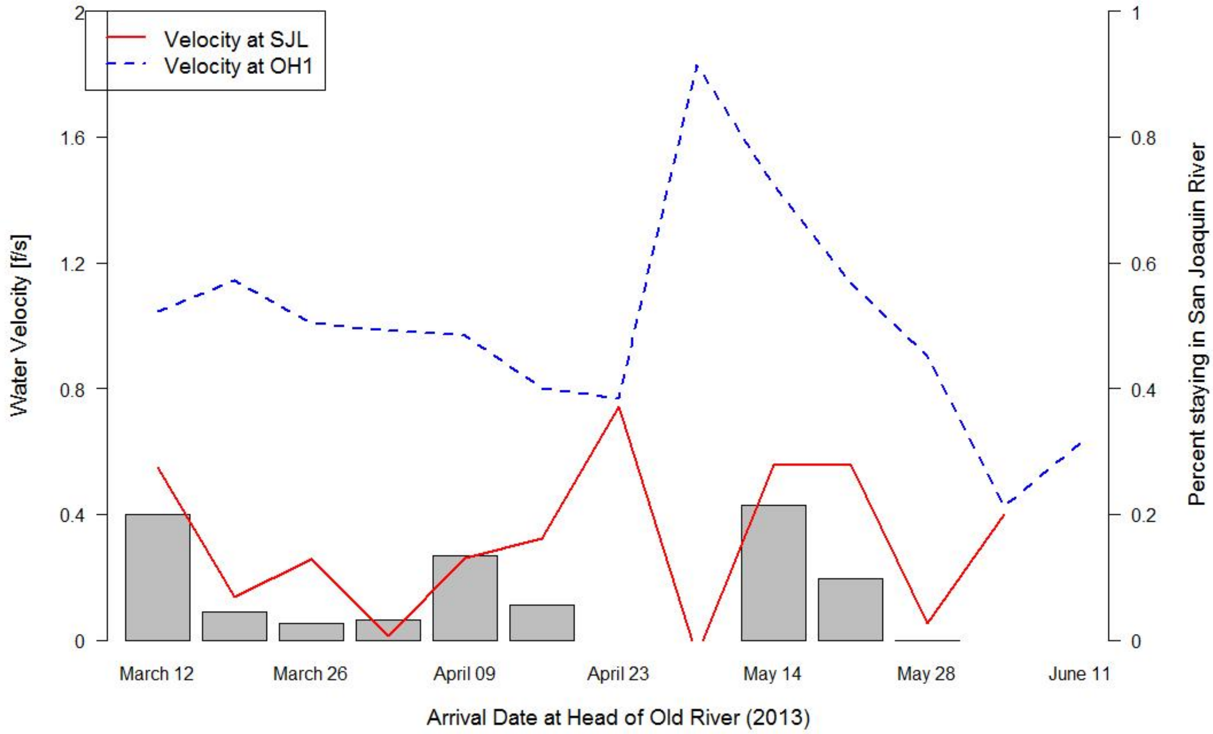


Figure 21. The observed proportion of tagged juvenile steelhead that remained in the San Joaquin River at the head of Old River during the 2013 tagging study (gray bars, representing weekly periods), and the measured water velocity at the SJL and OH1 gaging stations at the estimated time of fish arrival at the junction, averaged over fish. Proportion of fish remaining in the San Joaquin River is shown only for time periods with at least 10 fish detected. The week from April 29 – May 5 is not included because no fish were observed at the head of Old River junction during that week.

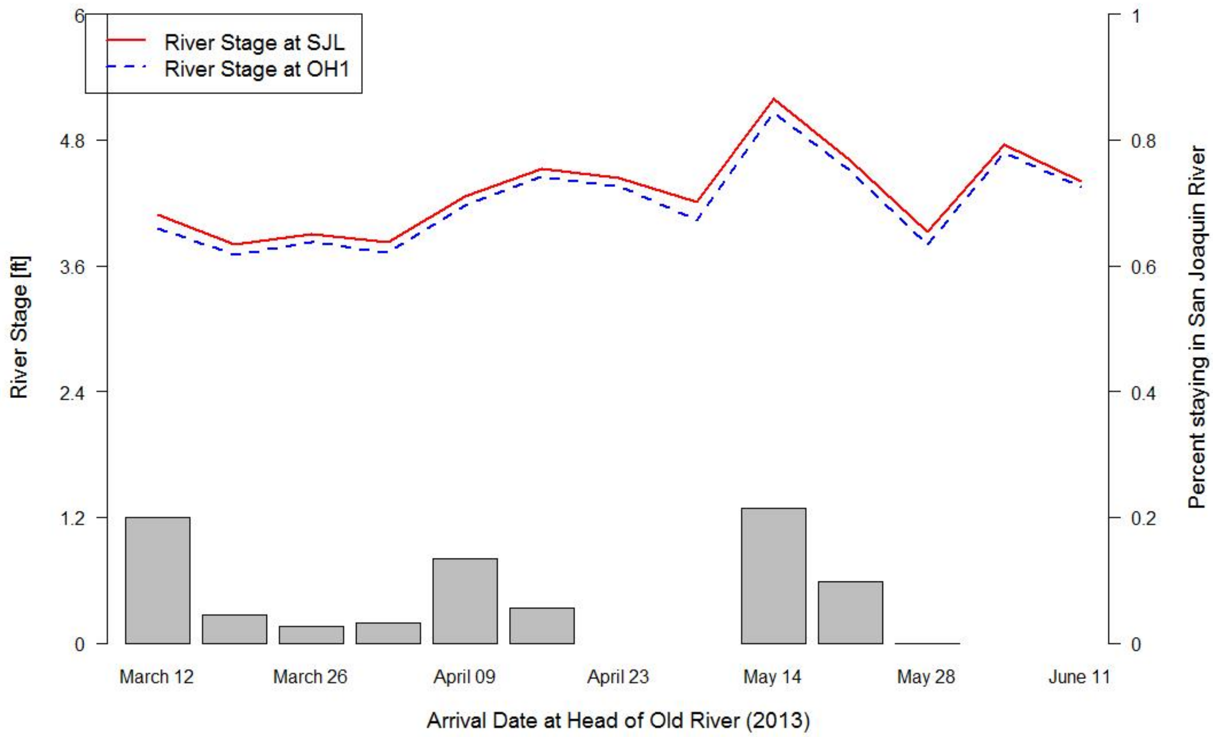


Figure 22. The observed proportion of tagged juvenile steelhead that remained in the San Joaquin River at the head of Old River during the 2013 tagging study (gray bars, representing weekly periods), and the measured river stage at the SJL and OH1 gaging stations at the estimated time of fish arrival at the junction, averaged over fish. Proportion of fish remaining in the San Joaquin River is shown only for time periods with at least 10 fish detected. The week from April 29 – May 5 is not included because no fish were observed at the head of Old River junction during that week.

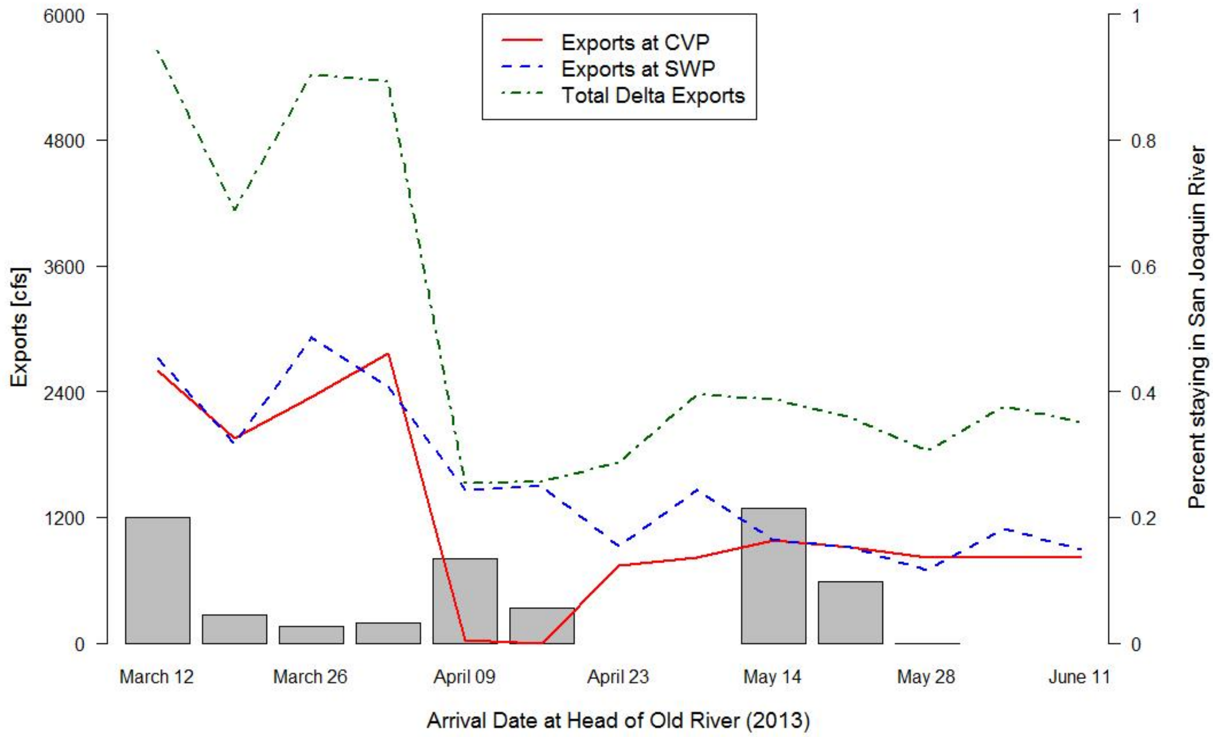


Figure 23. The observed proportion of tagged juvenile steelhead that remained in the San Joaquin River at the head of Old River during the 2013 tagging study (gray bars, representing weekly periods), and the measured daily export rate at CVP, SWP, and total in the Delta on the estimated day of fish arrival at the junction, averaged over fish. Proportion of fish remaining in the San Joaquin River is shown only for time periods with at least 10 fish detected. The week from April 29 – May 5 is not included because no fish were observed at the head of Old River junction during that week.

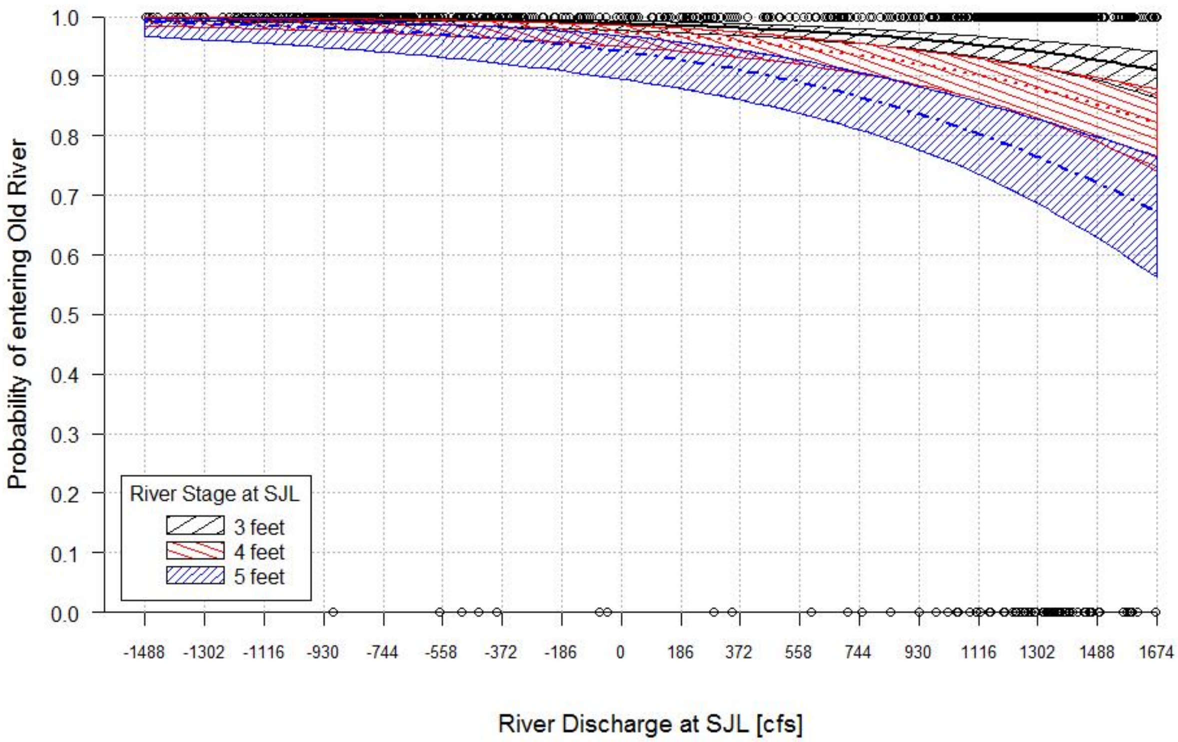


Figure 24. Fitted probability of entering Old River at its head versus river discharge (flow) measured at the SJL gaging station in the San Joaquin River, for river stage = 3, 4, and 5 ft, with 95% confidence bands, in 2013.

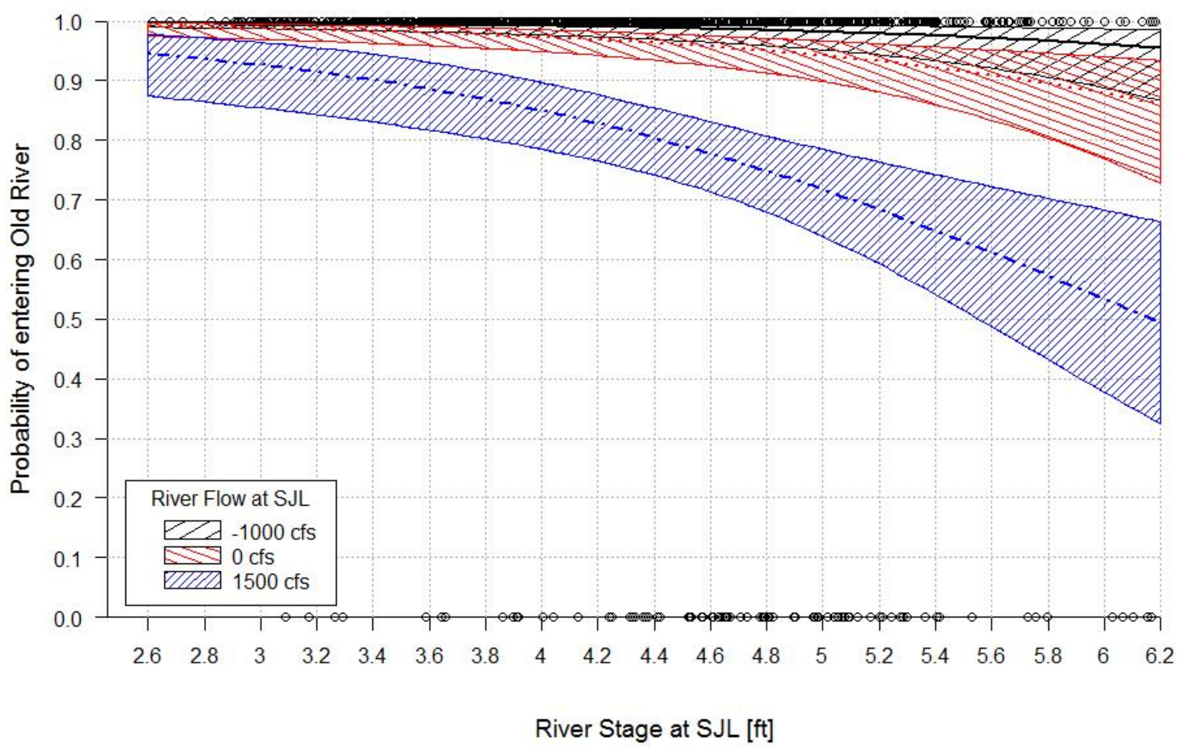


Figure 25. Fitted probability of entering Old River at its head versus river stage measured at the SJL gaging station in the San Joaquin River, for river flow = -1,000, 0, and 1,500 cfs, with 95% confidence bands, in 2013.

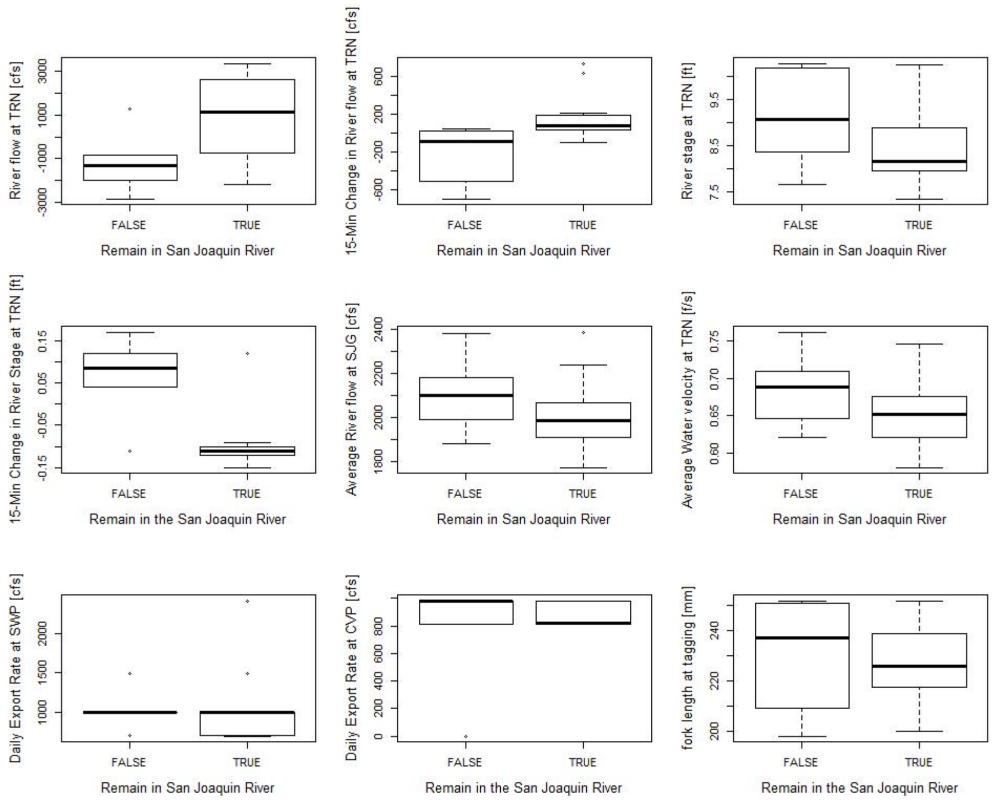


Figure 26. Conditions upon arrival at Turner Cut junction (i.e., at departure from SJS receivers) (TRN conditions), or root mean square of conditions during tag transition from SJG to SJS, daily export rates, and fork length at tagging, for steelhead that remained in the San Joaquin River at Turner Cut, or else entered Turner Cut. Bolded horizontal bar is median measure, upper and lower boundaries of box are the 25th and 75th quantiles (defining the interquartile range), and whiskers are the extremes of 1.5 × the interquartile range.

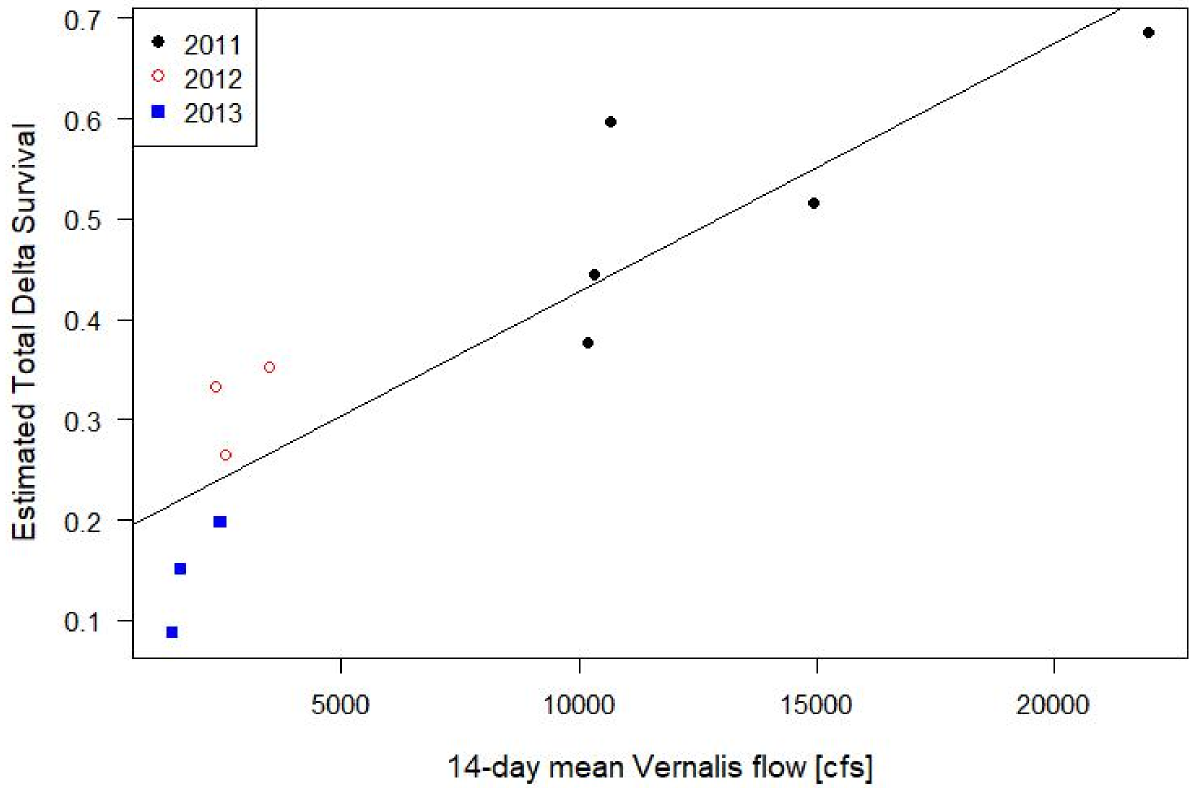


Figure 27. Estimated total delta survival (Mossdale to Chipps Island) for acoustic-tagged steelhead in the 2011, 2012, and 2013 Six-Year Study, versus 14-day mean San Joaquin River flow at Vernalis. Survival and flow data are from Tables 26 and 27. The line is the best fit linear predictor of survival as a function of 14-day Vernalis flow for these data (r^2 = 0.8007).

Tables

Table 1. Tagging, transport and holding date and times and the number of steelhead release as part of the Six-Year Steelhead Study in 2013. Fish that were found dead prior to release are in parentheses.

Tagging Date	Transport Date/ Time	Start Holding Date time	Total released (A+B+C+ D+E+F)	Release A Date/ Time	Release A Number released	Release B Date/ Time	Release B Number released	Release C Date/ Time	Release C Number released	Release D Date/ time	Release D Number released	Release E Date/ Time	Release E Number released	Release F Date/ time	Release F Number released	Fish Health Dummy Tag
	3/5/13; 1146-1418	3/5/13; 1505		3/6; 1506, 1507	24	3/6; 1900, 1901	30									
3/5/13	3/5/13; 1538-1710	3/5/13; 1745	162			3/6; 1900	6	3/6; 2302, 2303	24	3/7; 0300	24					12
	3/5/13; 1915-2020	3/5/13; 2055										3/7; 0701	36	3/7; 1100	18	
	3/6/13; 1035-1153	3/6; 1300		3/7; 1505, 1506	24	3/7; 1901, 1902	24	3/7; 2259	6							
3/6/13	3/6/13; 1312-1453	3/6; 1520	161 (1)			3/6; 14:55		3/7; 2259, 2300	32	3/8; 0301	20 (1)					12
	3/6/13; 1650-1752	3/6; 1827										3/8; 0700	36	3/8; 1100	18	
	3/7/13; 1100-1215	3/7; 1250		3/8; 1500, 1501	24	3/8; 1901, 1902	24	3/8; 2302	4							
3/7/13	3/7/13; 1345-1500	3/7; 1540	154 (2)					3/8; 2301, 2302	27[e]	3/9; 0305	23 (1)					24[d]
	3/7/13; 1705-1805	3/7; 1842						3/8; 2301, 2302	5			3/9; 0700	24	3/9; 1108	23 (1)	

a: One fish released during transfer on 3/6; 1455.

b: Three fish released during transfer on 4/4; 1158.

c: One fish released during transfer on 5/8; 1200.

d: Fish given to CA/NV Fish Health Center for fish health studies.

e: One fish culled after transport (not included in the release number of 27 or counted as a mortality).

Table 1 (Continued)

Tagging Date	Transport Date/ Time	Start Holding Date time	Total released (A+B+C+ D+E+F)	Release A Date/Time	Release A Number released	Release B Date/ Time	Release B Number released	Release C Date/ Time	Release C Number released	Release D Date/ time	Release D Number released	Release E Date/ Time	Release E Number released	Release F Date/ time	Release F Number released	Fish Health Dummy Tag
	4/2/13; 1055-1201	4/2; 1235		4/3; 1513, 1514	24	4/3; 1904, 1905, 1906	30									
4/2/2013	4/2/13; 1325-1440	4/2; 1506	162			4/3; 1906	6	4/3; 2303, 2304	24	4/4; 0302	24					12
	4/2/13; 1602-1700	4/2; 1727										4/4; 0709, 0711, 0713	36	4/4; 1057	18	
	4/3/13; 1030-1135	4/3; 1206		4/4; 1511, 1513	24	4/4; 1859, 1900	24	4/4; 2302	6							
4/3/2013	4/3/13; 1300-1420	4/3; 1453	162					4/4; 2302, 2303	30	4/5; 0259	24					12
	4/3/13; 1541-1641	4/3; 1720										4/5; 0657, 0658, 0659	36	4/5; 1100	18	
	4/4/13; 1030-1142	4/4; 1240		4/4: 11:58 4/5; 1501	3 [b] 21	4/5; 1859	24	4/5; 2259	4							
4/4/2013	4/4/13; 1300-1420	4/4; 1500	156					4/5; 2259, 2300	28	4/6; 0258	24					24[d]
	4/4/13; 1550-1650	4/4; 1740						4/6; 2259	4			4/6; 0705	24	4/6; 1106	24	

a: One fish released during transfer on 3/6; 1455.
b: Three fish released during transfer on 4/4; 1158.
c: One fish released during transfer on 5/8; 1200.
d: Fish given to CA/NV Fish Health Center for fish health studies.
e: One fish culled after transport (not included in the release number of 27 or counted as a mortality).

Table 1 (Continued)

Tagging Date	Transport Date/ Time	Start Holding Date time	Total released (A+B+C+ D+E+F)	Release A Date/ Time	Release A Number released	Release B Date/ Time	Release B Number released	Release C Date/ Time	Release C Number released	Release D Date/ time	Release D Number released	Release E Date/ Time	Release E Number released	Release F Date/ time	Release F Number released	Fish Health Dummy Tag
5/7/2013	5/7/13; 1150-1315	5/7; 1420	162	5/8 1200 5/8; 1458	1 [c] 24	5/8; 1900, 1901	30									12
	5/7/13; 1430-1520	5/7; 1605				5/8; 1901	6	5/8; 2259	24	5/9; 0302	24					
	5/7/13; 1652-1752	5/7; 1827										5/9; 0700	36	5/9; 1108	18	
5/8/2013	5/8/13; 1035-1150	5/8; 1230	160 (2)	5/9; 1507	23	5/9; 1856	24	5/9; 2258	6							12
	5/8/13; 1330-1505	5/8; 1529						5/9; 2258	30	5/10; 0258	24					
	5/8/13; 1600-1715	5/8; 1744										5/10; 0705	36	5/10; 1059	16 (2)	
5/9/2013	5/9/13; 1116-1236	5/9; 1310	151 (5)	5/10; 1458	24	5/10; 1900	24	5/10; 2258	4							24[d]
	5/9/13; 1350-1500	5/9; 1538						5/10; 2257, 2258	25 (3)	5/11; 0309	22 (2)					
	5/9/13; 1700-1800	5/9; 1838						5/10; 2258	4			5/11; 0659	24	5/11; 1103	24	

a: One fish released during transfer on 3/6; 1455.

b: Three fish released during transfer on 4/4; 1158.

c: One fish released during transfer on 5/8; 1200.

d: Fish given to CA/NV Fish Health Center for fish health studies.

e: One fish culled after transport (not included in the release number of 27 or counted as a mortality).

Table 2. Characteristics Assessed for Steelhead Smolt Condition and Short-term Survival

Characteristic	Normal	Abnormal
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 3. The parameters assessed during the necropsy of dummy tagged steelhead held for 70 days (tag retention) during the 2013 Six-Year Study. The score from each of the six numerical parameters was summed to generate a composite score (0–7) to measure possible tagging effects on survival. The anterior and posterior sutures were scored separately and each was included in the composite score. Parameters were provided by T. Liedtke, USGS.

Composite Score Parameter	Score	Score Definition
Suture present?	0	No
(Anterior/Posterior assessed separately)	1	Yes
Suture pattern intact	0	Yes
	1	No
Incision apposition	0	Completely closed, perfect apposition
	1	Incision partially open due to gape or overlap
	2	Incision completely open (>75%)
Fungus present?	0	No fungus present
	1	Fungus present
Organ inclusion	0	No organ damage present (i.e., no signs of damage either due to the surgery or the presence of the tag). Tags can be adhered to organs as part of encapsulation process, but that does not constitute damage
	1	Some organ damage present. I.e., the suture captures, punctures, or entangles the pyloric caeca, stomach, spleen, or intestine
Signs of tag expulsion	0	No signs of tag expulsion. I.e., no signs that the tag is being forced out through the incision or the lateral body wall. Simple encapsulation may be present
	1	Some bulging or lateral pressure or expulsion process obvious or complete. (i.e., some evidence that the tag is causing pressure on the incision or the lateral body wall or tag is obviously being forced out through the incision or the lateral body wall, or the tag is already out

Table 4. Names and descriptions of receivers and hydrophones used in the 2013 steelhead tagging study, with receiver codes used in Figure 11, the survival model (Figures 12, 13), and in data processing by the United States Geological Survey (USGS). The release site was located at Durham Ferry.

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°41'10.80"N	121°15'24.12"W	DFU1	A0a	300856 (unit stolen)
San Joaquin River near Durham Ferry upstream of the release site, downstream node	37°41'13.56"N	121°15'26.04"W	DFU2	A0b	300857
San Joaquin River near Durham Ferry; release site (no acoustic hydrophone located here)	37°41'13.24"N	121°15'48.41"W	DF	A1	
San Joaquin River near Durham Ferry downstream of the release site, upstream node	37°41'32.16"N	121°16'15.24"W	DFD1	A2a	300858
San Joaquin River near Durham Ferry downstream of the release site, downstream node	37°41'37.41"N[a]	121°16'13.47"W[a]	DFD2	A2b	460010/460021
San Joaquin River near Banta Carbona	37°43'39.42"N	121°17'55.02"W	BCA	A3	300859
San Joaquin River near Mossdale Bridge, upstream node	37°47'33.06"N	121°18'25.62"W	MOSU	A4a	300860
San Joaquin River near Mossdale Bridge, downstream node	37°47'36.18"N	121°18'24.48"W	MOSD	A4b	300861
San Joaquin River upstream of Head of Old River, upstream node (not used in survival model)	37°48'20.19"N[a]	121°19'10.38"W[a]	HORU	B0a	300862/450048
San Joaquin River upstream of Head of Old River, downstream node (not used in survival model)	37°48'19.11"N[a]	121°19'14.37"W[a]	HORD	B0b	300863/455000
San Joaquin River near Lathrop, upstream	37°48'38.70"N[a]	121°19'16.56"W[a]	SJLU	A5a	300864/300865
San Joaquin River near Lathrop, downstream	37°48'38.85"N[a]	121°19'14.49"W[a]	SJLD	A5b	450020/450023
San Joaquin River near Garwood Bridge, upstream	37°56'06.54"N[a]	121°19'48.21"W[a]	SJGU	A6a	450045/300930
San Joaquin River near Garwood Bridge, downstream	37°56'07.32"N[a]	121°19'49.56"W[a]	SJGD	A6b	450046/300931
San Joaquin River at Stockton Navy Drive Bridge	37°56'48.30"N	121°20'22.02"W	SJNB	A7	300875
Burns Cutoff at Rough and Ready Island (not used in survival model)	37°56'24.72"N	121°21'3.66"W	RRI	R1	300876
San Joaquin River Shipping Channel, upstream (not used in survival model)	37°59'41.70"N	121°26'17.52"W	SJSU	A8a	300881
San Joaquin River Shipping Channel, downstream (not used in survival model)	37°59'43.86"N	121°26'20.64"W	SJSD	A8b	300882
San Joaquin River at MacDonald Island, upstream	38°01'04.86"N[a]	121°27'45.93"W[a]	MACU	A9a	300878/300879
San Joaquin River at MacDonald Island, downstream	38°01'26.34"N[a]	121°27'58.29"W[a]	MACD	A9b	300883/300884
San Joaquin River near Medford Island, east	38°03'11.07"N[a]	121°30'41.07"W[a]	MFE	A10a	300885/300886
San Joaquin River near Medford Island, west	38°03'13.44"N[a]	121°30'47.43"W[a]	MFW	A10b	300887/300888

a = Average latitude and longitude given for sites with multiple hydrophones or for sites with multiple locations throughout the study

Table 4. (Continued)

Individual Receiver Name and Description	Hydrophone Location		Receiver Code	Survival Model Code	Data Processing Code
	Latitude (°N)	Longitude (°W)			
Old River East, near junction with San Joaquin, upstream	37°48'41.85"N[a]	121°20'14.52"W[a]	OREU	B1a	300866/300867
Old River East, near junction with San Joaquin, downstream	37°48'43.65"N[a]	121°20'08.10"W[a]	ORED	B1b	450021/450022
Old River South, upstream	37°49'13.92"N	121°22'39.42"W	ORSU	B2a	300868
Old River South, downstream	37°49'12.00"N	121°22'40.14"W	ORSD	B2b	300869
Old River at Highway 4, upstream	37°53'37.89"N[a]	121°34'01.53"W[a]	OR4U	B3a	300900/300901
Old River at Highway 4, downstream	37°53'42.15"N[a]	121°33'59.64"W[a]	OR4D	B3b	300902/300903
Middle River Head, upstream	37°49'29.28"N	121°22'48.60"W	MRHU	C1a	300870
Middle River Head, downstream	37°49'29.94"N	121°22'50.76"W	MRHD	C1b	300871
Middle River at Highway 4, upstream	37°53'45.48"N	121°29'36.24"W	MR4U	C2a	300898
Middle River at Highway 4, downstream	37°53'45.96"N	121°29'33.72"W	MR4D	C2b	300899
Middle River at Empire Cut, upstream receiver (not used in survival model)	37°56'28.38"N	121°31'57.36"W	MREU	C3a	300873
Middle River at Empire Cut, downstream receiver (not used in survival model)	37°56'34.26"N	121°31'54.48"W	MRED	C3b	300872
Radial Gate at Clifton Court Forebay, upstream (in entrance channel to forebay), array 1	37°49'48.09"N	121°33'23.80"W	RGU1	D1a	300894
Radial Gate at Clifton Court Forebay, upstream, array 2	37°49'46.57"N	121°33'25.10"W	RGU2	D1b	300895
Radial Gate at Clifton Court Forebay, downstream (inside forebay), array 1 in dual array	37°49'50.40"N	121°33'25.32"W	RGD1	D2a	300896/460011
Radial Gate at Clifton Court Forebay, downstream, array 2 in dual array	37°49'47.34"N	121°33'28.74"W	RGD2	D2b	300897/460009
Central Valley Project trashracks, upstream	37°49'0.79"N	121°33'30.40"W	CVPU	E1a	300889/460012/ 460023
Central Valley Project trashracks, downstream	37°48'59.93"N	121°33'32.20"W	CVPD	E1b	300890
Central Valley Project holding tank (all holding tanks pooled)	37°48'57.04"N	121°33'32.86"W	CVPtank	E2	300891
Turner Cut, east (closer to San Joaquin)	37°59'30.03"N[a]	121°27'17.52"W[a]	TCE	F1a	300880/450043
Turner Cut, west (farther from San Joaquin)	37°59'28.53"N[a]	121°27'19.83"W[a]	TCW	F1b	300877/450044
San Joaquin River at Jersey Point, east (upstream)	38°03'22.84"N[a]	121°41'11.41"W[a]	JPE	G1a	300912 - 300920
San Joaquin River at Jersey Point, west (downstream)	38°03'18.58"N[a]	121°41'17.21"W[a]	JPW	G1b	300921 - 300929
False River, west (closer to San Joaquin)	38°03'26.61"N[a]	121°40'14.13"W[a]	FRW	H1a	300906/300907
False River, east (farther from San Joaquin)	38°03'24.99"N[a]	121°40'09.69"W[a]	FRE	H1b	300904/300905

a = Average latitude and longitude given for sites with multiple hydrophones or for sites with multiple locations throughout the study

Table 4. (Continued)

Individual Receiver Name and Description	Hydrophone Location		Receiver Code	Survival Model Code	Data Processing Code
	Latitude (°N)	Longitude (°W)			
Chipps Island (aka Mallard Island), east (upstream)	38°02'53.85"N[a]	121°55'51.35"W[a]	MAE	G2a	300933 - 300943, 300979
Chipps Island (aka Mallard Island), west (downstream)	38°02'57.25"N[a]	121°56'0.90"W[a]	MAW	G2b	300980 - 300983, 300985 - 300990, 301153/301154
Threemile Slough, south (not used in survival model)	38°06'27.72"N[a]	121°41'01.98"W[a]	TMS	T1a	300910-300911
Threemile Slough, north (not used in survival model)	38°06'41.22"N[a]	121°40'59.19"W[a]	TMN	T1b	300908/300909

a = Average latitude and longitude given for sites with multiple hydrophones or for sites with multiple locations throughout the study

Table 5. Environmental monitoring sites used in predator decision rule and route entrainment analysis for 2013 steelhead study. Database = CDEC (http://cdec.water.ca.gov/) or Water Library (http://www.water.ca.gov/waterdatalibrary/).

Environmental Monitoring Site			Detection Site	Data Available					Database
Site Name	Latitude (°N)	Longitude (°W)		River Flow	Water Velocity	River Stage	Pumping	Reservoir Inflow	
CLC	37.8298	121.5574	RGU, RGD	No	No	No	No	Yes	CDEC
FAL	38.0554	121.6672	FRE/FRW	Yes	Yes	Yes	No	No	CDEC
GLC	37.8201	121.4497	ORS	Yes	Yes	Yes	No	No	CDEC
MAL	38.0428	121.9201	MAE/MAW	No	Yes	Yes	No	No	CDEC
MDM	37.9425	121.5340	MR4, MRE	Yes	Yes	Yes	No	No	CDEC[a]
MRU	37.8339	121.3860	MRU	Yes	Yes	No	No	No	CDEC
MSD	37.7860	121.3060	HOR, MOS	Yes	Yes	Yes	No	No	Water Library
ODM	37.8101	121.5419	CVP	Yes	Yes	Yes	No	No	CDEC
OH1	37.8080	121.3290	ORE	Yes	Yes	Yes	No	No	Water Library[b]
OH4	37.8900	121.5697	OR4	Yes	Yes	Yes	No	No	CDEC
PRI	38.0593	121.5575	SJS, MAC, MFE/MFW	Yes	Yes	Yes	No	No	CDEC
RMID040	37.8350	121.3838	MRH	No	No	Yes	No	No	Water Library
ROLD040	37.8286	121.5531	RGU, RGD	No	No	Yes	No	No	Water Library
SJG	37.9351	121.3295	SJG, SJNB, RRI	Yes	Yes	Yes	No	No	CDEC
SJJ	38.0520	121.6891	JPE/JPW	Yes	Yes	Yes	No	No	CDEC
SJL	37.8100	121.3230	SJL	Yes	Yes	Yes	No	No	Water Library
TRN	37.9927	121.4541	TCE/TCW	Yes	Yes	Yes	No	No	CDEC
TRP	37.8165	121.5596	CVP/CVPtank	No	No	No	Yes	No	CDEC
TSL	38.1004	121.6866	TMS/TMN	Yes	Yes	Yes	No	No	CDEC
VNS	37.6670	121.2670	DFU, DFD, BCA	Yes	No	Yes	No	No	CDEC
WCI	37.8316	121.5541	RGU, RGD	Yes	Yes	No	No	No	Water Library

a = California Water Library was used for river stage

b = CDEC was used for river stage.

Table 6a. Cutoff values used in predator filter in 2013. Observed values past cutoff or unmet conditions indicate a predator. ID = Interior Delta. Time durations are in hours unless otherwise specified. See Table 6b for Flow, Water Velocity, Extra Conditions, and Comment. Footnotes refer to both this table and Table 6b.

Detection Site	Previous Site	Residence Time[a] (hr)			Migration Rate[c, d] (km/hr)		Time since last visit (hr)	BLPS (Magnitude)	No. of Visits	No. of Cumulative Upstream Forays
		Near Field	Mid-field	ID/Facilities[b]						
		Maximum	Maximum	Maximum	Minimum	Maximum	Maximum	Maximum	Maximum	Maximum
DFU	DF	500	1,000		0	4			1	0
	DFU, DFD	500	1,000		0	4			3	2
DFD	DF	500	1,000		0	4.5			1	0
	DFU, DFD	500	1,000		0	4.5			10 (15[g])	0 (2[g])
	BCA, MOS	500 (0[g])	1,000 (50[g])		0.2 (100[g])	4 (NA[g])			3	2
BCA	DF	30 (1000[g])	60 (1000[g])		0	4.5		4	1	0
	DFD	30 (1000[g])	60 (1000[g])		0	4.5		4	3	0
	BCA	60 (1000[g])	340 (1000[g])						5	1
	MOS	1	2		0.1	4		4	2	2
MOS	DFU	50 (100[g])	100 (200[g])		0.1	6		4.5	2 (1[g])	0
	DF, DFD	50 (100[g])	100 (200[g])		0.1	6		4.5	1	0
	BCA	50 (100[g])	100 (200[g])		0	6		4.5	2	0
	MOS	30	250						3	1
	HOR	50	100		0	6		4.5	2	1
SJL	HOR	24	48		0.1	6	15	4.5	2	0
	SJL	5	164 (89[g])						2	1
	ORE	5	10		0.4	6	15		1	0
	SJG	0.1	10		1.5	4		4.5	2	0
SJG	SJL	30	60		0.1	6		4.5	2	0
	SJG	15	89						5	1
	SJNB, RRI	10	20		0.2	4		4.5	2	3

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 = Interior Delta residence time (Facilities residence time in parentheses) after leaving first site in Interior Delta (or Facilities, respectively)

c = Approximate migration rate calculated on most direct pathway

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

g = See comments for alternate criteria

Table 6a. (Continued)

Detection Site	Previous Site	Residence Time[a] (hr)			Migration Rate[c, d] (km/hr)		Time since last visit (hr)	BLPS (Magnitude)	No. of Visits	No. of Cumulative Upstream Forays
		Near Field	Mid-field	ID/Facilities[b]						
		Maximum	Maximum	Maximum	Minimum	Maximum	Maximum	Maximum	Maximum	Maximum
SJNB	SJG	30	60		0.1	6		4.5	1	0
	SJNB	15	105						2	4
	RRI	15	30		0.1	6			2	0
RRI	SJG	30	60		0.1	6		4.5	1	0
	RRI	15	96						2	4
	SJNB	15	30		0.1	6			2	0
SJS	SJNB, RRI	35 (20[g])	70 (40[g])		0.1 (0.3[g])	6		4.5	1	0
	SJS	30 (15[g])	134 (119[g])						2	4
	MAC	15	30		0.3	4	24	4.5	3	4
MAC	SJS	35 (20[g])	70 (40[g])		0.1 (0.3[g])	6	24	4.5	1	0
	MFE/MFW	15	30		0.5	4	36	4.5	2	4
	TCE/TCW	15	30		0.1	6	24		2	1
MFE/MFW	RRI, MAC	35 (20[g])	70 (40[g])		0.1 (0.3[g])	6		4.5	1	0
	MFE/MFW	10	150						2	4
	MRE	35	70		0.1	4.5			1	0
	OLD	10	20		0.1	4.5			0	0
	JPE/JPW	10	20		1.5	4		4.5	1	0
HOR	DF, DFD, BCA, MOS	12 (100[g])	24 (200[g])		0	6		4.5	2	0
	HOR	12	250						2	1
	SJL, ORE	5	10		0.1 (0.2[g])	6	15	4.5	2	2
ORE	HOR, MOS	15	30		0.1 (0.2[g])	6	15	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 = Interior Delta residence time (Facilities residence time in parentheses) after leaving first site in Interior Delta (or Facilities, respectively)

c = Approximate migration rate calculated on most direct pathway

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

g = See comments for alternate criteria

Table 6a. (Continued)

Detection Site	Previous Site	Residence Time[a] (hr) Near Field	Mid-field	ID/Facilities[b]	Migration Rate[c, d] (km/hr)		Time since last visit (hr)	BLPS (Magnitude)	No. of Visits	No. of Cumulative Upstream Forays
		Maximum	Maximum	Maximum	Minimum	Maximum	Maximum	Maximum	Maximum	Maximum
ORE	ORE	5	70						3	1
	SJL	7	14		0.4	6	15		2	0
	ORS, MRH	1	2		0.6	4	24	5	2	1
ORS	ORE	24	48		0.1	6		4.5	1	0
	ORS	12	220						4	1
	MRH	12	24		0.2	6	100		1	0
	OR4, MR4	12	24		0.3	4	100	4.5	2	1
	RGU, CVP	12	24		0.3	4	200	4.5	2	1 (2[g])
OR4	ORS, MRH	100	200	120 (10)	0.2	4.5	200	4.5	2	0
	ORE	100	200		0.2	4.5	200	4.5	1	0
	RGU	100	200	120 (10)	0	4.5	600	4.5	15	4
	CVP	100	200	120 (10)	0.1	4.5	200	4.5	15	4
	OR4	100	700	120 (10)					15	4
	TMN/TMS	30	60	120 (10)	0.2	4		4.5	1	0
	MRE	30	60	120 (10)	0	4.5	200		15	0
	MR4	100	200	120 (10)	0.1	4.5	200		4	0
MRH	ORE	10	20		0	6	48		1	0
	ORS	2	4		0.2	6	48		1	1
	MRH	2	33						0	0
MR4	ORS, MRH	15	30	120 (10)	0.1	4.5		4.5	1	0
	MR4	10	75	120 (10)					2	0
	MRE	15	30	120 (10)	0.1	4	100	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 = Interior Delta residence time (Facilities residence time in parentheses) after leaving first site in Interior Delta (or Facilities, respectively)

c = Approximate migration rate calculated on most direct pathway

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

g = See comments for alternate criteria

Table 6a. (Continued)

Detection Site	Previous Site	Residence Time[a] (hr)			Migration Rate[c, d] (km/hr)		Time since last visit (hr)	BLPS (Magnitude)	No. of Visits	No. of Cumulative Upstream Forays
		Near Field	Mid-field	ID/Facilities[b]						
		Maximum	Maximum	Maximum	Minimum	Maximum	Maximum	Maximum	Maximum	Maximum
MR4	RGU	15	30	120 (10)	0.1	4.5	100		1	0
	CVP	15	30	120 (10)	0.1	4.5	100		1	0
MRE	OR4	30	60	120 (10)	0.1	4.5			1	0
	MR4	50	100	120 (10)	0.1	4.5	100	4.5	1	0
	MRE	30	160	120 (10)					4	0
	TCE/TCW	50	100		0.1	4.5	100		1	0
RGU/RGD	ORS, MRH	80 (336[i]; 800[j])		120 (100)	0.08	4.5	200	4.5	1	0
	ORE	80 (336[i]; 800[j])			0.08	4.5	200	4.5	1	0
	CVP	80 (336[i]; 800[j])		120 (100)	0.02	4.5	200	4.5	3	0
	OR4	80 (336[i]; 800[j])		120 (100)	0	4	200	4.5	3	2
	MR4	10 (336[i])[k]		120 (100)	0.1	4.5	200		1	0
CVP	ORS, MRH	150	300	120 (100)	0.1	4.5	200	4	1	0
	HOR	150	300	120 (100)	0.1	4.5	200	4	1	0
	DFU, BCA	150	300		0.1	6	200		1	0
	CVP	100	560	180 (100)					4	3
	CVPtank	100	663	180 (100)	0	1			5	3

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 = Interior Delta residence time (Facilities residence time in parentheses) after leaving first site in Interior Delta (or Facilities, respectively)

c = Approximate migration rate calculated on most direct pathway

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

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

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

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

Table 6a. (Continued)

Detection Site	Previous Site	Residence Time[a] (hr)			Migration Rate[c, d] (km/hr)		Time since last visit (hr)	BLPS (Magnitude)	No. of Visits	No. of Cumulative Upstream Forays
		Near Field	Mid-field	ID/Facilities[b]						
		Maximum	Maximum	Maximum	Minimum	Maximum	Maximum	Maximum	Maximum	Maximum
CVP	RGU	100 (150[g])	200 (300[g])	120(180[g]) (100)	0	4	200	4	10 (1[g])	9 (3[g])
	OR4	100 (150[g])	200 (300[g])	120(180[g]) (100)	0.1	4	200	4	10 (1[g])	9 (3[g])
	MR4	150	300	180 (100)	0.1	4.5	200		1	0
CVPtank	CVP	20	150	120 (100)	0				2	3
TCE/TCW	SJS	24	48		0.1	6		4.5	1	0
	TCE/TCW	12	130						2	4
	MAC	12	24		0.2	6			1	4
	MRE	12	24		0.2	4.5			1	4
JPE/JPW	MAC, MFE/MFW	40	80		0.2	4.5	30	4.5	1	0
	TMN/TMS	40	80		0.2	4.5	30	4.5	2	4
	MRE, OR4	40	80		0.2	4.5	30	4.5	1	0
	CVPtank	40	80		0.2	3.4	30	4.5	1	0
	RGU	40	80		0	0.8	30	4.5	1	0
	JPE/JPW	20	80						3	0
	FRE/FRW	20	80		0.1	7	30		3	0
MAE/MAW	MAC, MRE	40	200		0.2	7		4.5	1	0
	CVP, CVPtank	40	200		0.2	3		4.5	1	0
	RGU/RGD	40	200		0	2		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 = Interior Delta residence time (Facilities residence time in parentheses) after leaving first site in Interior Delta (or Facilities, respectively)

c = Approximate migration rate calculated on most direct pathway

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

g = See comments for alternate criteria

Table 6a. (Continued)

Detection Site	Previous Site	Residence Time[a] (hr)			Migration Rate[c, d] (km/hr)		Time since last visit (hr)	BLPS (Magnitude)	No. of Visits	No. of Cumulative Upstream Forays
		Near Field	Mid-field	ID/Facilities[b]						
		Maximum	Maximum	Maximum	Minimum	Maximum	Maximum	Maximum	Maximum	Maximum
MAE/MAW	JPE/JPW, FRE/FRW, TMN/TMS	40	200		0.2	7		4.5	2	0
FRE/FRW	MAE/MAW	20	100						2	0
	MFE/MFW, OR4, MRE	30	80		0.1	4.5	15	4.5	1	0
	JPE/JPW	30	80		0.1	7	15		3	0
TMN/TMS	FRE/FRW	10	80						3	0
	MAC, MFE/MFW	6	30		0.2	4.5	15	4.5	1	0
	MRE	6	30		0.2	4.5	15	4.5	1	0
	RGU/RGD, CVPtank	6	30		0.1 (0.2[g])	4.5	15	4.5	1	0
	TMN/TMS	3	67						2	0
	JPE/JPW, FRE/FRW	6	30		0.3	4.5	15	4.5	2	4

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

b = Interior Delta residence time (Facilities residence time in parentheses) after leaving first site in Interior Delta (or Facilities, respectively)

c = Approximate migration rate calculated on most direct pathway

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

g = See comments for alternate criteria

Table 6b. Cutoff values used in predator filter in 2013. Observed values past cutoff or unmet conditions indicate a predator. Time durations are in hours unless otherwise specified. Footnotes, Extra Conditions and Comment refer to both this table and Table 6a.

		Flow[e] (cfs)		Water Velocity[e] (ft/sec)			Extra Conditions	Comment
Detection Site	Previous Site	At arrival	At departure[f]	At arrival	At departure[f]	Average during transition		
DFU	DF						Travel time < 300	
	DFU, DFD						Travel time < 300 (600[g])	Alternate values if coming from DFU
DFD	DF						Travel time < 500	
	DFU, DFD						Travel time < 350 (400[g])	Alternate values if coming from DFD
	BCA, MOS							Alternate values if coming from MOS
BCA	DF						Travel time < 700	Alternate values if next transition is downstream
	DFD						Travel time < 700	Alternate values if next transition is downstream
	BCA						Maximum of 3 visits if arrival flow > 12000 cfs; Travel time < 200 (500[g])	Alternate values if next transition is downstream; otherwise, known presence in detection range < 30
	MOS		<5000					
MOS	DFU							Alternate values if next transition is downstream
	DF, DFD	>11000					Allow 2 visits, travel time < 700 if arrival flow < 11000 cfs	Alternate values if next transition is downstream

e = Classified as predator if flow or velocity condition, if any, is violated.

f = Condition at departure from previous site.

g = See comments for alternate criteria

Table 6b. (Continued)

Detection Site	Previous Site	Flow[e] (cfs) At arrival	Flow[e] (cfs) At departure[f]	Water Velocity[e] (ft/sec) At arrival	Water Velocity[e] (ft/sec) At departure[f]	Water Velocity[e] (ft/sec) Average during transition	Extra Conditions	Comment
MOS	BCA	<11000					Travel time < 700; allow 1 visit, travel time < 200 if arrival flow > 11000 cfs	Alternate values if next transition is downstream
	MOS	<14000				<2.7	Travel time < 35	
	HOR	<14000				<3	Travel time < 60	
SJL	HOR						Regional residence time < 96	
	SJL					<1.9	Regional residence time < 328 (178[g]); travel time < 200 (50[g])	Alternate values if average transition water velocity outside range
	ORE						Regional residence time < 20 on departure from previous site and from current site	
	SJG					<1	Regional residence time < 20	
SJG	SJL							
	SJG	<1000 (>-1000)[h]	>-1000 (<1000)[h]	<0.5 (>-0.5)[h]	>-0.5 (<0.5)[h]	<0.8		
	SJNB, RRI	<3500	<3500	<1.1	<1.1	<1.1		
SJNB	SJG						Migration rate < 2 if average water velocity < -0.15 and arrival flow < 2000; known presence in detection range < 12	
	SJNB						Travel time < 20; known presence in detection range < 9	
	RRI						Known presence in detection range < 9	

e = Classified as predator if flow or velocity condition, if any, is violated.

f = Condition at departure from previous site.

g = See comments for alternate criteria

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

Table 6b. (Continued)

Detection Site	Previous Site	Flow^e (cfs) At arrival	Flow^e (cfs) At departure^f	Water Velocity^e (ft/sec) At arrival	Water Velocity^e (ft/sec) At departure^f	Water Velocity^e (ft/sec) Average during transition	Extra Conditions	Comment
RRI	SJG						Migration rate < 2 if average water velocity < -0.15 and arrival flow < 2000	
	RRI						Travel time < 20	
	SJNB							
SJS	SJNB, RRI					-0.2 to 0.5		Alternate values if average transition water velocity is outside range
	SJS					<0.2		Alternate values if average transition water velocity is outside range
	MAC			-1 to 1		<0.2	Known presence in detection range < 15 (8^g)	Alternate values if arrival water velocity is outside range
MAC	SJS					-0.1 to 0.4	No prior transition to ID from lower SJR	Alternate values if average transition water velocity is outside range
	MFE/MFW			-0.8 to 0.8			Known presence in detection range < 15 (8^g)	Alternate values if arrival water velocity is outside range
	TCE/TCW							
MFE/MFW	RRI, MAC					-0.1 to 0.4	Maximum of 2 visits if coming from MAC; no prior transition to ID from lower SJR if coming from RRI	Alternate values if average transition water velocity is outside range

e = Classified as predator if flow or velocity condition, if any, is violated.

f = Condition at departure from previous site.

g = See comments for alternate criteria

Table 6b. (Continued)

Detection Site	Previous Site	Flow[e] (cfs)		Water Velocity[e] (ft/sec)			Extra Conditions	Comment
		At arrival	At departure[f]	At arrival	At departure[f]	Average during transition		
MFE/MFW	MFE/MFW						Travel time < 60	
	MRE		>-1500		>-0.1		No prior transition to ID from lower SJR	
	JPE/JPW	<5000		<0.1		<0.1	No prior transition to ID from lower SJR	Not allowed
HOR	DF, DFD, BCA, MOS	<11000					Travel time < 700; 1 visit allowed and travel time < 200 if arrival flow is outside range	Alternate values if next transition is downstream
	HOR	<14000				<2.7	Travel time < 35	
	SJL, ORE	<14000				< 3	Regional residence time < 20 at departure from previous site	Alternate values if coming from ORE
ORE	HOR, MOS						Regional residence time < 60	Alternate values if coming from MOS
	ORE						Regional residence time < 140; travel time < 40	
	SJL	>200					Regional residence time < 20 on departure from previous site and < 28 from current site; no previous transition via HOR from SJR downstream of HOR	
	ORS, MRH	<3000					Regional residence time < 370	
ORS	ORE					>1.8	Travel time < 250 if average transition water velocity is outside range	
	ORS						Travel time < 100	
	MRH							
	OR4, MR4					<1.5		
	RGU, CVP					<1.5		Alternate value if coming from CVP
OR4	ORS, MRH	>-1500		>-0.5				
	ORE	>-1500		>-0.5				

e = Classified as predator if flow or velocity condition, if any, is violated.

f = Condition at departure from previous site.

Table 6b. (Continued)

		Flow[e] (cfs)		Water Velocity[e] (ft/sec)			Extra Conditions	Comment
Detection Site	Previous Site	At arrival	At departure[f]	At arrival	At departure[f]	Average during transition		
OR4	RGU	>-1500		>-0.5			Travel time < 600; CCFB inflow < 3000 cfs on departure[f]	
	CVP	>-1500	>-1500	>-0.5	>-1.0		CVP pumping < 1500 cfs on departure[f]	
	OR4	<1500 (>-1500)[h]	>-1500 (<1500)[h]	<0.5 (>-0.5)[h]	>-0.5 (<0.5)[h]		Travel time < 500	
	TMN/TMS	<1500		<0.5			No prior transition from lower SJR through HOR	Not allowed
	MRE	<1500	<1500	<0.5	<0.5		Known presence in detection range < 10 hours; travel time < 200	
	MR4							
MRH	ORE						Travel time < 250	
	ORS							
	MRH						Travel time < 15	Not allowed
MR4	ORS, MRH							
	MR4	<-5500 (>-6000)[h]	>-6000 (<-5500)[h]	<-0.5 (>-0.5)[h]	>-0.5 (<-0.5)[h]		Travel time < 30	
	MRE	<2500	<1500	<0.25	<0.1	<0.1		
	RGU						CCFB inflow < 3000 cfs on departure[f]	
	CVP						CVP pumping < 4000 cfs on departure[f]	
MRE	OR4	>-1500	>-1500	>-0.1	>-0.5		Known presence in detection range < 10 hours	
	MR4	>-1500		>-0.1				
	MRE	<1500 (>-1500)[h]	>-1500 (<1500)[h]	<0.1 (>-0.1)[h]	>-0.1 (<0.1)[h]		Travel time < 100	
	TCE/TCW	<1500	<200	<0.1	<0.05		No prior detection in N/W region of study area	

e = Classified as predator if flow or velocity condition, if any, is violated.

f = Condition at departure from previous site.

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

Table 6b. (Continued)

Detection Site	Previous Site	Flow[e] (cfs) At arrival	Flow[e] (cfs) At departure[f]	Water Velocity[e] (ft/sec) At arrival	Water Velocity[e] (ft/sec) At departure[f]	Water Velocity[e] (ft/sec) Average during transition	Extra Conditions	Comment
RGU/RGD	ORS, MRH							
	ORE							
	CVP		>-1500		>-1.0		CVP pumping < 4000 cfs at departure[f]	
	OR4		<2000		<0.8		Travel time < 200	
	MR4							
CVP	ORS, MRH							
	HOR							
	DFU, BCA							Allowed only for release group 1
	CVP						Travel time < 150; CVP pumping > 800 cfs on arrival	
	CVPtank						Travel time < 3	
	RGU	<3000		<1.5			Travel time < 200	Alternate values if came via lower SJR
	OR4	<3000	<2000	<1.5	<0.8		CVP pumping > 800 cfs on arrival	Alternate values if came from lower SJR
	MR4							
CVPtank	CVP						Travel time < 100	
TCE/TCW	SJS			<0.1			No prior transition to ID from lower SJR	
	TCE/TCW	<1500 (>-1500)[h]	>-1500 (<1500)[h]	<0.3 (>-0.3)[h]	>-0.3 (<0.3)[h]		Travel time < 60	
	MAC			<0.1		<0.1	No prior transition to ID from lower SJR	
	MRE	>-500	>-1500	>-0.1	>-0.1	>-0.2		
JPE/JPW	MAC, MFE/MFW						No prior detections in N/W region of study area	

e = Classified as predator if flow or velocity condition, if any, is violated.

f = Condition at departure from previous site.

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

Table 6b. (Continued)

Detection Site	Previous Site	Flow[e] (cfs) At arrival	Flow[e] (cfs) At departure[f]	Water Velocity[e] (ft/sec) At arrival	Water Velocity[e] (ft/sec) At departure[f]	Water Velocity[e] (ft/sec) Average during transition	Extra Conditions	Comment
JPE/JPW	TMN/TMS							
	MRE, OR4							
	CVPtank						Travel time < 2	Trucking release sites are downstream of JPE/JPW
	RGU						Travel time < 300	Trucking release sites are downstream of JPE/JPW
	JPE/JPW						Travel time < 50	
	FRE/FRW						No minimum travel time	
MAE/MAW	MAC, MRE			>-0.2				
	CVP, CVPtank			>-0.2				
	RGU/RGD			>-0.2			Travel time < 500	
	JPE/JPW, FRE/FRW, TMN/TMS MAE/MAW			>-0.2				
FRE/FRW	MFE/MFW, OR4, MRE						No prior detection in N/W region of study area if coming from MFE/MFW	
	JPE/JPW						No minimum travel time	
	FRE/FRW							
TMN/TMS	MAC, MFE/MFW		>-50000		> -1		No prior detection in N/W region of study area	
	MRE		>0		>0			
	RGU/RGD, CVPtank							Alternate value if come from CVPtank
	TMN/TMS	<0 (>0)[h]	>0 (<0)[h]	<0 (>0)[h]	>0 (<0)[h]			
	JPE/JPW, FRE/FRW							

e = Classified as predator if flow or velocity condition, if any, is violated.

f = Condition at departure from previous site.

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

Table 7. Water temperature and dissolved oxygen in the transport tank after loading prior to transport, after transport, and in the river at the Durham Ferry release site just prior to placing fish in holding containers, and the number of mortalities after transport and prior to release for steelhead as part of the Six-Year Study in 2013.

Date	River Temp (˚C)	River DO (mg/L)
3/5/2013	15.5	9.95
3/5/2013	15.2	10.08
3/5/2013	14.6	9.90
03/06/13	14.1	10.12
03/06/13	14.7	10.42
03/06/13	13.9	10.62
03/07/13	13.7	10.26
03/07/13	14.2	10.46
03/07/13	14.0	10.44
4/2/2013	18.9	9.93
4/2/2013	20.2	11.49
4/2/2013	20.6	12.56
4/3/2013	19.2	9.72
4/3/2013	20.8	10.85
4/3/2013	21.5	11.81
4/4/2013	19.8	10.04
4/4/2013	20.2	11.24
4/4/2013	20.9	12.65
05/07/13	15.8	9.91
05/07/13	15.8	10.05
05/07/13	16.0	10.09
05/08/13	15.4	9.75
05/08/13	16.2	9.81
05/08/13	16.4	10.00
05/09/13	16.2	9.95
05/09/13	16.7	10.09
05/09/13	16.9	10.10

Table 8. Results of dummy tagged steelhead evaluated after being held for 48 hours at the release site as part of the 2013 Six-Year Study. Only live fish at the end of the 48 hour holding period were evaluated for the five condition characteristics or measured.

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	3/7/13, 1130	198.3 (21.5)	0/12	7.9 (5.0)	12/12	12/12	12/12	12/12
Durham Ferry	3/8/13, 1130	212.9 (11.0)	0/12	10.4 (7.8)	12/12	12/12	12/12	12/12
Durham Ferry	4/4/13, 1130	213.5 (15.9)	0/12	13.3 (8.9)	12/12	12/12	12/12	12/12
Durham Ferry	4/5/13, 1130	210.4 (29.9)	0/12	5.0 (5.2)	12/12	12/12	12/12	12/12
Durham Ferry	5/9/13, 1130	226.1 (15.8)	0/12	17.5 (6.9)	12/12	12/12	12/12	12/12
Durham Ferry	5/10/13, 1115	224.8 (15.5)	1/12	27.3 (16.2)	11/11	11/11	11/11	11/11

Table 9. Scores of six criteria used in the assessment of steelhead held for 70 days as part of the tag retention study during the 2013 Six-Year Study. The score from each of the six numerical parameters (see Table 3 for explanation of scoring of variables) was summed to generate a composite score (0–8) of possible tagging effects on survival. The anterior and posterior sutures were scored separately and each was included in the composite score. Parameters were provided by T. Liedtke, USGS.

Fish#	Suture Present (Anterior/Posterior)	Suture Pattern	Incision Apposition	Fungus	Organ Inclusion	Tag Expulsion	Overall Score
1	0/0	0	0	0	0	0	**2**
2	1/1	1	0	1	0	0	**2**
3	0/0	0	0	0	0	0	**2**
4	0/0	0	0	0	1	0	**3**
5	0/0	0	0	0	0	0	**2**
6	0/0	0	0	0	1	0	**3**
7	1/1	0	0	0	1	0	**1**
8	1/0	0	0	0	0	0	**1**
9	0/1	0	0	0	0	0	**1**
10	0/0	0	0	0	0	0	**2**
11	1/1	0	0	0	0	0	**0**
12	0/0	0	0	0	0	0	**2**
13	0/0	0	0	0	0	0	**2**
14	0/1	0	0	0	0	0	**1**
15	0/1	0	0	0	0	0	**1**
16	0/1	0	0	0	0	0	**1**
17	1/1	0	0	0	1	0	**1**
18	1/1	1	0	0	1	0	**2**
19	1/1	1	0	0	1	0	**2**
20	0/0	1	0	0	0	0	**3**
21	1/1	0	0	0	0	0	**0**
22	1/1	0	0	0	1	0	**1**
23	0/1	1	0	0	0	0	**2**
24	0/1	1	0	0	1	1	**4**
25	1/1	1	0	1	1	0	**3**
26	0/0	0	0	0	0	0	**2**
27	0/0	0	0	0	0	0	**2**
28	0/0	0	0	0	0	0	**2**
29	0/1	1	0	0	1	0	**3**
30	0/0	0	0	0	0	0	**2**

Table 10. Number of tags from each release group that were detected after release in 2013, including predator-type detections and detections omitted from the survival analysis.

Release Group	1	2	3	Total
Number Released	476	477	472	1,425
Number Detected	441	447	397	1,285
Number Detected Downstream	428	426	385	1,239
Number Detected Upstream of Study Area	441	446	341	1,228
Number Detected in Study Area	305	319	311	935
Number Detected in San Joaquin River Route	85	115	85	285
Number Detected in Old River Route	284	282	273	839
Number Assigned to San Joaquin River Route	16	31	40	87
Number Assigned to Old River Route	278	279	265	822

Table 11. Number of tags observed from each release group at each detection site in 2013, including predator-type detections. Routes (SJR = San Joaquin River, OR = Old River) represent route assignment at the head of Old River. Pooled counts are summed over all receivers in array and all routes. Route could not be identified for some tags.

Detection Site	Site Code	Survival Model Code	Release Group 1	Release Group 2	Release Group 3	Total
Release site at Durham Ferry			476	477	472	1,425
Durham Ferry Upstream	DFU	A0	45	67	34	146
Durham Ferry Downstream	DFD	A2	427	423	309	1,159
Banta Carbona	BCA	A3	260	185	109	554
Mossdale	MOS	A4	304	317	305	926
Head of Old River	HOR	B0	301	312	309	922
Lathrop	SJL	A5	84	112	84	280
Garwood Bridge	SJG	A6	6	15	29	50
Navy Drive Bridge	SJNB	A7	5	14	27	46
Rough and Ready Island	RRI	R1	0	7	13	20
San Joaquin River Shipping Channel, Upstream	SJSU	A8a	1	13	20	34
San Joaquin River Shipping Channel, Downstream	SJSD	A8b	1	13	20	34
San Joaquin River Shipping Channel (Pooled)	SJS	A8	1	13	20	34
MacDonald Island Upstream	MACU	A9a	1	10	16	27
MacDonald Island Downstream	MACD	A9b	1	10	14	25
MacDonald Island (Pooled)	MAC	A9	1	10	16	27
Medford Island East	MFE	A10a	1	8	13	22
Medford Island West	MFW	A10b	1	8	13	22
Medford Island (Pooled)	MFE/MFW	A10	1	8	13	22
Turner Cut East	TCE	F1a	0	6	8	14
Turner Cut West	TCW	F1b	0	6	8	14
Turner Cut (Pooled)	TCE/TCW	F1	0	6	8	14
Old River East	ORE	B1	284	282	273	839
Old River South Upstream	ORSU	B2a	258	264	254	776
Old River South Downstream	ORSD	B2b	258	265	254	777
Old River South (Pooled)	ORS	B2	258	265	255	778
Old River at Highway 4, Upstream	OR4U	B3a	39	58	73	170
Old River at Highway 4, Downstream	OR4D	B3b	38	58	72	168
Old River at Highway 4, SJR Route	OR4	B3	0	0	2	2
Old River at Highway 4, OR Route	OR4	B3	39	58	72	169
Old River at Highway 4 (Pooled)	OR4	B3	39	58	74	171
Middle River Head, Upstream	MRHU	C1a	11	7	7	25
Middle River Head, Downstream	MRHD	C1b	11	7	7	25
Middle River Head (Pooled)	MRH	C1	11	7	7	25
Middle River at Highway 4, Upstream	MR4U	C2a	8	10	11	29
Middle River at Highway 4, Downstream	MR4D	C2b	7	10	11	28

Table 11. (Continued)

Detection Site	Site Code	Survival Model Code	Release Group 1	Release Group 2	Release Group 3	Total
Middle River at Highway 4, SJR Route	MR4	C2	0	1	3	4
Middle River at Highway 4, OR Route	MR4	C2	8	9	8	25
Middle River at Highway 4 (Pooled)	MR4	C2	8	10	11	29
Middle River near Empire Cut, Upstream	MREU	C3a	9	16	12	37
Middle River near Empire Cut, Downstream	MRED	C3b	3	10	8	21
Middle River near Empire Cut, SJR Route	MRE	C3	0	3	2	5
Middle River near Empire Cut, OR Route	MRE	C3	9	13	10	32
Middle River near Empire Cut (Pooled)	MRE	C3	9	16	12	37
Radial Gates Upstream: SJR Route	RGU	D1	0	0	1	1
Radial Gates Upstream: OR Route	RGU	D1	74	97	69	240
Radial Gates Upstream (Pooled)	RGU	D1	74	97	70	241
Radial Gates Downstream #1	RGD1	D2a	53	64	44	161
Radial Gates Downstream #2	RGD2	D2b	53	64	44	161
Radial Gates Downstream: SJR Route	RGD	D2	0	0	1	1
Radial Gates Downstream: OR Route	RGD	D2	53	66	43	162
Radial Gates Downstream (Pooled)	RGD	D2	53	66	44	163
CVP Trashrack: SJR Route	CVP	E1	0	0	3	3
CVP Trashrack: OR Route	CVP	E1	103	99	174	376
Central Valley Project Trashrack (Pooled)	CVP	E1	103	99	178	380
CVP tank: SJR Route	CVPtank	E2	0	0	0	0
CVP tank: OR Route	CVPtank	E2	30	8	32	70
Central Valley Project Holding Tank (Pooled)	CVPtank	E2	30	8	32	70
Threemile Slough South	TMS	T1a	6	9	6	21
Threemile Slough North	TMN	T1b	6	9	6	21
Threemile Slough (Pooled)	TMS/TMN	T1	6	9	6	21
Jersey Point East	JPE	G1a	15	14	29	58
Jersey Point West	JPW	G1b	15	12	29	56
Jersey Point: SJR Route	JPE/JPW	G1	0	6	10	16
Jersey Point: OR Route	JPE/JPW	G1	16	8	19	43
Jersey Point (Pooled)	JPE/JPW	G1	16	14	29	59
False River West	FRW	H1a	7	7	17	31
False River East	FRE	H1b	7	7	17	31
False River: SJR Route	FRE/FRW	H1	0	3	2	5
False River: OR Route	FRE/FRW	H1	7	5	15	27
False River (Pooled)	FRE/FRW	H1	7	8	17	32

Table 11. (Continued)

Detection Site	Site Code	Survival Model Code	Release Group 1	Release Group 2	Release Group 3	Total
Chipps Island East	MAE	G2a	46	29	59	134
Chipps Island West	MAW	G2b	47	29	60	136
Chipps Island: SJR Route	MAE/MAW	G2	0	6	10	16
Chipps Island: OR Route	MAE/MAW	G2	47	26	53	126
Chipps Island (Pooled)	MAE/MAW	G2	47	32	63	142

Table 12. Number of tags observed from each release group at each detection site in 2013 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	Total
Release site at Durham Ferry			476	477	472	1,425
Durham Ferry Upstream	DFU	A0	21	42	22	85
Durham Ferry Downstream	DFD	A2	419	402	299	1,120
Banta Carbona	BCA	A3	256	175	105	536
Mossdale	MOS	A4	304	314	302	920
Lathrop	SJL	A5	16	31	40	87
Garwood Bridge	SJG	A6	5	15	26	46
Navy Drive Bridge	SJNB	A7	2	14	21	37
MacDonald Island Upstream	MACU	A9a	1	8	13	22
MacDonald Island Downstream	MACD	A9b	1	8	13	22
MacDonald Island (Pooled)	MAC	A9	1	8	13	22
Medford Island East	MFE	A10a	0	5	12	17
Medford Island West	MFW	A10b	0	5	12	17
Medford Island (Pooled)	MFE/MFW	A10	0	5	12	17
Turner Cut East	TCE	F1a	0	4	8	12
Turner Cut West	TCW	F1b	0	4	8	12
Turner Cut (Pooled)	TCE/TCW	F1	0	4	8	12
Old River East	ORE	B1	278	277	264	819
Old River South Upstream	ORSU	B2a	255	256	244	755
Old River South Downstream	ORSD	B2b	256	258	248	762
Old River South (Pooled)	ORS	B2	256	259	250	765
Old River at Highway 4, Upstream	OR4U	B3a	27	44	49	120
Old River at Highway 4, Downstream	OR4D	B3b	27	43	50	120
Old River at Highway 4, SJR Route	OR4	B3	0	0	0	0
Old River at Highway 4, OR Route	OR4	B3	27	44	50	121
Old River at Highway 4 (Pooled)	OR4	B3	27	44	50	121
Middle River Head, Upstream	MRHU	C1a	8	6	3	17
Middle River Head, Downstream	MRHD	C1b	8	6	3	17
Middle River Head (Pooled)	MRH	C1	8	6	3	17
Middle River at Highway 4, Upstream	MR4U	C2a	6	6	5	17
Middle River at Highway 4, Downstream	MR4D	C2b	6	6	5	17
Middle River at Highway 4, SJR Route	MR4	C2	0	1[a]	2[a]	3[a]
Middle River at Highway 4, OR Route	MR4	C2	6	5	3	14

a = detections were not used in the survival model

Table 12. (Continued)

Detection Site	Site Code	Survival Model Code	Release Group 1	2	3	Total
Radial Gates Upstream: OR Route	RGU	D1	55	73	44	11
Radial Gates Upstream (Pooled)	RGU	D1	55	73	45	31
Radial Gates Downstream #1	RGD1	D2a	53	64	44	27
Radial Gates Downstream #2	RGD2	D2b	53	64	44	25
Radial Gates Downstream: SJR Route	RGD	D2	0	0	1	19
Radial Gates Downstream: OR Route	RGD	D2	53	66	43	8
Radial Gates Downstream (Pooled)	RGD	D2	53	66	44	27
CVP Trashrack: SJR Route	CVP	E1	0	0	1	40
CVP Trashrack: OR Route	CVP	E1	74	49	107	15
Central Valley Project Trashrack (Pooled)	CVP	E1	74	49	108	55
CVP tank: SJR Route	CVPtank	E2	0	0	0	15
CVP tank: OR Route	CVPtank	E2	30	8	31	3
Central Valley Project Holding Tank (Pooled)	CVPtank	E2	30	8	31	18
Jersey Point East	JPE	G1a	3	10	23	257
Jersey Point West	JPW	G1b	3	9	24	245
Jersey Point: SJR Route	JPE/JPW	G1	0	6	10	271
Jersey Point: OR Route	JPE/JPW	G1	3	4	14	0
Jersey Point (Pooled)	JPE/JPW	G1	3	10	24	271
False River West	FRW	H1a	0	0	0	9
False River East	FRE	H1b	0	0	0	4
False River: SJR Route	FRE/FRW	H1	0	0	0	10
False River: OR Route	FRE/FRW	H1	0	0	0	0
False River (Pooled)	FRE/FRW	H1	0	0	0	10
Chipps Island East	MAE	G2a	45	29	57	234
Chipps Island West	MAW	G2b	47	29	60	241
Chipps Island: SJR Route	MAE/MAW	G2	0	6	10	251
Chipps Island: OR Route	MAE/MAW	G2	47	26	53	4
Chipps Island (Pooled)	MAE/MAW	G2	47	32	63	255

Table 13. Number of tags from each release group in 2013 first classified as in a predator at each detection site, 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	Survival Model Code	1	2	3	Total	1	2	3	Total
Durham Ferry Upstream	DFU	A0	0	2	1	3	0	0	1	1
Durham Ferry Downstream	DFD	A2	2	7	0	9	0	0	0	0
Banta Carbona	BCA	A3	5	2	0	7	0	0	1	1
Mossdale	MOS	A4	5	0	0	5	2	2	0	4
Head of Old River	HOR	B0	5	10	6	21	0	1	1	2
Lathrop	SJL	A5	4	6	5	15	3	2	3	8
Garwood Bridge	SJG	A6	0	1	1	2	1	0	1	2
Navy Drive Bridge	SJNB	A7	1	0	0	1	0	0	1	1
Rough and Ready Island	RRI	R1	0	0	0	0	0	0	0	0
San Joaquin River Shipping Channel	SJS	A8	0	0	0	0	0	0	0	0
MacDonald Island	MAC	A8	0	0	0	0	0	0	0	0
Medford Island	MFE/MFW	A9	1	0	0	1	0	0	0	0
Old River East	ORE	B1	1	3	4	8	5	4	1	10
Old River South	ORS	B2	2	1	2	5	0	1	9	10
Old River at Highway 4	OR4	B3	0	0	0	0	1	0	0	1
Middle River Head	MRH	C1	0	1	1	2	0	0	0	0
Middle River at Highway 4	MR4	C2	0	1	0	1	0	0	1	1
Middle River near Empire Cut	MRE	C3	0	0	0	0	0	2	1	3
Radial Gates Upstream	RGU	D1	1	0	0	1	10	14	9	33
Radial Gates Downstream	RGD	D2	0	0	0	0	0	0	0	0
Central Valley Project Trashrack	CVP	E1	8	7	3	18	3	3	18	24
Central Valley Project Holding Tank	CVPtank	E2	0	0	0	0	0	0	0	0
Turner Cut	TCE/TCW	F1	0	1	1	2	0	0	0	0
Jersey Point	JPE/JPW	G1	0	0	1	1	0	0	0	0
Chipps Island	MAE/MAW	G2	0	0	0	0	0	0	0	0
False River	FRE/FRW	H1	1	0	0	1	0	0	0	0
Threemile Slough	TMS/TMN	T1	0	0	0	0	0	1	1	2
Total Tags			36	42	25	103	25	30	48	103

Table 14. Number of tags from each release group that were detected after release in 2013, excluding predator-type detections, and including detections omitted from the survival analysis.

Release Group	1	2	3	Total
Number Released	476	477	472	1,425
Total Number Detected	441	446	397	1,284
Total Number Detected Downstream	426	425	385	1,236
Total Number Detected Upstream of Study Area	441	445	341	1,227
Total Number Detected in Study Area	300	315	311	926
Number Detected in San Joaquin River Route	80	110	79	269
Number Detected in Old River Route	267	269	264	800
Number Assigned to San Joaquin River Route	23	38	49	110
Number Assigned to Old River Route	265	268	258	791

Table 15. Number of tags observed from each release group at each detection site in 2013, excluding predator-type detections. Routes (SJR = San Joaquin River, OR = Old River) represent route assignment at the head of Old River. Pooled counts are summed over all receivers in array and all routes. Route could not be identified for some tags.

Detection Site	Site Code	Survival Model Code	Release Group 1	Release Group 2	Release Group 3	Total
Release site at Durham Ferry			476	477	472	1,425
Durham Ferry Upstream	DFU	A0	45	62	33	140
Durham Ferry Downstream	DFD	A2	425	423	309	1,157
Banta Carbona	BCA	A3	260	183	107	550
Mossdale	MOS	A4	300	315	304	919
Head of Old River	HOR	B0	294	308	309	911
Lathrop	SJL	A5	80	109	78	267
Garwood Bridge	SJG	A6	6	12	28	46
Navy Drive Bridge	SJNB	A7	4	11	26	41
Rough and Ready Island	RRI	R1	0	6	13	19
San Joaquin River Shipping Channel, Upstream	SJSU	A8a	0	10	18	28
San Joaquin River Shipping Channel, Downstream	SJSD	A8b	0	10	18	28
San Joaquin River Shipping Channel (Pooled)	SJS	A8	0	10	18	28
MacDonald Island Upstream	MACU	A9a	0	6	15	21
MacDonald Island Downstream	MACD	A9b	0	6	13	19
MacDonald Island (Pooled)	MAC	A9	0	6	15	21
Medford Island East	MFE	A10a	0	5	12	17
Medford Island West	MFW	A10b	0	5	12	17
Medford Island (Pooled)	MFE/MFW	A10	0	5	12	17
Turner Cut East	TCE	F1a	0	5	7	12
Turner Cut West	TCW	F1b	0	5	7	12
Turner Cut (Pooled)	TCE/TCW	F1	0	5	7	12
Old River East	ORE	B1	267	269	264	800
Old River South Upstream	ORSU	B2a	242	246	239	727
Old River South Downstream	ORSD	B2b	242	247	239	728
Old River South (Pooled)	ORS	B2	242	247	240	729
Old River at Highway 4, Upstream	OR4U	B3a	31	53	69	153
Old River at Highway 4, Downstream	OR4D	B3b	30	53	68	151
Old River at Highway 4, SJR Route	OR4	B3	0	0	0	0
Old River at Highway 4, OR Route	OR4	B3	31	53	70	154
Old River at Highway 4 (Pooled)	OR4	B3	31	53	70	154
Middle River Head, Upstream	MRHU	C1a	10	7	5	22
Middle River Head, Downstream	MRHD	C1b	10	7	5	22
Middle River Head (Pooled)	MRH	C1	10	7	5	22
Middle River at Highway 4, Upstream	MR4U	C2a	7	9	11	27
Middle River at Highway 4, Downstream	MR4D	C2b	6	9	11	26

Table 15. (Continued)

Detection Site	Site Code	Survival Model Code	Release Group 1	Release Group 2	Release Group 3	Total
Middle River at Highway 4, SJR Route	MR4	C2	0	1	1	2
Middle River at Highway 4, OR Route	MR4	C2	7	8	10	25
Middle River at Highway 4 (Pooled)	MR4	C2	7	9	11	27
Middle River near Empire Cut, Upstream	MREU	C3a	8	14	11	33
Middle River near Empire Cut, Downstream	MRED	C3b	3	9	7	19
Middle River near Empire Cut, SJR Route	MRE	C3	0	3	1	4
Middle River near Empire Cut, OR Route	MRE	C3	8	11	10	29
Middle River near Empire Cut (Pooled)	MRE	C3	8	14	11	33
Radial Gates Upstream: SJR Route	RGU	D1	0	0	0	0
Radial Gates Upstream: OR Route	RGU	D1	65	92	63	220
Radial Gates Upstream (Pooled)	RGU	D1	65	92	63	220
Radial Gates Downstream #1	RGD1	D2a	38	46	31	115
Radial Gates Downstream #2	RGD2	D2b	38	46	31	115
Radial Gates Downstream: SJR Route	RGD	D2	0	0	0	0
Radial Gates Downstream: OR Route	RGD	D2	38	48	31	117
Radial Gates Downstream (Pooled)	RGD	D2	38	48	31	117
CVP Trashrack: SJR Route	CVP	E1	0	0	1	1
CVP Trashrack: OR Route	CVP	E1	95	86	170	351
Central Valley Project Trashrack (Pooled)	CVP	E1	95	86	171	352
CVP tank: SJR Route	CVPtank	E2	0	0	0	0
CVP tank: OR Route	CVPtank	E2	30	6	30	66
Central Valley Project Holding Tank (Pooled)	CVPtank	E2	30	6	30	66
Threemile Slough South	TMS	T1a	5	4	6	15
Threemile Slough North	TMN	T1b	5	5	6	16
Threemile Slough (Pooled)	TMS/TMN	T1	5	5	6	16
Jersey Point East	JPE	G1a	14	11	28	53
Jersey Point West	JPW	G1b	14	9	28	51
Jersey Point: SJR Route	JPE/JPW	G1	0	5	10	15
Jersey Point: OR Route	JPE/JPW	G1	15	6	18	39
Jersey Point (Pooled)	JPE/JPW	G1	15	11	28	54
False River West	FRW	H1a	6	5	17	28
False River East	FRE	H1b	6	6	17	29
False River: SJR Route	FRE/FRW	H1	0	3	2	5
False River: OR Route	FRE/FRW	H1	6	3	15	24
False River (Pooled)	FRE/FRW	H1	6	6	17	29

Table 15. (Continued)

Detection Site	Site Code	Survival Model Code	Release Group 1	Release Group 2	Release Group 3	Total
Chipps Island East	MAE	G2a	44	24	57	125
Chipps Island West	MAW	G2b	45	25	58	128
Chipps Island: SJR Route	MAE/MAW	G2	0	5	10	15
Chipps Island: OR Route	MAE/MAW	G2	45	22	51	118
Chipps Island (Pooled)	MAE/MAW	G2	45	27	61	133

Table 16. Number of tags observed from each release group at each detection site in 2013 and used in the 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	Release Group 2	Release Group 3	Total
Release site at Durham Ferry			476	477	472	1,425
Durham Ferry Upstream	DFU	A0	23	38	22	83
Durham Ferry Downstream	DFD	A2	417	406	299	1,122
Banta Carbona	BCA	A3	257	176	104	537
Mossdale	MOS	A4	299	314	303	916
Lathrop	SJL	A5	23	38	49	110
Garwood Bridge	SJG	A6	6	12	28	46
Navy Drive Bridge	SJNB	A7	1	11	21	33
MacDonald Island Upstream	MACU	A9a	0	5	12	17
MacDonald Island Downstream	MACD	A9b	0	5	12	17
MacDonald Island (Pooled)	MAC	A9	0	5	12	17
Medford Island East	MFE	A10a	0	4	11	15
Medford Island West	MFW	A10b	0	4	11	15
Medford Island (Pooled)	MFE/MFW	A10	0	4	11	15
Turner Cut East	TCE	F1a	0	4	6	10
Turner Cut West	TCW	F1b	0	4	6	10
Turner Cut (Pooled)	TCE/TCW	F1	0	4	6	10
Old River East	ORE	B1	265	268	257	790
Old River South Upstream	ORSU	B2a	241	237	235	713
Old River South Downstream	ORSD	B2b	242	240	237	719
Old River South (Pooled)	ORS	B2	242	240	239	721
Old River at Highway 4, Upstream	OR4U	B3a	21	38	48	107
Old River at Highway 4, Downstream	OR4D	B3b	21	38	49	108
Old River at Highway 4, SJR Route	OR4	B3	0	0	0	0
Old River at Highway 4, OR Route	OR4	B3	21	38	49	108
Old River at Highway 4 (Pooled)	OR4	B3	21	38	49	108
Middle River Head, Upstream	MRHU	C1a	7	6	4	17
Middle River Head, Downstream	MRHD	C1b	7	6	4	17
Middle River Head (Pooled)	MRH	C1	7	6	4	17
Middle River at Highway 4, Upstream	MR4U	C2a	6	8	6	20
Middle River at Highway 4, Downstream	MR4D	C2b	6	8	6	20
Middle River at Highway 4, SJR Route	MR4	C2	0	1[a]	1[a]	2[a]
Middle River at Highway 4, OR Route	MR4	C2	6	7	5	18
Middle River at Highway 4 (Pooled)	MR4	C2	6	8	6	20
Radial Gates Upstream: SJR Route	RGU	D1	0	0	0	0
Radial Gates Upstream: OR Route	RGU	D1	46	68	39	153

[a] = detections were not used in the survival model

Table 16. (Continued)

Detection Site	Site Code	Survival Model Code	Release Group			Total
			1	2	3	
Radial Gates Upstream (Pooled)	RGU	D1	46	68	39	153
Radial Gates Downstream #1	RGD1	D2a	38	46	31	115
Radial Gates Downstream #2	RGD2	D2b	38	46	31	115
Radial Gates Downstream: SJR Route	RGD	D2	0	0	0	0
Radial Gates Downstream: OR Route	RGD	D2	38	48	31	117
Radial Gates Downstream (Pooled)	RGD	D2	38	48	31	117
CVP Trashrack: SJR Route	CVP	E1	0	0	1	1
CVP Trashrack: OR Route	CVP	E1	72	40	101	213
Central Valley Project Trashrack (Pooled)	CVP	E1	72	40	102	214
CVP tank: SJR Route	CVPtank	E2	0	0	0	0
CVP tank: OR Route	CVPtank	E2	30	6	30	66
Central Valley Project Holding Tank (Pooled)	CVPtank	E2	30	6	30	66
Jersey Point East	JPE	G1a	3	7	23	33
Jersey Point West	JPW	G1b	3	6	24	33
Jersey Point: SJR Route	JPE/JPW	G1	0	5	10	15
Jersey Point: OR Route	JPE/JPW	G1	3	2	14	19
Jersey Point (Pooled)	JPE/JPW	G1	3	7	24	34
False River West	FRW	H1a	0	0	0	0
False River East	FRE	H1b	0	0	0	0
False River: SJR Route	FRE/FRW	H1	0	0	0	0
False River: OR Route	FRE/FRW	H1	0	0	0	0
False River (Pooled)	FRE/FRW	H1	0	0	0	0
Chipps Island East	MAE	G2a	43	24	55	122
Chipps Island West	MAW	G2b	45	25	58	128

Table 17. Number of juvenile steelhead tagged by each surgeon in each release group during the 2013 tagging study.

Surgeon	Release Group 1	2	3	Total Tags
A	160	160	158	478
B	161	157	156	474
C	155	160	158	473
Total Tags	476	477	472	1,425

Table 18. Release size and counts of tag detections at key detection sites by surgeon in 2013, excluding predator-type detections. * = omitted from chi-square test of independence because of low counts.

Detection Site	Surgeon		
	A	B	C
Release at Durham Ferry	478	474	473
Mossdale (MOS)	295	322	299
Lathrop (SJL)	44	31	35
MacDonald Island (MAC)	5	4	8
Turner Cut (TCE/TCW)*	3	4	3
Medford Island (MFE/MFW)*	4	4	7
Old River East (ORE)	248	283	259
Old River South (ORS)	233	258	230
Old River at Highway 4 (OR4)	32	36	40
Middle River at its Head (MRH)	5	5	7
Middle River at Highway 4 (MR4)	7	7	6
Clifton Court Forebay Interior (RGD)	42	41	34
Central Valley Project Holding Tank (CVPtank)	19	23	24
Jersey Point (JPE/JPW)	7	13	14
Chipps Island (MAE/MAW)	41	48	44

Table 19. Performance metric estimates (standard error in parentheses) for tagged juvenile steelhead released in the 2013 tagging study, excluding predator-type detections. South Delta ("SD") survival extended to MacDonald Island and Turner Cut in Route A, and the Central Valley Project trash rack, exterior radial gate receiver at Clifton Court Forebay, and Old River and Middle River receivers at Highway 4 in Route B. (Population-level estimates were weighted averages over the release-specific estimates, using weights proportional to release size.)

Parameter	Release Group 1	Release Group 2	Release Group 3	Population Estimate
ψ_{AA}	NA[a]	0.07 (0.02)	0.11 (0.02)	NA[a]
ψ_{AF}	NA[a]	0.06 (0.02)	0.05 (0.02)	NA[a]
ψ_{BB}	0.89 (0.02)	0.85 (0.02)	0.83 (0.02)	0.86 (0.01)
ψ_{BC}	0.03 (0.01)	0.02 (0.01)	0.01 (0.01)	0.02 (< 0.01)
S_{AA}	NA[a]	0.19 (0.07)	0.31 (0.07)	NA[a]
S_{AF}	NA[a]	0.06 (0.05)	0.00	NA[a]
S_{BB}	0.17 (0.02)	0.08 (0.02)	0.20 (0.03)	0.15 (0.01)
S_{BC}	0.07 (0.05)	0.06 (0.04)	0.06 (0.06)	0.06 (0.03)
ψ_A[b]	0.08 (0.02)	0.12 (0.02)	0.16 (0.02)	0.12 (0.01)
ψ_B[b]	0.92 (0.02)	0.88 (0.02)	0.84 (0.02)	0.88 (0.01)
S_A[c]	0.00[c]	0.13 (0.05)	0.20 (0.06)	0.11 (0.03)
S_B[c]	0.16[c] (0.02)	0.08 (0.02)	0.20 (0.02)	0.15 (0.01)
S_{Total}	0.15 (0.02)	0.09 (0.02)	0.20 (0.02)	0.15 (0.01)
$S_{A(MD)}$	0.00[c]	0.13[e] (0.05)	0.24[e] (0.06)	0.12[e] (0.03)
$S_{B(MD)}$[d]	0.01[c] (0.01)	0.01[e] (0.01)	0.06[e] (0.02)	0.03[e] (0.01)
$S_{Total(MD)}$	0.01 (0.01)	0.03 (0.01)	0.09 (0.02)	0.04 (0.01)
$S_{A(SD)}$	NA[a]	0.23 (0.07)	0.37 (0.07)	NA[a]
$S_{B(SD)}$	0.53 (0.03)	0.56 (0.03)	0.75 (0.03)	0.61 (0.02)
$S_{Total(SD)}$	NA[a]	0.52 (0.03)	0.69 (0.03)	NA[a]
ϕ_{A1A4}	0.63 (0.02)	0.66 (0.02)	0.66 (0.02)	0.65 (0.01)

a = There were too few tags detected in route A (San Joaquin River Route) to estimate route entrainment and survival within subroutes, or survival through the South Delta region.

b = Significant preference for route B (Old River Route) ($\alpha = 0.05$) for all release groups.

c = Estimated survival is significantly higher in route B (Old River Route) than in route A (San Joaquin River Route) ($\alpha = 0.05$) (tested only for Delta and Mid-Delta survival).

d = Most tags from fish that entered Old River at its head that were subsequently detected were observed at Chipps Island but not at Jersey Point or False River.

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

Table 20. Performance metric estimates (standard error in parentheses) for tagged juvenile steelhead released in the 2013 tagging study, including predator-type detections. South Delta ("SD") survival extended to MacDonald Island and Turner Cut in Route A, and the Central Valley Project trash rack, exterior radial gate receiver at Clifton Court Forebay, and Old River and Middle River receivers at Highway 4 in Route B. (Population-level estimates were weighted averages over the release-specific estimates, using weights proportional to release size.)

Parameter	Release Group 1	Release Group 2	Release Group 3	Population Estimate
ψ_{AA}	NA[a]	0.07 (0.02)	0.08 (0.02)	NA[a]
ψ_{AF}	NA[a]	0.03 (0.01)	0.05 (0.02)	NA[a]
ψ_{BB}	0.91 (0.02)	0.88 (0.02)	0.86 (0.02)	0.88 (0.01)
ψ_{BC}	0.03 (0.01)	0.02 (0.01)	0.01 (0.01)	0.02 (< 0.01)
S_{AA}	NA[a]	0.24 (0.09)	0.40 (0.09)	NA[a]
S_{AF}	NA[a]	0.10 (0.09)	0.00	NA[a]
S_{BB}	0.17 (0.02)	0.09 (0.02)	0.20 (0.02)	0.15 (0.01)
S_{BC}	0.08 (0.04)	0.06 (0.04)	0.08 (0.07)	0.07 (0.03)
ψ_A[b]	0.06 (0.01)	0.10 (0.02)	0.13 (0.02)	0.10 (0.01)
ψ_B[b]	0.94 (0.01)	0.90 (0.02)	0.87 (0.02)	0.90 (0.01)
S_A[ac]	0.00[c]	0.19[d] (0.07)	0.25 (0.07)	0.15 (0.03)
S_B[c]	0.16[c] (0.02)	0.09[d] (0.02)	0.20 (0.02)	0.15 (0.01)
S_{Total}	0.15 (0.02)	0.10 (0.02)	0.20 (0.02)	0.15 (0.01)
$S_{A(MD)}$	0.00[c]	0.23[d] (0.08)	0.31[d] (0.07)	0.18[d] (0.03)
$S_{B(MD)}$[e]	0.01[c] (0.01)	0.02[d] (0.01)	0.06[d] (0.01)	0.03[d] (0.01)
$S_{Total(MD)}$	0.01 (0.01)	0.04 (0.01)	0.09 (0.02)	0.05 (0.01)
$S_{A(SD)}$	NA[a]	0.38 (0.09)	0.52 (0.08)	NA[a]
$S_{B(SD)}$	0.57 (0.03)	0.61 (0.03)	0.77 (0.03)	0.65 (0.02)
$S_{Total(SD)}$	NA[a]	0.59 (0.03)	0.73 (0.03)	NA[a]
ϕ_{A1A4}	0.65 (0.02)	0.66 (0.02)	0.65 (0.02)	0.66 (0.01)

a = There were too few tags detected in route A (San Joaquin River Route) to estimate route entrainment and survival within subroutes, or survival through the South Delta region.

b = Significant preference for route B (Old River Route) (α = 0.05) for all release groups.

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

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

e = Most tags from fish that entered Old River at its head that were subsequently detected were observed at Chipps Island but not at Jersey Point or False River.

Table 21a. Average travel time in days (harmonic mean) of acoustic-tagged juvenile steelhead from release at Durham Ferry during the 2013 tagging study, without predator-type detections. Standard errors are in parentheses. See Table 21b for travel time from release with predator-type detections.

	Without Predator-Type Detections							
	All Releases		Release 1		Release 2		Release 3	
Detection Site and Route	N	Travel Time	N	Travel Time	N	Travel Time	N	Travel Time
Durham Ferry Upstream (DFU)	83	1.01 (0.24)	23	1.42 (0.50)	38	0.59 (0.17)	22	9.20 (3.24)
Durham Ferry Downstream (DFD)	1122	0.09 (<0.01)	417	0.11 (0.01)	406	0.08 (<0.01)	299	0.08 (<0.01)
Banta Carbona (BCA)	537	1.02 (0.06)	257	1.32 (0.13)	176	0.66 (0.04)	104	1.68 (0.29)
Mossdale (MOS)	916	1.98 (0.07)	299	5.03 (0.41)	314	1.40 (0.05)	303	1.69 (0.10)
Lathrop (SJL)	110	2.16 (0.18)	23	5.28 (1.17)	38	1.97 (0.18)	49	1.80 (0.22)
Garwood Bridge (SJG)	46	5.01 (0.54)	6	7.93 (1.81)	12	9.34 (2.17)	28	3.92 (0.45)
Navy Drive Bridge (SJNB)	33	4.90 (0.57)	1	4.62 (NA)	11	10.21 (2.35)	21	3.86 (0.43)
MacDonald Island (MAC)	17	7.41 (1.06)	0	NA	5	14.88 (3.67)	12	6.13 (0.83)
Turner Cut (TCE/TCW)	10	6.26 (1.03)	0	NA	4	10.96 (4.71)	6	4.87 (0.48)
Medford Island (MFE/MFW)	15	7.82 (1.25)	0	NA	4	20.36 (1.58)	11	6.39 (0.90)
Old River East (ORE)	790	2.76 (0.10)	265	6.80 (0.49)	268	1.96 (0.08)	257	2.32 (0.13)
Old River South (ORS)	721	3.45 (0.12)	242	7.74 (0.50)	240	2.40 (0.10)	239	3.09 (0.17)
Old River at Highway 4 (OR4), SJR Route	0	NA	0	NA	0	NA	0	NA
Old River at Highway 4 (OR4), OR Route	108	8.28 (0.50)	21	20.55 (3.44)	38	6.23 (0.52)	49	8.26 (0.56)
Middle River Head (MRH)	17	5.04 (0.95)	7	6.55 (3.32)	6	4.39 (0.77)	4	4.27 (1.21)
Middle River at Highway 4 (MR4), SJR Route	2	8.30 (6.73)	0	NA	1	43.87 (NA)	1	4.58 (NA)
Middle River at Highway 4 (MR4), OR Route	18	5.93 (1.82)	6	16.69 (3.38)	7	3.37 (1.36)	5	8.40 (1.86)
Radial Gates Upstream (DFU), SJR Route	0	NA	0	NA	0	NA	0	NA
Radial Gates Upstream (DFU), OR Route	153	6.64 (0.44)	46	13.88 (1.49)	68	5.49 (0.43)	39	5.32 (0.68)
Radial Gates Downstream (DFD), SJR Route	0	NA	0	NA	0	NA	0	NA
Radial Gates Downstream (DFD), OR Route	117	6.78 (0.50)	38	14.67 (1.23)	48	5.26 (0.47)	31	5.59 (0.76)
Central Valley Project Trashrack (CVP), SJR Route	1	5.67 (NA)	0	NA	0	NA	1	5.67 (NA)
Central Valley Project Trashrack (CVP), OR Route	213	7.75 (0.42)	72	13.74 (1.15)	40	7.50 (0.76)	101	5.97 (0.41)
Central Valley Project Holding Tank (CVPtank), SJR Route	0	NA	0	NA	0	NA	0	NA
Central Valley Project Holding Tank (CVPtank), OR Route	66	7.93 (0.75)	30	16.66 (1.04)	6	12.69 (0.68)	30	4.96 (0.45)

Table 21a. (Continued)

Detection Site and Route	Without Predator-Type Detections							
	All Releases		Release 1		Release 2		Release 3	
	N	Travel Time	N	Travel Time	N	Travel Time	N	Travel Time
Jersey Point (JPE/JPW), SJR Route	15	10.19 (1.50)	0	NA	5	22.65 (1.48)	10	7.99 (0.99)
Jersey Point (JPE/JPW), OR Route	19	11.24 (1.45)	3	33.97 (3.29)	2	8.12 (5.18)	14	10.33 (1.09)
False River (FRE/FRW), SJR Route	0	NA	0	NA	0	NA	0	NA
False River (FRE/FRW), OR Route	0	NA	0	NA	0	NA	0	NA
Chipps Island (MAE/MAW), SJR Route	15	11.02 (1.48)	0	NA	5	23.55 (1.52)	10	8.70 (0.93)
Chipps Island (MAE/MAW), OR Route	118	11.30 (0.65)	45	20.06 (0.99)	22	11.44 (1.04)	51	8.13 (0.57)
Chipps Island (MAE/MAW)	133	11.27 (0.60)	45	20.06 (0.99)	27	12.64 (1.17)	61	8.22 (0.50)

Table 21b. Average travel time in days (harmonic mean) of acoustic-tagged juvenile steelhead from release at Durham Ferry during the 2013 tagging study, with predator-type detections. Standard errors are in parentheses. See Table 21a for travel time from release without predator-type detections.

	With Predator-Type Detections							
	All Releases		Release 1		Release 2		Release 3	
Detection Site and Route	N	Travel Time	N	Travel Time	N	Travel Time	N	Travel Time
Durham Ferry Upstream (DFU)	85	1.12 (0.29)	21	2.05 (0.71)	42	0.66 (0.19)	22	9.31 (3.34)
Durham Ferry Downstream (DFD)	1120	0.09 (<0.01)	419	0.11 (0.01)	402	0.08 (<0.01)	299	0.08 (<0.01)
Banta Carbona (BCA)	536	1.03 (0.06)	256	1.32 (0.13)	175	0.66 (0.04)	105	1.70 (0.29)
Mossdale (MOS)	920	2.03 (0.07)	304	5.15 (0.42)	314	1.42 (0.05)	302	1.75 (0.10)
Lathrop (SJL)	87	2.15 (0.18)	16	5.21 (1.53)	31	2.06 (0.22)	40	1.79 (0.21)
Garwood Bridge (SJG)	46	5.30 (0.57)	5	7.27 (1.61)	15	8.00 (2.18)	26	4.25 (0.48)
Navy Drive Bridge (SJNB)	37	5.41 (0.68)	2	7.99 (5.85)	14	8.45 (2.45)	21	4.26 (0.54)
MacDonald Island (MAC)	22	7.59 (1.20)	1	31.43 (NA)	8	9.88 (4.28)	13	6.32 (0.83)
Turner Cut (TCE/TCW)	12	6.84 (1.11)	0	NA	4	10.96 (4.71)	8	5.76 (0.86)
Medford Island (MFE/MFW)	17	8.33 (1.31)	0	NA	5	22.60 (2.92)	12	6.59 (0.90)
Old River East (ORE)	819	2.89 (0.10)	278	7.05 (0.50)	277	2.04 (0.09)	264	2.44 (0.15)
Old River South (ORS)	765	3.62 (0.12)	256	8.00 (0.51)	259	2.55 (0.11)	250	3.23 (0.18)
Old River at Highway 4 (OR4), SJR Route	0	NA	0	NA	0	NA	0	NA
Old River at Highway 4 (OR4), OR Route	121	8.76 (0.52)	27	22.59 (3.35)	44	6.67 (0.55)	50	8.31 (0.56)
Middle River Head (MRH)	17	5.67 (1.19)	8	7.35 (3.73)	6	4.80 (0.72)	3	4.56 (1.90)
Middle River at Highway 4 (MR4), SJR Route	3	10.26 (6.42)	0	NA	1	43.87 (NA)	2	7.42 (4.60)
Middle River at Highway 4 (MR4), OR Route	14	5.30 (1.85)	6	16.69 (3.38)	5	2.72 (1.18)	3	6.79 (1.67)
Radial Gates Upstream (DFU), SJR Route	1	20.34 (NA)	0	NA	0	NA	1	20.34 (NA)
Radial Gates Upstream (DFU), OR Route	172	7.19 (0.48)	55	15.41 (1.62)	73	5.74 (0.45)	44	5.76 (0.74)
Radial Gates Downstream (DFD), SJR Route	1	20.35 (NA)	0	NA	0	NA	1	20.35 (NA)
Radial Gates Downstream (DFD), OR Route	162	7.24 (0.47)	53	15.24 (1.63)	66	5.73 (0.45)	43	5.82 (0.71)
Central Valley Project Trashrack (CVP), SJR Route	1	5.67 (NA)	0	NA	0	NA	1	5.67 (NA)
Central Valley Project Trashrack (CVP), OR Route	230	8.54 (0.48)	74	14.21 (1.24)	49	8.84 (0.96)	107	6.62 (0.49)
Central Valley Project Holding Tank (CVPtank), SJR Route	0	NA	0	NA	0	NA	0	NA
Central Valley Project Holding Tank (CVPtank), OR Route	69	8.24 (0.79)	30	16.66 (1.04)	8	14.02 (1.49)	31	5.17 (0.50)

Table 21b. (Continued)

Detection Site and Route	With Predator-Type Detections							
	All Releases		Release 1		Release 2		Release 3	
	N	Travel Time	N	Travel Time	N	Travel Time	N	Travel Time
Jersey Point (JPE/JPW), SJR Route	16	10.70 (1.64)	0	NA	6	24.64 (2.59)	10	7.99 (0.99)
Jersey Point (JPE/JPW), OR Route	21	11.80 (1.51)	3	36.33 (5.39)	4	11.71 (5.39)	14	10.33 (1.09)
False River (FRE/FRW), SJR Route	0	NA	0	NA	0	NA	0	NA
False River (FRE/FRW), OR Route	0	NA	0	NA	0	NA	0	NA
Chipps Island (MAE/MAW), SJR Route	16	11.41 (1.54)	0	NA	6	23.65 (1.25)	10	8.70 (0.93)
Chipps Island (MAE/MAW), OR Route	126	11.70 (0.67)	47	20.57 (1.07)	26	12.41 (1.17)	53	8.29 (0.58)
Chipps Island (MAE/MAW)	142	11.66 (0.62)	47	20.57 (1.07)	32	13.62 (1.25)	63	8.35 (0.51)

Table 22a. Average travel time in days (harmonic mean) of acoustic-tagged juvenile steelhead through the San Joaquin River Delta river reaches during the 2013 tagging study, without predator-type detections. Standard errors are in parentheses. See Table 22b for travel time through reaches with predator-type detections.

Reach		Without Predator-Type Detections							
		All Releases		Release 1		Release 2		Release 3	
Upstream Boundary	Downstream Boundary	N	Travel Time	N	Travel Time	N	Travel Time	N	Travel Time
Durham Ferry (Release)	BCA	537	1.02 (0.06)	257	1.32 (0.13)	176	0.66 (0.04)	104	1.68 (0.29)
BCA	MOS	460	0.68 (0.03)	216	0.92 (0.07)	151	0.55 (0.03)	93	0.57 (0.04)
MOS	SJL	110	0.28 (0.02)	23	0.44 (0.12)	38	0.36 (0.05)	49	0.21 (0.02)
	ORE	785	0.24 (0.01)	265	0.27 (0.01)	268	0.26 (0.01)	252	0.20 (0.01)
SJL	SJG	46	2.26 (0.21)	6	3.16 (0.70)	12	3.04 (0.83)	28	1.93 (0.19)
SJG	SJNB	33	0.15 (0.02)	1	0.14 (NA)	11	0.15 (0.05)	21	0.15 (0.03)
SJNB	MAC	15	1.08 (0.13)	0	NA	5	1.02 (0.31)	10	1.11 (0.11)
	TCE/TCW	10	1.00 (0.14)	0	NA	4	1.15 (0.19)	6	0.92 (0.18)
MAC	MFE/MFW	15	0.17 (0.03)	0	NA	4	0.24 (0.16)	11	0.15 (0.02)
	JPE/JPW/FRE/FRW	14	1.67 (0.22)	0	NA	4	1.74 (0.50)	10	1.65 (0.26)
	RGU	0	NA	0	NA	0	NA	0	NA
	CVP	0	NA	0	NA	0	NA	0	NA
MFE/MFW	JPE/JPW/FRE/FRW	14	1.36 (0.18)	0	NA	4	1.28 (0.23)	10	1.40 (0.24)
	RGU	0	NA	0	NA	0	NA	0	NA
	CVP	0	NA	0	NA	0	NA	0	NA
TCE/TCW	JPE/JPW/FRE/FRW	1	11.79 (NA)	0	NA	1	11.79 (NA)	0	NA
	RGU	0	NA	0	NA	0	NA	0	NA
	CVP	1	2.16 (NA)	0	NA	0	NA	1	2.16 (NA)
ORE	ORS	721	0.25 (0.01)	242	0.25 (0.01)	240	0.26 (0.01)	239	0.25 (0.01)
	MRH	17	0.41 (0.07)	7	0.32 (0.07)	6	0.78 (0.29)	4	0.33 (0.11)
ORS	OR4	104	2.81 (0.22)	19	3.04 (0.59)	37	2.78 (0.29)	48	2.76 (0.37)
	MR4	18	2.03 (0.67)	6	4.35 (1.21)	7	1.12 (0.47)	5	4.03 (0.54)
	RGU	151	2.07 (0.12)	46	2.15 (0.22)	66	2.13 (0.17)	39	1.89 (0.22)
	CVP	209	1.88 (0.10)	71	1.86 (0.15)	38	3.16 (0.44)	100	1.65 (0.12)

Table 22a. (Continued)

Reach		Without Predator-Type Detections							
		All Releases		Release 1		Release 2		Release 3	
Upstream Boundary	Downstream Boundary	N	Travel Time	N	Travel Time	N	Travel Time	N	Travel Time
OR4 via OR	JPE/JPW/FRE/FRW	18	1.96 (0.32)	3	1.27 (0.33)	2	1.38 (1.13)	13	2.42 (0.41)
MRH	OR4	3	2.97 (0.92)	2	2.27 (0.02)	0	NA	1	7.77 (NA)
	MR4	0	NA	0	NA	0	NA	0	NA
	RGU	1	11.99 (NA)	0	NA	1	11.99 (NA)	0	NA
	CVP	2	5.20 (1.09)	1	6.57 (NA)	1	4.30 (NA)	0	NA
MR4 via OR	JPE/JPW/FRE/FRW	1	1.43 (NA)	0	NA	0	NA	1	1.43 (NA)
RGU via OR[a]	RGD	91	0.01 (<0.01)	30	0.01 (<0.01)	38	0.01 (<0.01)	23	0.01 (<0.01)
RGU via OR[b]	RGD	26	0.04 (0.01)	8	0.08 (0.03)	10	0.03 (0.01)	8	0.04 (0.02)
RGU via SJR[a]	RGD	0	NA	0	NA	0	NA	0	NA
RGU via SJR[b]	RGD	0	NA	0	NA	0	NA	0	NA
CVP via OR	CVPtank	66	0.14 (0.05)	30	0.10 (0.05)	6	0.54 (0.29)	30	0.18 (0.05)
CVP via SJR	CVPtank	0	NA	0	NA	0	NA	0	NA
JPE/JPW	MAE/MAW (Chipps Island)	28	0.90 (0.11)	2	1.16 (0.04)	6	0.73 (0.27)	20	0.95 (0.10)
MAC		14	2.80 (0.17)	0	NA	4	2.77 (0.38)	10	2.81 (0.20)
MFE/MFW		13	2.51 (0.15)	0	NA	4	2.23 (0.13)	9	2.65 (0.22)
TCE/TCW		1	12.88 (NA)	0	NA	1	12.88 (NA)	0	NA
OR4		17	3.54 (0.32)	2	2.48 (0.54)	2	4.57 (2.38)	13	3.65 (0.33)
MR4		1	1.89 (NA)	0	NA	0	NA	1	1.89 (NA)
RGD		45	4.64 (0.36)	16	4.40 (0.57)	14	4.51 (0.64)	15	5.06 (0.67)
CVPtank		52	1.21 (0.11)	24	1.41 (0.22)	6	1.94 (0.25)	22	0.96 (0.11)

a = Radial gates open upon arrival at RGU.

b = Radial gates closed upon arrival at RGU.

Table 22b. Average travel time in days (harmonic mean) of acoustic-tagged juvenile steelhead through the San Joaquin River Delta river reaches during the 2013 tagging study, with predator-type detections. Standard errors are in parentheses. See Table 22a for travel time through reaches without predator-type detections.

Reach		With Predator-Type Detections							
		All Releases		Release 1		Release 2		Release 3	
Upstream Boundary	Downstream Boundary	N	Travel Time	N	Travel Time	N	Travel Time	N	Travel Time
Durham Ferry (Release)	BCA	536	1.03 (0.06)	256	1.32 (0.13)	175	0.66 (0.04)	105	1.70 (0.29)
BCA	MOS	464	0.69 (0.03)	219	0.94 (0.07)	151	0.55 (0.03)	94	0.57 (0.04)
MOS	SJL	87	0.28 (0.03)	16	0.48 (0.18)	31	0.35 (0.05)	40	0.22 (0.02)
	ORE	813	0.25 (0.01)	277	0.28 (0.01)	277	0.27 (0.01)	259	0.21 (0.01)
SJL	SJG	46	2.15 (0.31)	5	3.15 (0.55)	15	2.16 (0.89)	26	2.01 (0.21)
SJG	SJNB	37	0.13 (0.02)	2	0.11 (0.02)	14	0.12 (0.03)	21	0.14 (0.02)
SJNB	MAC	20	1.09 (0.13)	1	1.66 (NA)	8	1.03 (0.26)	11	1.10 (0.09)
	TCE/TCW	12	1.03 (0.15)	0	NA	4	1.15 (0.19)	8	0.97 (0.19)
MAC	MFE/MFW	17	0.17 (0.03)	0	NA	5	0.28 (0.19)	12	0.15 (0.02)
	JPE/JPW/FRE/FRW	15	1.75 (0.24)	0	NA	5	2.00 (0.60)	10	1.65 (0.26)
	RGU	0	NA	0	NA	0	NA	0	NA
	CVP	0	NA	0	NA	0	NA	0	NA
MFE/MFW	JPE/JPW/FRE/FRW	15	1.42 (0.19)	0	NA	5	1.46 (0.32)	10	1.40 (0.24)
	RGU	0	NA	0	NA	0	NA	0	NA
	CVP	0	NA	0	NA	0	NA	0	NA
TCE/TCW	JPE/JPW/FRE/FRW	1	11.79 (NA)	0	NA	1	11.79 (NA)	0	NA
	RGU	1	4.78 (NA)	0	NA	0	NA	1	4.78 (NA)
	CVP	1	2.16 (NA)	0	NA	0	NA	1	2.16 (NA)
ORE	ORS	765	0.25 (0.01)	256	0.25 (0.01)	259	0.26 (0.01)	250	0.25 (0.01)
	MRH	17	0.42 (0.08)	8	0.32 (0.06)	6	0.91 (0.41)	3	0.33 (0.15)
ORS	OR4	116	2.72 (0.22)	24	3.13 (0.51)	43	2.78 (0.29)	49	2.50 (0.37)
	MR4	14	1.71 (0.60)	6	4.35 (1.21)	5	0.84 (0.34)	3	3.46 (0.47)
	RGU	170	2.12 (0.12)	55	2.29 (0.23)	71	2.14 (0.17)	44	1.91 (0.23)
	CVP	224	1.92 (0.11)	73	1.94 (0.16)	45	3.06 (0.40)	106	1.64 (0.13)

Table 22b. (Continued)

Reach		With Predator-Type Detections							
		All Releases		Release 1		Release 2		Release 3	
Upstream Boundary	Downstream Boundary	N	Travel Time	N	Travel Time	N	Travel Time	N	Travel Time
OR4 via OR	JPE/JPW/FRE/FRW	19	2.14 (0.38)	3	1.74 (0.99)	3	1.68 (1.05)	13	2.42 (0.41)
MRH	OR4	4	3.00 (0.66)	3	2.49 (0.23)	0	NA	1	7.77 (NA)
	MR4	0	NA	0	NA	0	NA	0	NA
	RGU	1	11.99 (NA)	0	NA	1	11.99 (NA)	0	NA
	CVP	2	5.20 (1.09)	1	6.57 (NA)	1	4.30 (NA)	0	NA
MR4 via OR	JPE/JPW/FRE/FRW	2	2.68 (2.35)	0	NA	1	21.76 (NA)	1	1.43 (NA)
RGU via OR[a]	RGD	122	0.01 (<0.01)	42	0.01 (<0.01)	52	0.02 (<0.01)	28	0.01 (<0.01)
RGU via OR[b]	RGD	40	0.05 (0.01)	11	0.10 (0.03)	14	0.04 (0.01)	15	0.05 (0.02)
RGU via SJR[a]	RGD	1	0.01 (NA)	0	NA	0	NA	1	0.01 (NA)
RGU via SJR[b]	RGD	0	NA	0	NA	0	NA	0	NA
CVP via OR	CVPtank	69	0.13 (0.04)	30	0.10 (0.05)	8	0.23 (0.14)	31	0.17 (0.04)
CVP via SJR	CVPtank	0	NA	0	NA	0	NA	0	NA
JPE/JPW	MAE/MAW (Chipps Island)	29	0.90 (0.10)	3	1.06 (0.09)	6	0.73 (0.27)	20	0.95 (0.10)
MAC		15	2.86 (0.18)	0	NA	5	2.97 (0.40)	10	2.81 (0.20)
MFE/MFW		13	2.51 (0.15)	0	NA	4	2.23 (0.13)	9	2.65 (0.22)
TCE/TCW		1	12.88 (NA)	0	NA	1	12.88 (NA)	0	NA
OR4		18	3.71 (0.37)	3	3.50 (1.56)	2	4.57 (2.38)	13	3.65 (0.33)
MR4		1	1.89 (NA)	0	NA	0	NA	1	1.89 (NA)
RGD		48	4.68 (0.35)	17	4.38 (0.53)	16	4.70 (0.67)	15	5.06 (0.67)
CVPtank		56	1.20 (0.11)	24	1.41 (0.22)	8	1.84 (0.22)	24	0.95 (0.10)

a = Radial gates open upon arrival at RGU.

b = Radial gates closed upon arrival at RGU.

Table 23. Results of single-variate analyses of 2013 route entrainment at the head of Old River. The values df1, df2 are degrees of freedom for the F-test. Covariates are ordered by P-value and F statistic.

	F-test			
Covariate	*F*	df1	df2	*P*
Flow at SJL[a]	11.4646	1	84	0.0011
Velocity at SJL[a]	8.2877	1	84	0.0051
Flow proportion into San Joaquin River[a]	8.0473	1	84	0.0057
Negative flow at SJL[a]	7.8214	1	84	0.0064
Negative velocity at SJL[a]	7.8214	1	84	0.0064
Change in stage at SJL[a]	7.5807	1	86	0.0072
Change in stage at OH1[a]	6.9859	1	85	0.0098
Stage at OH1[a]	4.9150	1	86	0.0293
Stage at SJL[a]	4.3601	1	86	0.0397
Velocity at OH1	2.1965	1	86	0.1420
Exports at SWP	1.9793	1	86	0.1631
Change in velocity at OH1	1.3625	1	86	0.2463
Total Exports in Delta	1.2900	1	86	0.2592
Change in velocity at SJL	0.8624	1	84	0.3557
Release Group	1.0380	2	85	0.3586
Exports at CVP	0.7984	1	86	0.3741
Change in flow at OH1	0.7764	1	86	0.3807
Flow at OH1	0.6957	1	86	0.4065
Change in flow at SJL	0.6447	1	84	0.4243
Arrive at junction during twilight	0.2632	1	86	0.6092
Change in flow proportion into San Joaquin River	0.2038	1	84	0.6528
Negative flow at OH1	0.1415	1	86	0.7077
Negative velocity at OH1	0.1415	1	86	0.7077
Fork Length	0.0535	1	86	0.8177
Time of day of arrival	0.1544	3	84	0.9266

a = Significant at 5% level

Table 24. Results of multivariate analyses of route entrainment at the head of Old River in 2013. Modeled response is the probability of selecting the San Joaquin River route.

Model Type	Covariate[a]	Estimate	S.E.	*t*-test		
				t	df	*P*
Flow	Intercept	-2.6542	0.1874	-14.162	84	< 0.0001
	Q_{SJL}	1.2639	0.2046	6.179	84	< 0.0001
	Goodness-of-fit: χ^2= 13.8787, df=13, P=0.3824; AIC = 487.02					
Flow Proportion	Intercept	-3.0476	0.3776	-8.0719	82	< 0.0001
	pQ_{SJL}	0.1222	0.2545	0.4802	82	0.6323
	u_{QSJL}	2.6028	1.1056	2.3542	82	0.0210
	u_{QSJL}*Q_{SJL}	1.5740	0.3953	3.9823	82	0.0001
	Goodness-of-fit: χ^2= 8.0714, df=13, P=0.8389; AIC = 486.80					
Velocity	Intercept	-2.4809	0.1591	-15.5931	84	< 0.0001
	V_{SJL}	1.0056	0.1734	5.7991	84	< 0.0001
	Goodness-of-fit: χ^2=15.3854, df=13, P=0.2839; AIC = 503.65					
Stage	Intercept	-2.6086	0.1707	-15.2846	85	< 0.0001
	C_{SJL}	0.6828	0.1328	5.1406	85	< 0.0001
	ΔC_{SJL}	-0.9621	0.1619	-5.9414	85	< 0.0001
	Goodness-of-fit: χ^2=5.3486, df=13, P=0.9667; AIC = 489.67[b]					
Flow + Stage	Intercept	-2.7771	0.1925	-14.4261	83	< 0.0001
	Q_{SJL}	1.2143	0.1965	6.1797	83	< 0.0001
	C_{SJL}	0.6116	0.1335	4.5825	83	< 0.0001
	Goodness-of-fit: χ^2=8.2590, df=13, P=0.8263; AIC = 466.27					

a = Continuous covariates (Q_{SJL}, pQ_{SJL}, u_{QSJL}, V_{SJL}, C_{SJL}, ΔC_{SJL}) are standardized. Intercept and slope estimates for the unstandardized covariates are -6.7641 (SE=0.8604), 0.001228 (SE=0.0002), and 0.7978 (SE=0.1741) for the flow + stage model.

b = The Stage model used two observations that were unavailable for the flow, flow proportion, velocity, and flow + stage models. When restricted to the same data set as the competing models, the Stage model had AIC = 483.29.

Table 25. Estimates of survival from downstream receivers at water export facilities (CVP holding tank or interior of Clifton Court Forebay at radial gates) through salvage to receivers after release from truck in 2013, excluding predator-type detections (95% profile likelihood interval in parentheses). Population estimate is based on data pooled from all release groups.

Facility	Upstream Model Site Code	Release Group 1	Release Group 2	Release Group 3	Population Estimate
CVP	E2	0.83 (0.68, 0.94)	1 (*n*=6)	0.77 (0.61, 0.90)	0.82 (0.72, 0.90)
SWP	D2	0.45 (0.30, 0.61)	0.30 (0.18, 0.43)	0.49 (0.32, 0.66)	0.40 (0.31, 0.49)

Table 26. 14-day (A) and 30-day (B) average hydrologic and operation conditions during the 2011-2013 Six-Year Steelhead Study (Data sourced from California Data Exchange Center and Central Valley Operations.

A) 14-day Averages

Year	Tagging dates	Release Dates	Vernalis	Combined Export	I:E	Head of Old River	Old & Middle River
2011	March 21-24	March 22-26	21972	4,112	5.6	8,880	7,193
2011	May 2-5	May 3-7	14,939	3,782	4	6,391	3,426
2011	May 16-19	May 17-21	10,319	2,576	4.1	2,247	5,000
2011	June 6-9	June 7-11	10,653	9,285	1.2	5,296	-4,156
2011	June 14-17	June 15-19	10,196	10,039	1	5,121	-5,108
2012	April 3-5	April 4-7	2,553	2,596	1.1	709	-2,137
2012	April 30-	May 1-6	3,481	2,465	1.6	736	-2,601
2012	May17-21	May 18-23	2354	3,438	0.9	448	-3,926
2013	March 5-7	March 6-9	1,632	4,591	0.3	1,397	-3,645
2013	April 2-4	April 3-5	1,445	1,467	1	1,083	-283
2013	May 7-9	May 8-11	2,459	1,714	1.5	1,701	-859

B) b) 30-day Averages

Year	Tagging Dates	Release Dates	Vernalis	Combined Export	I:E	Head of Old River	Old & Middle River
2011	March 21-24	March 22-26	24,688	5,056	5.1	9,969	7,950
2011	May 2-5	May 3-7	12,481	3,272	4	5,928	2,736
2011	May 16-19	May 17-21	10,600	5,858	2.7	5,229	-899
2011	June 6-9	June 7-11	10,634	10,068	1.1	5,391	-4,955
2011	June 14-17	June 15-19	10,458	10,627	1	5,408	-5,765
2012	April 3-5	April 4-7	2,598	2,295	1.2	657	-2,042
2012	April 30-May 4	May 1-6	2,988	3,050	1.2	599	-3,368
2012	May17-21	May 18-23	1,834	3,367	0.7	567	-3,870
2013	March 5-7	March 6-9	1,509	4,455	0.4	1,285	-3,463
2013	April 2-4	April 3-5	2,350	1,932	1.2	1,552	-323
2013	May 7-9	May 8-11	1,642	1,665	1	1,552	-1,489

Table 27. Comparisons in survival estimates from Mossdale to Chipps Island for the San Joaquin and Old River routes and total through both routes for each of the steelhead release groups released in 2011 to 2013. * indicates survival is significantly higher in the route. Source: USBR 2018a (2011 estimates), USBR 2018b (2012 estimates), and Table 19 of this report (2013 estimates).

Year	San Joaquin River route					Old River route					Total					
	Release groups					Release groups					Release groups					Population estimate
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	
2011	0.69 (0.04)	0.55 (0.04)	0.45 (0.04)	0.66* (0.04)	0.32 (0.06)	0.68 (0.04)	0.48 (0.04)	0.44 (0.04)	0.53 (0.05)	0.44 (0.07)	0.69 (0.03)	0.52 (0.03)	0.44 (0.03)	0.60 (0.03)	0.38 (0.05)	0.54 (0.01)
2012	0.28* (0.03)	0.36* (0.03)	0.36* (0.04)			0.07 (0.04)	0.10 (0.07)	0.05 (0.03)			0.26 (0.02)	0.35 (0.03)	0.33 (0.04)			0.32 (0.02)
2013	0.00	0.13 (0.05)	0.20 (0.06)			0.16* (0.02)	0.08 (0.02)	0.20 (0.02)			0.15 (0.02)	0.09 (0.02)	0.20 (0.02)			0.15 (0.01)

Table 28. Coefficients of determination (r^2) between the 14 day mean of 1) Vernalis flows, 2) combined exports, 3) Inflow/export ratio (I/E), 4) Old River flows at the head of Old River (Old River), and 5) Old and Middle River flows (OMR) and estimates of total Delta survival from Mossdale to Chipps Island combined over all routes (total Delta survival), via the San Joaquin (SJ) River route, and via the Old River route, for steelhead released in 2011-2013 (n= 11; data in Tables 26 and 27). * indicates statistically significant relationship at α <0.05.

	Vernalis	Exports	I/E	Old River	OMR
Delta survival	0.8088*	0.1921	0.5106*	0.6779*	0.2178
SJ survival	0.6905*	0.1108	0.4830*	0.5500*	0.2225
Old River survival	0.8882*	0.2706	0.5214*	0.8737*	0.2946

Table 29. Correlation coefficients (r) between the mean 14-day Vernalis flows to flows at 1) the head of Old River (Old River), 2) Inflow/export ratio (I/E), 3) Old and Middle River flows (OMR) and 4) exports for the same 14-day period, for the 2011–2013 steelhead release groups. Flow data are provided in Table 26. * indicates statistically significant relationship at $\alpha<0.05$.

Old River	I/E Ratio	OMR	Exports
0.9505*	0.8495*	0.6705*	0.3532

Table 30. Survival estimates through the Delta (Mossdale to Chipps Island) in the San Joaquin route, in the Old River route, and total for steelhead and Chinook salmon released in 2013. * = estimated survival is significantly higher in noted route compared to alternate route (α=0.05). Source of Chinook Salmon estimates: Buchanan et al (2016).

Year: 2013 Species, release group and release dates	San Joaquin route			Old River route			Total		
Steelhead, Release 1 3/6 – 3/9	0.00			0.16* (0.02)			0.15 (0.02)		
Steelhead, Release 2 4/3 – 4/6		0.13 (0.05)			0.08 (0.02)			0.09 (0.02)	
Steelhead, Release 3 5/8 – 5/11			0.20 (0.06)			0.20 (0.02)			0.20 (0.02)
Salmon, Release 1 4/30 – 5/5			0.01 (0.01)			0.03 (0.01)			0.02 (0.01)
Salmon , Release 2 5/14 – 5/19			0			0			0

Table 31. Survival estimates through the Delta (Mossdale to Chipps Island) in the San Joaquin route, in the Old River route, and total for steelhead and Chinook salmon released in 2011. * = estimated survival is significantly higher in noted route compared to alternate route (α=0.05). Source: SJGRA (2013) (Chinook Salmon estimates), USBR 2018b (steelhead estimates).

Year: 2011 Species, release group: release dates	San Joaquin route					Old River route					Total				
Steelhead, Release 1: 3/22-3/26	0.69 (0.04)					0.68 (0.04)					0.69 (0.03)				
Steelhead, Release 2: 5/3-5/7		0.55 (0.04)					0.48 (0.04)					0.52 (0.03)			
Steelhead, Release 3: 5/17 – 5/21			0.45 (0.04)					0.44 (0.04)					0.44 (0.03)		
Steelhead, Release 4: 5/22- 5/26				0.66* (0.04)					0.53 (0.05)					0.60 (0.03)	
Steelhead, Release 5: 6/15 – 6/19					0.32 (0.06)					0.44 (0.07)					0.38 (0.05)
Salmon, Release 1 5/17-5/21			0.01 (0.01)					0.00 (0.00)					0.01 (0.01)		
Salmon, Release 2: 5/22-5/27				0.004 (0.004)					0.02 (0.01)					0.01 (0.01)	
Salmon, Release 3: 6/7 – 6/11					0.01 (0.01)					0.07* (0.02)					0.03 (0.01)
Salmon, Release 4: 6/15-6/19					0.005 (0.005)					0.07* (0.02)					0.03 (0.01)

Table 32. Survival estimates through the Delta (Mossdale to Chipps Island) in the San Joaquin route, in the Old River route, and total for steelhead and Chinook salmon released in 2012. * = estimated survival is significantly higher in noted route compared to alternate route (α=0.05). Source: Buchanan et al (2015) (Chinook Salmon estimates), OCAP (2015) (steelhead estimates).

Year: 2012 Species, release group: release dates	San Joaquin route			Old River route			Mossdale to Chipps Island		
Steelhead, release 1: 4/4/12 – 4/6/12	0.28* (0.03)			0.07 (0.04)			0.26 (0.02)		
Steelhead, release 2: 5/1/12 – 5/6/12		0.36* (0.03)			0.10 (0.07)			0.35 (0.03)	
Steelhead, release 3: 5/18-5/23			0.36* (0.04)			0.05 (0.03)			0.33 (0.04)
Salmon, release 1: 5/2 to 5/7		0.05 (0.01)			0.16 (0.15)			0.05 (0.01)	
Salmon, release 2: 5/17 to 5/22			0			0			0

Appendices

Appendix A. Power Analysis: Survival to Chipps Island

Power Analysis: Survival to Chipps Island

Prepared for: South Delta Salmon Research Collaboration Group

Prepared by: Rebecca Buchanan, University of Washington

July 10, 2013

Executive Summary

Sample sizes were calculated to provide 80% power to detect a treatment effect on survival to Chipps Island with an error rate of α=0.05 or α=0.10. For steelhead, the desired treatment effect was a 10% increase in survival; for Chinook salmon, it was a 100% increase in survival. Steelhead were assumed to have higher survival than Chinook salmon. However, the smaller treatment effect to be detected for steelhead resulted in higher sample sizes than for Chinook. Necessary sample sizes for steelhead using a single replicate ranged from approximately 800 to 17,000 (α=0.10), depending on whether survival is high or low, the location of the release site (Durham Ferry or head of Old River), where survival is measured from (Mossdale or the head of Middle River), and whether the route is restricted to salvage routes or includes all routes to Chipps Island. Using two replicates halved the necessary sample size per replicate. For Chinook, necessary sample sizes for a single replicate ranged from approximately 100 to 3,000. Larger treatment effects require fewer fish. Power curves (e.g., Figure B1) showing necessary sample sizes for alternative treatment effects and survival levels are included in Appendix B.1.

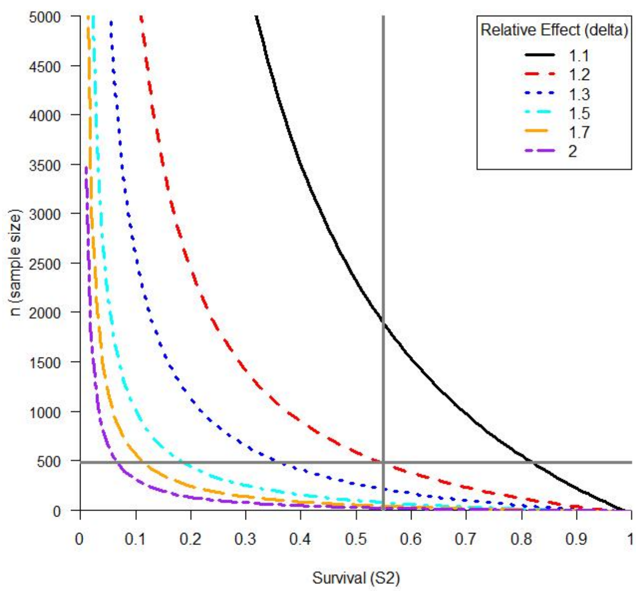


Figure A1. Sample sizes (*n*) necessary versus survival (S_2) to achieve 80% power to detect a relative effect of size delta (δ) in a one-tailed test with a single replicate (α=0.10). Survival and detection parameters are: S_1=0.55, p_1=0.75, p_{2a}=p_{2b}=0.88. The cross-bars indicate the observed survival and sample size in 2011 (steelhead).

Introduction

A power analysis was performed to determine the appropriate sample size necessary to detect an effect of different water export operations on juvenile salmonid survival through the Delta. Survival is to be measured to Chipps Island both in total (all routes) and via the salvage facilities at the State Water Project and the Central Valley Project. For the purposes of the power analysis, two release locations were considered:

1. Durham Ferry (DF), with survival measured from Mossdale Bridge (assumes barrier at the Head of Old River [HOR] is not installed), and
2. Old River (OR) just downstream of its head, with survival measured from the Head of Middle River (HMR).

In each case, sample sizes were computed to provide 80% power to detect a given relative (i.e., multiplicative) effect on survival of different treatments using either 1 or 2 replicates. For steelhead, the size of the relative effect (δ) was 1.1 (i.e., 10% increase). For Chinook salmon, the relative effect size was δ=2.0 (i.e., 100% increase). The probability of a Type I error (error rate) was fixed at α=0.05 or α=0.10. One-tailed tests were used (i.e., one-sided alternative hypotheses).

Methods

For each scenario, a simplified version of the Delta survival release-recapture model was used, including only two reaches and two detection sites (Figure A1). The first reach was the region between the release site and the study area, i.e., the San Joaquin River between Durham Ferry and Mossdale Bridge for the DF releases, and the Old River between the HOR and the HMR for the OR releases. The first detection site was either Mossdale or the pooled receivers at the HMR, depending on the release site. The second reach consisted of the routes through the Delta from the first detection site to Chipps Island. For estimating total Delta survival, the routes included both inriver (non-salvage) routes and salvage and transport routes. For estimating survival to Chipps Island via salvage, only the salvage routes were included in the second reach. For Durham Ferry releases, all routes, including salvage routes, included routes using the San Joaquin River at the head of Old River, because fish that remain in the San Joaquin River at that junction may nevertheless arrive at the salvage facilities by entering the interior Delta downstream of Stockton.

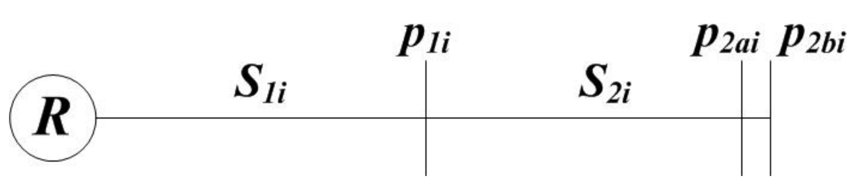


Figure A2. Model schematic. R = release of size *n*, S_{ji}=probability of survival through reach *j* (*j*=1,2) for treatment *i* (*i*=1,2). p_{1i}=conditional detection probability at site 1 for treatment *i*, p_{2ai} (p_{2bi}) = conditional detection probability at the first (second) station in dual array at site 2 for treatment i.

For each desired survival comparison, the power to detect the given treatment effect size (δ) was derived assuming that the ratio of survival estimates under the two treatments is log-normally distributed. It was assumed that different treatments affected oly survival in the second reach (S_{2i}). All other parameters were equated across treatment groups for the purpose of the power analysis:

$S_{i1} = S_i$, $p_{1i} = p_1$, $p_{2ai} = p_{2a}$, and $p_{2bi} = p_{2b}$ for $i = 1, 2$. The variance of the survival ratio was derived based on the CJS model (Cormack 1964), and used to compute the power for the various sample sizes, or alternatively to compute the necessary sample size for a power level of 80% (Snedecor and Cochran 1989). Details are provided in Appendix A.1.

Parameter values (This appendix, Table 1) used in the power analysis were based on recent VAMP studies for Chinook salmon (SJRGA 2011, 2013), and the 2011 6-year study for steelhead (preliminary results). Parameters were considered for a "high survival" year and a "low survival" year, based on the range of available estimates from the VAMP and 6-year studies. Detection probabilities were selected based on the assumption that higher survival is more likely in high flow years, when detection probabilities are likely to be lower.

Table A1. Parameter values used in power analysis.

	Mossdale to Chipps Island				**Head of Middle River to Chipps Island**				**Detection at Chipps Island**	
Species	S_1	S_2 (total)	S_2 (salvage)	p_1	S_1	S_2 (total)	S_2 (salvage)	p_1	p_{2a}	p_{2b}
Steelhead										
High Survival	0.55	0.55	0.25	0.75	0.95	0.60	0.40	0.85	0.85	0.85
Low Survival	0.35	0.35	0.15	0.90	0.75	0.45	0.30	0.95	0.90	0.90
Chinook										
High Survival	0.85	0.10	0.05	0.80	0.85	0.20	0.10	0.85	0.85	0.85
Low Survival	0.50	0.02	0.01	0.95	0.70	0.05	0.03	0.95	0.90	0.90

Results

Survival: Mossdale to Chipps Island

Total Survival from Mossdale

For steelhead, using the parameters in Table A1 and a single replicate, the size of the release group at Durham Ferry necessary to achieve 80% power to detect an increase in total survival from Mossdale to Chipps Island of 10% (δ=1.1) with a Type I error rate of α=0.05 is n = 2,594 for a high survival year, and n = 7,607 for a low survival year (Figure A1; Table A2). For a Type I error rate of α=0.10 (1 replicate), n = 1,891 for high survival, and n = 5,546 for low survival (Table A2, Figure A2). Using two replicates, the necessary sample sizes decrease to n = 1,297 for high survival and n = 3,803 for a low survival (α=0.05), and n = 946 for a high survival year and n = 2,773 for a low survival year (α=0.10) (Table A2, Figures A3, A4). In general, increasing the number of replicates and increasing the Type I error rate (α) require smaller sample sizes for a given effect size (δ) and power level. Detecting a larger effect size also requires fewer fish.

For Chinook salmon, using the parameters in Table 1 and a single replicate, the size of the release group at Durham Ferry necessary to achieve 80% power to detect a 100% increase (δ=2.0) in total survival from Mossdale to Chipps Island with a Type I error rate of α=0.05 is n = 254 for a high survival year, and n = 2,002 for a low survival year (Figure B5; Table B2). For a Type I error rate of α=0.10 with a single replicate, n = 185 for a high survival year, and n = 1,460 for a low survival year (Table A2, Figure A6). Using two replicates halves the necessary sample size per replicate, with n = 127 for a high survival year and n = 1,001 for a low survival year (α=0.05), and n = 93 for a high survival year and n = 730 for a low survival year (α=0.10) (Table A2).

Table A2. Sample sizes necessary at Durham Ferry to have a probability (power) of 80% to detect a relative effect of size δ with a Type I error rate of α on total survival from Mossdale to Chipps Island. Sample sizes are based on the parameters in Table 1.

Species	Relative Effect Size (δ)	Number of replicates (k)	Error Rate (α)	Survival	Sample Size (n)
Steelhead	1.1	1	0.05	High	2,594
				Low	7,607
			0.10	High	1,891
				Low	5,546
		2	0.05	High	1,297
				Low	3,803
			0.10	High	946
				Low	2,773
Chinook	2.0	1	0.05	High	254
				Low	2,002
			0.10	High	185
				Low	1,460
		2	0.05	High	127
				Low	1,001
			0.10	High	93
				Low	730

Survival via Salvage from Mossdale

For steelhead, using the parameters in Table 1 and a single replicate, the size of the release group at Durham Ferry necessary to achieve 80% power to detect a 10% increase (δ=1.1) in survival via salvage from Mossdale to Chipps Island of with a Type I error rate of α=0.05 is n = 9,666 for a year with high survival (low detection probabilities), and n = 23,511 for a year with low survival (high detection probabilities) (Table A3). For a Type I error rate of α=0.10, n = 7,048 for high survival, and n = 17,142 for low survival. Using two replicates, the necessary sample sizes decrease to n = 4,833 for a high survival year and n = 11,755 for a low survival year with α=0.05, and n = 3,524 for high survival and n = 8,571 for low survival with α=0.10 (Table A3). Larger effect sizes require fewer fish (Figure A7, Figure A8).

For Chinook salmon, using the parameters in Table 1 and a single replicate, the size of the release group at Durham Ferry necessary to achieve 80% power to detect a 100% increase (δ=2.0) in survival via salvage from Mossdale to Chipps Island with a Type I error rate of α=0.05 is n = 547 for a year with high survival, and n = 4,059 for a year with low survival (Table A3, Figure B9). For an error rate of α=0.10, n = 399 for a high survival year, and n = 2,960 for a low survival year (Table A3, Figure B10). Using two replicates, the necessary sample sizes decrease to n = 273 for high survival and n = 2,030 for low survival with α=0.05, and n = 199 for high survival and n = 1,480 for low survival with α=0.10 (Table A3).

Table A3. Sample sizes necessary at Durham Ferry to have a probability (power) of 80% to detect a relative effect of size δ with a Type I error rate of α on survival via salvage from Mossdale to Chipps Island. Sample sizes are based on the parameters in Table A1.

Species	Relative Effect Size (δ)	Number of replicates (k)	Error Rate (α)	Survival	Sample Size (n)
Steelhead	1.1	1	0.05	High	9,666
				Low	23,511
			0.10	High	7,048
				Low	17,142
		2	0.05	High	4,833
				Low	11,755
			0.10	High	3,524
				Low	8,571
Chinook	2.0	1	0.05	High	547
				Low	4,059
			0.10	High	399
				Low	2,960
		2	0.05	High	273
				Low	2,030
			0.10	High	199
				Low	1,480

Survival: Head of Middle River to Chipps Island

Total Survival from Head of Middle River

For steelhead, using the parameters in Table 1 and a single replicate, the size of the release group at the head of Old River necessary to achieve 80% power to detect a 10% increase (δ=1.1) in total survival from the head of Middle River to Chipps Island with an error rate of α=0.05 is n = 1,076 for a year with high survival, and n = 2,192 for a year with low survival (Table A4, Figure A11). For a Type I error rate of α=0.10, n = 785 for high survival, and n = 1,598 for low survival (Table A4, Figure A12). Using two replicates, the necessary sample sizes decrease to n = 538 for high survival and n = 1,096 for low survival with α=0.05, and n = 392 for high survival and n = 799 for low survival with α=0.10 (Table A4).

For Chinook salmon, using the parameters in Table 1 and a single replicate, the size of the release group at the head of Old River necessary to achieve 80% power to detect a 100% increase (δ=2.0) in total survival from head of Middle River to Chipps Island with a Type I error rate of α=0.05 is n = 102 for a year with high survival, and n = 549 for year with low survival (Table A4, Figure A13). For a Type I error rate of α=0.10, n = 74 for high survival, and n = 400 for low survival (Table A4, Figure B14). Using two replicates, the necessary sample sizes halve to n = 51 for high survival and n = 274 for low survival with α=0.05, and n = 37 for high survival and n = 200 for low survival with α=0.10 (Table A4).

Table A4. Sample sizes necessary at the head of Old River to have a probability (power) of 80% to detect a relative effect of size δ with a Type I error rate of α on total survival from the head of Middle River to Chipps Island. Sample sizes are based on the parameters in Table 1.

Species	Relative Effect Size (δ)	Number of replicates (k)	Error Rate (α)	Survival	Sample Size (n)
Steelhead	1.1	1	0.05	High	1,076
				Low	2,192
			0.10	High	785
				Low	1,598
		2	0.05	High	538
				Low	1,096
			0.10	High	392
				Low	799
Chinook	2.0	1	0.05	High	102
				Low	549
			0.10	High	74
				Low	400
		2	0.05	High	51
				Low	274
			0.10	High	37
				Low	200

Survival via Salvage from Head of Middle River

For steelhead, using the parameters in Table 1 and a single replicate, the size of the release group at the head of Old River necessary to achieve 80% power to detect a 10% increase (δ=1.1) in survival via salvage from the head of Middle River to Chipps Island with a Type I error rate of α=0.05 is n = 2,457 for a year with high survival, and n = 4,243 for a year with low survival (Table A5**)**. For a Type I error rate of α=0.10, n = 1,792 for high survival and n = 3,093 for low survival (Table A5). Using two replicates, the necessary sample sizes halve to n = 1,229 for a year with high survival and n = 2,121 for a year with low survival with α=0.05, and n = 896 for high survival and n = 1,547 for low survival with α=0.10 (Table A5).

For Chinook salmon, using the parameters in Table 1 and a single replicate, the size of the release group at the head of Old River necessary to achieve 80% power to detect a 100% increase (δ=2.0) in survival via salvage from head of Middle River to Chipps Island with a Type I error rate of α=0.05 is n = 240 for a year with high survival, and n = 941 for a year with low survival (Table A5). For a Type I error rate of α=0.10, n = 175 for high survival, and n = 686 for low survival (Table A5). Using two replicates, the necessary sample sizes halve to n = 120 for a high survival year and n = 470 for a low survival year with α=0.05, and n = 87 for a high survival year and n = 343 for a low survival year with α=0.10 (Table B5).

Table A5. Sample sizes necessary at the head of Old River to have a probability (power) of 80% to detect a relative effect of size δ with a Type I error rate of α on survival via salvage from the head of Middle River to Chipps Island. Sample sizes are based on the parameters in Table A1.

Species	Relative Effect Size (δ)	Number of replicates (k)	Error Rate (α)	Survival	Sample Size (n)
Steelhead	1.1	1	0.05	High	2,457
				Low	4,243
			0.10	High	1,792
				Low	3,093
		2	0.05	High	1,229
				Low	2,121
			0.10	High	896
				Low	1,547
Chinook	2.0	1	0.05	High	240
				Low	941
			0.10	High	175
				Low	686
		2	0.05	High	120
				Low	470
			0.10	High	87
				Low	343

List of References

Cormack, R. M. 1964. Estimates of Survival from the Sighting of Marked Animals. *Biometrika* 51: 429-438.

Snedecor, G. W., and W. G. Cochran. 1989. Statistical Methods, 8th edition. Iowa State University Press, Ames, Iowa.

San Joaquin River Group Authority (SJRGA) 2011. 2010 Technical Report on Implementation and Monitoring of the San Joaquin River Agreement and the Vernalis Adaptive Management Plan (VAMP). Prepared for the California Water Resources Control Board in compliance with D-1641. Available at http://www.sjrg.org/.

San Joaquin River Group Authority (SJRGA) 2013. 2011 Technical Report on Implementation and Monitoring of the San Joaquin River Agreement and the Vernalis Adaptive Management Plan (VAMP). Prepared for the California Water Resources Control Board in compliance with D-1641. Available at http://www.sjrg.org/.

Appendix A.1: Statistical Methods

Consider a two-reach release-recapture model with a dual array at the end of the second reach (Figure A1), with two treatments, where a treatment is defined by the water export operations protocol. For treatment i $(\mathrm{i}=1,2)$, survival parameters are S_{1i} and S_{2i}; detection parameters are p_{1i} at site 1, and p_{2ai} and p_{2bi} at the dual array at site 2. Let δ be the relative effect of treatment 2 on survival in reach 2, compared to treatment 1:

$$\delta = \frac{S_{22}}{S_{21}}.$$

If treatment 2 has a positive effect on survival in the second reach, then $\delta > 1$. No effect would yield $\delta = 1$. Thus, the appropriate hypotheses to test are

$$H_0 : \delta = 1 \text{ vs. } H_a : \delta > 1.$$

The sample size n necessary to achieve power of $1-\beta$ to detect a relative effect of size δ or larger with error rate α is

$$n = \frac{V_R\left(z_{1-\alpha} + z_{1-\beta}\right)^2}{\left(ln(\delta)\right)^2},$$

where

z_q is the qth quantile of the standard normal distribution (for $q = 1 - \alpha$ or $q = 1 - \beta$), and

$$V_R = \frac{1}{S_{21}^2}\left(V_1 \quad \frac{V_2}{\delta^2}\right).$$

The quantity V_i $(i = 1,2)$ is the variance of the CJS estimator of S_{2i}, scaled by the sample size (Cochran 1964):

$$V_i = \frac{S_{2i}}{S_{1i}p_{2i}}\left[\frac{q_{2ai}q_{2bi}}{p_{2ai}p_{2bi}}\left(p_{2i} \quad p_{2ai}p_{2bi}\right) - \frac{1-S_{2i}p_{2i}}{p_{1i}} +\right],$$

where

$q_{2ai} = 1 - p_{2ai}$, $q_{2bi} = 1 - p_{2bi}$, and $p_{2i} = 1 - q_{2ai}q_{2bi}$.

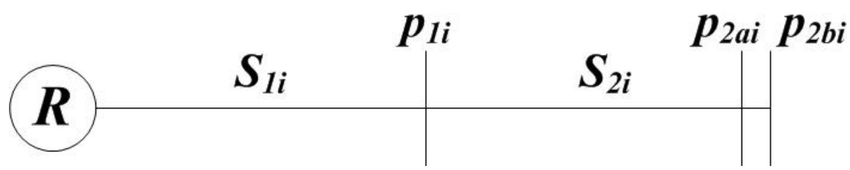


Figure A1A1. Model schematic. R = release of size *n*, S_{ji}=probability of survival through reach *j* (*j*=1,2) for treatment *i* (*i*=1,2). p_{1i}=conditional detection probability at site 1 for treatment *i*, p_{2ai} (p_{2bi}) = conditional detection probability at the first (second) station in dual array at site 2 for treatment i.

Appendix A.2: Power Plots

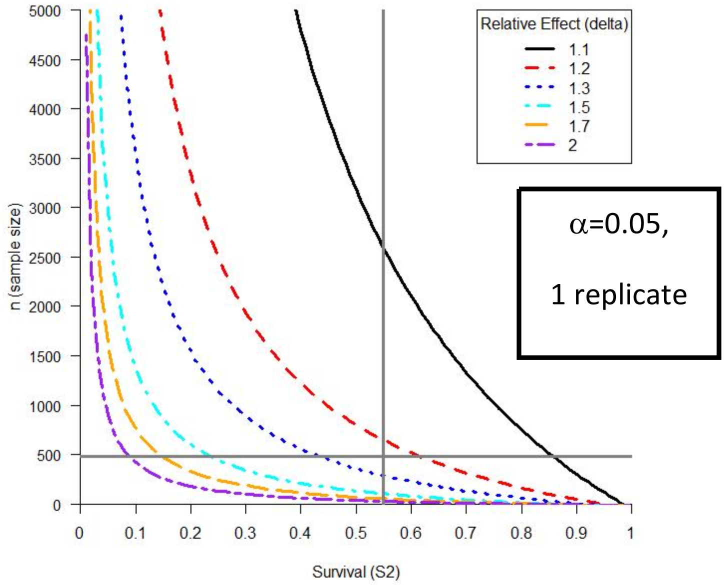


Figure A2A1. Sample sizes (*n*) necessary versus survival (S_2) to achieve 80% power to detect a relative effect of size delta (δ) in a one-tailed test with a single replicate (α=0.05). Survival and detection parameters are: S_1=0.55, p_1=0.75, p_{2a}=p_{2b}=0.85. The cross-bars indicate the observed survival and sample size in 2011 (steelhead).

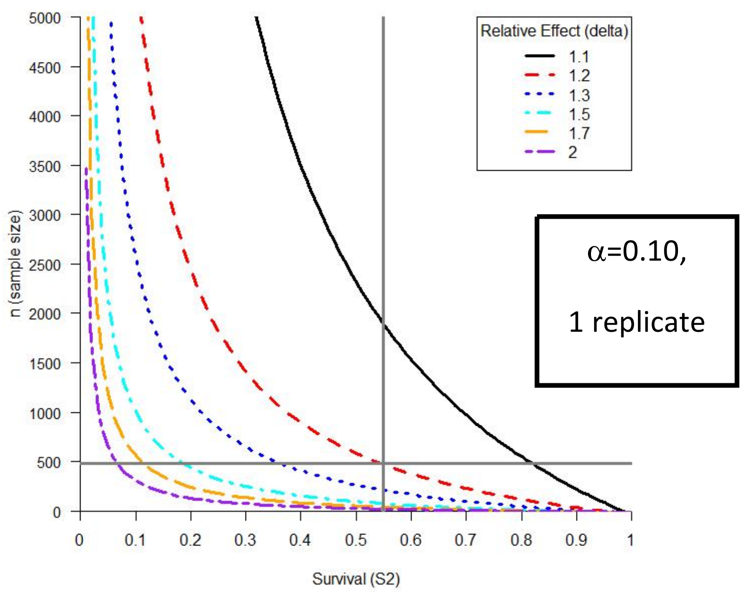


Figure A2A2. Sample sizes (*n*) necessary versus survival (S_2) to achieve 80% power to detect a relative effect of size delta (δ) in a one-tailed test with a single replicate (α=0.10). Survival and detection parameters are: S_1=0.55, p_1=0.75, p_{2a}=p_{2b}=0.88. The cross-bars indicate the observed survival and sample size in 2011 (steelhead).

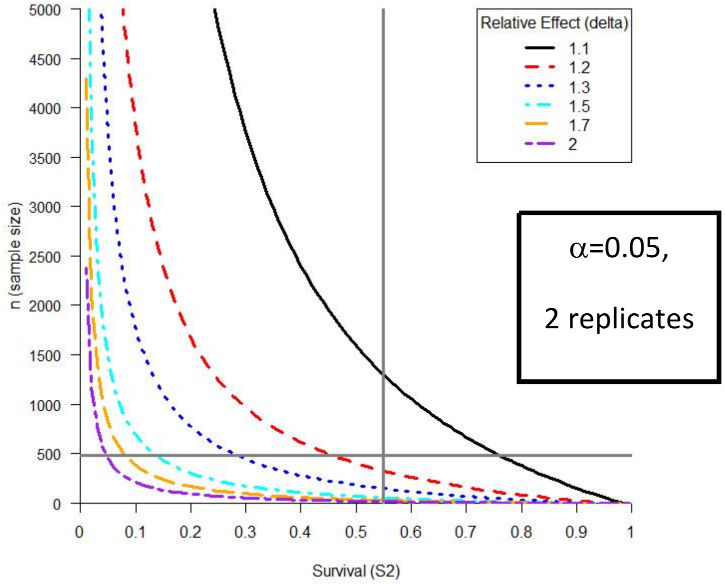


Figure A2A3. Sample sizes (*n*) necessary versus survival (S2) to achieve 80% power to detect a relative effect of size delta (δ) in a one-tailed test with two replicates (α=0.05). Survival and detection parameters are: S1=0.55, p1=0.75, p_{2a}=p_{2b}=0.88. The cross-bars indicate the observed survival and sample size in 2011 (steelhead).

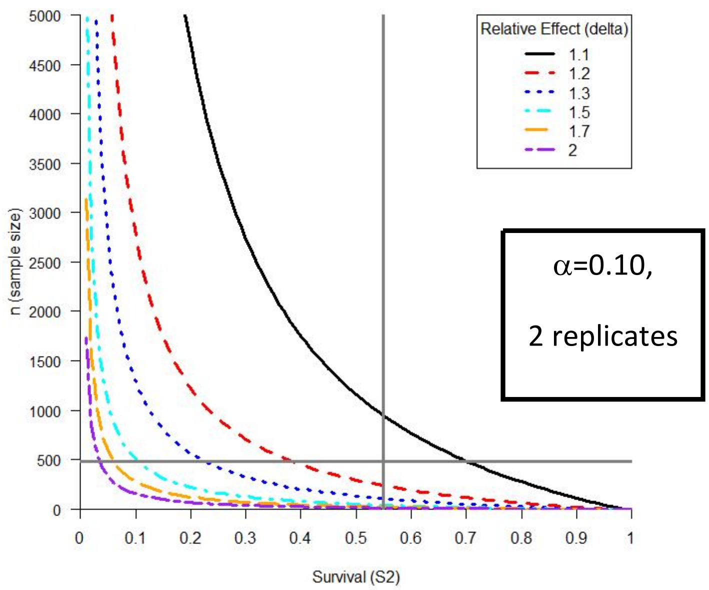


Figure A2A4. Sample sizes (*n*) necessary versus survival (S_2) to achieve 80% power to detect a relative effect of size delta (δ) in a one-tailed test with two replicates (α=0.10). Survival and detection parameters are: S_1=0.55, p_1=0.75, p_{2a}=p_{2b}=0.88. The cross-bars indicate the observed survival and sample size in 2011 (steelhead).

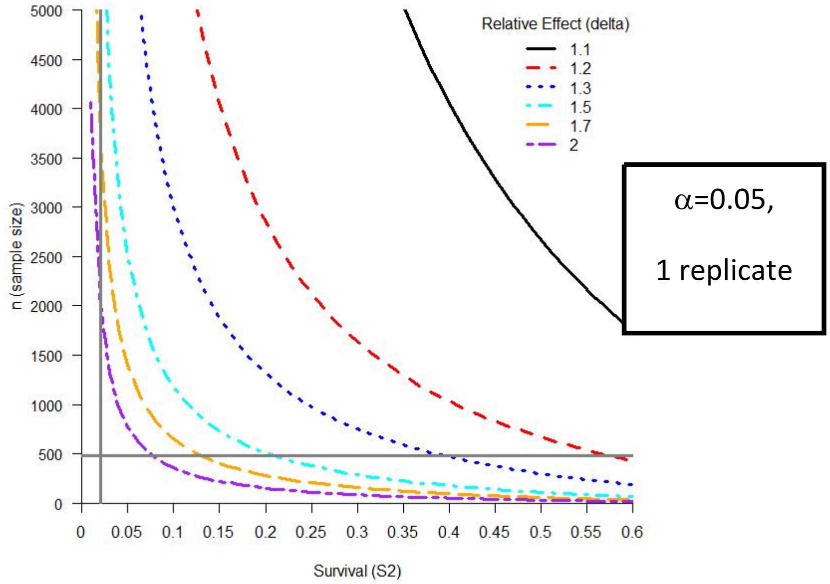


Figure A2A5. Sample sizes (*n*) necessary versus survival (S_2) to achieve 80% power to detect a relative effect of size delta (δ) in a one-tailed test with a single replicate (α=0.05). Survival and detection parameters are: S_1=0.50, p_1=0.95, p_{2a}=p_{2b}=0.90. The cross-bars indicate the observed survival and sample size in 2011 (Chinook salmon).

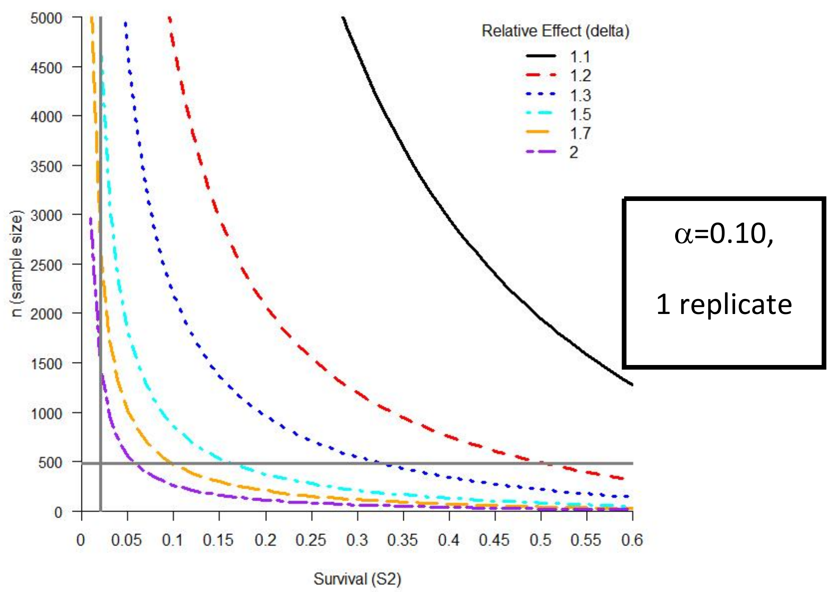


Figure A2A6. Sample sizes (*n*) necessary versus survival (S_2) to achieve 80% power to detect a relative effect of size delta (δ) in a one-tailed test with a single replicate (α=0.10). Survival and detection parameters are: S_1=0.50, p_1=0.95, p_{2a}=p_{2b}=0.90. The cross-bars indicate the observed survival and sample size in 2011 (Chinook salmon).

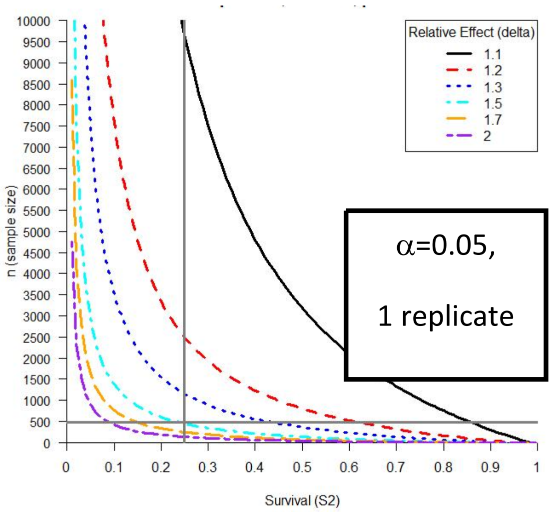


Figure A2A7. Sample sizes (*n*) necessary versus survival (S_2) to achieve 80% power to detect a relative effect of size delta (δ) in a one-tailed test with a single replicate (α=0.05). Survival and detection parameters are: S_1=0.55, p_1=0.75, p_{2a}=p_{2b}=0.85. The cross-bars indicate the assumed survival via salvage for a high survival year, and the observed sample size in 2011 (steelhead).

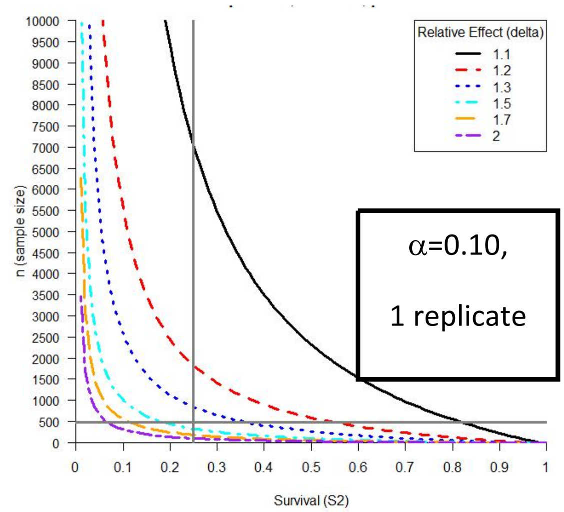


Figure A2A8. Sample sizes (*n*) necessary versus survival (S_2) to achieve 80% power to detect a relative effect of size delta (δ) in a one-tailed test with a single replicate (α=0.10). Survival and detection parameters are: S_1=0.55, p_1=0.75, p_{2a}=p_{2b}=0.85. The cross-bars indicate the assumed survival via salvage for a high survival year, and the observed sample size in 2011 (steelhead).

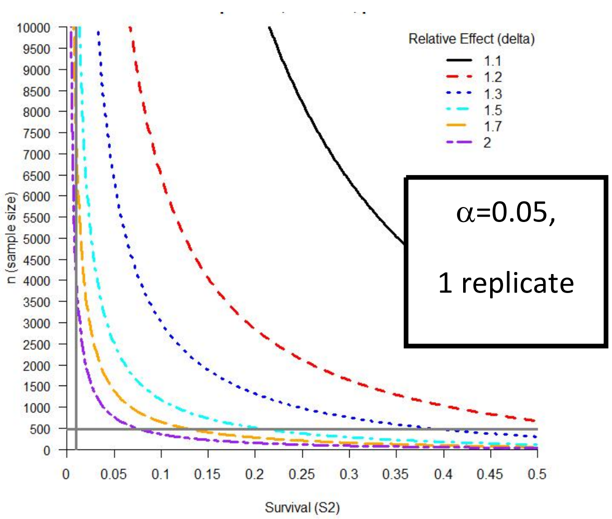


Figure A2A9. Sample sizes (*n*) necessary versus survival (S_2) to achieve 80% power to detect a relative effect of size delta (δ) in a one-tailed test with a single replicate (α=0.05). Survival and detection parameters are: S_1=0.50, p_1=0.95, p_{2a}=p_{2b}=0.90. The cross-bars indicate the assumed survival via salvage for a low survival year, and the observed sample size in 2011 (Chinook).

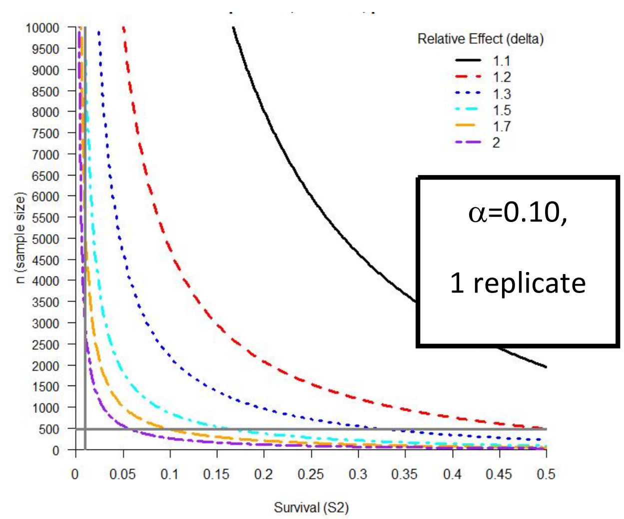


Figure A2A10. Sample sizes (*n*) necessary versus survival (S_2) to achieve 80% power to detect a relative effect of size delta (δ) in a one-tailed test with a single replicate (α=0.10). Survival and detection parameters are: S_1=0.50, p_1=0.95, p_{2a}=p_{2b}=0.90. The cross-bars indicate the assumed survival via salvage for a low survival year, and the observed sample size in 2011 (Chinook).

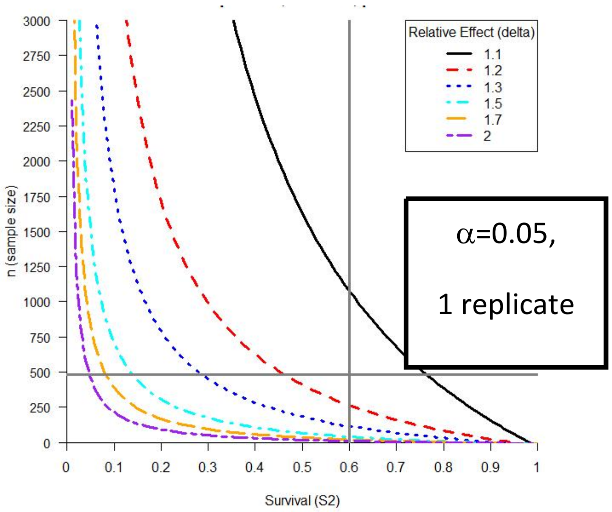


Figure A2A11. Sample sizes (*n*) necessary versus survival (S_2) to achieve 80% power to detect a relative effect of size delta (δ) in a one-tailed test with a single replicate (α=0.05). Survival and detection parameters are: S_1=0.95, p_1=0.85, p_{2a}=p_{2b}=0.85. The cross-bars indicate the assumed survival via salvage for a high survival year, and the observed sample size in 2011 (steelhead).

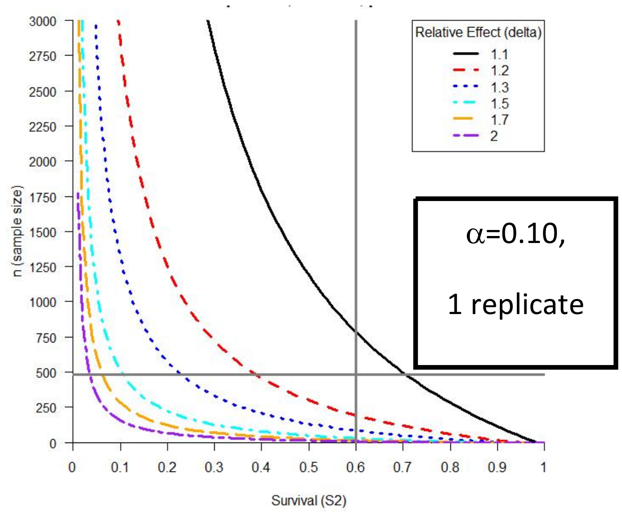


Figure A2A12. Sample sizes (*n*) necessary versus survival (S_2) to achieve 80% power to detect a relative effect of size delta (δ) in a one-tailed test with a single replicate (α=0.10). Survival and detection parameters are: S_1=0.95, p_1=0.85, p_{2a}=p_{2b}=0.85. The cross-bars indicate the assumed survival via salvage for a high survival year, and the observed sample size in 2011 (steelhead).

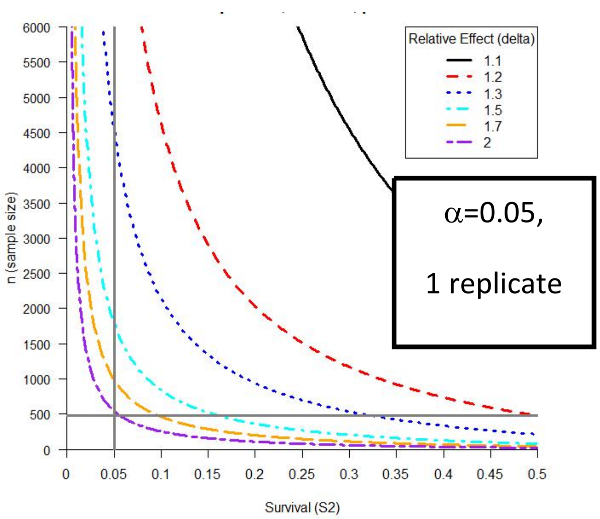


Figure A2A13. Sample sizes (*n*) necessary versus survival (S_2) to achieve 80% power to detect a relative effect of size delta (δ) in a one-tailed test with a single replicate (α=0.05). Survival and detection parameters are: S_1=0.70, p_1=0.95, p_{2a}=p_{2b}=0.90. The cross-bars indicate the assumed survival via salvage for a low survival year, and the observed sample size in 2011 (Chinook).

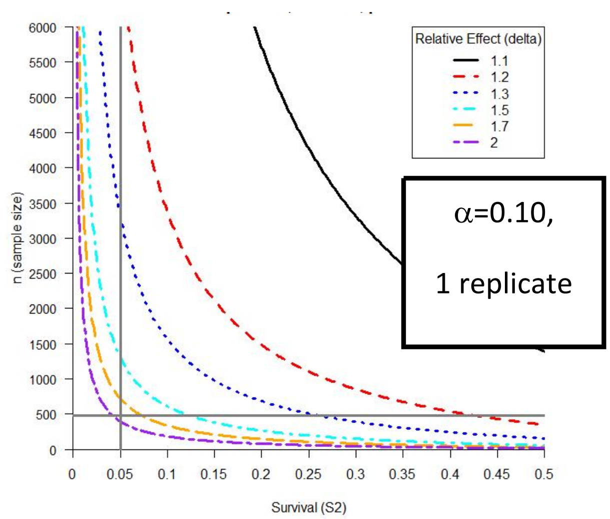


Figure A2A14. Sample sizes (*n*) necessary versus survival (S_2) to achieve 80% power to detect a relative effect of size delta (δ) in a one-tailed test with a single replicate (α=0.10). Survival and detection parameters are: S_1=0.70, p_1=0.95, p_{2a}=p_{2b}=0.90. The cross-bars indicate the assumed survival via salvage for a low survival year, and the observed sample size in 2011 (Chinook).

Appendix B. Standard Operating Procedures Acoustic Tagging for Steelhead 2012 South Delta Studies

MATERIALS NEEDED:

- Thermometer
- Dissolved oxygen (DO) meter
- Acoustic tags and acoustic tag activation and monitoring equipment
- Chlorhexidine solution (30mL/L D-H_2O)
- Distilled or de-ionized water (D-H_2O)
- Tricaine methanesulfonate (MS-222; 100g/L),
- Sodium bicarbonate solution (buffer; 100g/L)
- Stress coat - stock concentration and 25% solution (250mL/L D-H_2O)
- Disinfectant solution (Virkon Aquatic or 70% ETOH)
- 19 L bucket(s) marked at 10 L and clearly labeled ‘Anesthesia’
- 19 L bucket clearly labeled ‘Reject’ for fish not selected for tagging procedures
- Two gravity feed containers marked at 10 L, and connected by rubber tubing with in-line shut-off valves (one labeled ‘anesthesia’ and one labeled ‘freshwater’)
- Syringes (10 mL) for measuring anesthetic, buffer, and stress coat
- Oxygen delivery system (cylinder, regulator, airline, air diffusers)
- Dip nets
- Nitrile gloves
- Scale measuring to the nearest 0.1 g
- Large plastic weigh boats
- Measuring board with ruler to the nearest millimeter
- Surgical platform
- Trays for holding solutions used to disinfect surgical tools
- Needle drivers
- Forceps
- Scalpel handle and blades
- Sutures: Vicryl plus 4-0 with an RB-1 needle
- Spray bottles for disinfectant solution
- Timer(s)
- Sharps container
- Datasheets and writing tools

Equipment Set Up:

- Fill surgical instrument disinfection trays with chlorhexidine (brand name Nolvasan)
  - Autoclave instruments such that each tagging event begins with sterile instruments
- Activate transmitters and confirm operational status
  - Remove labels from the Vemco V6 transmitters and scrub the transmitter surface to ensure thatno label residue remains
  - Position the transmitter in an isolated compartment to enable tracking of the transmitter ID through the implantation process
- Disinfect transmitters in chlorhexidine
  - Ensure at least 20 minutes of contact time with chlorhexidine
  - Following disinfection, thoroughly rinse transmitters in distilled or de-ionized water prior to implantation
  - Following disinfection, transmitters should only be handled by gloved hands or cleansurgical instruments such as forceps
- Fill rinse tray with de-ionized or distilled water
- Set up scale, measuring board, and surgical platform or foam
  - Apply stress coat to weigh boat, measuring board, and platform to reduce damage to fish skin ormucus layer
- Fill gravity feed carboys. Add 2 ml of the MS-222 stock solution and 2 ml of the sodium bicarbonate stock solution to the 10 L of water in the MS-222 carboy. Concentration may be increased upon group consensus and in consultation with coordinator.
- Fill anesthesia container to indicated volume line. Set the initial concentration in collaboration with the tagging coordinator. Suggested starting concentration is 70 mg/ L. Concentration may be adjusted upon group consensus and in consultation with coordinator. Concentration changes should be executed for all taggers simultaneously and recorded on the tagging datasheet.
- Prepare recovery containers by filling with water, adding stress coat, and supersaturating with oxygen
  - Immediately following surgery fish will be held in recovery containers that provide 130% to 150% DO for a minimum of 10 minutes
  - Holding time in recovery containers begins when the last fish is added to the container and willbe monitored using a timer
- Prepare a reject container for fish that cannot be tagged by filling with water and equipping with a bubbler. These fish will be returned to a separate raceway.
- Start tagging data sheets. Note the time the tagging session was started and complete all appropriate data fields. Start a Daily Fish Reject Tally datasheet to account for fish that are handled but nottagged.
- The tagger should wear medical-grade exam gloves during all fish handling and tagging procedures
- Prepare the transport truck to be able to circulate water through containers
- Remove transport containers from the freezer and prepare them to receive tagged fish

- Transport containers that leave the hatchery grounds and are delivered to the release site at Durham Ferry must be frozen for 24 h prior to being used again for the tagging operation. These details are outlined in the project biosecurity plan.
- When removing containers from the freezer, be sure to consult with the tagging coordinator to ensure that all containers undergo the full 24 h of exposure before they are removed and used.

Surgery

- Food should be withheld from fish for ~24 h prior to surgical implantation of the transmitter.
- Anesthetize fish
    - Net one fish from source tank/raceway and place directly into an anesthesia container. Immediately start a timer to monitor anesthesia exposure time and place a lid on the container.
    - Remove the lid after about 1 minute to observe the fish for loss of equilibrium. Keep the fish in the water for an additional 30-60 seconds after it has lost equilibrium. Time to sedation should normallybe 2-4 minutes, with an average of about 3 minutes. If loss of equilibrium takes less than 1 minute or if a fish is exposed to anesthesia for more than 5 minutes, reject that fish. If after anesthetizing a fewfish

      they are consistently losing equilibrium in more or less time than typical, the anesthesia concentration may need to be adjusted. Anesthesia concentration should only be adjusted in coordination with all study taggers and the tagging coordinator.
        - Changes to anesthesia concentration should be done at 5 mg/L increments. For example, if the initial dosage was 70 mg/L, an adjusted dose should be 65 mg/L or 75 mg/L.
        - When an anesthesia change is agreed upon, all taggers should drain their anesthesia containers, refill with 10 L of water, and re-mix to the new anesthesia concentration
    - If a fish is unacceptable for tagging due to issues with anesthesia, place the fish in the "Reject" container and log it on the reject tally datasheet.
    - The anesthesia container should be emptied and remixed at regular intervals throughout the tagging operation to ensure the appropriate concentration and to avoid warming
    - The gravity feed containers should be monitored for volume and temperature and changed as neededto avoid inadequate volume to complete a surgery and significant warming

- Recording fish length, weight, and condition
    - Start a timer when a fish is removed from the anesthesia container to record the

time the fish is out of water (recorded as “air time”).

- Transfer the fish to the scale and record the weigh to the nearest 0.1g
    - Scales should be calibrated regularly to ensure accuracy
    - Fish must weigh at least 20 g to be selected for tagging so that tag burden does not exceed 5% of the weight of the fish. Transmitters used for this study are Vemco brand V6 models,weighing 1.0 g in air.
- Transfer the fish to the measuring board and determine forklength to the nearest mm.
- Check for any abnormalities and descaling. If the fish is abnormal or grossly descaled, note this on the datasheet and place the fish in the reject container.
    - Scale condition is noted as Normal (N), Partial (P), or Descaled (D) and is assessed on the most compromised side of each fish. The normal scale condition is defined as loss of less than 5% of scales on one side of the fish. Partial descaling is defined as loss of 6-19% of scales on one side of the fish. Fish are classified as descaled if they have lost 20% or more of the scales on one side of the fish, and should not be tagged due to compromised osmoregulatory ability.
- Data must be vocally relayed to the recorder, and the recorder should repeat the information back to the tagger to avoid miscommunication.
- Any fish dropped on the floor should be rejected.

- Transmitter Implantation
    - Anesthesia should be administered through the gravity feed irrigation system as soon as the fish is on the surgical platform. Use the flow control valves to adjust the flow rate as needed so that theopercular rate of the fish is steady.
        - Note that low-flow or inconsistent irrigation can mimic shallow anesthesia
    - Using a scalpel, make an incision approximately 3-5 mm in length beginning a few mm in front of the pelvic girdle. The incision should be about 3 mm away from and parallel to the mid-ventral line, and just deep enough to penetrate the peritoneum, avoiding the internal organs. The spleen is generally near the incision point so the depth and placement of the incision are critical.
        - There is no exact specification for the selection of a micro scalpel for steelhead. A general recommendation is to use a 5 mm blade for fish larger than about 50 g.
        - The incision should only be long enough to allow entry of the tag.
    - Forceps may be used to open the incision to check for potential organ damage. If you observe damage or note excessive bleeding, reject the fish.
    - Scalpel blades can be used on several fish, but if the scalpel is pulling roughly or making jagged incisions, it should be changed prior to tagging the next fish.
    - Gently insert the tag into the body cavity and position it so that it lies directly

beneath the incision and the ceramic head is facing forward. This positioning will provide a barrier between the suture needle and internal organs.

  - Close the incision with two simple interrupted stitches.
    - Vicryl Plus sutures are recommended
    - 4-0 suture size is appropriate for juvenile steelhead or similar fish with weights above about 50 g
    - If the incision cannot effectively be closed with two stitches, a third stitch may be added. The presence of a third suture should be noted on the datasheet.
  - Ideally the gravity feed irrigation system should be switched to fresh water or a combination of sedation and freshwater during the final stages of surgery to begin recovery from anesthesia. Typically a good time to switch to freshwater is when the second suture is initiated.
  - Transfer the fish from the surgical platform to a recovery container and stop the timer recording airtime
    - Avoid excessive handling of fish during transfer. Ideally the fish will be moved to the recovery container on the surgical platform to reduce handling.
  - Once a recovery container has been fully stocked, start a timer to monitor the 10 min of exposure to high DO concentrations for recovery.
  - Between surgeries the tagger should place surgical instruments and any partially consumed suture material into the chlorhexidine bath. Multiple sets of surgical instruments should be rotated to ensure 10 min of contact time with chlorhexidine. Once disinfected, instruments should be rinsed in distilled or de-ionized water. Organic debris in the disinfectant bath reduces effectiveness, so be sure to change the bath regularly.

Tag Validation

- Filled recovery containers will be moved to the tag validation station.
  - Recovery containers may be moved from the tagging location to the tag validation station during the10 min recovery time, but they must not be established on flow-through water exchange. The flow- through exchange will immediately reduce the DO saturation.
- Use the appropriate receiving system to confirm the identity and function of the transmitters in the recovery container. Record validation on the datasheet.
- Following tag validation, recovery containers are loaded onto a truck for transport to the holding andrelease location.

Cleanup

- Both the tagger and assistant must review the full complement of tagging datasheets and initial each sheet to confirm that the set of transmitters they were assigned to implant have been implanted. Use the list of transmitters provided by the tag coordinator to ensure that all transmitters supplied to you were implanted and recorded. Both the tagger and the assistant must initial the header of each of the datasheets. This review step is completed for each tagging session (that is, for each transport truck that is loaded).

- Return tag tray and datasheets to coordinator at end of each tagging session.
- Complete the reject fish tally datasheet and return to the tag coordinator.
- Use a spray disinfectant to disinfect tagging surfaces and supplies, and position them to dry.
- Return any rejected fish to the appropriate raceway where they cannot be selected for future tagging efforts.
- At the completion of the tagging effort each day, package surgical instruments for the autoclave so they can be sterilized prior to the next tagging session.

Important things to remember:

- Water containers used for tagging should be filled just prior to tagging to avoid temperature changes and should be changed frequently.
- Fish cannot be transferred between water sources until the difference between the water temperatures of the two sources is less than two degrees Celsius.
- No water sources used in the tagging operation should be more than two degrees different inwater temperature from the source water temperature.
- All containers holding fish should have lids in place.
- If a tag is dropped bring it to the tagging coordinator to confirm that it is still functioning before it is implanted. The transmitter may also require disinfection if it fell onto a dirty surface.
- Carefully handle all fish containers to minimize disturbances to fish.
- Containers used to transport fish to the release site cannot be used for tagging operations until they have been held in the freezer for 24 h.

Appendix C. 2013 Six-Year Acoustic Study Biosecurity Awareness and Procedure Form

Biosecurity awareness and procedures are essential to minimize the possibility of contamination of San Joaquin River water, bearing waterborne diseases and organisms, into the Mokelumne River Hatchery and other facilities potentially being used by the Six-Year Study during 2013.

Biosecurity starts with awareness and requires implementation of simple steps to control contamination between San Joaquin River and the Mokelumne River.

Biosecurity awareness and procedures helps to protect again known biorisks (i.e. New Zealand Mud Snails) and unknown risks (let's practice common sense to keep these isolated).

Biosecurity is the responsibility of each of the study's personnel.

Control Points at Facilities

Standard Protocols for tagging and transport are designed to ensure that the hygiene of personnel and tagging buckets/totes are maintained by:

1. Not bringing waders or boots from the San Joaquin River into contact with raceway water or drain water at the Mokelumne River Hatchery or other facility.
2. Totes taken to the San Joaquin River will be decontamination before reuse at the Mokelumne River hatchery by rinsing off mud and aquatic vegetation and freezing. All surfaces (i.e. lids) will be rinsed and frozen.

Control Points at River

Standard protocols for transport and holding are designed to ensure that the hygiene of personnel, equipment and the transport truck are maintained by:

1. Personnel only using designated CLEAN waders or boots to step into the transport tank and unload buckets/totes. CLEAN waders and boots should not make contact with the ground.
2. Personnel only using a designated CLEAN dissolved oxygen meter in the transport tank.
3. The fish transport vehicle will remain on the levee at the San Joaquin River and equipment attached to the truck will not be in contact with San Joaquin River water. If the truck gets into mud, it should go to a power wash and get a spray down before returning to the hatchery.
4. Emptied buckets/totes and their lids will not be put onto the transport truck, but returned to Mokelumne Hatchery after drying at the USFWS Stockton office yard. Buckets/totes and lids should be rinsed and stored on a clean surface at the Stockton office, so that they go into the freezer in the cleanest possible conditions.

Appendix D. QA/QC checklist used in 2013

QA/QC Site Visit Checklist
Tagging Procedures for South Delta Studies 2013

Tagger: ______________________________ Site: ______________________________
Assistants: ______________________________ Date: ______________________________
QA Inspector: ______________________________ Time: ______________________________

---

1. Were transmitters activated prior to implantation?

☐ Yes ☐ No ☐ Did not observe

Corrective action (if applicable):

---

2. Were transmitters disinfected in chlorhexidine (20 min contact time) and rinsed prior to implantation?

☐ Yes ☐ No ☐ Did not observe

Comments:

Corrective action (if applicable):

---

3. Did the tagger wear gloves during fish handling and tag implantation procedures?
Were disinfected transmitters handled with gloves or clean instruments?

☐ Yes ☐ No ☐ Did not observe

Comments:

Corrective action (if applicable):

---

4. Were MS-222 and bicarbonate solution added to anesthesia containers
resulting in the proper concentrations?

☐ Yes ☐ No ☐ Did not observe

Comments:

Corrective action (if applicable):

---

5. Was anesthesia exposure time monitored? If fish exceeded 5 min were they rejected?

☐ Yes ☐ No ☐ Did not observe

Comments:

Corrective action (if applicable):

QA/QC Site Visit Checklist
Tagging Procedures for South Delta Studies 2013
Continued

---

6. Were labels applied to recovery buckets to ensure transfer to proper transport containers?

☐ Yes ☐ No ☐ Did not observe

Comments:

Corrective action (if applicable):

---

7. Was stress coat used appropriately on surfaces and in buckets?
(especially important on the tagging platform and in the recovery buckets)

☐ Yes ☐ No ☐ Did not observe

Comments:

Corrective action (if applicable):

---

8. Were source fish netted carefully? Was care taken to minimize chasing?

☐ Yes ☐ No ☐ Did not observe

Comments:

Corrective action (if applicable):

---

9. Were lids used on all buckets containing fish?

☐ Yes ☐ No ☐ Did not observe

Comments:

Corrective action (if applicable):

---

10. Did staff ensure that all fish in a recovery bucket were held for at least 10 min and had regained equilibrium before moving them to the transport truck?

☐ Yes ☐ No ☐ Did not observe

Comments:

Corrective action (if applicable):

QA/QC Site Visit Checklist
Tagging Procedures for South Delta Studies 2013
Continued

---

11. Were the following water quality parameters within specifications:

Temp in anesthesia bucket <2 ^{o}C different from raceway? ☐ Yes ☐ No ☐ Did not observe

Temp in gravity feed <2 ^{o}C different from raceway? ☐ Yes ☐ No ☐ Did not observe

Temp in recovery buckets <2 ^{o}C different from raceway? ☐ Yes ☐ No ☐ Did not observe

DO in recovery buckets 140-150%? ☐ Yes ☐ No ☐ Did not observe

Comments:

Corrective action (if applicable):

---

12. If water quality measurements were outside the acceptable range, was corrective action taken?

☐ Yes ☐ No ☐ Did not observe ☐ WQ readings were within acceptable range

Comments:

Corrective action (if applicable):

---

13. Were fish held at appropriate densities for short-term holding (i.e., no more than 2 fish per recovery bucket)?

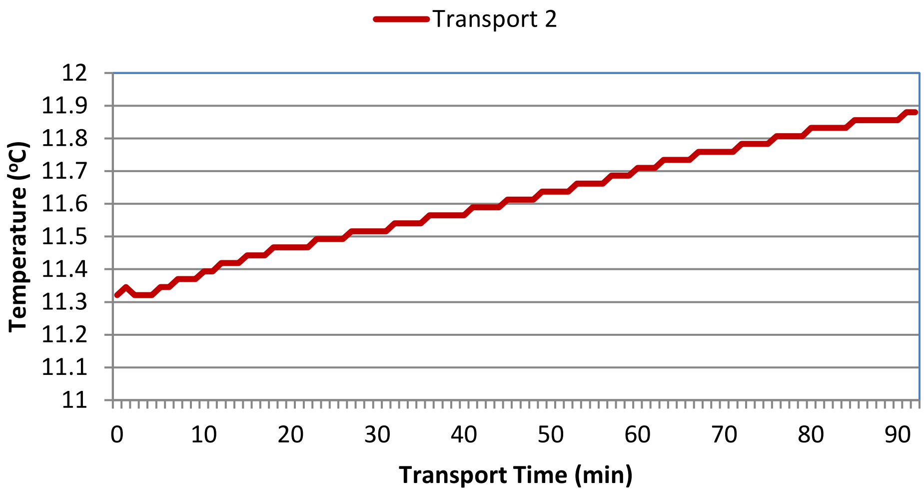
☐ Yes ☐ No ☐ Did not observe

Comments:

Corrective action (if applicable):

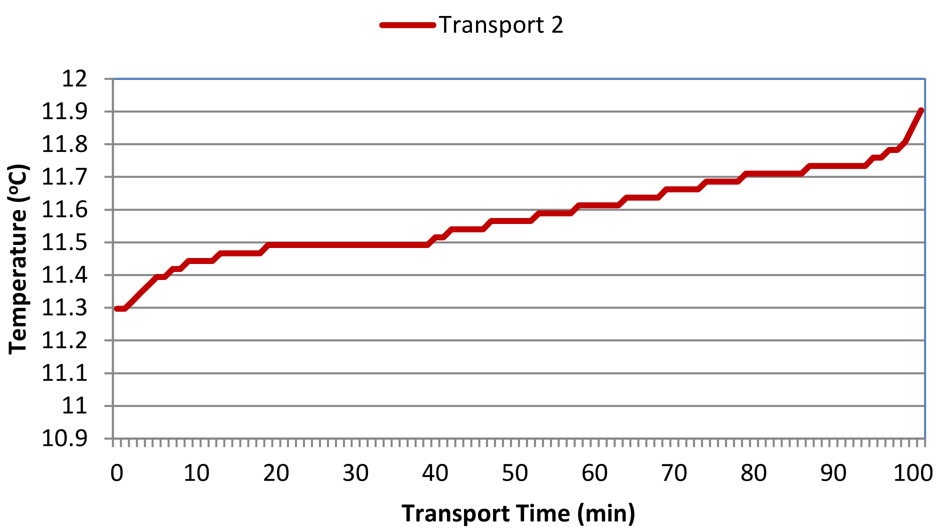
Appendix E. Transport temperatures during steelhead transport in 2013.

Date: 3/5/13
Transport 1 – 11:46-14:18*
Transport 2 – 15:38-17:10
Transport 3 – 19:15-20:20**



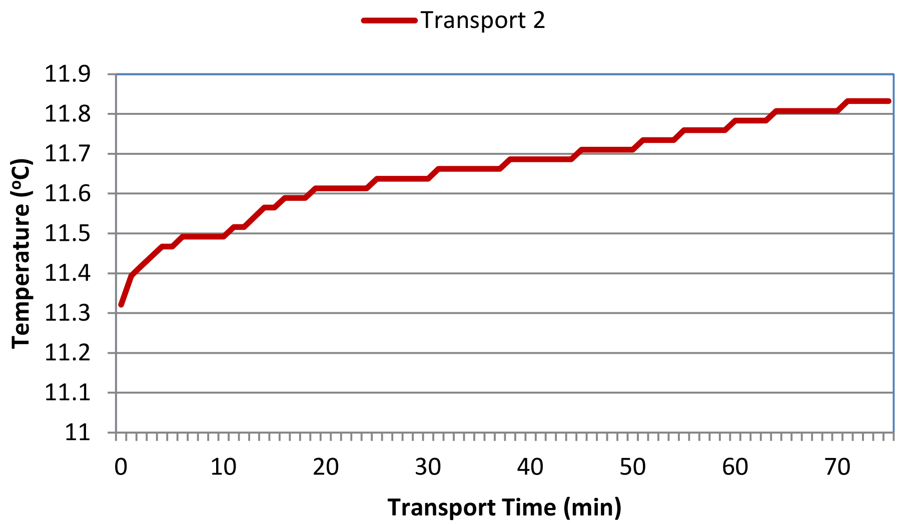
*NOTE: Fish in Transport 1 were transferred to the truck used for Transport 3 due to a mechanical problem with Truck 1. The logger on Truck 3 did not record any temperature data due a full memory.
**NOTE: Temperatures for Transport 3 were not recorded because the logger's memory was full

Date: 3/6/13
Transport 1 – 10:35-11:53*
Transport 2 – 13:12-14:53
Transport 3 – 16:50-17:52*



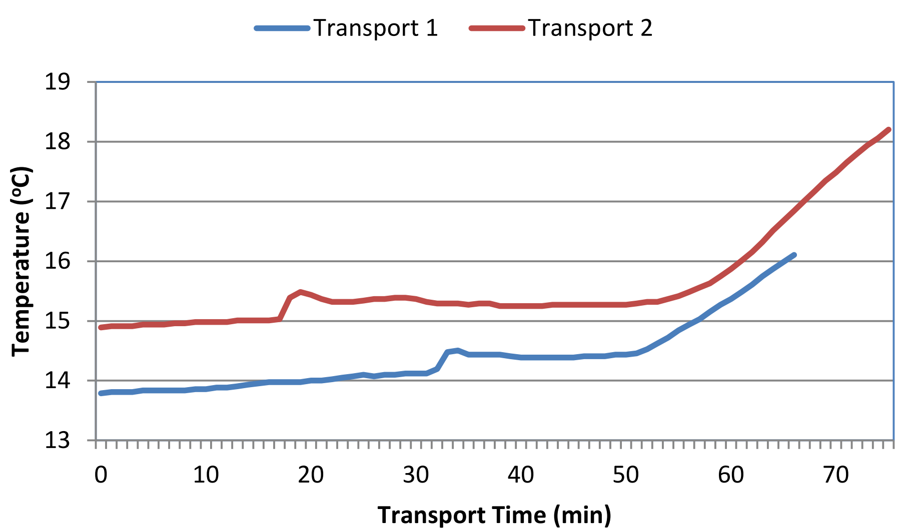
*NOTE: Temperature data not logged due to full memory on logger.

Date: 3/7/13
Transport 1 – 11:00-12:15*
Transport 2 – 13:45-15:00
Transport 3 – 17:05-18:05*



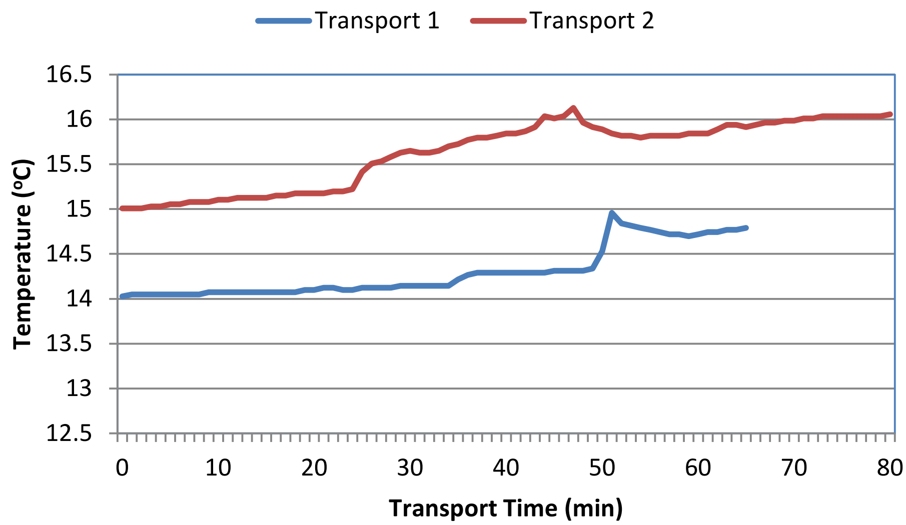
*NOTE: Temperature data not logged due to full memory on logger.

Date: 4/2/13
Transport 1 – 10:55-12:01
Transport 2 – 13:25-14:40
Transport 3 – 16:02-17:00*



*NOTE: Temperature data not logged due to full memory on logger.

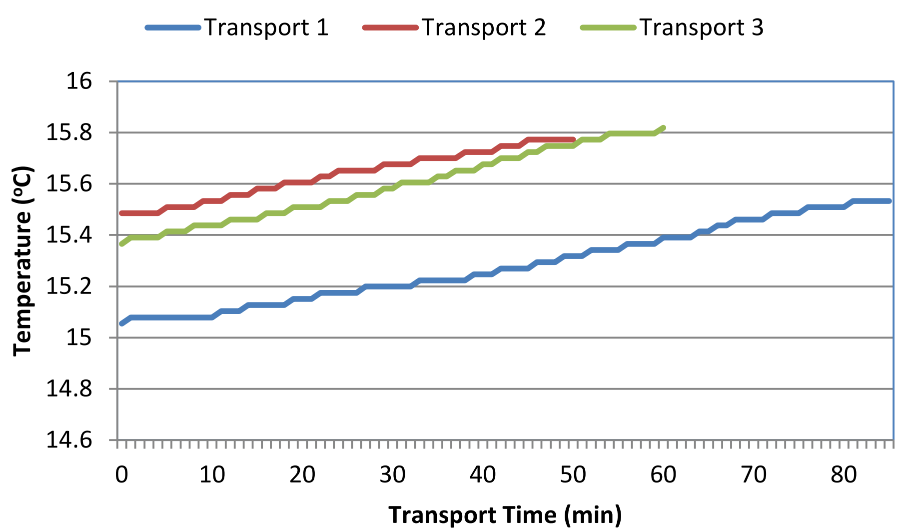
Date: 4/3/13
Transport 1 – 10:30-11:35
Transport 2 – 13:00-14:20
Transport 3 – 15:41-16:41*



*NOTE: Temperature data not logged due to full memory on logger.

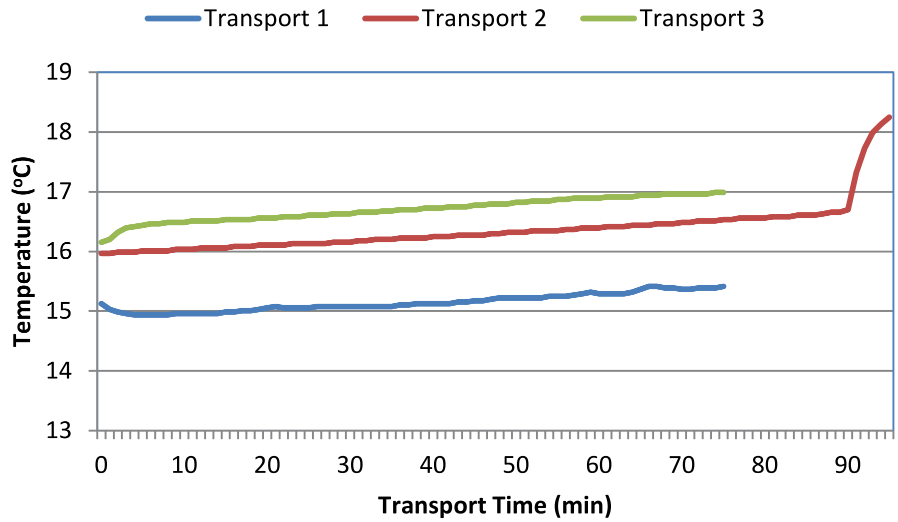
Date: 4/4/13
No temperature data logged due to full memories on loggers.

Date: 5/7/13
Transport 1 – 11:50-13:15
Transport 2 – 14:30-15:20
Transport 3 – 16:52-17:52

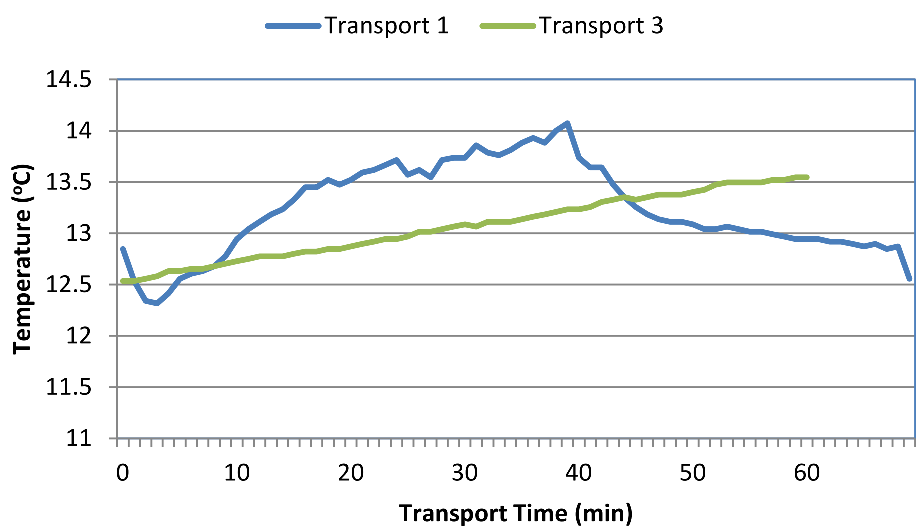


Date: 5/8/13

Transport 1 – 10:35-11:50
Transport 2 – 13:30-15:05
Transport 3 – 16:00-17:15



Date: 5/9/13
Transport 1 – 11:16-12:36*
Transport 2 – 13:50-15:00**
Transport 3 – 17:00-18:00



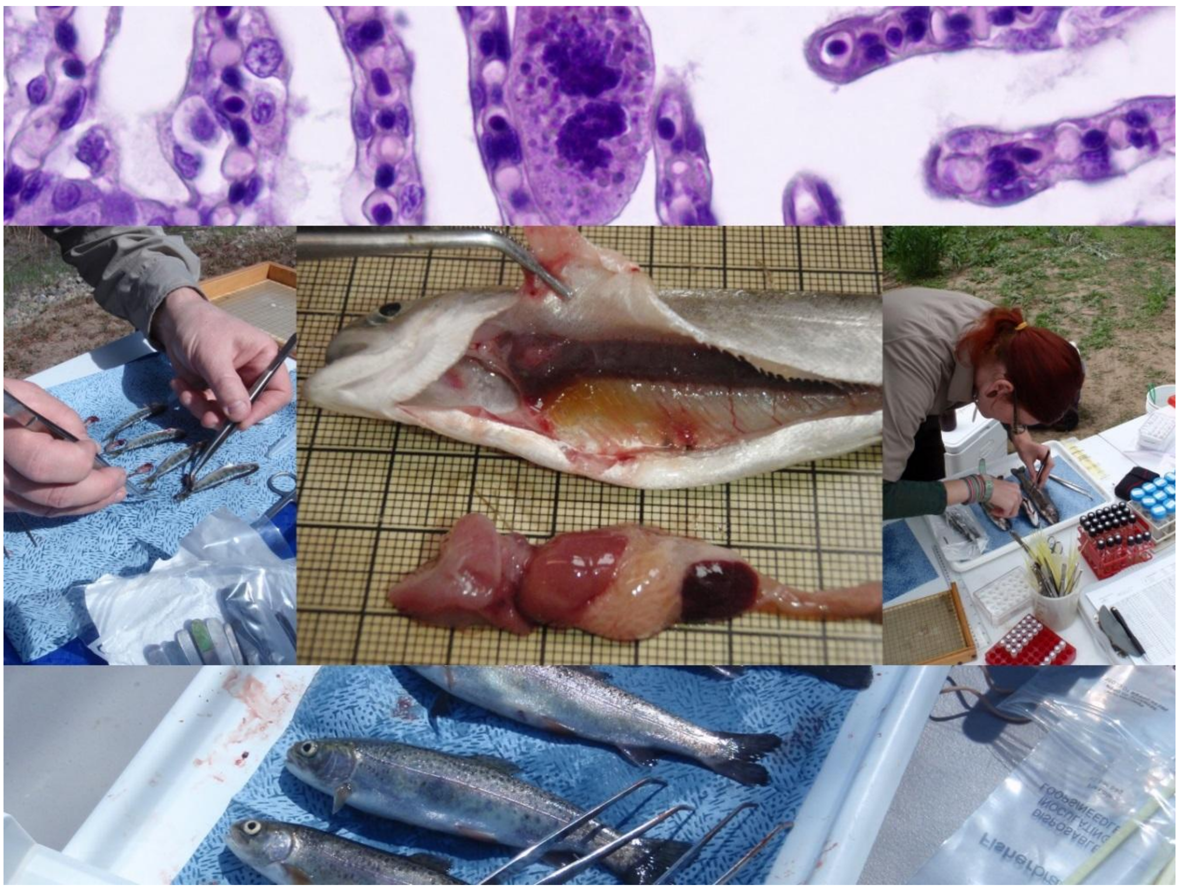
*NOTE: The temperatures recorded for Transport 1 were unlikely for the first ten minutes, so they were deleted. The time recorded on the datasheet or the internal clock of the logger may have been off.
**NOTE: Transport 2 temperatures do not match those recorded at MRH or at the release site so they were not included on this graph; no explanation why the temperatures do not match.

Appendix F. Fish Health Report

U.S. Fish & Wildlife Service

FY2013 Technical Report: Pathogen Screening and Gill Na^+/K^+- ATPase Assessment of South Delta Chinook and Steelhead 2013 Release Groups

Ken Nichols



August 2013

US Fish and Wildlife Service
California-Nevada Fish Health Center
24411 Coleman Fish Hatchery Rd
Anderson, CA 96007
(530) 365-4271 Fax: (530) 365-7150
http://www.fws.gov/canvfhc/

Summary

As a component of studies examining the reach-specific survival and distribution of migrating juvenile Chinook salmon and steelhead in the San Joaquin River and Delta, the CA-NV Fish Health Center conducted a general pathogen screening and smolt physiological assessment. Juvenile Chinook salmon and steelhead trout were surveyed for specific fish pathogens and smolt development using gill Na^+/K^+-ATPase (gill ATPase) activity levels. The health and physiological condition of the study fish can help explain their performance and survival during the studies. In both steelhead and Chinook release groups, survival over the 24 holding period was high. The myxozoan parasite *Tetracapsuloides bryosalmonae* was detected at moderate to high levels in a majority of the Chinook sampled. Anemia associated with late stage PKD was not observed. The infection was progressive and impacts on survival could occur within the study period (30 days). No other significant pathogen infections were detected in either the Chinook or steelhead. Gill ATPase activity levels were lower in later release groups of both Chinook and Steelhead suggesting these later groups were beyond the peak of smoltification.

Recommended citation for this report is:

Nichols, K. 2013. FY2013 Technical Report: Pathogen Screening and Gill Na+/K+- ATPase Assessment of South Delta Chinook and Steelhead 2013 Release Groups. U.S. Fish & Wildlife Service, California-Nevada Fish Health Center, Anderson, CA. Available: http://www.fws.gov/canvfhc/reports.asp.

Background

As a component of studies examining the reach-specific survival and distribution of migrating juvenile Chinook salmon and steelhead in the San Joaquin River and Delta, the CA-NV Fish Health Center conducted a general pathogen screening and smolt physiological assessment. Steelhead trout were examined in support of the 6-year Study required by the 2009 Biological Opinion on Central Valley Project and State Water Project operations (RPA IV.2.2). The health and physiological condition of the study fish can help explain their performance and survival during the studies. Similar pathogen screening and physiological assessments have been conducted on south delta study fish since 1996. These past examinations have identified the myxozoan parasite *Tetracapsuloides bryosalmonae*, the causative agent of Proliferative Kidney Disease (PKD), in juvenile Merced River Hatchery Chinook. This parasite has been shown to cause mortality in Chinook salmon with increased mortality and faster disease progression in fish at higher water temperatures (Ferguson 1981; Foott et al. 2007). In 2013, juvenile Chinook salmon and steelhead trout were surveyed for specific fish pathogens and smolt development using gill Na^+/K^+-ATPase activity levels.

Methods

Fish Sampling

All study fish were cohorts of acoustic tagged release groups and shadowed each release group through handling, tagging (dummy tagged), transport, and in-river holding. Study fish were held for 48 hours at the Durham Ferry release site on the San Joaquin River before sampling. Groups of 30 juvenile Merced River Hatchery Chinook salmon were sampled on 5 May and 19 May, 2013. Groups of 24 Mokelumne River Hatchery yearling steelhead trout were sampled on 9 March, 6 April and 11 May, 2013. Fish were euthanized; fork length (FL), weight (Wt) and any abnormalities were noted; and tissue samples for lab assays were collected. In addition to the release groups, an additional 30 Chinook were sampled at Merced River Hatchery on 3 May, 2013 (MRH group). Only kidney tissue for the histopathology assay was collected from the MRH group.

Lab Assays

Bacteriology – A sample of kidney tissue was collected aseptically and inoculated onto brain-heart infusion agar. Bacterial isolates were screened by standard microscopic and biochemical tests (USFWS and AFS-FHS 2010). These screening methods would not detect *Flavobacterium columnare*. *Renibacterium salmoninarum* (the bacteria that causes bacterial kidney disease) was screened by fluorescent antibody test of kidney imprints.

Virology – Three fish pooled samples of kidney and spleen were inoculated onto EPC and CHSE-214 at 15°C as described in the AFS Bluebook (USFWS and AFS-FHS 2010) with the exception that no blind pass was performed.

Histopathology – The gill and/or posterior kidney were removed from the fish and immediately fixed in Davidson's fixative. In the lab, the tissues were processed for 5 µm paraffin sections and stained with hematoxylin and eosin (Humason 1979). All tissues for a given fish were placed on one slide and identified by a unique code number. Each slide was examined under a light microscope and observations of abnormalities were noted. Gill was sampled from both Chinook and steelhead release groups and examined for signs of external parasite infection. Kidney was sampled from Chinook release groups and screened for the *T. bryosalmonae* parasite. Infections of the myxozoan parasite *T. bryosalmonae* were rated for intensity of parasite infection and associated tissue inflammation. Intensity of infection was rated as none (zero), low (<10), moderate (11-30) or high (>30) based on number of *T. bryosalmonae* trophozoites observed in the kidney section. Severity of kidney inflammation was rated as normal, focal, multifocal or diffuse.

Gill ATPase – Gill Na^+/K^+-Adenosine Triphosphatase (gill ATPase) activity was assayed by the method of McCormick (1993). Gill ATPase activity is correlated with osmoregulatory ability in saltwater, and high concentrations are found in the chloride cells of the lamellae.

Results

Fish Condition

Chinook – The size and condition of the release groups are summarized in Table F1. No mortality occurred with either sample group. Externally, there were no observations of pale gills, significant scale loss or external hemorrhaging. Sutures were all in good condition with minor inflammation noted in 3% (1/30) of fish on 5 May and 7% (2/30) of fish on 19 May. Internally, clinical signs of PKD (swollen kidney and/or spleen) were observed in 23% (7/30) of fish on 5 May and 23% (7/30) fish on 19 May.

Table F1. Mean (± standard deviation) fork length (FL), weight (Wt), Fulton condition factor (KFL) and sample size (N) for Chinook salmon release groups.

Group	FL (mm)	Wt (g)	KFL	N
5 May	113.9 ±5.0	17.0 ±2.4	1.15 ±0.06	30
19 May	117.2 ±5.9	18.6 ±2.9	1.15 ±0.04	30

Steelhead – The size and condition of the release groups are summarized in Table F2. No mortalities prior to sampling occurred in the March group, one moribund (dying) fish was observed in the April group, and there was one mortality and one moribund fish in the May group. All fish were euthanized at once on the March sample, so some fish were dead up to 2 hours before sampling. In the April and May samples, fish were euthanized in three fish groups immediately before sampling. No pale gills, excessive scale loss or external hemorrhaging were observed; however one fish with a missing eye and another with a healed wound on the belly were noted in the March fish group. No problems with sutures were noted in the fish sampled in March (0/23); minor inflammation at the suture site was noted in 17% (4/24) of the April fish; and 8% (2/24) of the May fish had poorly healed partly open sutures. Internally, an unidentified kidney cyst was observed in one (1/23) fish from the March group, and no other gross internal abnormalities were observed in the steelhead examined in March, April or May.

Table F2. Mean (± standard deviation) fork length (FL), weight (Wt), Fulton condition factor (KFL) and sample size (N) for steelhead sample groups.

Group	FL (mm)	Wt (g)	KFL	N
March	201 ±21	79 ±27	0.94 ±0.08	23
April	209 ±19	84 ±23	0.89 ±0.06	24
May	221 ±14	102 ±18	0.93 ±0.10	24

Bacteriology and Virology

In both Chinook and steelhead sample groups, no virus or other cytopathic effects were observed by cell culture over the 21 day incubation period. No obligate fish pathogens were detected, and other isolates were isolated in 5-23% of sample groups (Table F2). These other isolates were common fauna in the environment and fishes GI tract (Aoki 1999) and were likely contaminates due to field sampling conditions.

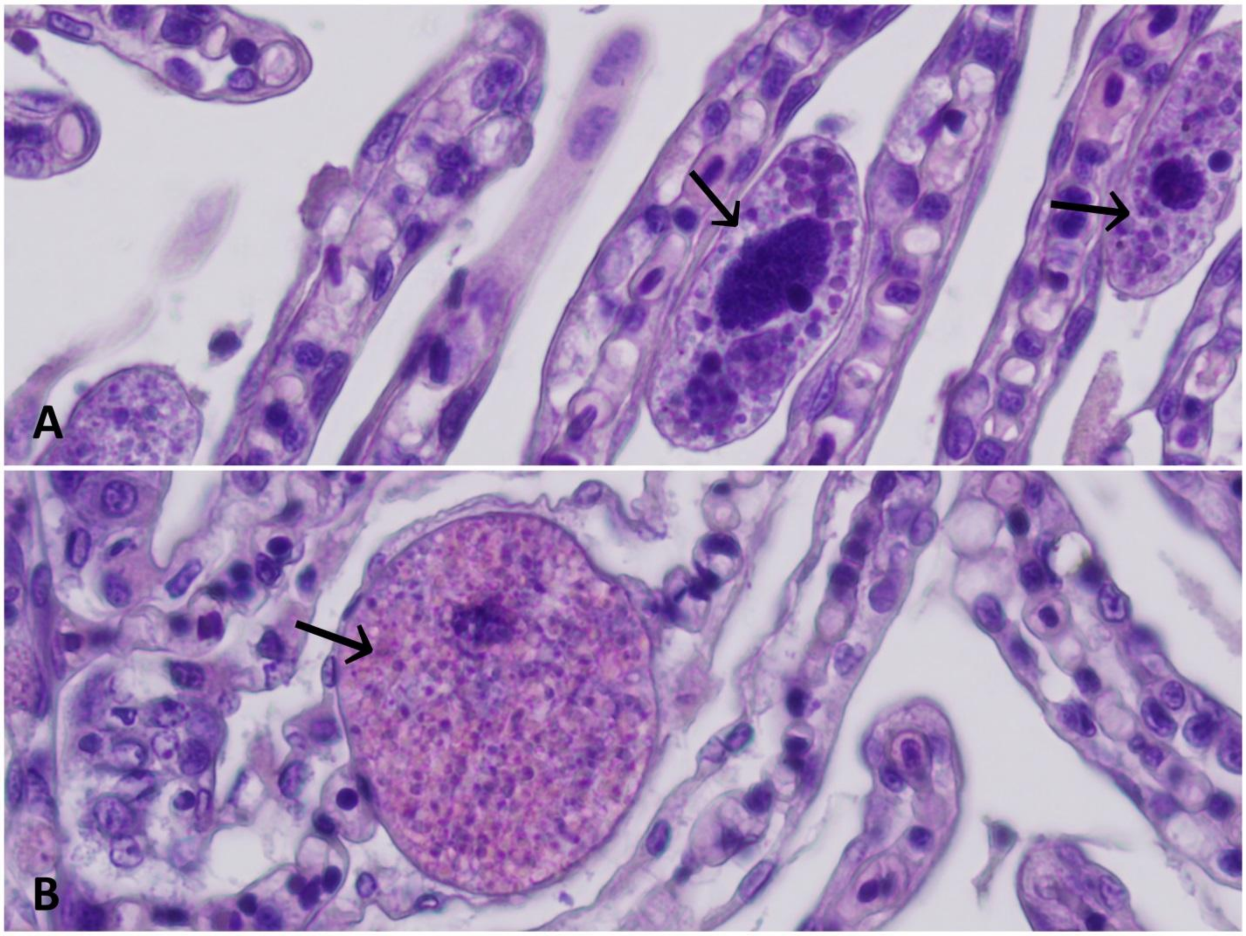
Table F3. Summary of bacteria isolated from the kidneys of dummy tagged fish. These isolates were likely contaminates from which are commonly found in surface water, soil or the fish's GI tract.

Species	*Aeromonas /Pseudomonas*	various Gram positive bacteria
Chinook	5% (3/60)	23% (14/60)
Steelhead	6% (4/71)	10% (7/71)

Gill Histology

Chinook – No parasite infections or significant inflammation was seen in gill sections from the 5 May or 19 May Chinook sample groups.

Steelhead – The majority of the fish sampled in March demonstrated epithelial edema which was most likely a post mortem change due to premature euthanization of this group. Minor gill edema was observed in 33% (8/24) of steelhead in the April sample and 4% (1/24) in May, but no significant inflammation or gill lesions were observed in any of the sample groups. An unidentified protozoan parasite (Figure F1**FigureF**A) was observed in 39% (9/23) of fish sampled in March, 63% (15/24) of fish in April and 8% (2/24) of fish sampled in May. Cyst-like zenomas of an unidentified Microsporidia (Figure F1B) were noted in 8% (2/24) of fish from the April and May samples groups, but were not observed in fish from the March group. As noted above, there was no significant gill inflammation or other signs of gill damage associated with these infections.



FigureF1. Parasite infections observed in histopathological examination of steelhead gills. No inflammation or other tissue damage was associated with these infections. (A) Unidentified external protozoan observed on steelhead gills from March, April and May release groups. (B) Zenoma of an unidentified Microsporidea observed in April and May release groups.

Kidney Histology

Chinook – The *T. bryosalmonae* parasite was detected in fish from all three Chinook release groups, with 80% to 100% of the fish infected. The intensity of the infections (based on number of parasites) was rated as high in over half of the fish from each release group (Table F3). There was no significant difference detected in the severity of the infections between release groups (Table F4**Table**, p=0.089, Fisher's exact test for count data).

Table F4. Prevalence and intensity of *T. bryosalmonae* infection in kidney tissue of juvenile Steelhead. Data presented as number of fish with zero (None), few than 10 (Low), 11-30 (Moderate) or greater than 30 (High) parasites observed in kidney tissue by histopathology. No significant difference was detected between release groups (p=0.101, Fisher's Exact Test for Count Data).

Group	None	Low	Moderate	High
MRH (3 May)	1	10	2	16
5 May	5	5	1	14
19 May	0	9	5	16

Table F5. Severity of kidney inflammation associated with *T. bryosalmonae* infection in juvenile Chinook. Data presented as the number of fish with kidney inflammation rated as normal, focal, multifocal or diffuse by histopathology. No significant difference was detected between release groups (p=0.089, Fisher's Exact Test for Count Data).

Group	Normal	Focal	Multifocal	Diffuse
MRH (3 May)	4	11	11	3
5 May	5	9	7	4
19 May	0	12	8	10

Gill ATPase Activity

Chinook – Gill ATPase activity levels (μmol ADP*mg protein^{-1}*hr^{-1}) ranged from 2.8 to 19.3. The activity levels in the 5 May release group was significantly higher than 19 May (Figure F2**Figure F2**, P<0.001, Wilcoxen rank sum test)).

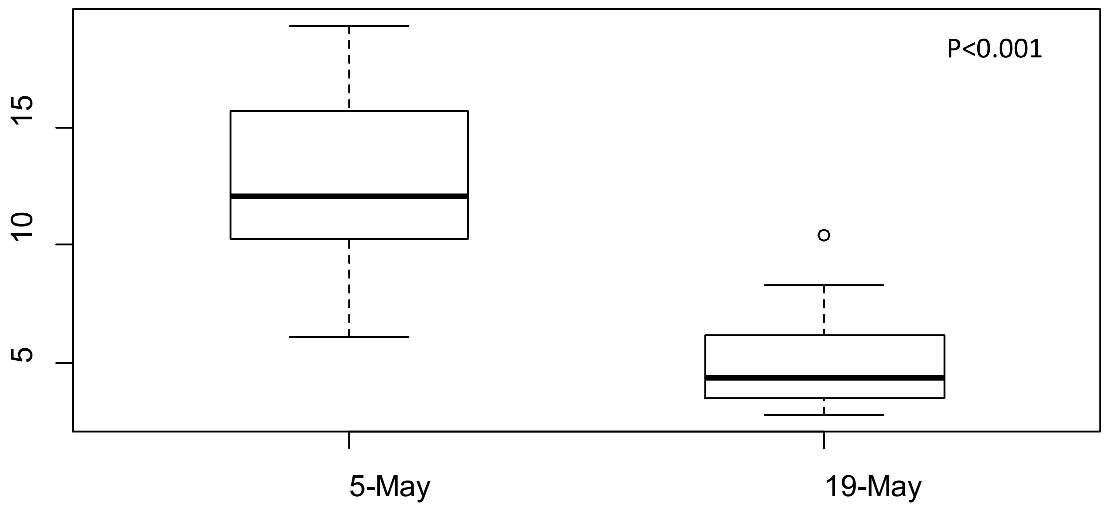


Figure F2. Boxplot of median gill ATPase activity (µmol ADP·mg protein^{-1}·hr^{-1}) in juvenile Chinook salmon sampled from the 5 May and 19 May release groups. A significant difference was detected between the release groups (P<0.001, Wilcoxon rank sum test).

Steelhead – Gill ATPase activity levels (µmol ADP*mg protein^{-1}*hr^{-1}) ranged from 0.78 to 10.34. Activity levels were greatest in the March release group and decreased in the April and May groups (Figure F3, P<0.001, ANOVA)

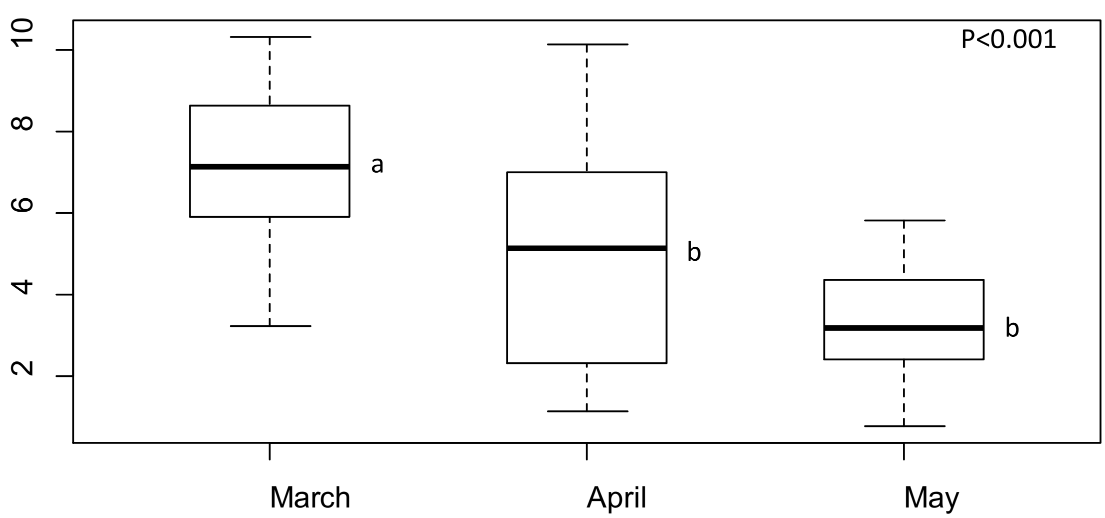


Figure F3. Boxplot of median gill ATPase activity (µmol ADP·mg protein^{-1}·hr^{-1}) in juvenile steelhead from the March, April or May release groups. Groups with letter subscripts in common were not significantly different (P<0.001, ANOVA).

Discussion

The most significant health problem observed was the *T. bryosalmonae* infection in the Chinook release groups. Anemia associated with late stage PKD was not observed. The infection is progressive and may have impacted survival of the Chinook release groups within the typical (30 day) battery life of the acoustic tags (Ferguson 1981; Foott, Stone and Nichols 2007). In past VAMP studies where fish were held in the laboratory for monitoring, total mortality due to the disease was low at 20%-27% (Foott, Stone and Nichols 2007; Foott and Stone 2008). Direct and indirect mortality rates due to PKD in study fish which must actively traverse the Delta are not known.

Gill ATPase activity levels in both the Steelhead and Chinook release groups were lower in the later release(s) which suggests activities were beyond peak levels and declining in those groups. Gill ATPase activity in salmonds 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 gill ATPase activity can also occur due to increases in water temperature (Duston et al. 1991). More active migratory behavior in the 5 May Chinook and March steelhead release groups would be consistent with the gill ATPase levels.

Acknowledgments

Biologists with the USFWS Stockton FWO provided help with logistics and fish handling. Scott Foott and Jennifer Jacobs with at the CA-NV Fish Health Center provided valuable assistance with field sampling and laboratory assays.

References

Aoki T. 1999. Motile Aeromonads. Chapter 11 In: Fish Diseases and Disorders, Vol. 3: Viral, Bacterial and Fungal Infections, Woo P T K and Bruno D W, editors, CABI Pub. New York.

Duston J, R L Saunders and D E 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 R D, G S Ewing and T D 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.

Ferguson H W. 1981. The effects of water temperature on the development of Proliferative Kidney Disease in rainbow trout, Salmo gairdneri Richardson. Journal of Fish Disease 4: 175-177.

Foott J S and R Stone. 2008. FY 2008 Investigational report: Evaluation of sonic tagged Chinook juveniles used in the 2008 VAMP study for delayed mortality and saltwater survival – effects of Proliferative Kidney Disease. US Fish and Wildlife Service, California-Nevada Fish Health Center, Anderson, CA. Available: http://www.fws.gov/canvfhc/reports.asp (September 2010).

Foott J S, R Stone and K Nichols. 2007. Proliferative Kidney Disease (*Tetracapsuloides bryosalmonae*) in Merced River Hatchery juvenile Chinook salmon: mortality and performance impairment in 2005 smolts. California Fish and Game 93: 57-76.

Humason G L. 1979. Animal Tissue Techniques, 4th edition. W H Freeman and Co., San Francisco.

McCormick S D. 1993. Methods for Nonlethal Gill Biopsy and Measurement of Na+, K+-ATPase Activity. Canadian Journal of Fisheries and Aquatic Sciences. 50: 656-658.

USFWS and AFS-FHS (U.S. Fish and Wildlife Service and American Fisheries Society-Fish Health Section). 2010. Standard procedures for aquatic animal health inspections. In AFS-FHS. FHS blue book: suggested procedures for the detection and identification of certain finfish and shellfish pathogens, 2010 edition. AFS-FHS, Bethesda, Maryland.

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

Appendix G. Survival Model Parameters

Table G1. Definitions of parameters used in the release-recapture survival model in the 2013 tagging study. 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 Mossdale (MOS)
S_{A4}	Probability of survival from Mossdale (MOS) to Lathrop (SJL) or Old River East (ORE)
S_{A5}	Probability of survival from Lathrop (SJL) to Garwood Bridge (SJG)
S_{A6}	Probability of survival from Garwood Bridge (SJG) to Navy Drive Bridge (SJNB)
$S_{A6,G2}$	Overall survival from Garwood Bridge (SJG) to Chipps Island (MAE/MAW) (estimated directly or derived from Submodel I)
S_{A7}	Probability of survival from Navy Drive Bridge (SJNB) to MacDonald Island (MAC) or Turner Cut (TCE/TCW)
$S_{A7,G2}$	Overall survival from Navy Drive Bridge (SJNB) to Chipps Island (MAE/MAW) (derived from Submodel I)
S_{B1}	Probability of survival from Old River East (ORE) to Old River South (ORS)
$S_{B2,G2}$	Overall survival from Old River South (ORS) to Chipps Island (MAE/MAW) (derived from Submodel I)
$S_{B2(SD)}$	Overall survival from Old River South (ORS) to the exit points of the Route B Southern Delta Region: OR4, MR4, RGU, CVP (derived from Submodel I)
$S_{C1,G2}$	Overall survival from head of Middle River (MRH) to Chipps Island (MAE/MAW) (derived from Submodel I)
$S_{C1(SD)}$	Overall survival from head of Middle River (MRH) to the exit points of the Route B Southern Delta Region: OR4, MR4, RGU, CVP (derived from Submodel I)
$S_{F1,G2}$	Overall survival from Turner Cut (TCE/TCW) to Chipps Island (MAE/MAW) (Submodel I)
$\phi_{A1,A0}$	Joint probability of moving from Durham Ferry release site upstream toward DFU, and surviving to DFU
$\phi_{A1,A2}$	Joint probability of moving from Durham Ferry release site downstream toward DFD, and surviving to DFD
$\phi_{A1,A3}$	Joint probability of moving from Durham Ferry release site downstream toward BCA, and surviving to BCA; = $\phi_{A1,A2}$ S_{A2}
$\phi_{A6,D1O}$	Joint probability of moving from SJG toward RGU, surviving to RGU, and arriving when the radial gates are open (Submodel II)
$\phi_{A6,D1C}$	Joint probability of moving from SJG toward RGU, surviving to RGU, and arriving when the radial gates are closed (Submodel II)
$\phi_{A6,D1}$	Joint probability of moving from SJG toward RGU and surviving to RGU (Submodel II)
$\phi_{A6,E1}$	Joint probability of moving from SJG toward CVP and surviving to CVP (Submodel II)
$\phi_{A6,GH}$	Joint probability of moving from SJG directly toward Jersey Point (JPE/JPW) or False River (FRE/FRW), and surviving JPE/JPW or FRE/FRW (Submodel II)
$\phi_{A6,G1}$	Joint probability of moving from SJG directly toward Jersey Point (JPE/JPW) and surviving to JPE/JPW (Submodel II); = $\phi_{A6,GH}\psi_{G1(A)}$
$\phi_{A9,A10}$	Joint probability of moving from MAC toward MFE/MFW, and surviving from MAC to MFE/MFW (Submodel II)
$\phi_{A9,D1O}$	Joint probability of moving from MAC toward RGU, surviving to RGU, and arriving when the radial gates are open (Submodel II)
$\phi_{A9,D1C}$	Joint probability of moving from MAC toward RGU, surviving to RGU, and arriving when the radial gates are closed (Submodel II)
$\phi_{A9,D1}$	Joint probability of moving from MAC toward RGU and surviving to RGU (Submodel II)
$\phi_{A9,E1}$	Joint probability of moving from MAC toward CVP and surviving to CVP (Submodel II)
$\phi_{A9,GH}$	Joint probability of moving from MAC directly toward Jersey Point (JPE/JPW) or False River (FRE/FRW), and surviving JPE/JPW or FRE/FRW (Submodel II)
$\phi_{A9,G1}$	Joint probability of moving from MAC directly toward Jersey Point (JPE/JPW) and surviving to JPE/JPW (Submodel II); = $\phi_{A9,GH}\psi_{G1(A)}$
$\phi_{A10,D1O}$	Joint probability of moving from MFE/MFW toward RGU, surviving to RGU, and arriving when the radial gates are open (Submodel II)
$\phi_{A10,D1C}$	Joint probability of moving from MFE/MFW toward RGU, surviving to RGU, and arriving when the radial gates are closed (Submodel II)
$\phi_{A10,D1}$	Joint probability of moving from MFE/MFW toward RGU and surviving to RGU (Submodel II)

Table G1. (Continued)

Parameter	Definition
$\phi_{A10,E1}$	Joint probability of moving from MFE/MFW toward CVP and surviving to CVP (Submodel II)
$\phi_{A10,GH}$	Joint probability of moving from MFE/MFW directly toward Jersey Point (JPE/JPW) or False River (FRE/FRW), and surviving to JPE/JPW or FRE/FRW (Submodel II)
$\phi_{A10,G1}$	Joint probability of moving from MFE/MFW directly toward Jersey Point (JPE/JPW) and surviving to JPE/JPW (Submodel II); = $\phi_{A10,GH}\psi_{G1(A)}$
$\phi_{B2,B3}$	Joint probability of moving from ORS toward OR4, and surviving from ORS to OR4
$\phi_{B2,C2}$	Joint probability of moving from ORS toward MR4, and surviving from ORS to MR4
$\phi_{B2,D1O}$	Joint probability of moving from ORS toward RGU, surviving to RGU, and arriving when the radial gates are open
$\phi_{B2,D1C}$	Joint probability of moving from ORS toward RGU, surviving to RGU, and arriving when the radial gates are closed
$\phi_{B2,D1}$	Joint probability of moving from ORS toward RGU, and surviving from ORS to RGU
$\phi_{B2,E1}$	Joint probability of moving from ORS toward CVP, and surviving from ORS to CVP
$\phi_{B3,GH(B)}$	Joint probability of moving from OR4 toward Jersey Point (JPE/JPW) or False River (FRE/FRW), and surviving from OR4 to JPE/JPW or FRE/FRW (Submodel I [route B])
$\phi_{B3,G1(B)}$	Joint probability of moving from OR4 toward Jersey Point (JPE/JPW) and surviving from OR4 to JPE/JPW (Submodel I [route B]); = $\phi_{B3,GH(B)}\psi_{G1(B)}$
$\phi_{C1,B3}$	Joint probability of moving from MRH toward OR4, and surviving from MRH to OR4
$\phi_{C1,C2}$	Joint probability of moving from MRH toward MR4, and surviving from MRH to MR4
$\phi_{C1,D1O}$	Joint probability of moving from MRH toward RGU, surviving to RGU, and arriving when the radial gates are open
$\phi_{C1,D1C}$	Joint probability of moving from MRH toward RGU, surviving to RGU, and arriving when the radial gates are closed
$\phi_{C1,D1}$	Joint probability of moving from MRH toward RGU, and surviving from MRH to RGU
$\phi_{C1,E1}$	Joint probability of moving from MRH toward CVP, and surviving from MRH to CVP
$\phi_{C2,GH(B)}$	Joint probability of moving from MR4 toward Jersey Point (JPE/JPW) or False River (FRE/FRW), and surviving from MR4 to JPE/JPW or FRE/FRW (Submodel I [route B])
$\phi_{C2,G1(B)}$	Joint probability of moving from MR4 toward Jersey Point (JPE/JPW) and surviving from MR4 to JPE/JPW (Submodel I [route B]); = $\phi_{C2,GH(B)}\psi_{G1(B)}$
$\phi_{D1O,D2}$	Joint probability of moving from RGU toward RGD, and surviving from RGU to RGD, conditional on arrival at RGU when the radial gates are open (equated between submodels I and II)
$\phi_{D1C,D2}$	Joint probability of moving from RGU toward RGD, and surviving from RGU to RGD, conditional on arrival at RGU when the radial gates are closed (equated between submodels I and II)
$\phi_{D1,D2}$	Joint probability of moving from RGU toward RGD, and surviving from RGU to RGD (equated between submodels I and II)
$\phi_{D2,G2}$	Joint probability of moving from RGD toward Chipps Island (MAE/MAW) and surviving from RGU to MAE/MAW (equated between submodels I and II)
$\phi_{D1O,G2}$	Joint probability of moving from RGU toward Chipps Island (MAE/MAW) via CCFB and surviving to MAE/MAW, conditional on arrival at RGU when the radial gates are open (equated between submodels I and II); = $\phi_{D1O,D2}\phi_{D2,G2}$
$\phi_{D1C,G2}$	Joint probability of moving from RGU toward Chipps Island (MAE/MAW) via CCFB and surviving to MAE/MAW, conditional on arrival at RGU when the radial gates are closed (equated between submodels I and II); = $\phi_{D1C,D2}\phi_{D2,G2}$
$\phi_{D1,G2}$	Joint probability of moving from RGU toward Chipps Island (MAE/MAW) via CCFB and surviving to MAE/MAW (equated between submodels I and II); = $\phi_{D1,D2}\phi_{D2,G2}$
$\phi_{E1,E2}$	Joint probability of moving from CVP toward CVPtank, and surviving from CVP to CVPtank (equated between submodels I and II)
$\phi_{E2,G2}$	Joint probability of moving from CVPtank toward Chipps Island (MAE/MAW) and surviving from CVPtank to MAE/MAW (equated between submodels I and II)

Table G1. (Continued)

Parameter	Definition
$\phi_{F1,D1O}$	Joint probability of moving from TCE/TCW toward RGU, surviving to RGU, and arriving when the radial gates are open (Submodel II)
$\phi_{F1,D1C}$	Joint probability of moving from TCE/TCW toward RGU, surviving to RGU, and arriving when the radial gates are closed (Submodel II)
$\phi_{F1,D1}$	Joint probability of moving from TCE/TCW toward RGU and surviving to RGU (Submodel II)
$\phi_{F1,E1}$	Joint probability of moving from TCE/TCW toward CVP and surviving to CVP (Submodel II)
$\phi_{F1,GH}$	Joint probability of moving from TCE/TCW directly toward Jersey Point (JPE/JPW) or False River (FRE/FRW), and surviving to JPE/JPW or FRE/FRW (Submodel II)
$\phi_{F1,G1}$	Joint probability of moving from TCE/TCW directly toward Jersey Point (JPE/JPW) and surviving to JPE/JPW (Submodel II); = $\phi_{F1,GH}\psi_{G1(A)}$
$\phi_{G1,G2(A)}$	Joint probability of moving from JPE/JPW toward Chipps Island (MAE/MAW), and surviving to MAE/MAW (Submodel II [route A])
$\phi_{G1,G2(B)}$	Joint probability of moving from JPE/JPW toward Chipps Island (MAE/MAW), and surviving to MAE/MAW (Submodel I [route B])
ψ_{A1}	Probability of remaining in the San Joaquin River at the head of Old River; = 1 - ψ_{B1}
ψ_{A2}	Probability of remaining in the San Joaquin River at the junction with Turner Cut; = 1 - ψ_{F2}
ψ_{B1}	Probability of entering Old River at the head of Old River; = 1 - ψ_{A1}
ψ_{B2}	Probability of remaining in Old River at the head of Middle River; = 1 - ψ_{C2}
ψ_{C2}	Probability of entering Middle River at the head of Middle River; = 1 - ψ_{B2}
ψ_{F2}	Probability of entering Turner Cut at the junction with the San Joaquin River; = 1 - ψ_{A2}
$\psi_{G1(A)}$	Probability of moving downriver in the San Joaquin River at the Jersey Point/False River junction (Submodel II [route A]); = 1 - $\psi_{H1(A)}$
$\psi_{G1(B)}$	Probability of moving downriver in the San Joaquin River at the Jersey Point/False River junction (Submodel I [route B]); = 1 - $\psi_{H1(B)}$
$\psi_{H1(A)}$	Probability of entering False River at the Jersey Point/False River junction (Submodel II [route A]); = 1 - $\psi_{G1(A)}$
$\psi_{H1(B)}$	Probability of entering False River at the Jersey Point/False River junction (Submodel I [route B]); = 1 - $\psi_{G1(B)}$
P_{A0a}	Conditional probability of detection at DFU1
P_{A0b}	Conditional probability of detection at DFU2
P_{A0}	Conditional probability of detection at DFU (either DFU1 or DFU2)
P_{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 MOS
P_{A5}	Conditional probability of detection at SJL
P_{A6}	Conditional probability of detection at SJG
P_{A7}	Conditional probability of detection at SJNB
P_{A9a}	Conditional probability of detection at MACU
P_{A9b}	Conditional probability of detection at MACD
P_{A9}	Conditional probability of detection at MAC (either MACU or MACD)
P_{A10a}	Conditional probability of detection at MFE
P_{A10b}	Conditional probability of detection at MFW
P_{A10}	Conditional probability of detection at MFE/MFW (either MFE or MFW)

Table G1. (Continued)

Parameter	Definition
P_{B1}	Conditional probability of detection at ORE
P_{B2a}	Conditional probability of detection at ORSU
P_{B2b}	Conditional probability of detection at ORSD
P_{B2}	Conditional probability of detection at ORS (either ORSU or ORSD)
P_{B3a}	Conditional probability of detection at OR4U
P_{B3b}	Conditional probability of detection at OR4D
P_{B3}	Conditional probability of detection are OR4 (either OR4U or OR4D)
P_{C1a}	Conditional probability of detection at MRHU
P_{C1b}	Conditional probability of detection at MRHD
P_{C1}	Conditional probability of detection at MRH (either MRHU or MRHD)
P_{C2a}	Conditional probability of detection at MR4U
P_{C2b}	Conditional probability of detection at MR4D
P_{C2}	Conditional probability of detection at MR4 (either MR4U or MR4D)
P_{D1}	Conditional probability of detection at RGU (either RGU1 or RGU2)
P_{D2a}	Conditional probability of detection at RGD1
P_{D2b}	Conditional probability of detection at RGD2
P_{D2}	Conditional probability of detection at RGD (either RGD1 or RGD2)
P_{E1}	Conditional probability of detection at CVP
P_{E2}	Conditional probability of detection at CVPtank
P_{F1a}	Conditional probability of detection at TCE
P_{F1b}	Conditional probability of detection at TCW
P_{F1}	Conditional probability of detection at TCE/TCW (either TCE or TCW)
P_{G1a}	Conditional probability of detection at JPE
P_{G1b}	Conditional probability of detection at JPW
P_{G1}	Conditional probability of detection at JPE/JPW (either JPE or JPW)
P_{G2a}	Conditional probability of detection at MAE
P_{G2b}	Conditional probability of detection at MAW
P_{G2}	Conditional probability of detection at MAE/MAW (either MAE or MAW)
P_{H1a}	Conditional probability of detection at FRW
P_{H1b}	Conditional probability of detection at FRE
P_{H1}	Conditional probability of detection at FRE/FRW (either FRE or FRW)

Table G2. Parameter estimates (standard errors in parentheses) for tagged juvenile steelhead released in 2013, excluding predator-type detections. Parameters without standard errors were estimated at fixed values in the model. Population-level estimates are weighted averages of the release-specific estimates. Some parameters were not estimable because of sparse data.

Parameter	Release Group 1	Release Group 2	Release Group 3	Population Estimate
S_{A2}	0.85 (0.02)	0.90 (0.02)	0.89 (0.03)	0.88 (0.02)
S_{A3}	0.84 (0.02)	0.86 (0.03)	0.89 (0.03)	0.86 (0.02)
S_{A4}	0.96 (0.01)	0.97 (0.01)	0.99 (<0.01)	0.98 (<0.01)
S_{A5}	0.26 (0.09)	0.32 (0.08)	0.57 (0.07)	0.38 (0.05)
S_{A6}		0.92 (0.08)	0.84 (0.08)	
$S_{A6,G2}$	0	0.42 (0.14)	0.36 (0.09)	0.26 (0.06)
S_{A7}		0.82 (0.12)	0.76 (0.09)	
$S_{A7,G2}$		0.46 (0.15)	0.43 (0.10)	
$S_{A9,G2}$		0.81 (0.18)	0.84 (0.11)	
S_{B1}	0.94 (0.01)	0.94 (0.02)	0.95 (0.01)	0.94 (0.01)
$S_{B2,G2}$	0.18 (0.02)	0.09 (0.02)	0.21 (0.03)	0.16 (0.01)
$S_{B2(SD)}$	0.59 (0.03)	0.62 (0.03)	0.81 (0.03)	0.67 (0.02)
$S_{C1,G2}$	0.08 (0.05)	0.06 (0.04)	0.07 (0.06)	0.07 (0.03)
$S_{C1(SD)}$	0.43 (0.19)	0.34 (0.19)	0.25 (0.22)	0.34 (0.12)
$S_{F1,G2}$		0.25 (0.22)	0	
$\phi_{A1,A0}$	0.08 (0.03)	0.09 (0.01)		
$\phi_{A1,A2}$	0.88 (0.02)	0.86 (0.02)	0.83 (0.02)	0.85 (0.01)
$\phi_{A1,A3}$	0.75 (0.02)	0.77 (0.03)	0.73 (0.03)	0.75 (0.01)
$\phi_{A6,D1O}$	0	0	0	0
$\phi_{A6,D1C}$	0	0	0	0
$\phi_{A6,D1}$	0	0	0	0
$\phi_{A6,E1}$	0	0	0.04 (0.04)	0.01 (0.01)
$\phi_{A6,GH}$				
$\phi_{A6,G1}$	0	0.42 (0.14)	0.43 (0.09)	0.28 (0.06)
$\phi_{A9,A10}$		0.80 (0.18)	0.92 (0.08)	
$\phi_{A9,D1O}$		0	0	
$\phi_{A9,D1C}$		0	0	
$\phi_{A9,D1}$		0	0	
$\phi_{A9,E1}$		0	0	
$\phi_{A9,GH}$				
$\phi_{A9,G1}$		0	0.08 (0.08)	
$\phi_{A10,D1O}$		0	0	
$\phi_{A10,D1C}$		0	0	
$\phi_{A10,D1}$		0	0	
$\phi_{A10,E1}$		0	0	
$\phi_{A10,GH}$				
$\phi_{A10,G1}$		1	1	
$\phi_{B2,B3}$	0.08 (0.02)	0.16 (0.02)	0.20 (0.03)	0.14 (0.01)

Table G2. (Continued)

Parameter	Release Group 1	Release Group 2	Release Group 3	Population Estimate
$\phi_{B2,C2}$	0.02 (0.01)	0.03 (0.01)	0.02 (0.01)	0.02 (0.01)
$\phi_{B2,D1O}$	0.15 (0.02)	0.21 (0.03)	0.08 (0.01)	0.15 (0.01)
$\phi_{B2,D1C}$	0.04 (0.01)	0.07 (0.02)	0.08 (0.01)	0.06 (0.01)
$\phi_{B2,D1}$	0.19 (0.03)	0.27 (0.03)	0.16 (0.02)	0.21 (0.02)
$\phi_{B2,E1}$	0.29 (0.03)	0.16 (0.02)	0.42 (0.03)	0.29 (0.02)
$\phi_{C2,E1}$	0.33 (0.19)	0.65 (0.12)	0.43 (0.19)	0.47 (0.10)
$\phi_{B3,GH(B)}$				
$\phi_{B3,G1(B)}$	0.14 (0.08)	0.08 (0.05)	0.31 (0.07)	0.18 (0.04)
$\phi_{C1,B3}$	0.29 (0.17)	0	0.25 (0.22)	0.18 (0.09)
$\phi_{C1,C2}$	0	0	0	0
$\phi_{C1,D1O}$	0	0.17 (0.15)	0	0.06 (0.05)
$\phi_{C1,D1C}$	0	0	0	0
$\phi_{C1,D1}$	0	0.17 (0.15)	0	0.06 (0.05)
$\phi_{C1,E1}$	0.14 (0.13)	0.17 (0.15)	0	0.10 (0.07)
$\phi_{C2,GH(B)}$				
$\phi_{C2,G1(B)}$	0	0	0.20 (0.18)	0.07 (0.06)
$\phi_{D1O,D2}$	0.81 (0.06)	0.73 (0.06)	0.79 (0.06)	0.78 (0.04)
$\phi_{D1C,D2}$	0.89 (0.10)	0.63 (0.12)	0.79 (0.06)	0.77 (0.06)
$\phi_{D1,D2}$	0.83 (0.06)	0.71 (0.06)	0.79 (0.06)	0.78 (0.03)
$\phi_{D2,G2}$	0.42 (0.08)	0.29 (0.07)	0.49 (0.09)	0.40 (0.05)
$\phi_{D1O,G2}$	0.34 (0.07)	0.22 (0.05)	0.39 (0.08)	0.31 (0.04)
$\phi_{D1C,G2}$	0.37 (0.08)	0.18 (0.05)	0.39 (0.08)	0.32 (0.04)
$\phi_{D1,G2}$	0.35 (0.07)	0.21 (0.05)	0.39 (0.08)	0.31 (0.04)
$\phi_{E1,E2}$	0.47 (0.06)	0.15 (0.06)	0.29 (0.05)	0.30 (0.03)
$\phi_{E2,G2}$	0.80 (0.07)	1	0.74 (0.08)	0.85 (0.04)
$\phi_{F1,D1O}$		0	0	
$\phi_{F1,D1C}$		0	0	
$\phi_{F1,D1}$		0	0	
$\phi_{F1,E1}$		0	0.17 (0.15)	
$\phi_{F1,GH}$				
$\phi_{F1,G1}$		0.25 (0.22)	0	
$\phi_{G1,G2(A)}$		1	0.83 (0.11)	
$\phi_{G1,G2(B)}$	0.66 (0.27)	0.64 (0.29)	0.86 (0.09)	0.72 (0.14)
ψ_{A1}	0.08 (0.02)	0.12 (0.02)	0.16 (0.02)	0.12 (0.01)
ψ_{A2}		0.56 (0.17)	0.67 (0.11)	
ψ_{B1}	0.92 (0.02)	0.88 (0.02)	0.84 (0.02)	0.88 (0.01)
ψ_{B2}	0.97 (0.01)	0.98 (0.01)	0.98 (0.01)	0.98 (0.01)
ψ_{C2}	0.03 (0.01)	0.02 (0.01)	0.02 (0.01)	0.02 (0.01)
ψ_{F2}		0.44 (0.17)	0.33 (0.11)	
$\psi_{G1(A)}$				
$\psi_{G1(B)}$				

Table G2. (Continued)

Parameter	Release Group 1	Release Group 2	Release Group 3	Population Estimate
$\psi_{H1(A)}$				
$\psi_{H1(B)}$				
P_{A0a}	0.38 (0.13)	0.68 (0.09)		
P_{A0b}	0.33 (0.12)	0.66 (0.09)		
P_{A0}	0.59 (0.15)	0.89 (0.05)		
P_{A2a}		0.44 (0.02)	0.10 (0.02)	
P_{A2b}		0.99 (0.00)	0.75 (0.02)	
P_{A2}	1	1	0.78 (0.02)	0.92 (0.01)
P_{A3}	0.72 (0.03)	0.48 (0.03)	0.30 (0.03)	0.50 (0.02)
P_{A4}	1	1	0.98 (0.01)	0.99 (<0.01)
P_{A5}	1	1	1	1
P_{A6}	1	1	1	1
P_{A7}		1	0.89 (0.07)	
P_{A9a}		1	1	
P_{A9b}		1	1	
P_{A9}		1	1	
P_{A10a}		1	1	
P_{A10b}		1	1	
P_{A10}		1	1	
P_{B1}	1	1	1	1
P_{B2a}	1		0.98 (0.01)	
P_{B2b}	1		0.99 (0.01)	
P_{B2}	1	0.98 (0.01)	1	0.99 (<0.01)
P_{B3a}	1	1	0.98 (0.02)	0.99 (0.01)
P_{B3b}	1	1	1	1
P_{B3}	1	1	1	1
P_{C1a}	1	1	1	1
P_{C1b}	1	1	1	1
P_{C1}	1	1	1	1
P_{C2a}	1	1	1	1
P_{C2b}	1	1	1	1
P_{C2}	1	1	1	1
P_{D1}	1	1	1	1
P_{D2a}	1	0.96 (0.03)	1	0.99 (0.01)
P_{D2b}	1	0.96 (0.03)	1	0.99 (0.01)
P_{D2}	1	1	1	1
P_{E1}	1	1	1	1
P_{E2}	0.89 (0.06)	1	1	0.96 (0.02)
P_{F1a}		1	1	
P_{F1b}		1	1	
P_{F1}		1	1	

Table G2. (Continued)

Parameter	Release Group 1	2	3	Population Estimate
P_{G1a}				
P_{G1b}				
P_{G1}	1	0.86 (0.13)	0.85 (0.07)	0.90 (0.05)
P_{G2a}	0.96 (0.03)	0.88 (0.06)	0.90 (0.04)	0.91 (0.03)
P_{G2b}	1	0.92 (0.05)	0.95 (0.03)	0.95 (0.02)
P_{G2}	1	0.99 (0.01)	0.99 (<0.01)	0.99 (<0.01)
P_{H1a}				
P_{H1b}				
P_{H1}				

Table G3. Parameter estimates (standard errors in parentheses) for tagged juvenile steelhead released in 2013, including predator-type detections. Parameters without standard errors were estimated at fixed values in the model. Population-level estimates are weighted averages of the release-specific estimates. Some parameters were not estimable because of sparse data.

	Release Group			
Parameter	1	2	3	Population Estimate
S_{A2}	0.85 (0.02)	0.90 (0.02)	0.88 (0.03)	0.88 (0.02)
S_{A3}	0.86 (0.02)	0.87 (0.03)	0.89 (0.03)	0.87 (0.02)
S_{A4}	0.97 (0.01)	0.98 (0.01)	0.99 (0.01)	0.98 (<0.01)
S_{A5}	0.29 (0.11)	0.49 (0.09)	0.65 (0.08)	0.48 (0.05)
S_{A6}		0.93 (0.06)	0.89 (0.06)	
$S_{A6,G2}$	0	0.41 (0.13)	0.39 (0.10)	0.26 (0.05)
S_{A7}		0.86 (0.09)	0.91 (0.06)	
$S_{A7,G2}$		0.43 (0.13)	0.43 (0.10)	
$S_{A9,G2}$		0.63 (0.17)	0.77 (0.12)	
S_{B1}	0.95 (0.01)	0.97 (0.01)	0.96 (0.01)	0.96 (0.01)
$S_{B2,G2}$	0.18 (0.02)	0.10 (0.02)	0.21 (0.03)	0.16 (0.01)
$S_{B2(SD)}$	0.63 (0.03)	0.65 (0.03)	0.81 (0.02)	0.70 (0.02)
$S_{C1,G2}$	0.09 (0.05)	0.06 (0.04)	0.09 (0.08)	0.08 (0.03)
$S_{C1(SD)}$	0.51 (0.18)	0.34 (0.19)	0.34 (0.27)	0.39 (0.13)
$S_{F1,G2}$		0.25 (0.22)	0	
$\phi_{A1,A0}$	0.07 (0.02)	0.11 (0.02)		
$\phi_{A1,A2}$	0.88 (0.01)	0.85 (0.02)	0.83 (0.02)	0.86 (0.01)
$\phi_{A1,A3}$	0.75 (0.02)	0.76 (0.03)	0.73 (0.03)	0.75 (0.01)
$\phi_{A6,D1O}$	0	0	0.02 (0.02)	0.01 (0.01)
$\phi_{A6,D1C}$	0	0	0.02 (0.02)	0.01 (0.01)
$\phi_{A6,D1}$	0	0	0.04 (0.04)	0.01 (0.01)
$\phi_{A6,E1}$	0	0	0.04 (0.04)	0.01 (0.01)
$\phi_{A6,GH}$				
$\phi_{A6,G1}$	0	0.47 (0.13)	0.48 (0.10)	0.32 (0.06)
$\phi_{A9,A10}$		0.63 (0.17)	0.92 (0.07)	
$\phi_{A9,D1O}$		0	0	
$\phi_{A9,D1C}$		0	0	
$\phi_{A9,D1}$		0	0	
$\phi_{A9,E1}$		0	0	
$\phi_{A9,GH}$				
$\phi_{A9,G1}$		0.13 (0.12)	0.08 (0.07)	
$\phi_{A10,D1O}$		0	0	
$\phi_{A10,D1C}$		0	0	
$\phi_{A10,D1}$		0	0	
$\phi_{A10,E1}$		0	0	
$\phi_{A10,GH}$				
$\phi_{A10,G1}$		1	0.95 (0.09)	
$\phi_{B2,B3}$	0.10 (0.02)	0.17 (0.02)	0.20 (0.03)	0.15 (0.01)

Table G3. (Continued)

Parameter	Release Group 1	Release Group 2	Release Group 3	Population Estimate
$\phi_{B2,C2}$	0.02 (0.01)	0.02 (0.01)	0.01 (0.01)	0.02 (<0.01)
$\phi_{B2,D1O}$	0.17 (0.02)	0.20 (0.02)	0.09 (0.01)	0.16 (0.01)
$\phi_{B2,D1C}$	0.04 (0.01)	0.07 (0.02)	0.09 (0.01)	0.07 (0.01)
$\phi_{B2,D1}$	0.22 (0.03)	0.27 (0.03)	0.18 (0.02)	0.22 (0.01)
$\phi_{B2,E1}$	0.29 (0.03)	0.19 (0.02)	0.43 (0.03)	0.30 (0.02)
$\phi_{B3,GH(B)}$				
$\phi_{B3,G1(B)}$	0.11 (0.06)	0.11 (0.05)	0.31 (0.07)	0.17 (0.03)
$\phi_{C1,B3}$	0.38 (0.17)	0	0.34 (0.27)	0.24 (0.11)
$\phi_{C1,C2}$	0	0	0	0
$\phi_{C1,D1O}$	0	0.17 (0.15)	0	0.06 (0.05)
$\phi_{C1,D1C}$	0	0	0	0
$\phi_{C1,D1}$	0	0.17 (0.15)	0	0.06 (0.05)
$\phi_{C1,E1}$	0.12 (0.12)	0.17 (0.15)	0	0.10 (0.06)
$\phi_{B2,C2}$	0.02 (0.01)	0.02 (0.01)	0.01 (0.01)	0.02 (<0.01)
$\phi_{C2,GH(B)}$				
$\phi_{C2,G1(B)}$	0	0.24 (0.22)	0.34 (0.28)	0.19 (0.12)
$\phi_{D1O,D2}$	0.95 (0.03)	0.95 (0.03)	0.98 (0.02)	0.96 (0.02)
$\phi_{D1C,D2}$	1	0.78 (0.10)	0.98 (0.02)	0.92 (0.03)
$\phi_{D1,D2}$	0.96 (0.03)	0.91 (0.03)	0.98 (0.02)	0.95 (0.02)
$\phi_{D2,G2}$	0.32 (0.06)	0.24 (0.05)	0.34 (0.07)	0.30 (0.04)
$\phi_{D1O,G2}$	0.30 (0.06)	0.23 (0.05)	0.34 (0.07)	0.29 (0.04)
$\phi_{D1C,G2}$	0.32 (0.06)	0.19 (0.05)	0.34 (0.07)	0.28 (0.04)
$\phi_{D1,G2}$	0.30 (0.06)	0.22 (0.05)	0.34 (0.07)	0.29 (0.04)
$\phi_{E1,E2}$	0.45 (0.06)	0.15 (0.05)	0.29 (0.04)	0.30 (0.03)
$\phi_{E2,G2}$	0.80 (0.07)	1	0.78 (0.08)	0.86 (0.03)
$\phi_{F1,D1O}$		0	0.06 (0.06)	
$\phi_{F1,D1C}$		0	0.06 (0.06)	
$\phi_{F1,D1}$		0	0.13 (0.12)	
$\phi_{F1,E1}$		0	0.12 (0.12)	
$\phi_{F1,GH}$				
$\phi_{F1,G1}$		0.26 (0.23)	0	
$\phi_{G1,G2(A)}$		0.88 (0.15)	0.81 (0.12)	
$\phi_{G1,G2(B)}$	1	0.34 (0.21)	0.86 (0.10)	0.73 (0.08)
ψ_{A1}	0.06 (0.01)	0.10 (0.02)	0.13 (0.02)	0.10 (0.01)
ψ_{A2}		0.67 (0.14)	0.62 (0.11)	
ψ_{B1}	0.94 (0.01)	0.90 (0.02)	0.87 (0.02)	0.90 (0.01)
ψ_{B2}	0.97 (0.01)	0.98 (0.01)	0.99 (0.01)	0.98 (0.01)
ψ_{C2}	0.03 (0.01)	0.02 (0.01)	0.01 (0.01)	0.02 (0.01)
ψ_{F2}		0.33 (0.14)	0.38 (0.11)	
$\psi_{G1(A)}$				
$\psi_{G1(B)}$				

Table G3. (Continued)

Parameter	Release Group 1	Release Group 2	Release Group 3	Population Estimate
$\psi_{H1(A)}$				
$\psi_{H1(B)}$				
P_{A0a}	0.42 (0.14)	0.56 (0.09)		
P_{A0b}	0.36 (0.13)	0.64 (0.09)		
P_{A0}	0.63 (0.15)	0.84 (0.06)		
P_{A2a}			0.10 (0.02)	
P_{A2b}			0.75 (0.02)	
P_{A2}	1	0.99 (0.01)	0.77 (0.02)	0.92 (0.01)
P_{A3}	0.72 (0.03)	0.48 (0.03)	0.31 (0.03)	0.50 (0.02)
P_{A4}	1	0.99 (<0.01)	0.98 (0.01)	0.99 (<0.01)
P_{A5}	1	1	1	1
P_{A6}	1	1	1	1
P_{A7}		1	0.90 (0.06)	
P_{A9a}		1	1	
P_{A9b}		1	1	
P_{A9}		1	1	
P_{A10a}		1	1	
P_{A10b}		1	1	
P_{A10}		1	1	
P_{B1}	1	0.99 (0.01)	1	1
P_{B2a}	1	0.97 (0.01)	0.97 (0.01)	0.98 (0.01)
P_{B2b}	1	0.98 (0.01)	0.99 (0.01)	0.99 (<0.01)
P_{B2}	1	1	1	1
P_{B3a}	1	1	0.98 (0.02)	0.99 (0.01)
P_{B3b}	1	0.98 (0.02)	1	0.99 (0.01)
P_{B3}	1	1	1	1
P_{C1a}	1	1	1	1
P_{C1b}	1	1	1	1
P_{C1}	1	1	1	1
P_{C2a}	1	1	1	1
P_{C2b}	1	1	1	1
P_{C2}	1	1	1	1
P_{D1}	1	1	1	1
P_{D2a}	1	0.97 (0.02)	1	0.99 (0.01)
P_{D2b}	1	0.97 (0.02)	1	0.99 (0.01)
P_{D2}	1	1	1	1
P_{E1}	1	1	1	1
P_{E2}	0.89 (0.06)	1	1	0.96 (0.02)
P_{F1a}		1	1	
P_{F1b}		1	1	
P_{F1}		1	1	

Table G3. (Continued)

Parameter	Release Group 1	Release Group 2	Release Group 3	Population Estimate
P_{G1a}				
P_{G1b}				
P_{G1}	1	0.77 (0.14)	0.83 (0.08)	0.87 (0.05)
P_{G2a}	0.96 (0.03)	0.90 (0.06)	0.90 (0.04)	0.92 (0.02)
P_{G2b}	1	0.90 (0.06)	0.95 (0.03)	0.95 (0.02)
P_{G2}	1	0.99 (0.01)	0.99 (<0.01)	0.99 (<0.01)
P_{H1a}				
P_{H1b}				
P_{H1}				

Appendix H. Tag Retention Study Photos