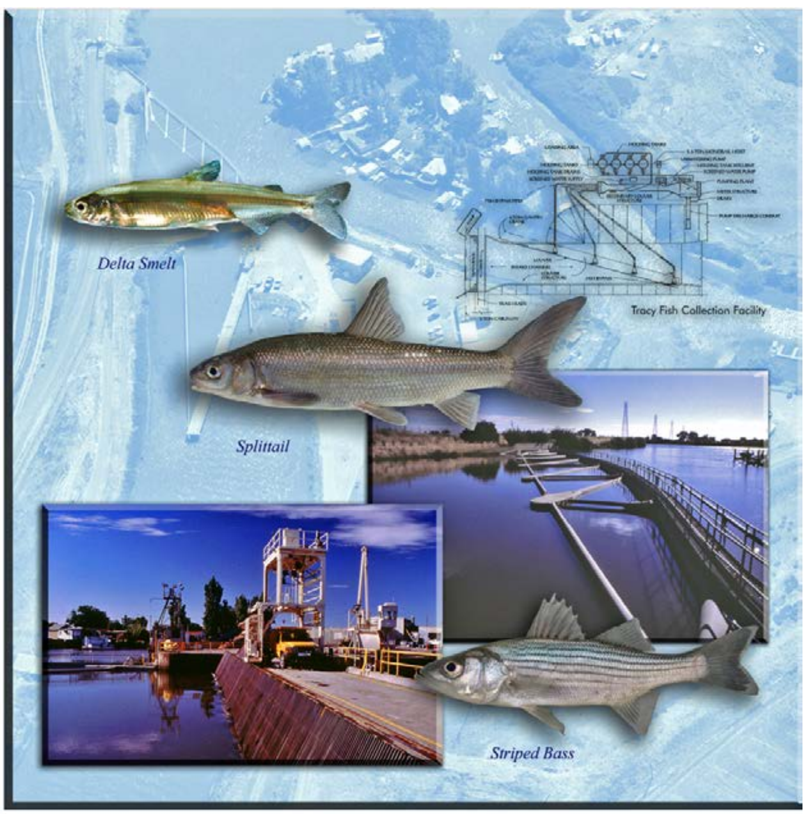
RECLAMATION

Managing Water in the West

Tracy Technical Bulletin 2017-1

Juvenile Chinook Salmon, Steelhead, and Adult Striped Bass Movements and Facility Efficiency at the Tracy Fish Collection Facility



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14. ABSTRACT
Acoustically tagged juvenile Chinook salmon (*Oncorhynchus tshawytscha*), steelhead (*O. mykiss*), and adult striped bass (*Morone saxatilis*) were tracked at the Bureau of Reclamation's Tracy Fish Collection Facility under a range of typical conditions to estimate facility efficiency and pre-screen loss. Salvage of 37 released fish (28 Chinook salmon [40.6%]; 9 steelhead [14.8%]) allowed for definitive determination of species-specific behavior. Across all conditions, cumulative primary and secondary louver loss of Chinook salmon and steelhead combined was 7.7%. Facility efficiency ranged from 0 to 75% for Chinook salmon, and from 0 to 100% for steelhead. Pre-screen loss ranged from 0 to 91.6% for Chinook salmon and from 0 to 100% for steelhead. In general, across both species tested, there tends to be an increase in facility efficiency as the number of Jones Pumping Plant (JPP) pumps in operation increase from 1 to 5, which suggests low pumping conditions may be more detrimental to salvage of Chinook salmon and steelhead. However, continued data collection efforts are necessary to elucidate if there is an optimal number of operating JPP pumps that promotes maximum facility efficiency. The high rate of predation upstream of and within the facility, together with observations of striped bass behavior and observations of experimental salmonids being delayed by the trash rack, suggests opening the trash rack would allow resident striped bass to move upstream and leave, while promoting entrance of entrained fish into the facility.

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Juvenile Chinook Salmon, Steelhead, and Adult Striped Bass Movements and Facility Efficiency at the Tracy Fish Collection Facility

by

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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.

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Fish photography by René Reyes, Tracy Fish Collection Facility, Tracy, California.
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Executive Summary

The U.S. Department of the Interior, Bureau of Reclamation's Tracy Fish Collection Facility (TFCF) was designed in the mid-1950s to divert and collect fish from flows en route to the C.W. "Bill" Jones Pumping Plant (JPP) and return salvaged fish to the Sacramento-San Joaquin River Delta (Delta). Exported flows, entrained fish and aquatic debris first pass beneath a surface debris collector, then through a trash rack to enter the first of two fish diversion bays. Fish are diverted into underground bypass pipes, through a second diversion channel, and eventually to holding/collection tanks for eventual release. The TFCF was originally designed to collect smaller, weaker swimming fish using trash racks with 5.70-cm (2.25-in) spacing, louvers with 2.54-cm (1-in) spacing, and high velocities. However, some fish are lost through the louver panels and to piscivorous species, in particular striped bass (*Morone saxatilis*), which congregate upstream of the trash rack and within the facility.

Acoustically tagged juvenile Chinook salmon (*Oncorhynchus tshawytscha*), juvenile steelhead (*O. mykiss*), and adult striped bass were released in front of and within the TFCF to estimate facility efficiency and pre-screen loss, as well as to understand fish behavior in the facility. Striped bass were released as they are considered the dominant predator at the facility (Liston *et al*. 1994; Wu *et al*. 2015; Bridges *et al*. In Draft). Fish were released twice in spring of 2013 at the trash boom day and night during experimental flows that represented the range of conditions occurring at the facility.

A total of 37 juvenile salmonids (28 Chinook salmon [40.6%]; 9 steelhead [14.8%]) of 130 released fish were salvaged. Recovery of these fish allowed for definitive statements regarding species-specific behavior in the facility. Chinook salmon exhibited more straight-forward movements with flow, particularly as flows increased. However, steelhead exhibited a variety of movements, and were more likely to hold within the facility, regardless of flow. Variability in behavior and travel times suggest that time between detections may not be a reliable parameter for assigning species identification or fate during survival studies in the Delta. The authors emphasize that the time estimates between detection points made in this study were entirely based on the 37 fish that were recovered in hand. Thus, there was 100% certainty of their specific identification.

The percentage of released Chinook salmon and steelhead noted as lost to predation was 24.6 and 8.2%, respectively, and occurred more so in the channel upstream of the trash rack than in the primary channel. More fish were lost to predation at lower and intermediate flows than high flows. However, 70% of the 10 fish lost through the louvers were lost at high flows (2 during louver cleaning). Estimates of facility efficiency (0–75% for Chinook salmon, 0–100% for steelhead) and pre-screen loss (0–91.6% for Chinook salmon, 0–100% for steelhead) were variable depending on number of fish salvaged and number of fish with an unknown fate during each experiment. In general, across both species tested, there tends to be an increase in facility efficiency as the number of JPP pumps in operation increases from 1 to 5. In addition, travel time, predation, and pre-screen loss to predation for Chinook salmon and steelhead generally decreased with increasing flow. These findings suggest that low pumping periods may be more detrimental to salvage of entrained salmonids. However, most statistical relationships that suggested improvements to salvage with increased pumping were weak due to low sample size,

high variability, and the high number of fish that were assigned an unknown fate. Estimates of facility efficiency and pre-screen loss would improve with development of reliable equipment and methods to determine predation events, and installation of additional acoustic equipment upstream of the trash boom.

All striped bass released upstream of the trash rack eventually moved upstream away from the facility (one was captured by an angler near Red Bluff, California). Most of the striped bass released into the primary channel remained there for months. More than 75% of the recovered salmonids exhibited some delay at the upstream side of the trash rack. It may be that some fish perceive the trash rack as a barrier, both to downstream and upstream movement. This, together with observed striped bass behavior and the high rate of predation in the upstream channel, suggests opening the trash rack, either by removing panels or widening the vertical slats, would allow entrained fish an easier path to the holding tanks, as well as allow striped bass within the primary channel access to the upstream Delta.

Introduction

The Bureau of Reclamation's Tracy Fish Collection Facility (TFCF) located in the southern Sacramento-San Joaquin Delta (Delta), was designed to divert juvenile Chinook salmon (*Oncorhynchus tshawytscha*) and striped bass (*Morone saxatilis*) from Delta Mendota Canal (DMC) inflow, thereby preventing entrainment loss to the downstream C.W. "Bill" Jones Pumping Plant (JPP; Bates and Vinsonhaler 1957; Bates *et al*. 1960; Figure 1). These facilities were built in the 1950s to export water from the Old River channel of the San Joaquin River in central California for irrigation, municipal, and industrial uses, while diverting and salvaging entrained fish.

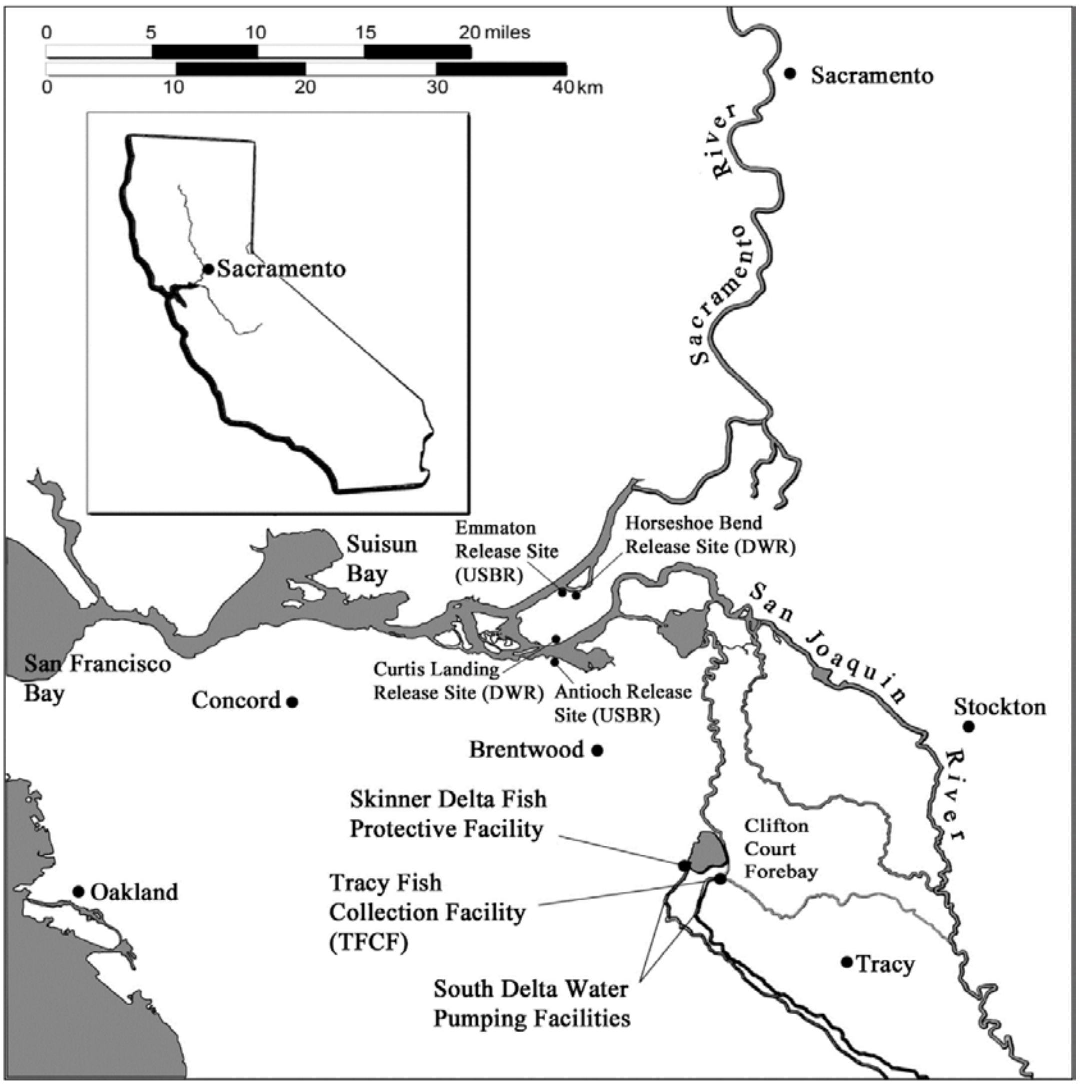


Figure 1. Location of the Tracy Fish Collection Facility in the south Sacramento-San Joaquin Delta, Byron, California.

The TFCF is situated at the head of the DMC so that flows (and entrained fish) drawn to the JPP first pass through the fish diversion channels (Figure 2). Fish and exported flows enter the facility underneath a surface debris collector (trash boom, about 1-m [3-ft] deep), through a trash rack with bar spacing of about 5.7 cm (2.25 in), and into the 25.6-m-wide (84-ft), 4.3–6.7-m-deep (14–22-ft; depth varies with tidal height) primary fish diversion channel. A 97.5-m-long (320-ft) louver wall on the south side spans the channel depth and contains four bypass entrances spaced about 23.5 m (77 ft) apart. Each bypass entrance is 15.2-cm wide (6-in) and also spans the channel depth. Once inside a bypass, fish move into 0.9-m (36-in) underground pipes to the 2.4-m-wide (8-ft), 0.9–2.7-m-deep (3–9-ft; water depth varies with tidal stage) secondary fish diversion channel where they encounter a double louver wall (9.3-m [30.2-ft] long). Here, fish and diverted aquatic material enter a common bypass (15.2 cm [6 in]) to one of four holding tanks. Both the primary and secondary channel louver walls are angled 15° to the flow and contain evenly spaced vertical slats (2.54 cm [1 in]) angled 90° to the flow. The louvers and trash rack become clogged with aquatic debris and are cleaned frequently. Salvaged fish are regularly removed and truck transported for release back to the central Delta. In 2014, a Hydrolox™ (Elmwood, Louisiana) traveling screen-bypass system was installed in the secondary fish diversion channel to replace the double louver system. This study was conducted in 2013 when the secondary channel louver structure was in place.

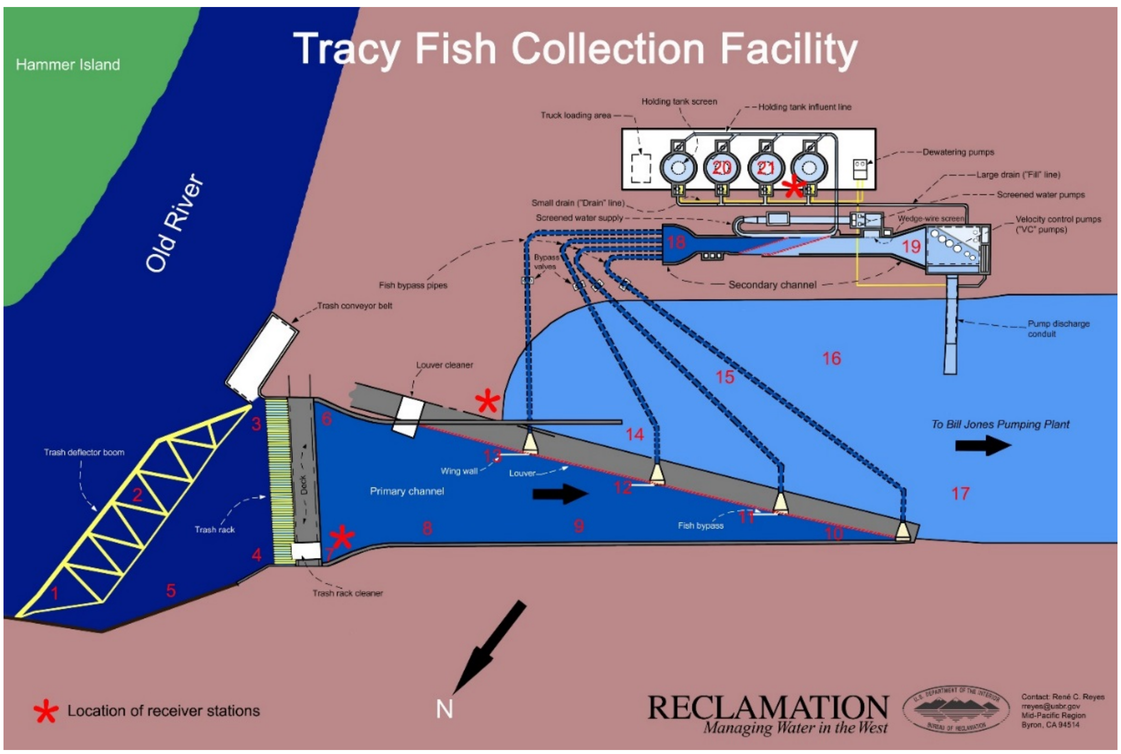


Figure 2. Overview of the Tracy Fish Collection Facility, Byron, California. Numbers in red indicate locations of hydrophones.

Louver fish diversion systems act as a behavioral barrier to fish that are entrained in flow such that fish sense the turbulence created by the vertical slats and move along the louver wall in the sweeping flows until they enter/encounter a bypass opening (Hallock *et al*. 1968; EPRI 1986).

The effectiveness of louvers at diverting fish to a nearby bypass entrance depends on many factors including fish species, life history stage, swimming ability, hydraulic conditions, and debris load (Bates *et al*. 1960, Hallock *et al*. 1968, Karp *et al*. 1995, Bowen *et al*. 1998, 2004). Regulatory criteria were established for the TFCF that define appropriate channel and bypass velocities (California State Water Resources Control Board 1978, NMFS 2004, USFWS 2004). These include maintaining bypass ratios (BR, ratio of bypass entrance velocity to channel velocity) > 1, and maintaining secondary channel velocities between 0.9–1.1 m/s (3.0—3.5 ft/s) November through mid-May and < 0.76 m/s (2.5 ft/s) mid-May through October. Primary channel velocity is determined by the number of JPP pumps in operation and tide stage and thus, there are no legal requirements for maintaining a certain velocity.

In the 1950s, pumping mostly occurred in the summer months and the TFCF was considered highly efficient at diverting fish from the entrained flow (Bates and Vinsonhaler 1957, Bates *et al*. 1960). Today however, both the JPP and the TFCF operate year-round, salvaging over 50 fish species under varying aquatic debris and fish entrainment conditions, and the TFCF is no longer as efficient (Karp *et al*. 1995, Bowen *et al*. 1998, Bowen *et al*. 2004, Bridges *et al*. In Draft, TFCF, unpublished data). Fish entrainment is defined as "the incidental trapping of any life stage of fish within waterways or structures that carry water being diverted for anthropogenic use" (NMFS 2010). However, not all entrained fish passing beneath the trash boom encounter the fish diversion systems. Some entrained fish may move upstream out of the facility, some may be lost to predation, some move or may be swept through the louvers or the gap in the louver wall during cleaning to the DMC, and some may hold in place. Thus, estimated entrainment includes all fish drawn into the TFCF while salvage is the estimated number of fish that were successfully diverted and recovered in the holding tanks.

Chinook salmon and Central Valley steelhead (*O. mykiss)* abundance is declining in the Delta due in part to non-native fish introductions and habitat alterations from long-term operations at JPP and California's Harvey O. Banks Pumping Plant (Moyle 2002; NMFS 1998, 2006, 2009). In 2009, the National Marine Fisheries Service (NMFS) completed a Biological Opinion stating TFCF operations are likely to jeopardize the continued existence of the endangered Sacramento River winter-run Chinook salmon, threatened Central Valley spring-run Chinook salmon and Central Valley steelhead (NMFS 2009). In a review of past TFCF efficiency experiments, Jahn (2011) suggested future efforts focus on determining overall facility survival/loss rather than focusing on specific components, *e.g.*, louver efficiency. To comply with these recommendations and those proposed by NMFS (2009), this study was conducted to determine juvenile salmonid and adult striped bass behavior in the facility, estimate pre-screen loss (upstream of the trash rack) and estimate facility efficiency from the trash boom to the holding/collection tanks under three typical flow scenarios (high [5 pumps operating at JPP], medium [3 pumps operating at JPP], and low pumping [1 pump operating at JPP]).

Methods

Experimental Design

Release-recapture experiments using acoustically tagged juvenile Chinook salmon, steelhead, and adult striped bass were conducted in March and May 2013 to evaluate fish behavior in front of and within the TFCF under a range of normal facility flows. These months were chosen for testing because they fall within the season when wild juvenile salmonids are typically collected in facility salvage (California Department of Fish and Wildlife's TFCF fish salvage database, www.dfg.ca.gov/delta/apps/salvage). Testing was conducted during normal day-to-day operations (*i.e.*, louver and trash rack cleaning, hydraulic changes, predator removals, etc.) as outlined in the TFCF Policy and Standard Operating Procedures.

An array of 21 fixed acoustic telemetry hydrophones (Hydroacoustic Technology, Inc., HTI, Seattle, Washington) were set up as illustrated in Figure 2 to allow quantification of fine scale fish behavior in front of, within, and downstream of the facility (see CDWR 2012 for background information on HTI technology). Hydrophones were placed about 3 m (9.8 ft) above the channel floor in the area upstream of the trash rack, primary channel, and DMC, and were shielded if necessary to reduce ambient electromagnetic noise and other interference. Number and placement of hydrophones was selected to allow for 2D positioning where possible. Hydrophones were no more than 50 m (164.0 ft) apart and were placed to allow for 330^{o} detection. Hydrophones were also placed in the secondary channel and collection tanks to allow for site-specific detections. HTI assisted with fine-tuning hydrophone placements and scanning angle using ping-around procedures described in CDWR (2012). Using HTI Model 690 hydrophone cables, the hydrophones were connected to one of three nearby acoustic tracking stations (*i.e.*, receiver/computer). These setups were synchronized using Global Position Satellite technology so that the internal clocks were set to the same time (as time of detection on multiple hydrophones/receivers was critical to track a fish's movement through the various areas). Acoustic telemetry data was recorded hourly and downloaded daily. The acoustic telemetry systems were verified to be running throughout the test period.

The experiments were first designed to run for 48 h at each of 3 flow conditions (high export pumping or 5 JPP pumps, intermediate export pumping or 3 JPP pumps, and low export pumping or 1 JPP pump) with fish releases occurring every 2 h, for 24 h, followed by a 24-h recovery period. However, the release schedule had to be modified to accommodate a restricted JPP pumping schedule due to drought. Final testing followed three consecutive 24-h periods of fish releases beginning with the highest flow first (5 JPP) at 0700 h on day 1. Each flow was maintained for 24 h (or until 0700 h the following day), followed by the next lower test flow condition. Fish were tracked for the experimental flow period and the following 48 h. Flow changes between the JPP and the TFCF took about 1 h to equilibrate and fish were first released at 0800 h each day of testing.

Acoustically tagged Chinook salmon (n = 2) and steelhead (n = 2) were released day and night (0800, 1100, 1400, 2000, 2300, and 0200 h) from the midpoint of the surface trash boom for a total of 12 fish per species per 24-h JPP flow condition (fish salvage in the holding tanks was also monitored for each 24-h test period). Thus, some fish were exposed to the experimental flow for the whole test period, while others had shorter exposure times. Total number of fish released per replicate was based on an examination of wild fish salvage data for February – May 2008-2011. In addition, two acoustically tagged striped bass were released at 0800, 1600, and 2400 h (1 into the primary channel and 1 into the area upstream of the trash rack along the north shore) for a total of six fish during each 24-h JPP flow condition.

Hydraulic variables measured included water temperature, light level, turbidity, primary channel depths and velocity, secondary channel depths and velocity, holding tank flow, the number of secondary channel velocity control pumps and holding tank pumps that were operating, and timing of louver cleaning. Facility hydraulic data was recorded hourly through each 3-d experiment. Bypass ratios were calculated for each 24-h experiment.

Fish Source and Care

Approximately 1,000 late-fall run juvenile Chinook salmon (from the Coleman National Fish Hatchery, Anderson, California) and juvenile steelhead (from the Mokelumne River Fish Hatchery, Clements, California) were transported to the TFCF in 1100-L tanks with dissolved oxygen at 100% saturation about 2-3 weeks prior to the start of each set of experiments. Fish were held in flow-through 711-L tanks, provided temperature controlled, aerated, treated (filtered, settled, ultraviolet [UV] sterilized, and ozonated) Delta water (16ºC), and fed O-Range Nurse XL (Inve Aquaculture, Inc., Salt Lake City, Utah) at ~4% body weight per day. Water quality (temperature, pH, ammonia, nitrite, salinity, and oxygen levels) was monitored daily. A range of fish sizes was used to represent wild salmonid entrainment but a minimum of 105-mm fork length (FL) was considered necessary for successful tag [transmitter] insertion.

Striped bass were collected by angling and predator removals within the TFCF and held at a density of 2 fish per tank for several months prior to the experiments in 1.2-m diameter (757-L) outdoor black tanks containing a mix of 16ºC well water and treated Delta water at about 8 g/L salinity. Striped bass were fed 4.5-mm extruded floating fish feed (Skretting USA, Tooele, Utah), frozen anchovies (Monterey Fish Company, Inc., Monterey, California), and live threadfin shad (*Dorosoma petenense*; salvaged fish, beginning about 1 week prior to each experiment) during this period.

Fish Processing

Surgeries were conducted 48 h prior to each salmonid release (following guidelines in Liedtke *et al*. 2012). Fish were captured from 1.2-m-diameter (757-L) tanks using monorail nets with 6.4-mm knotless nylon mesh (40.6-cm x 40.6-cm frame, 30.5-cm depth, 1.5-m handle, Pentair Aquatic Eco-systems, Inc., Apopka, Florida) and placed in a 10-L anesthetic bath containing a 70 mg/L dose of tricaine methanesulfonate (MS-222, Argent Chemical Laboratories, Redmond, Washington), 70 mg/L of sodium bicarbonate and 10 mL of Prime® water conditioner (Seachem Laboratories, Inc., Madison, Georgia). After the desired extent of anesthesia was reached (mean of 2.04 min [1.2–4.2 min] for Chinook salmon and 2.5 min [1.2–4.9 min] for steelhead), the fish was removed from the anesthetic bath, measured (FL), weighed (g), and given a white photonic mark on the dorsal fin using a BMX2000 BioPhotonic Marking System and BMX2000 Photonic Marking Formulation (NEWWEST Technologies, Santa Rosa, California; Figure 3, upper). This procedure was included to distinguish study fish from other study salmonids recovered in the holding tank salvage.

After photonic marking, fish were moved to the surgery station and an anesthetic mixture containing 40 mg/L MS-222, 40 mg/L of sodium bicarbonate and 10 mL of Prime® water conditioner was dispensed (along with fresh water if needed), using aquarium tubing placed into the fish's mouth. Surgical tools and sutures were sterilized in 70% isopropyl rubbing alcohol, while acoustic tags were sterilized in 3% hydrogen peroxide. All surgical tools and acoustic tags were rinsed in distilled water prior to surgery and implantation. For Chinook salmon, incisions were made using a 3-mm-deep microsurgical blade with a 15-degree blade angle (Surgical Specialties Puerto Rico, Inc., Rincon, Puerto Rico). A 5-mm restricted depth stab blade with a 15-degree blade angle (Walcott Rx Products, Ocean View, New Jersey) was used for steelhead incisions. Acoustic tags (307 kHz, HTI Model 800 micro, 0.5 gm in air, 6.1 mm X 13.5 mm, encapsulated in resin) were activated and programmed using HTI's Model 490 LP Tag Programmer the morning of surgery. Each tag was then inserted into the body cavity of the Chinook salmon or steelhead and tag code noted. Incisions were closed with two independent sutures (2 X 3 knot) in an interrupted pattern using 5/0 Ethicon VCP303H, taper point, RB-1, 17 mm, ½ circle, 68.6-cm, violet, coated VICRYL Plus sutures (Ethicon, Inc., Somerville, New Jersey) and Mayo-Hegar needle holders (Figure 3, lower). A modified surgeon's knot was used to secure each suture, sutures were trimmed using stainless steel operating scissors, and iodine was applied to the incision. The time to complete surgery averaged 3.9 min (2.5–5.6 min) for Chinook salmon and 3.7 min (2.4–5.8 min) for steelhead.

Following surgery, fish were placed in pairs in a perforated 18.9-L (5-gallon) black bucket (used for recovery, acclimation, and release) contained within a 70-L tub with highly oxygenated (120–150% saturation) 16°C treated Delta water. The 18.9-L perforated buckets containing experimental salmonids were transported to a 2,871.3-L oval flume (track width = 0.4 m, depth = 0.5 m, length = 8.2 m, Frigid Units Inc., Ohio) and held in 16°C treated Delta water for 2 d prior to release (Figure 4, upper). Two hours prior to each fish release, the appropriate buckets were transported to the trash boom and floated in Delta water flow just downstream of the trash deflector for a final acclimation (Figure 4, middle). Tagged Chinook salmon and steelhead were transported and released from the same buckets in which they were placed following surgery, and were released together. All fish were checked prior to release to verify that they were alive and swimming normally. Fish were removed from the study if they were dead or swimming abnormally (*e.g.*, swimming sideways; some steelhead were observed to display antagonistic behavior to the second of the pair in both experimental and control buckets during the 2-d holding, post handling, particularly in May). Fish were released in a water to water transfer after a final 2-h acclimation (see Figure 4, lower). Tag period for the salmonid tags ranged from 2.007 to 4.375 sec, which allowed for high precision in tag identification in the track analysis processing (see below). The Model 800 micro tags had a coded signal to increase detections for the March releases while the May release tags were non-encoded to increase battery life.

Figure 3. Applying a photonic mark to the dorsal fin of a study fish (upper figure); applying sutures to a study fish following acoustic tag implant (lower figure).

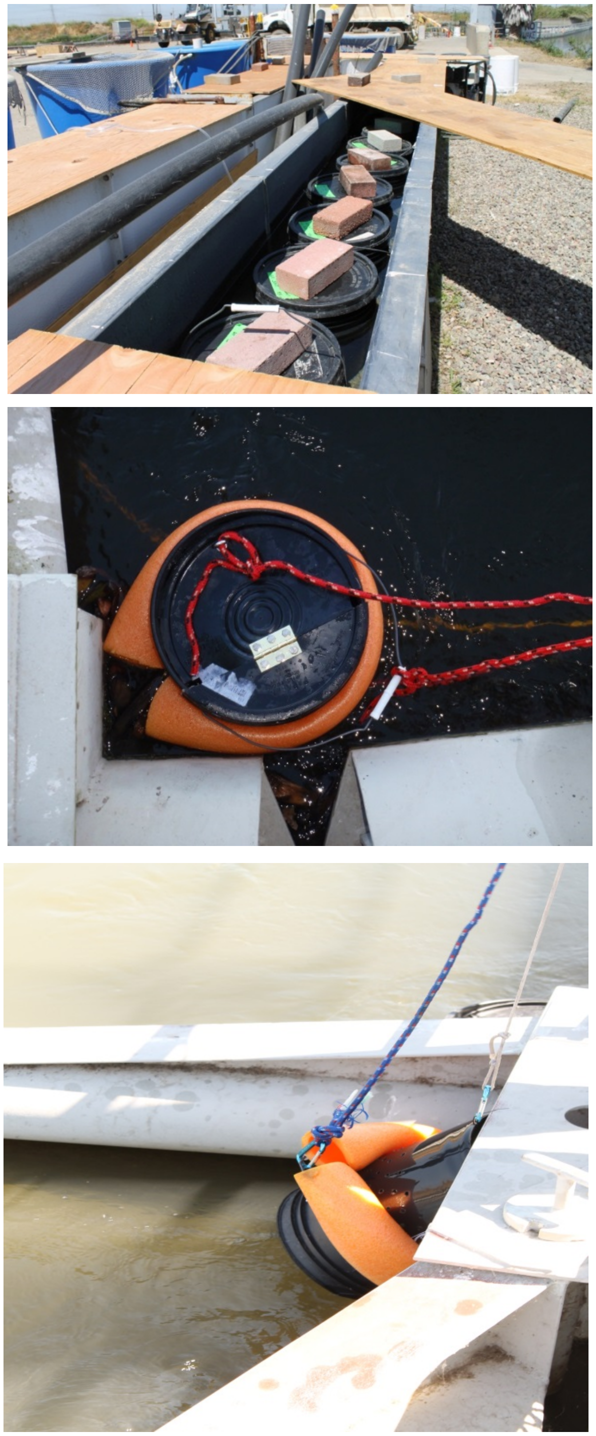


Figure 4. Post-surgical holding (2 days) of study fish (experimental and control) in well/Delta water (upper figure); fish acclimation in Delta water 2 h prior to release (middle figure); and release after 2 h (lower figure).

Two fish per species per day were processed during each surgical session as control fish. Fish were processed as described above and a dummy transmitter inserted. Control fish were held in perforated black buckets (similar to the experimental fish) in the oval flume with the experimental fish (for 2 days post handling recovery), after which they were transferred to 0.74-m-diameter (168-L) black tanks containing aerated, treated Delta water at approximately 16°C for 3 additional days.

Surgical implantation of acoustic tags in striped bass occurred 3-5 days prior to release. A 350-400 mg/L carbon dioxide (CO_2) concentration was obtained in an anesthesia tub (228.6 L, 78.7-cm-long × 50.8-cm-wide × 57.1-cm-deep) containing 16°C well water by injecting CO_2 from a pressurized cylinder into the water using a MBD-75 microbubble diffuser (Point Four Systems Inc., Richmond, BC, Canada). The CO_2 concentration was determined by hand-held titration cells using sodium hydroxide titrant with a phenolphthalein indicator (CHEMetrics Inc., Midland, Virginia; test kits K-1910, K-1920). Striped bass were transferred from 1.2-m-diameter (757-L) outdoor black tanks to the anesthetic tub using a 12.7-mm square knotless nylon mesh dip net (40.6-cm x 40.6-cm frame, 40.6-cm depth, 1.5-m handle, N&K Dip Nets, Viola, Wisconsin). After the desired extent of anesthesia was reached, each fish was measured (FL), weighed (kg), transported to the surgery station, and administered a maintenance dose of CO_2 (350–400 mg/L) using a 1,835.9 L/h submersible pump and aquarium tubing placed in the fish's mouth. Scales were removed from the incision site using Rankin forceps and an incision was made using a No. 10 stainless steel surgical blade (Feather Safety Razor CO., LTD., Medical Division, Osaka, Japan). An acoustic tag (307 kHz, HTI Model 795 LG, 4.5 gm in air, 11 mm × 24 mm) was then inserted into the body cavity and the incision closed with 2-3 independent sutures in a simple interrupted pattern using 4/0 Ethicon VCP303H, taper point, RB-1, 17 mm, ½ circle, 68.6-cm, violet, coated VICRYL Plus sutures (Ethicon, Inc., Somerville, New Jersey; Figure 5, upper). A modified surgeon's knot was used to secure each suture, sutures were trimmed using stainless steel operating scissors, and iodine was applied to the incision. A uniquely numbered white floy tag was then attached just below the dorsal fin using a Mark II™ Pistol L tag gun (Avery Dennison, Pasadena, California) for visual identification. Iodine was applied to the floy tag attachment location.

Striped bass were then hand-carried to a wheeled recovery tub (228.6 L, 78.7-cm-long x 50.8-cm-wide x 57.1-cm-deep) containing oxygenated 16°C well water and transported to outside 1.2-m-diameter (757-L) black tanks containing aerated, 16°C well water, where they were held at a density of one fish per tank. Salt was added daily to obtain 8 g/L salinity in each tank to improve fish recovery. One week before release, flow was gradually switched to Delta water to acclimate fish to ambient Delta water temperatures. Two hours prior to each release, striped bass were netted, using the dip net previously described, transferred to perforated garbage cans containing approximately 37.9 L of treated delta water and transported to one of two release locations for acclimation (see Figure 5, lower). As with the Model 800 micro tags, the 795 LG tags had a coded signal to increase detections for the March releases while the May release tags were non-encoded to increase battery life.

Figure 5. Suturing an incision in a striped bass following acoustic tag implant (upper figure); acclimation to Delta conditions 2 h prior to release (fish is inside the container; lower figure).

Determination of Fish Fates

The history of tag detections was used to create 2D tracks as well as detection signal patterns to evaluate fish behavior. The fate of each tagged fish was determined from 2D acoustic tag track analysis and positioning using HTI and Eonfusion (Echoview, Hobart, Tasmania, Australia) acoustic track processing software (see CDWR 2012 for summary of HTI track analyses). Each tag was tracked for a minimum of 3 days if possible (day 1 was the experimental hydraulic period, days 2+ the follow-up tracking). This was based in part on a study by Schultz *et al*. (2015) that found acoustically tagged juvenile Chinook salmon were defecated about 1.8 days after documented predation by acoustically tagged adult striped bass. The decision to assign one of five fates (*e.g.*, outcome of each tagged fish during the 24-h experimental period) was determined using the dichotomous key in Table 1. Possible fates included:

- *Salvage* = passage, capture and identification of experimental fish in the holding tanks (recovery of salvaged fish allowed assignment of this fate with 100% certainty)
- *Non-participation* = experimental fish that were recovered in the holding tanks following the experimental period
- *Loss through the primary and secondary channel louver*s = identification of experimental fish in the DMC downstream of the facility without subsequent defecation (primary louver loss) or identification of experimental fish downstream of the secondary channel louvers (secondary louver loss).
- *Loss to predation* = observation of an abrupt termination of movement of the target tag in the track analyses following a period of movement (further verified by flat line signal detection pattern; Figure 6)
- *Unknown* = experimental fish that could not be assigned to another fate category with any certainty (swim out was not considered a fate as it could not be confirmed without having the fish in-hand, and these fish were identified as unknowns)

All holding tank salvage was examined for acoustically tagged fish during the two 3-d experiments. Any experimental fish recovered in the holding tanks were identified by tag code identification, presence of the white photonic mark on the dorsal fin, and fork length (identification of two Chinook salmon collected in the holding tanks was confirmed by presence of the white photonic mark on the dorsal fin and fork length, as their acoustic tags had died sometime during the 3-d tracking period). The acoustic tags were removed for later use (either as a live tag, as a dummy tag for the control fish, or for another study). For the salvaged fish, travel times from release to holding tank, residence times within the facility, facility efficiencies, and pre-screen loss were estimated under the range of experimental flows.

Louver losses could occur due to experimental fish moving through gaps between the louver slats or during louver cleaning. This fate was assigned if the fish was tracked into the DMC from the primary channel (primary louver loss) or downstream of the louvers in the secondary channel (secondary louver loss). No experimental striped bass moved through the louvers into the DMC during the experimental period. Thus, all salmonid tags tracked into the DMC were presumed to be salmonids and not in the stomach of a striped bass. Predation was assigned if the salmonid tag was observed to become stationary after a period of movement during the 3-d tracking period. For these fish, time to defecation between fish release and cessation of tag movement was estimated as it was not possible to detect the moment of predation in the track analyses.

Table 1. This key is based on the 2013 acoustic telemetry studies (two 3-day experiments) in which day 1 = 24 h experimental hydraulic period and days 2–3 = post release tracking (assigned fish fates include: Salvage, Non-participation, Predation, Louver Loss, and Unknown), Tracy Fish Collection Facility.

1a	Fish dead	Delete
1b	Fish alive	Go to 2
2a	Tag dead	Delete
2b	Tag alive	Go to 3
3a	Fish released by trash boom	Go to 5
3b	Fish not released by trash boom	Go to 4
4a	Fish released north side upstream channel (striped bass only)	Go to 6
4b	Fish released into primary channel (striped bass only)	Go to 9
5a	Tag became stationary in upstream array	Unknown[1] and predation[2]
5b	Tag did not become stationary in upstream array	Go to 6
6a	Tag moved upstream and left array	Striped bass and unknown[1]
6b	Tag did not move upstream and leave array	Go to 7
7a	Tag remained moving in upstream array for study	Striped bass and unknown[1]
7b	Tag moved downstream through trash rack into primary channel	Go to 8[3]
8a	Tag remained in primary channel for study duration	Go to 9
8b	Tag left primary channel	Go to 10
9a	Tag became stationary	Unknown[1] and predation[2]
9b	Tag continued to move in primary channel during study period	Striped bass and unknown[1]
10a	Tag moved downstream through primary channel louvers into DMC	Primary channel louver loss[4]
10b	Tag did not move into DMC	Go to 11
11a	Tag moved upstream through trash rack	Unknown[1]
11b	Tag moved into primary channel bypass	Go to 12
12a	Tag remained in bypasses or was not again detected	Unknown[1]
12b	Tag detected in secondary channel, DMC, or holding tanks[5]	Go to 13
13a	Tag detected in DMC	Secondary channel louver loss[5]
13b	Tag not detected in DMC	Go to 14
14a	Tag remained in secondary channel or bypass	Unknown[1]
14b	Tag detected in holding tank	Go to 15
15a	Fish/tag collected in holding tank during study period (confirmation of sutures, white photonic mark on dorsal fin, detection on holding tank hydrophone/receiver)	Salvage
15b	Fish/tag collected in holding tank outside 24 h experimental period	Unknown[1] and non-participation

[1] Unknown = Chinook salmon or steelhead whose fates could not be assigned with any certainty.
[2] Predation = Chinook salmon only (confirmed in data processing software by presence of a flat line following tag movement and by Schultz *et al*. 2015).
[3] No tagged striped bass released into the upstream channel moved downstream through the trash rack so all salmonid tags detected moving into the primary channel considered tagged salmonids.
[4] No tagged striped bass moved through the primary or secondary channel louvers during the study period so predation was not considered a possible fate for these salmonids.

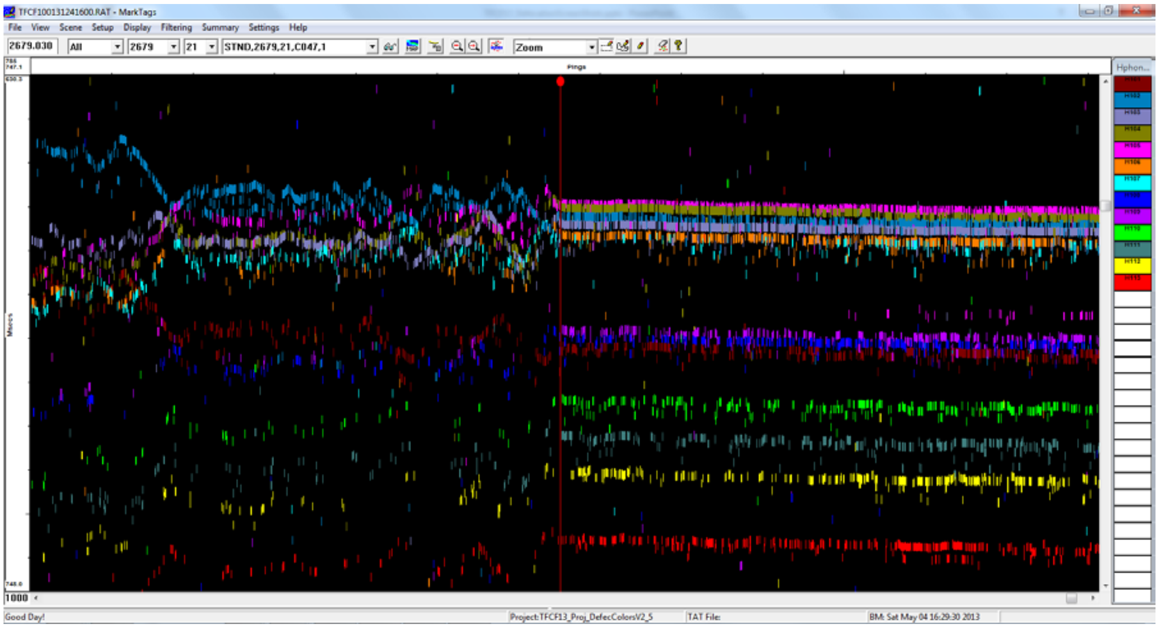


Figure 6. Confirmation of a defecated tag in data processing (clearly see flat line following movement, red marker separates moving tag from tag becoming stationary).

Data Analyses

Passage time, participation, secondary channel louver efficiency, primary channel louver efficiency, whole facility efficiency, and pre-screen loss were calculated for each JPP flow condition using the equations below. For whole facility efficiency, a low (all unknowns were assumed to be predation losses) and a high estimate (all unknowns were assumed to be non-participants) are provided. Likewise, a low estimate (all unknowns were assumed to be non-participants) and a high estimate (all unknowns were assumed to be predation losses) are provided for pre-screen loss to predation.

- *Travel Time* (Passage Time) = Time from release to collection in holding tank
- *Participation* (fish that moved downstream through the trash rack and entered the primary channel) = (# of fish detected in primary channel/# released)

Secondary Channel Louver Efficiency

- Secondary channel louver efficiency = # of fish salvaged/(# of fish salvaged + secondary channel louver loss)

Primary Channel Louver Efficiency

- Primary channel louver efficiency = (# of fish salvaged + secondary channel louver loss)/(# of fish salvaged + secondary louver loss + primary channel louver loss)

Whole Facility Efficiency

- Low Estimate = # of fish salvaged/(# of fish released – known non-participants); assumes all fish with an unknown fate are predation losses
- High Estimate = # of fish salvaged/(# of fish released – known non-participants – all fish with unknown fate); assumes all fish with an unknown fate are non-participants

Pre-screen Loss Estimate

- Low Estimate = # of losses to predation upstream of the trash rack/# fish released; assumes all fish with an unknown fate are non-participants
- High Estimate = (# of losses to predation upstream of the trash rack + fish with an unknown fate that did not enter the primary channel)/# released; assumes all fish with an unknown fate are predation losses

The amount of time a theoretical particle took to move from the trash boom to the holding tank was determined for each route that a tagged fish used (*i.e*., specific bypass and holding tank) using water velocities present at that time. Each estimated time was then compared to the time the associated fish took to complete the same route. Salmonid travel time and fish size data was not normally distributed and Wilcoxon Rank Sum Test (Statistix 8, Analytical Software, Tallahassee, Florida) was used to test for time-of-day, travel time, and size differences.

Results

Primary channel flows averaged 25.6 m^3/s (13.1–37.5 m^3/s; 903.2 ft^3/s, 461–1,323 ft^3/s) at 1 JPP pump (low flow), 78.3 m^3/s (60.0–98.7 m^3/s; 2,765.9 ft^3/s, 2,119–3,486 ft^3/s) at 3 JPP pumps (intermediate flow), and 119.6 m^3s (92.6–145.6 m^3/s; 4,223.0 ft^3/s, 3,271–5,141 ft^3/s) at 5 JPP pumps (high flow; Appendix A). Secondary channel flows averaged 3.6 m^3/s (2.1–4.3 m^3/s; 127.7 ft^3/s, 75.6–150.5 ft^3/s) at 1 JPP pump (low flow), 3.5 m^3/s (2.1–4.5 m^3/s; 121.9 ft^3/s, 74.5–160.5 ft^3/s) at 3 JPP pumps (intermediate flow), and 3.2 m^3/s (2.0–4.4 m^3/s; 113.1 ft^3/s, 69.9–155.2 ft^3/s) at 5 JPP pumps (high flow). Primary channel velocities averaged 0.2 m/s (0.1–0.3 m/s; 0.6 ft/s, 0.2–1.0 ft/s) at low flows, 0.5 m/s (0.4–0.8 m/s; 1.8 ft/s, 1.3–2.5 ft/s) at intermediate flows, and 0.9 m/s (0.7–1.1 m/s; 2.9 ft/s, 2.4–3.6 ft/s) at high flows and were influenced by the number of JPP pumps operating and tide stage. Secondary channel velocities averaged 0.8 m/s (0.4–1.1 m/s; 2.7 ft/s, 1.4–3.5 ft/s) and were influenced by the number of secondary channel velocity control/holding tank pumps in operation. Primary channel bypass ratios were mostly greater than 1 (dropped below 1 during periods of high primary channel velocity and low tide and were highest during periods of low velocity and high tide), and secondary channel bypass ratios were always greater than 1. Water temperatures were warmer in May (average = 19.7^{o}C [67.5^{o}F]) than March (average = 15.6^{o}C [60.1^{o}F]) and the paired steelhead were more visibly stressed during the 2-d post-handling holding in May. Light level ranged from 0 (dark) to 1,870 μmol/m^2/s (bright). Turbidity was higher in May (up to 21 NTU).

A total of 69 Chinook salmon (mean FL = 136.2 mm, range: 103–176 mm; mean weight = 26.7 g, range: 11.4–57.8 g; 3 Chinook salmon were deleted due to non-working acoustic tags), 61 steelhead (mean FL = 197.4 mm, range: 165–228 mm; mean weight = 79.5 g, range: 41.4–126.2 g; 9 steelhead were deleted due to non-working acoustic tags and 2 steelhead were not released due to poor condition from observed antagonistic behavior), and 34 striped bass (mean FL = 507.5 mm, range: 429–706 mm and mean weight = 1.8 kg, range: 0.9–4.1 kg; 18 into the primary channel and 16 into the channel upstream of the trash rack [2 fish were not released due to non-working acoustic tags]) were released. Both Chinook salmon (mean FL = 130.9 mm in March, 138.8 mm in May) and steelhead (mean FL = 190.1 mm in March, 206.6 mm in May) were slightly larger in May than March ($P < 0.05$).

Of the control salmonids, Chinook salmon averaged 137.2 mm FL (n = 12, 118–156 mm FL) and 25.9 g (16.9–37.8 g) and steelhead averaged 199.7 mm FL (n = 12, 181–244 mm FL) and 82.4 g (46.3–137.1 g; no difference in size between control and experimental fish, $P > 0.1$). Neither tag loss nor death was observed in Chinook salmon control fish and it was presumed that this did not occur in the experimental fish during the 3-d period of study. As regards to steelhead, 2 control fish (33.3%) died during the 3-d holding period in May. Thus, it was presumed that 33.3% of the May predation losses were due to similar conditions affecting the control fish and not to predation.

Salmonid Fish Fates

Of the 69 Chinook salmon released, 28 were recovered in the holding tanks (40.6%, one fish was salvaged about 8 h after the experimental hydraulic period ended and was categorized as a non-participant), 17 were determined to be lost to predation (24.6%), 8 were lost through the louvers (11.6%; 6 through the primary channel louvers [2 fish during louver cleaning, 1 at high flow, the other at intermediate flow], 2 through the secondary channel louvers not during cleaning, Figures 7 and 8), and 16 fish (23.2%) were assigned an unknown fate (Figure 9; Appendix B). Five of the louver losses occurred during high flows, 2 during intermediate flows, and one fish during low flows. Of the 17 Chinook salmon presumed lost to predation, time from release to defecation averaged 1.72 days (range: 0.76–2.83 days). Of these, 5 fish were lost to predation in the primary channel during the intermediate flow experiments, and 12 were lost in the channel upstream of the trash rack (8 at low flows, 1 at intermediate flows, and 3 at high flows). Two Chinook salmon released at the same time were consumed by the same predator about an hour apart in the primary channel and the tags were defecated at the same moment. Of the unknown fate group, one Chinook salmon tag released during the low flow experiment moved back and forth through the trash rack during the day, although it could not be determined if it was a Chinook salmon, or was in the stomach of a predator. Number of fish salvaged increased with increasing flow while the number of fish assigned an unknown fate declined with increasing flow (Figure 9).

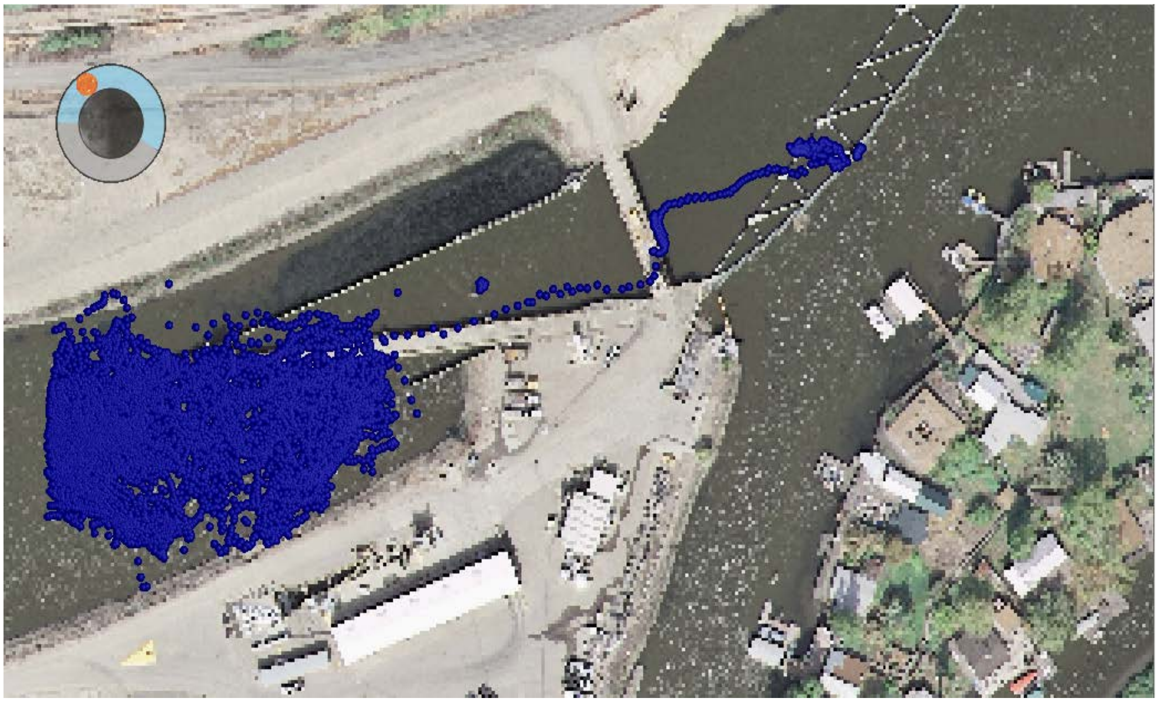


Figure 7. Example of primary louver loss of a Chinook salmon (fish was released during high flow experiment and passed through primary louver about 16 min later not during a cleaning event).

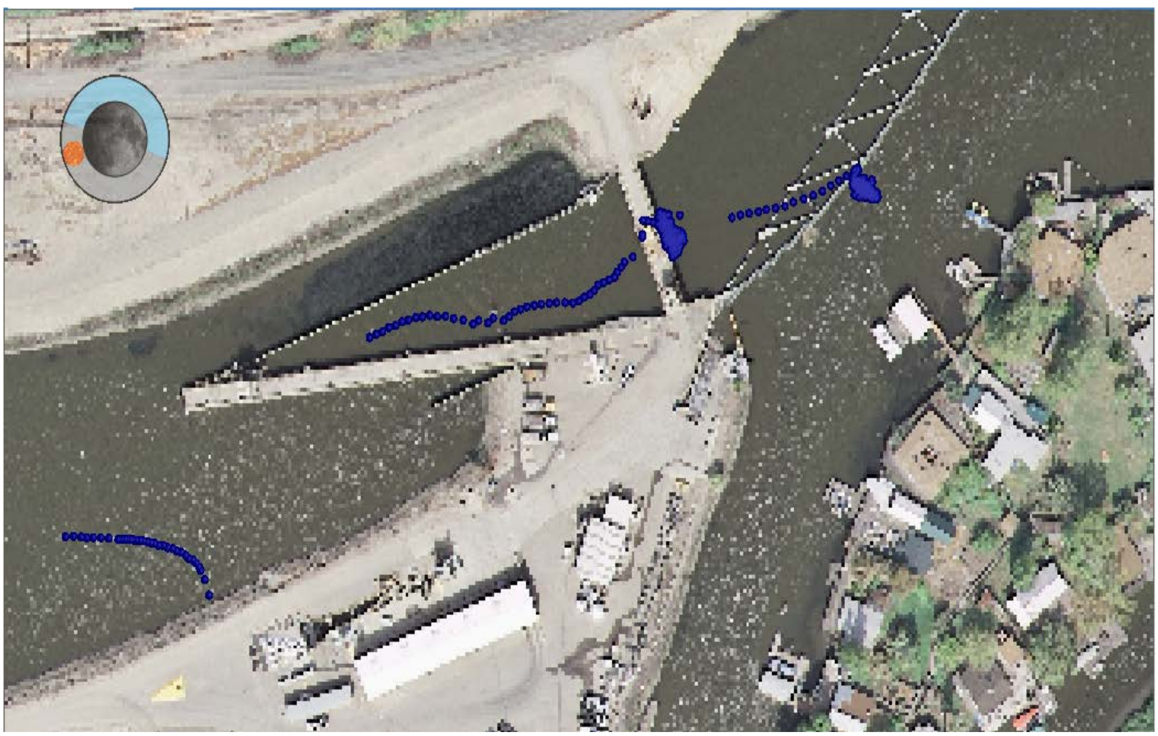


Figure 8. Example of secondary louver loss of a Chinook salmon (fish was released during high flow experiment and passed through the secondary louver not during a cleaning event).

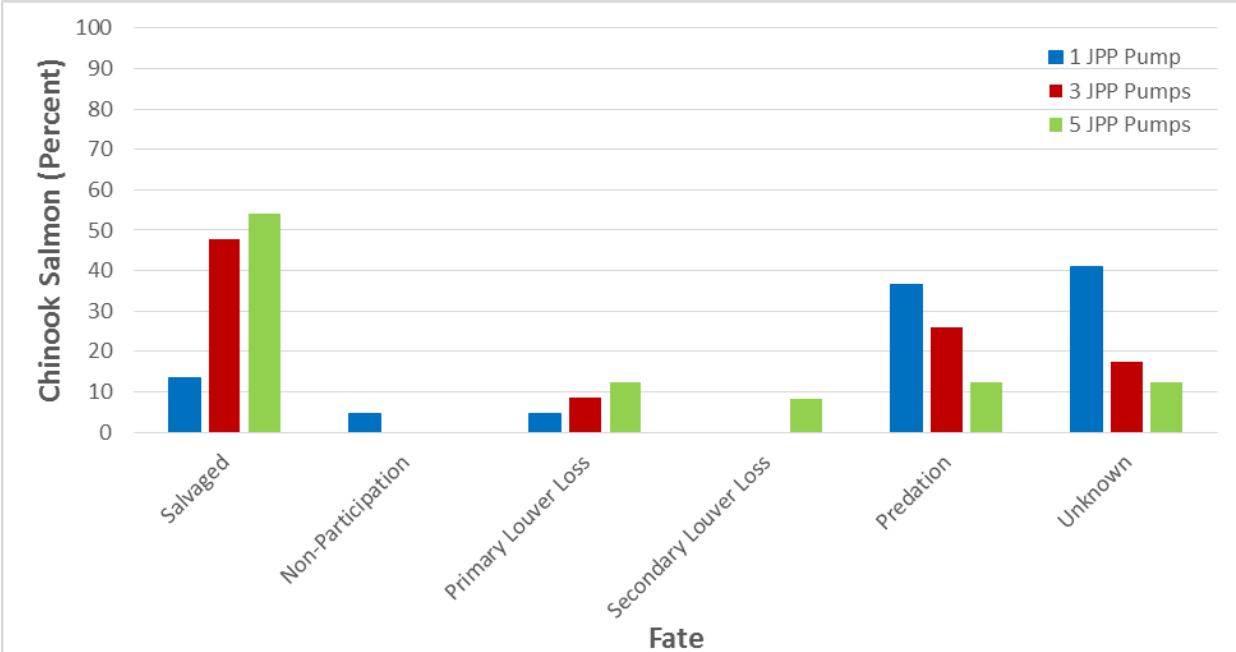
Of the 61 steelhead, 9 were recovered in the holding tanks (14.8%, 2 fish were salvaged within 5 h of the experimental period ending and were categorized as non-participants), 2 were lost through the louvers (3.3%, 1 fish through the primary channel louvers and 1 through the secondary channel louvers both during high flow experiments, neither associated with a louver cleaning; Figure 9, Appendix B), 5 were lost to predation in the channel upstream of the trash rack, and most (73.8%, n = 45) were assigned an unknown fate. Number of fish salvaged increased with increasing flow while the number of fish assigned an unknown fate remained similar among flows (Figure 9).

Salvaged Fish

A total of 37 fish (28.5% of 130 released salmonids, including 3 non-participants) were collected in the holding tanks (Appendix C, Figures C-1 through C-35, some track figures have positions in unexpected areas due to the acoustic noise [multipath] not removed during data processing; 2 salvaged Chinook salmon are not included as their acoustic tag died after release). Of these, 19 fish (13 Chinook salmon, 6 steelhead) were salvaged at high flows, 13 fish were salvaged at intermediate flows (11 Chinook salmon and 2 steelhead), and 5 fish were salvaged at low flows (4 Chinook salmon, 1 steelhead; Appendix B). No fish were detected moving from the secondary channel back upstream to the primary channel, nor did any experimental fish swim out of the holding tank back into the secondary channel.

It was estimated that a theoretical particle took an average of 0.1 h (± SD = 0.1 h, range 0.1–0.3 h) to move from the trash boom to the holding tanks (about 298.4 m) depending on the number of JPP pumps in operation (Appendix D). In contrast, both salvaged Chinook salmon (average 1.2 h, ± SD = 3.2 h, range 0.1–13.7 h) and steelhead (average 7.2 h, ± SD = 7.9 h, range 0.3–24.5 h) took significantly longer to move to the holding tanks, regardless of flow ($P < 0.05$; Table 2). Most of the salvaged fish moved from the primary channel to the secondary channel through bypasses 2 and 4 (Table 3).

Of the 28 salvaged Chinook salmon, most (85.7%) moved through the facility and into the holding tanks within the first hour following release. However, two Chinook salmon, both released during the low flow experiments, remained in the upstream channel for a much longer period (Appendix C, Figures C-1 and C-2).



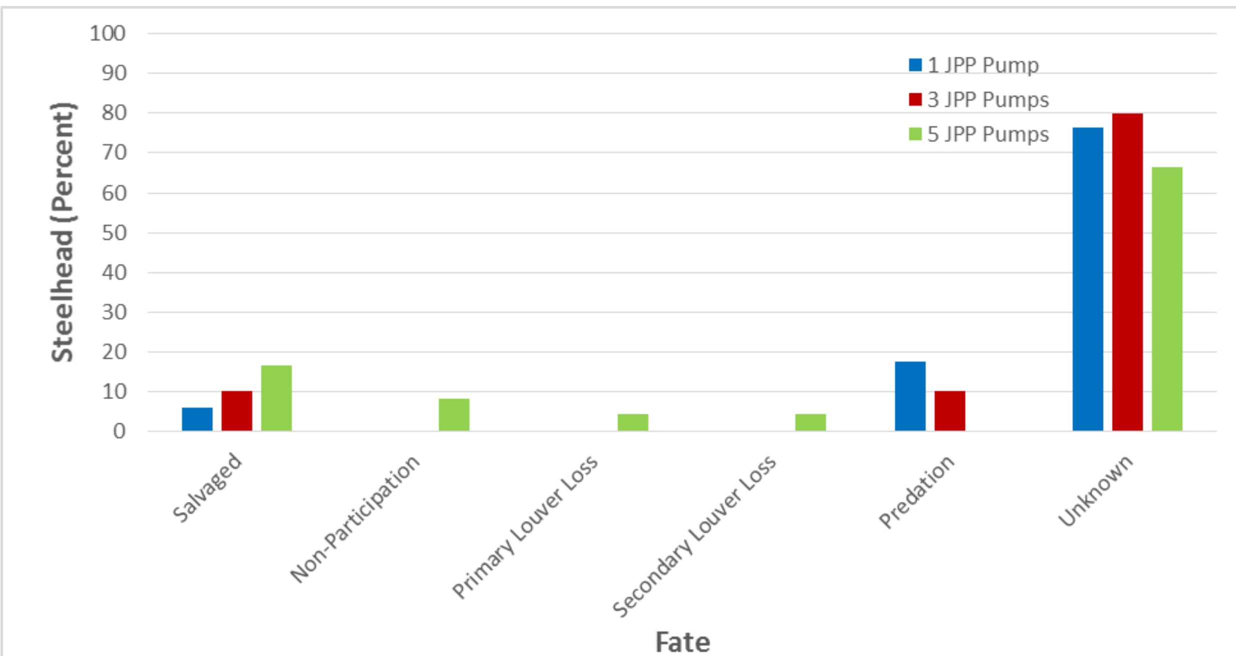


Figure 9. Summary of fate determinations for Chinook salmon (upper figure) and steelhead (lower figure). Salvage are fish that were recovered from the holding tanks, non-participation are fish recovered from the holding tanks after the experimental period, primary and secondary louver losses are fish lost through the respective louver systems, predation are fish determined to be lost to predation, and unknown includes fish not assigned to one of the other fates (as determined by using the dichotomous key in Table 1).

Table 2. Summary of amount of time salvaged acoustically tagged Chinook salmon and steelhead spent in various components of the Tracy Fish Collection Facility, Byron, California, 2013.

Species (N = total individuals salvaged)	**Jones Pumping Plant Pumps in Operation**	**Time from release to approaching trash rack (h, mean, range)**	**Time spent at upstream side of trash rack (h, mean, range)**	**Time spent in primary channel (h, mean, range)**	**Time spent in bypasses and secondary channel (h, mean, range)**	**Total time from release to detection in holding tanks (h, mean, range)**
Chinook salmon						
N = 4	1	2.51 (0.07–9.08)	3.64 (0.01–13.49)	0.09 (0.05–0.17)	0.25 (0.04–0.74)	6.26 (0.21–13.67)
N = 10	3	0.06 (0.04–0.16)	0.09 (0.00002–0.39)	0.06 (0.02–0.16)	0.08 (0.04–0.31)	0.27 (0.12–0.51)
N = 12	5	0.08 (0.02–0.25)	0.03 (0.00002–0.11)	0.05 (0.01–0.21)	0.17 (0.03–0.6)	0.31 (0.11–0.68)
Steelhead						
N = 1	1	0.29	8.74	0.19	0.06	9.27
N = 2	3	0.07 (0.05–0.09)	1.29 (0.17–2.41)	0.05 (0.05)	0.07 (0.06–0.08)	1.48 (0.33–2.63)
N = 6	5	0.07 (0.03–0.17)	0.3 (0.02–0.89)	1.57 (0.03–7.4)	6.79 (0.47–16.07)	8.73 (0.61–24.54)

Table 3. Summary of primary channel bypasses used by fish collected in the holding tanks (bypass used could not be determined for four Chinook salmon), Tracy Fish Collection Facility, Byron, California.

	Bypass 1	**Bypass 2**	**Bypass 3**	**Bypass 4**
Chinook salmon	3	8	4	11
Steelhead	0	2	0	7

One of these fish released in May at 0800, used more of the channel (9.1 h) and lingered along the trash rack for just over 1 h before passing through the facility into the holding tank. The other low flow fish released in March at 0200, used the area closer to the trash rack for almost 13.5 h, before moving into the primary channel. It then moved relatively slowly through that area (0.17 h) and remained in the primary channel bypasses and secondary channel for 0.73 h before moving into the holding tank. The latter Chinook salmon was salvaged 6 h after the hydraulic experimental period ended (thus, keyed as a non-participant). Both Chinook salmon were observed using the channel upstream of the trash rack during daylight hours in both months of experiments and were successfully salvaged. Two other salvaged Chinook salmon released in May at low flows passed through the facility in less than an hour, one at night and the other during the day (Appendix C, Figures C-3 and C-4). Salvaged Chinook salmon displayed a variety of swimming behaviors, mostly directional with flow as they moved through the facility, but some exhibited loops (Figure 10). Many (68%) salvaged Chinook salmon spent 1 min or more (up to 13.5 hours) at the trash rack before passing through into the primary channel. Time spent upstream of the trash rack and in the primary channel declined with increasing flow (see Table 2). The average amount of time a salvaged Chinook salmon remained in the facility ranged from 6.26 h ($n = 4$, $\pm$ SD = 6.8 h) at low flow, to 0.3 h at both intermediate ($n = 10$, $\pm$ SD = 0.2 h) and high ($n = 12$, $\pm$ SD = 0.2 h) flows (see Table 2).

Steelhead exhibited a variety of swimming behaviors, from moving relatively straight through the facility to the holding tank, to looping and holding within the facility (Figure 11; Appendix C, Figures C-27 through C-35). Of the nine salvaged steelhead, one fish spent 8.7 h in the area upstream of the trash rack under low flow conditions before moving through the trash rack (Appendix C, Figure C-27), another spent over 23 h in the primary channel and primary channel bypasses under high flows (Appendix C, Figure C-30), and 2 fish remained in the primary channel bypasses for 9.7–11.4 h also under high flows (Appendix C, Figures C-32 and C-33). The average amount of time a steelhead salvaged during the experimental hydraulic period spent in the facility was variable and appeared unrelated to flow: from 1.48 h at intermediate flow ($n = 3$, $\pm$ SD = 1.63 h) to 8.73 h at high flow ($n = 6$, $\pm$ SD = 9.1 h), and 9.27 h at low flow ($n = 1$; see Table 2). One steelhead released in March at 1100 h at high flow spent over 24 h in the facility (specifically, just over 1 h in the channel upstream of the facility, over 7 h in the primary channel, and about 16 h in the primary channel bypasses/secondary channel, Appendix C, Figure C-30) before moving into a holding tank after flows had dropped for the second hydraulic test. This fish was categorized as a non-participant. Salvaged steelhead released during both day and night under low and high flows

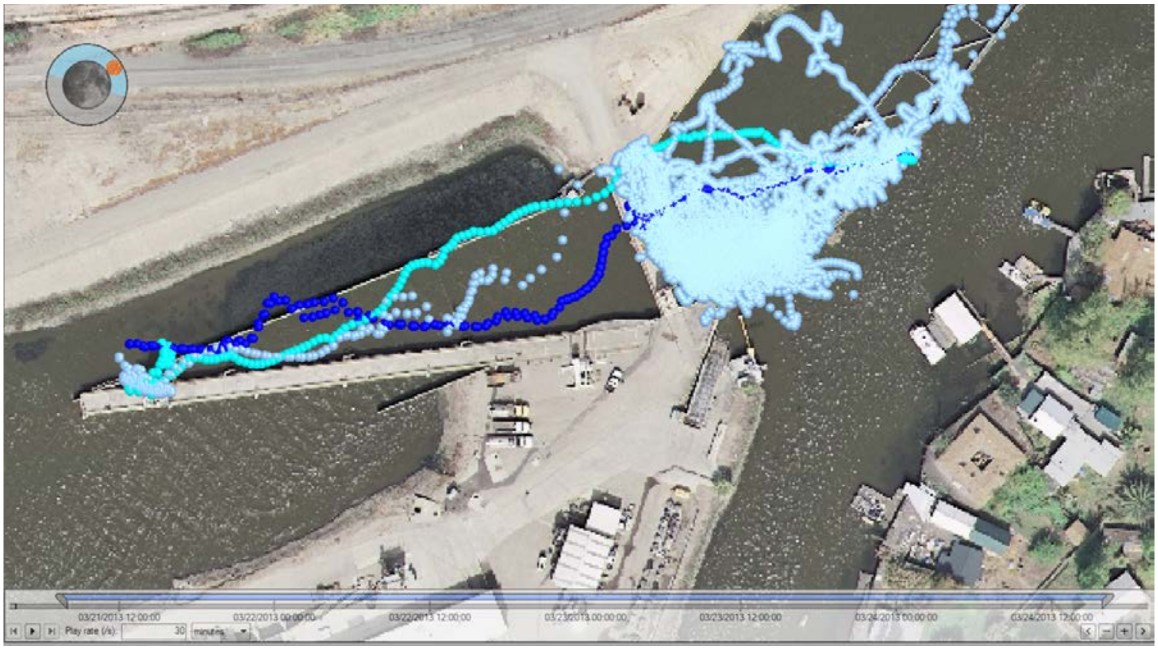


Figure 10. Tracks of 3 salvaged Chinook salmon under a range of flows (dark blue [fish 2847] = high flow, turquoise [fish 3015] = intermediate flow, light blue [fish 2315] = low flow).

Figure 11. Tracks of 3 salvaged steelhead under a range of flows (dark green [fish 2063] = high flow, bright green [fish 3127] = intermediate flow, and light green [fish 2203] = low flow).

held up in the bypass pipes and possibly secondary channel for long periods of time before moving into the holding tanks. All salvaged steelhead spent 1 min or more at the upstream side of the trash rack (up to 8 h) before passing through into the primary channel. Time spent upstream of the trash rack declined with increasing flow while time spent in the primary channel was variable as flow increased. Time spent in the bypasses and secondary channel increased with increasing flow (see Table 2).

Striped Bass Behavior

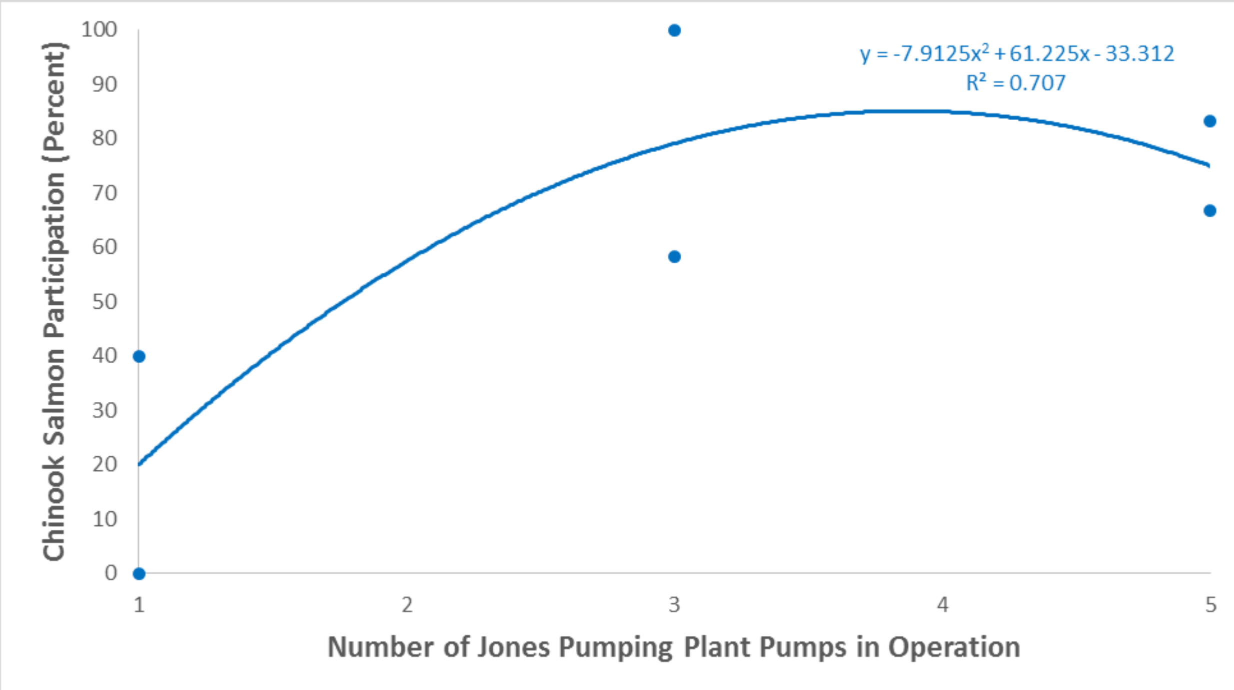
All 16 striped bass released into the channel upstream of the trash rack moved upstream and left after an average of 9.9 days (± SD = 10.6 d, range 0.01–37.6 d; Figure 12, pink track). These fish used all available area, including the area under the trash boom and the upstream side of the trash rack (Appendix E). One of the March fish was later captured by an angler near the city of Red Bluff on the Sacramento River, over 200 mi away.

Figure 12. Example tracks of a striped bass released into the primary channel (dark red) and into the channel upstream of the trash rack (pink).

On average, the striped bass released into the primary channel (n = 18) remained there for 57.2 days (± SD = 38 d, range 9–147.4 d). Two of the March releases moved upstream through the northern end of the trash rack into the upstream channel 9–12 d after release. One remained upstream of the trash rack for the next 29.7 days, then left the area in early May. The other striped bass only remained for 5.5 h then left. These two fish measured 476-mm FL (1.3 kg) and 485-mm FL (1.5 kg). Three of the primary channel March releases moved through the facility into the holding tank after 25 days (it is unknown if these fish moved into the holding tank naturally, or were captured by angling, returned to the primary channel and then moved to the holding tanks). One striped bass moved downstream through the gap in the primary channel louver wall during a louver cleaning about 54 days after release (well after the experimental period). This fish remained in the DMC intake area for about 6 days then disappeared from the tag detection system area. The striped bass released into the primary channel were observed to use all available area, day and night (see Figure 12, red track). Some fish moved into the primary channel bypasses and remained there for many hours after which they moved back into the primary channel. No acoustically tagged striped bass consumed an acoustically tagged Chinook salmon.

Facility Efficiency

Generally, both Chinook salmon and steelhead were more likely to participate in the experiment (move downstream after release and enter the facility through the trash track) with increasing flow (Figure 13). Travel time through the facility generally decreased for both species with increasing flows but many fish (76%) exhibited some trash rack delay (defined here as spending 1 minute or more on the upstream side of the trash rack; see Table 2; Figure 14). There was no difference in the total time either species took to move through the facility between salvaged fish that were released during the day or night ($P > 0.05$). Facility efficiency ranged from 0% (low estimate) to 75% (high estimate) for Chinook salmon and from 0% (low estimate) to 100% (high estimate) for steelhead (0 data were due to no fish being salvaged during a particular experiment). Facility efficiency generally increased with flow for both salmonids (Figure 15). Primary channel louver efficiency ranged from 71.4% to 100% for Chinook salmon and from 50% to 100% for steelhead (Figure 16). Secondary channel louver efficiency was 75%, or greater, for both species across all pumping conditions (Figure 17). Pre-screen loss estimates ranged from 0 to 100% and generally decreased with increasing flow (Figure 18). Many of the above relationships were weak presumably due to the small sample size, high variability, and high number of fish with an unknown fate.



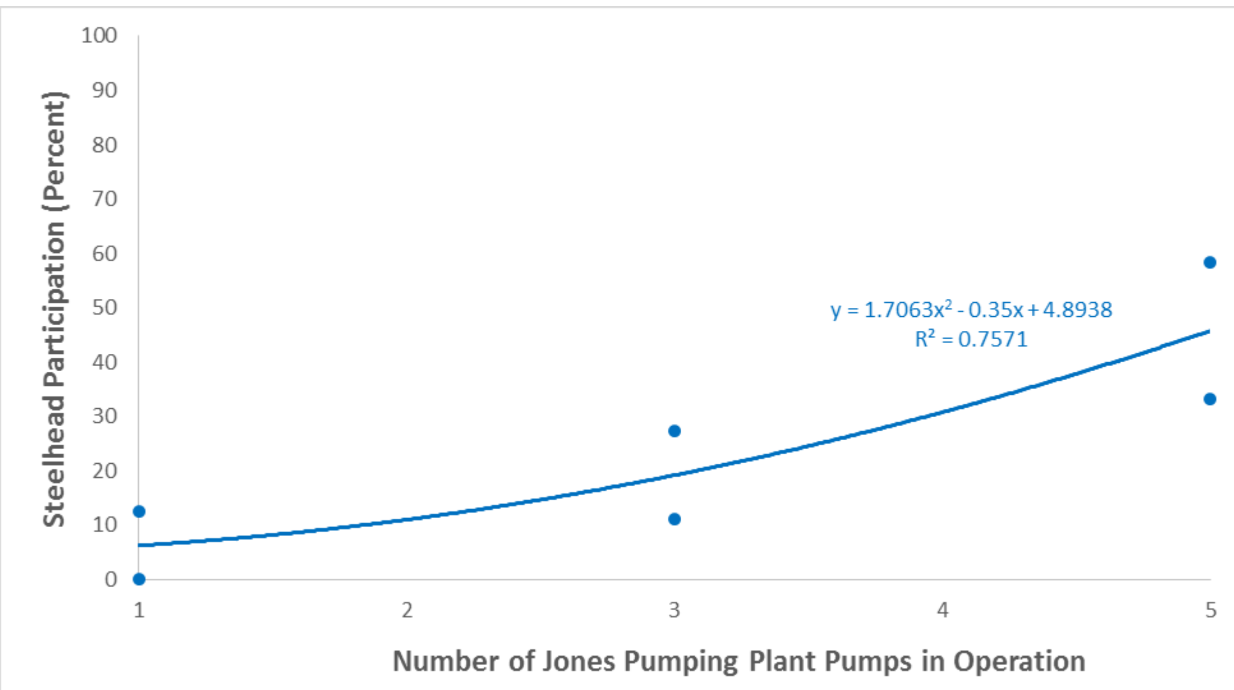
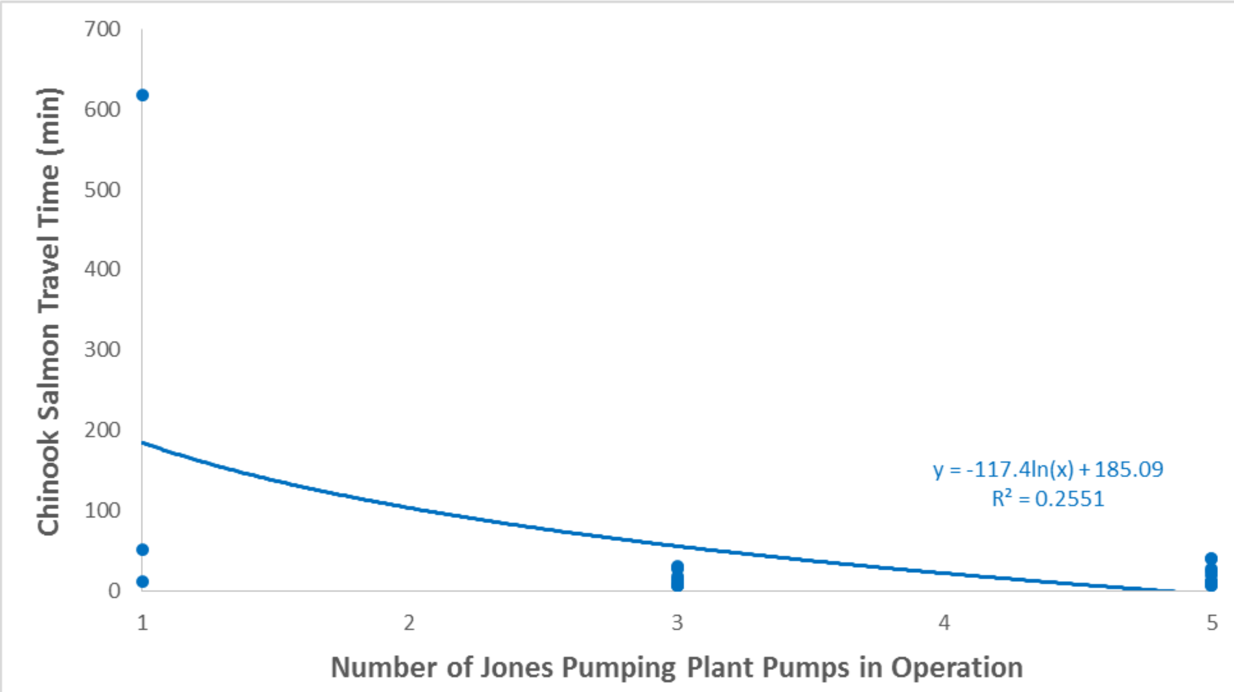


Figure 13. Summary of participation in the experiments (fish that crossed the trash rack and entered the primary channel) for Chinook salmon (upper figure) and steelhead (lower figure) per Jones Pumping Plant operation (1 pump: 13.1-37.5 m^3/s [461–1,323 ft^3/s], 3 pumps: 60.0-98.7 m^3/s [2,119-3,486 ft^3/s], 5 pumps: 92.6-145.6 m^3/s [3,271-5,141 ft^3/s]).



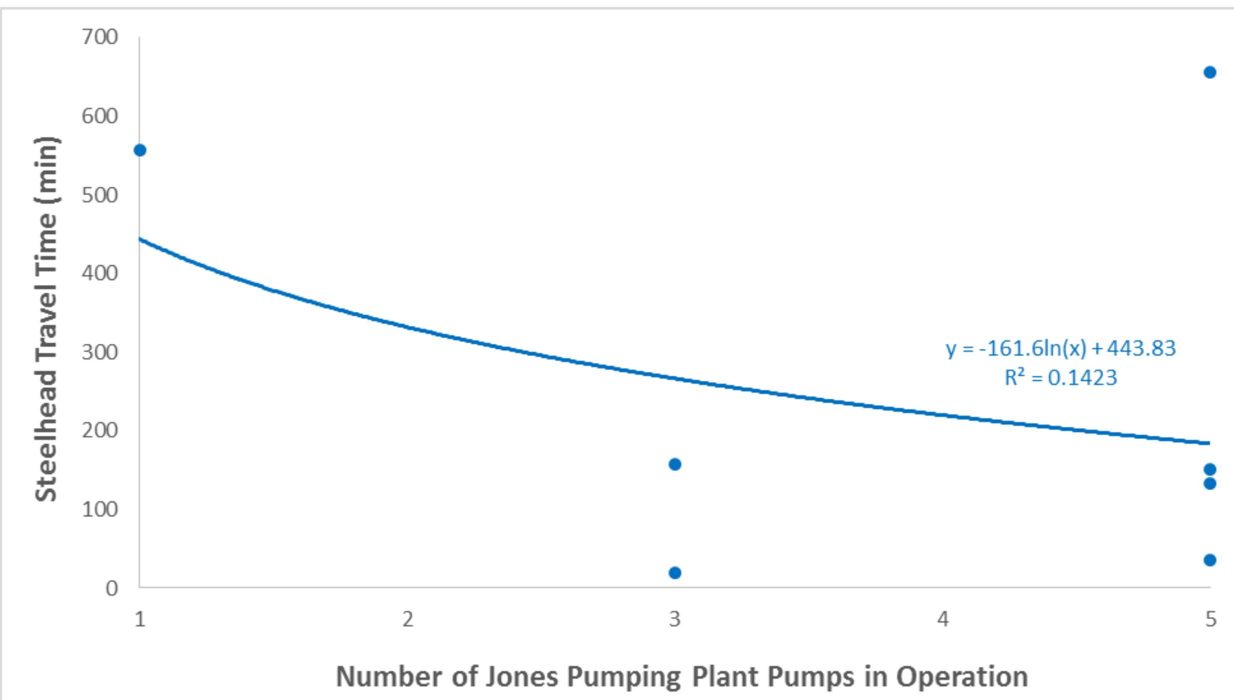
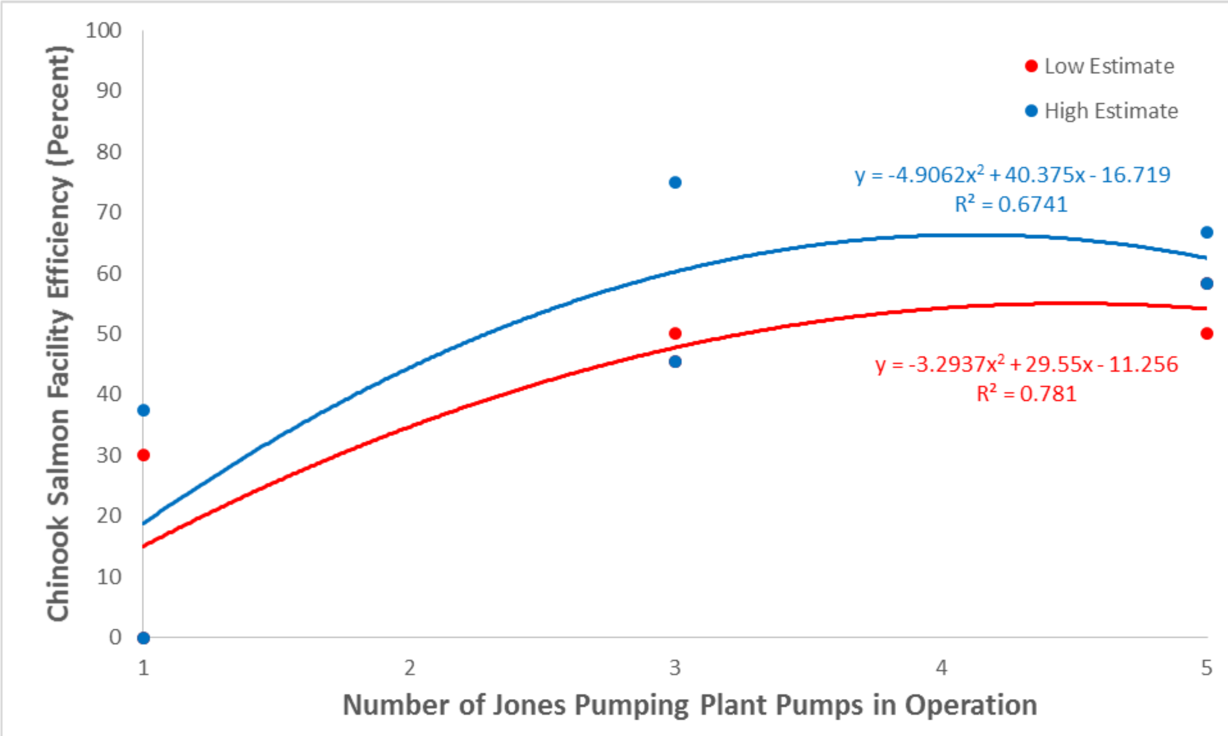


Figure 14. Summary of travel time through the Tracy Fish Collection Facility (from release to collection in the holding tanks) for salvaged Chinook salmon (upper figure) and steelhead (lower figure) per Jones Pumping Plant operation (1 pump: 13.1-37.5 m^3/s [461-1,323 ft^3/s], 3 pumps: 60.0-98.7 m^3/s [2,119-3,486 ft^3/s], 5 pumps: 92.6-145.6 m^3/s [3,271-5,141 ft^3/s]).



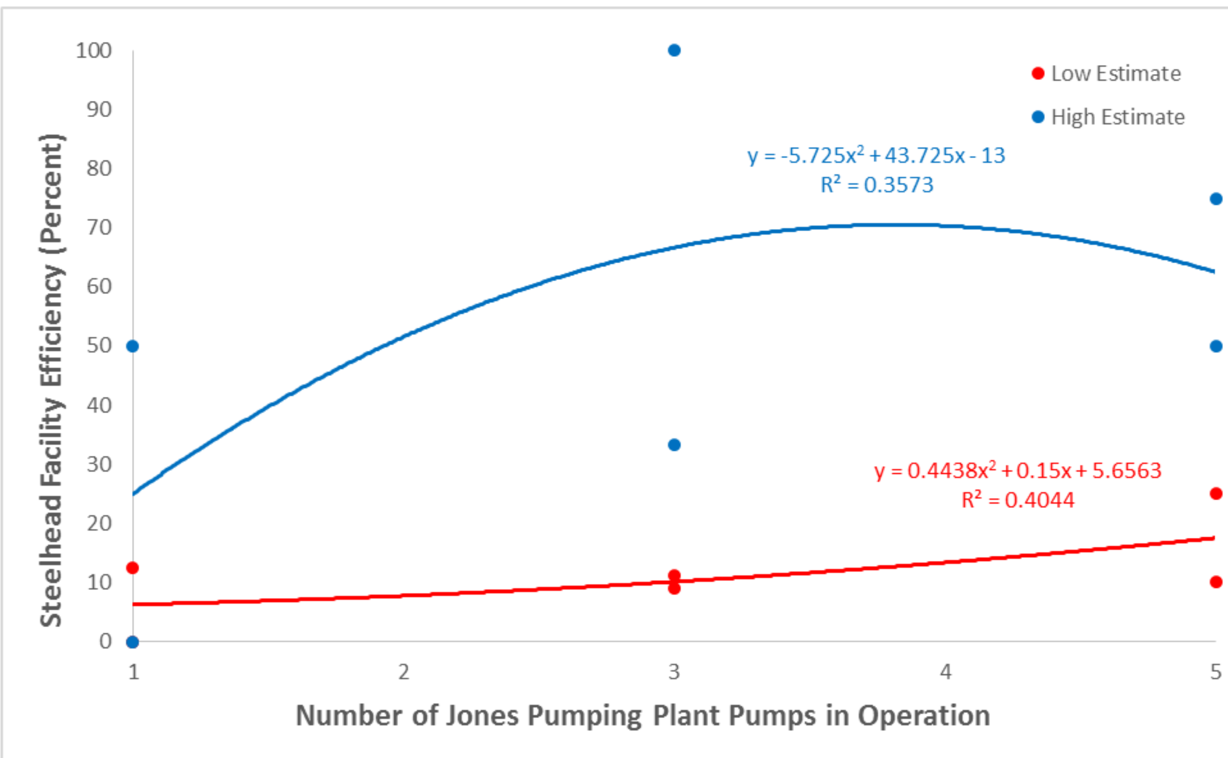
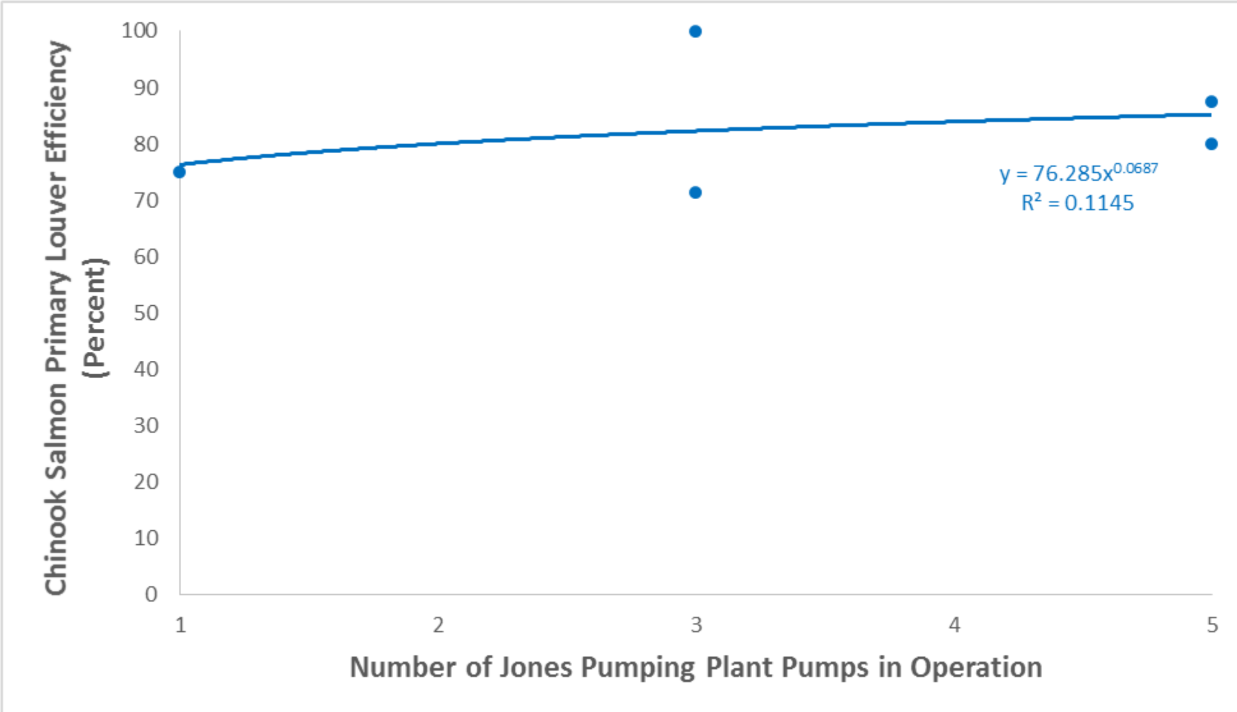


Figure 15. Summary of facility efficiency for Chinook salmon (upper figure) and steelhead (lower figure) per Jones Pumping Plant operation (1 pump: 13.1-37.5 m^3/s [461-1,323 ft^3/s], 3 pumps: 60.0-98.7 m^3/s [2,119-3,486 ft^3/s], 5 pumps: 92.6-145.6 m^3/s [3,271-5,141 ft^3/s]).



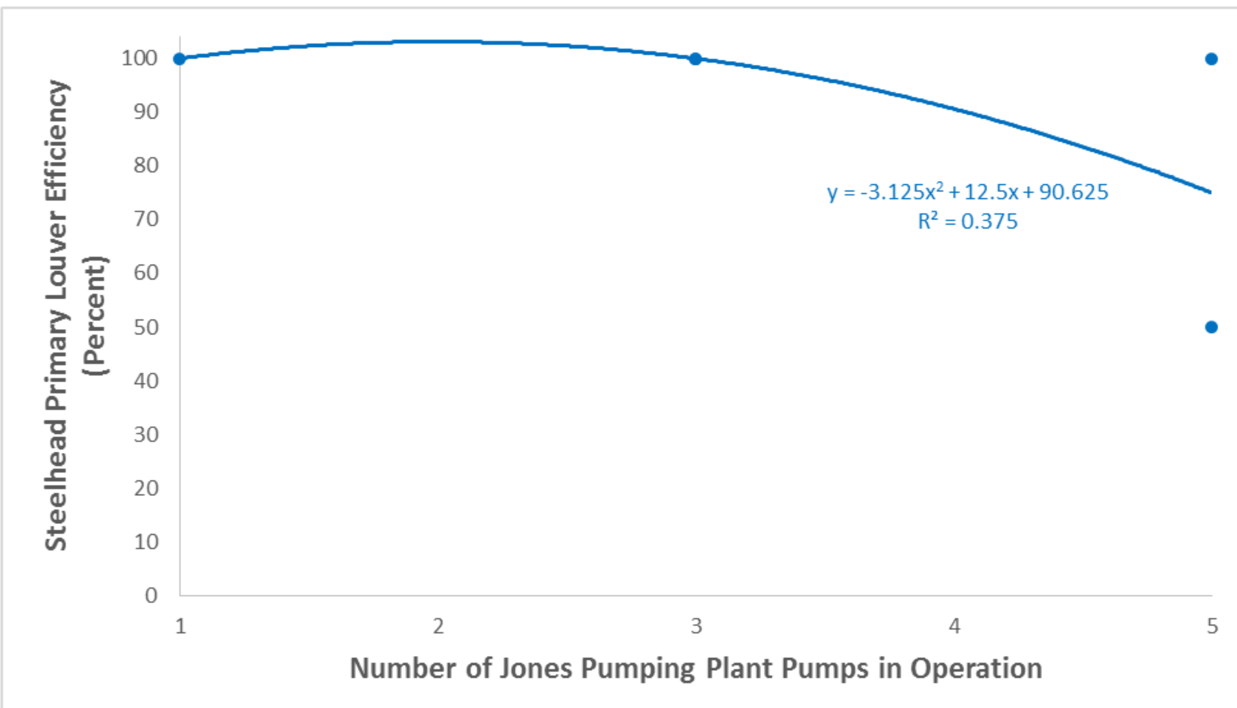
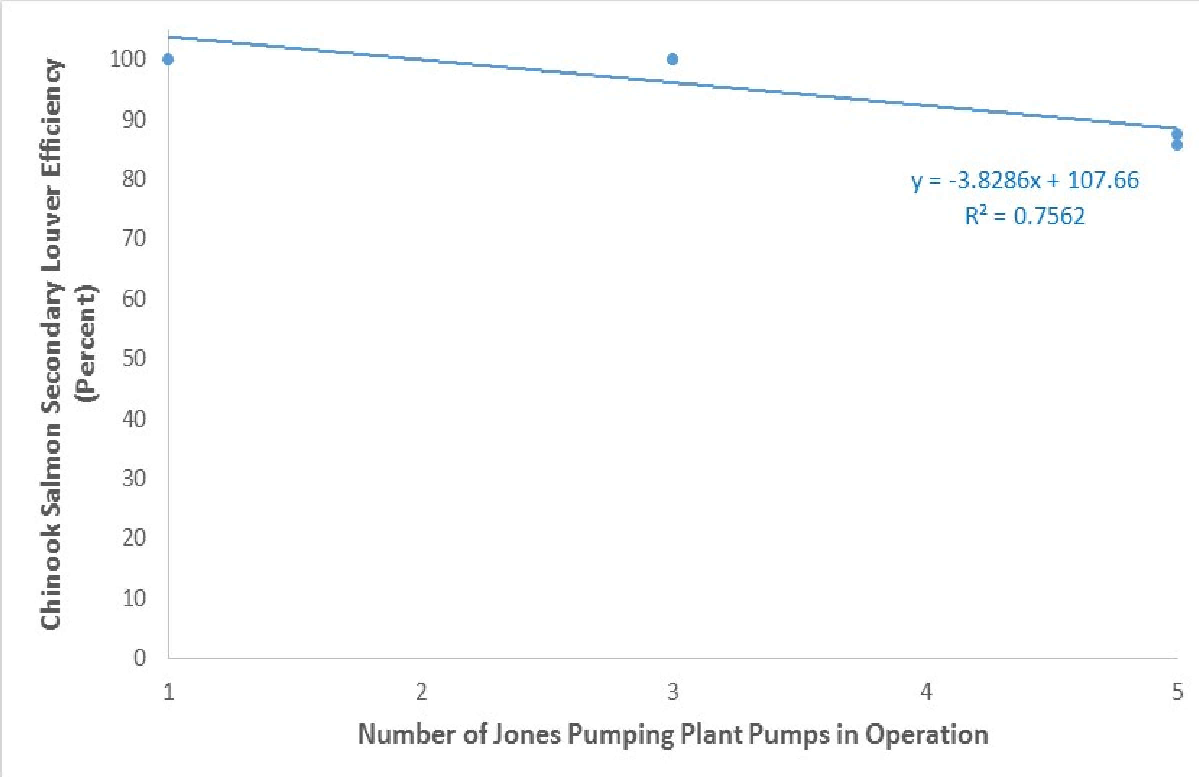


Figure 16. Summary of primary channel louver efficiency for Chinook salmon (upper figure) and steelhead (lower figure) per Jones Pumping Plant operation (1 pump: 13.1-37.5 m^3/s [461-1,323 ft^3/s], 3 pumps: 60.0-98.7 m^3/s [2,119-3,486 ft^3/s], 5 pumps: 92.6-145.6 m^3/s [3,271-5,141 ft^3/s]).



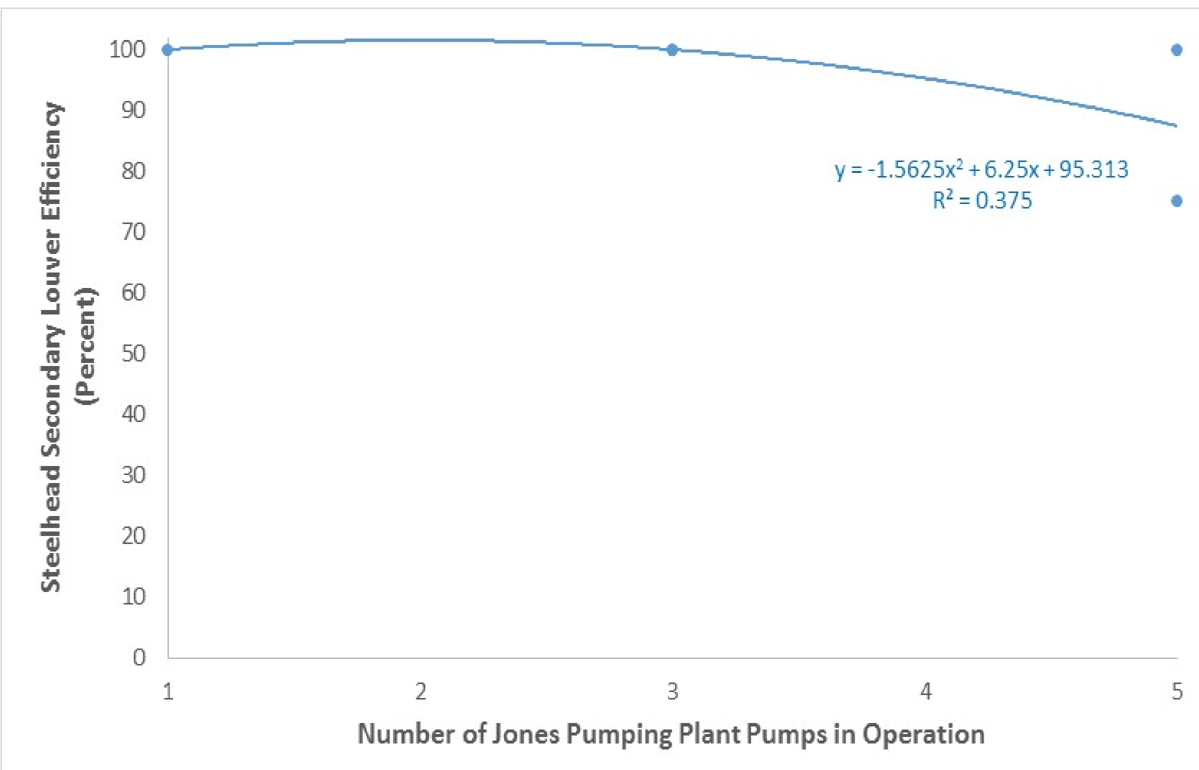
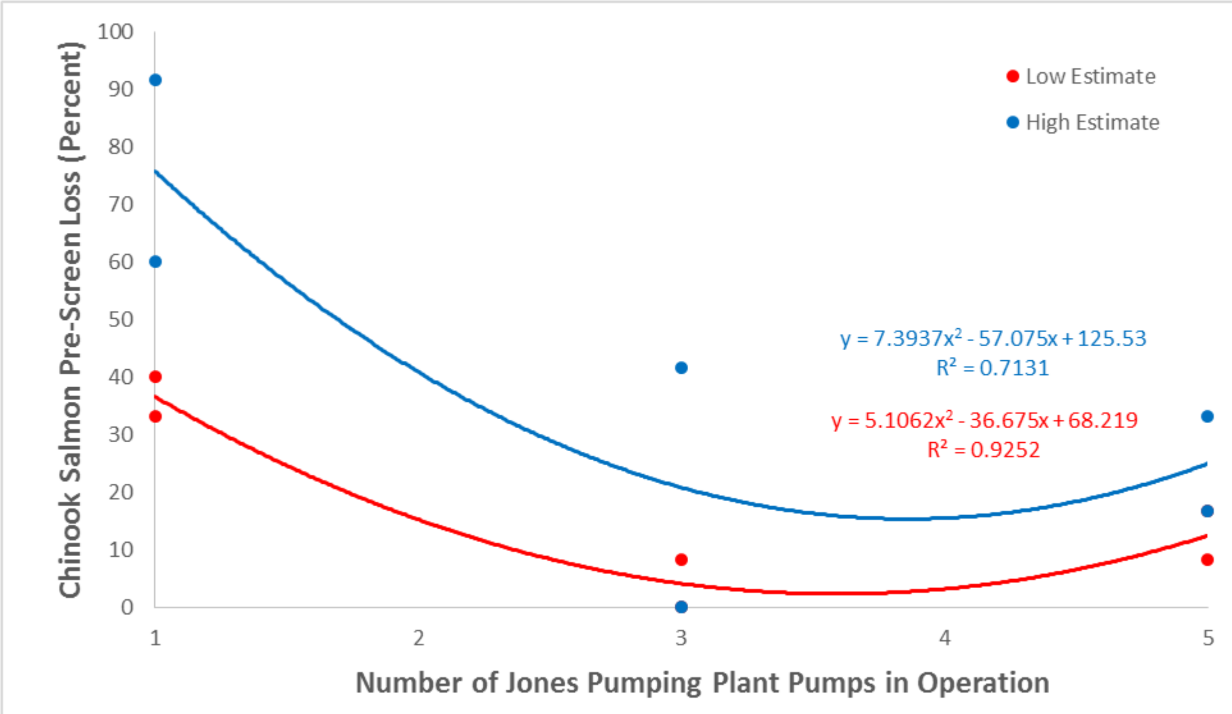


Figure 17. Summary of secondary channel louver efficiency for Chinook salmon (upper figure) and steelhead (lower figure) per Jones Pumping Plant operation (1 pump: 13.1-37.5 m^3/s [461-1,323 ft^3/s], 3 pumps: 60.0-98.7 m^3/s [2,119-3,486 ft^3/s], 5 pumps: 92.6-145.6 m^3/s [3,271-5,141 ft^3/s]).



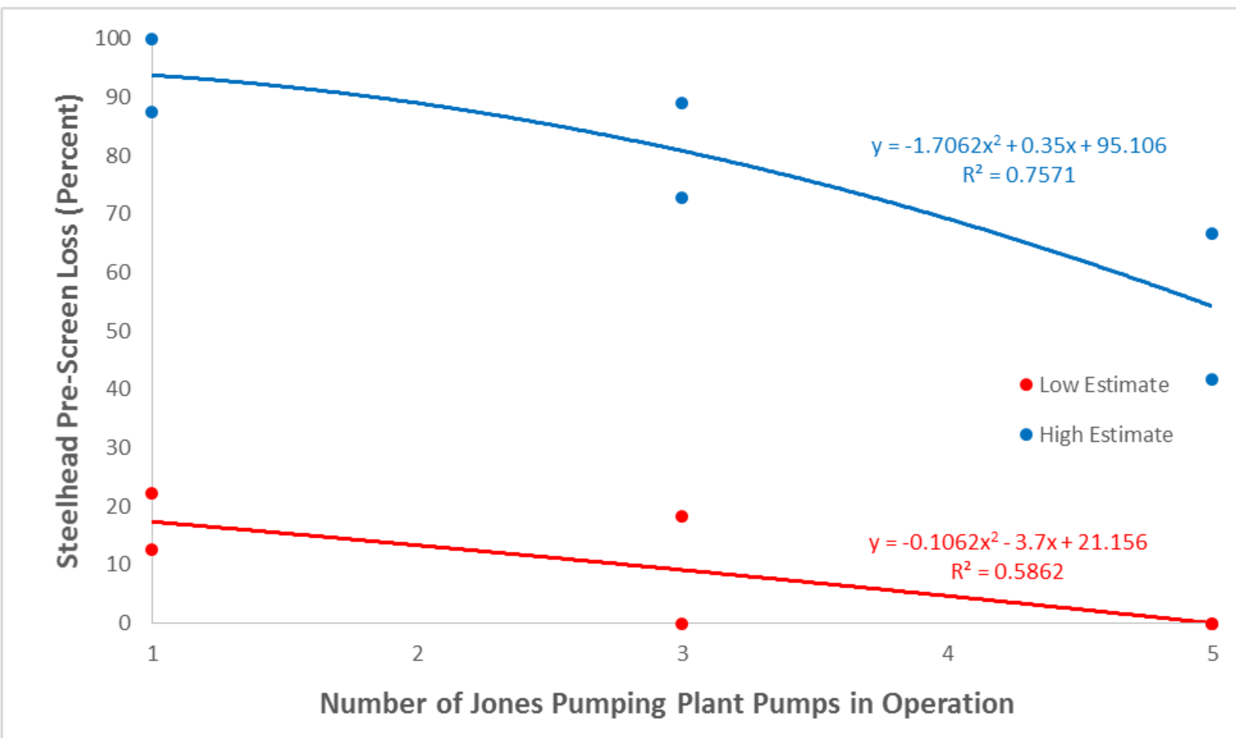


Figure 18. Summary of pre-screen loss estimates (upstream of the trash rack) for Chinook salmon (upper figure) and steelhead (lower figure) per Jones Pumping Plant operation (1 pump: 13.1-37.5 m^3/s [461-1,323 cfs], 3 pumps: 60.0-98.7 m^3/s [2,119-3,486 cfs], 5 pumps: 92.6-145.6 m^3/s [3,271-5,141 ft^3/s]).

Discussion

A total of 37 acoustically tagged juvenile salmonids (28 Chinook salmon, 9 steelhead) were recovered in the holding tanks from the 2 sets of fish releases (Appendix C, Figures C-1 through C-35). Their tracks cover a broad spectrum of behaviors from moving very quickly through the facility to lingering for hours either upstream of the trash rack, or in the primary channel/bypass pipes/secondary channel (*e.g.*, Figures 10 and 11). This variability in behavior and travel times suggest that time between detections may not be a reliable parameter for assigning species identification or fate during survival studies in the Delta.

Most salvaged Chinook salmon were salvaged within 1 h of release (85.7%), particularly at high flow, while just 2 of the recovered steelhead were salvaged within 1 h (22.2%; one at intermediate flow, the other at high flow). Chinook salmon appeared to move more directly with the flow than steelhead, particularly at intermediate and high flows. At these higher flows, 22 Chinook salmon (of the 26 salvaged Chinook salmon with live tags) exhibited relatively straight-forward movements into the facility (averaging just over 17 min from release at the trash boom to salvage in the holding tank). In contrast, 2 of the 4 Chinook salmon salvaged during the low flow experiments not only remained in the channel upstream of the trash racks over 10 h, they exhibited looping/turning behavior similar to tagged steelhead and striped bass, using much of the area before passing through the trash rack (see Figure 10; Appendix C, Figures C-1 and C-2). The other two low flow salvaged Chinook salmon moved through the facility in under an hour (Appendix C, Figures C-3 and C-4). Chinook salmon have been previously noted to make directed downstream movements with flow, sometimes turning when nearing an obstacle (CDWR 2015). The looping/turning patterns that were observed with some of the fish may have been due to them perceiving the trash racks and louvers as a barrier, escaping predators, or not being able to determine where to go.

Steelhead movements varied from moving relatively straight through the facility to exhibiting much looping/turning and holding within various parts of the facility, regardless of flow or direction of flow (see Figure 11; Appendix C, Figures C-27 through C-35). This variable behavior was noted by Clark et al. (2009) in their study of steelhead movements in the Clifton Court forebay. As mentioned above with some Chinook salmon, steelhead may have exhibited loops and turns (rather than moving with the flow) in response to the trash racks and louvers being perceived as a barrier, or escaping predators. The only steelhead salvaged from a low flow release spent over 8 h upstream of the trash rack (Appendix C, Figure C-27), while another fish released at high flow spent over 24 h in the facility (about 23 h in the primary channel and bypasses; Appendix C, Figure C-30). Five of the six high flow salvaged steelhead spent more than 1 h in the primary channel and or bypasses. It is possible that the two salvaged fish in Appendix F (assigned to the unknown fate category) were steelhead based on their behavior in the primary channel. Both tags spent over 20 h in the channel upstream of the trash rack before moving relatively quickly through the primary channel and within several hours, into the holding tanks. None of the tagged striped bass released into the channel upstream of the trash rack moved downstream into the primary channel, and none of the striped bass released into the primary channel exhibited such directed movements through that system. Although it could not be confirmed whether these fish were steelhead or the tags were in the digestive system of a predator, these two fish moved through the primary and secondary louver channels like some of the salvaged steelhead.

Of the 10 fish lost through the louvers (7.7% of all released salmonids), 7 were lost at high flow experiments, most not during louver cleanings. Thus, some fish, even fish that are considered better swimmers than other entrained fish species, fail to be diverted into a bypass by the louver system. Although none of the tagged striped bass moved through the louvers during the study, one fish moved downstream through the gap in the primary channel louver array at the same time that section of the louver array was being cleaned. This fish did not move back upstream into the primary channel although fish were noted to move upstream from the DMC through the facility to the Old River many years ago (Liston et al. 1994). It is possible any or all louver losses were due to tagged salmonids being chased through the louvers by a striped bass or other predator.

No time of day difference was detected in the amount of time either salmonid species used to pass through the facility, although several fish spent many hours either in the channel upstream of the trash rack (2 Chinook salmon at low flow; 3 steelhead at all flows) and in the primary channel and primary channel bypasses (3 Chinook salmon at high flow, 1 at low flow; all 6 salvaged steelhead released at high flow). The six steelhead remained in these bypasses for hours whereas the four Chinook salmon spent less than 1 h there. This indicates that some fish obviously hold up in the facility at all flows and thus, such behavior may make some fish more vulnerable to predation. It is believed that some fish may move between the primary and secondary fish diversion channels by entering the secondary channel and then moving back upstream into one of the four primary channel bypasses (Wu *et al*. 2015). This study did not detect such movements, but some fish of all three species spent considerable time in the primary channel bypasses, and in the two fish diversion channels.

More Chinook salmon were lost to predation at lower and intermediate flows than high flows (8, 6, and 3 predation losses, respectively). Presuming these fish were consumed soon after release, predation of experimental fish occurred about equally for day and night releases. Of the 17 Chinook salmon believed lost to predation (24.6% of all released Chinook salmon), five occurred in the primary channel and 12 in the channel upstream of the trash rack. It is likely the five Chinook salmon lost in the primary channel were consumed by striped bass because there's very little habitat for other known piscivores there. However, in reviewing the tracks of the 12 Chinook salmon presumed lost to predation in the upstream channel, it appears that a range of behaviors occurred prior to tag defecation (Appendix G). Specifically, some of these tags were observed most often on the north bank, others under the trash boom, and others in front of the trash rack. This suggests that multiple fish predator species may be active in the upstream channel, including largemouth bass (*Micropterus salmoides*), white catfish (*Ameiurus catus*) and birds (cormorants [*Phalacrocorax auritus*] and seagulls are frequently observed in the general area around the trash boom and trash rack). Therefore, the calculated digestion time of 1.72 d (for all 17 fish lost to predation) from release to defecation may include digestion from more than one piscivorous species. Interestingly, the calculated time to defecation agrees with the 1.8 d reported in Schultz *et al*. (2015) for 14 striped bass that were fed dead acoustically tagged Chinook salmon, and also is similar to the rate of 1.62 d for the five Chinook salmon consumed in the primary channel (presuming those losses were due to striped bass only). At least five steelhead were believed lost to predation at low (n = 3) and intermediate flows (n = 2; all within the channel upstream of the trash rack). The time from release to cessation of tag movement for steelhead was 2.49 d (1.62–3.63 d).

Of the tagged striped bass released into the primary channel, most remained there (up to 4.9 months) and used all available area. Two fish (over 475-mm FL) were noted to move upstream through the north end of the trash rack (possibly through the gap between the last bar of the rack and the concrete wall). As noted above, one striped bass moved downstream through the gap in the primary channel during louver cleaning several weeks after release. This residency of striped bass in the primary channel has been noted by others (Wu *et al*. 2015; Bridges *et al*. In Draft). All striped bass released upstream of the trash rack moved upstream and left the facility (including the 2 primary channel releases that moved up through the trash rack). This suggests that striped bass may not be residents in the channel between the trash rack and trash boom in the spring, rather they pass through during their migration period. Vogel (2010, 2011) noted a high level of tag defecation in front of the trash racks in survival studies of tagged Chinook salmon and striped bass in the south Delta. The above mentioned defecation rates together with the relatively high level of predation observed in the upstream channel suggests the predation noted in Vogel's studies may have occurred locally and that there may be more predators in the channel upstream of the trash rack than within the facility. The authors recognize that experimental salmonids were exposed to varying numbers of released striped bass depending on the month and time of release. However, no experimental salmonids were consumed by experimental striped bass. The intent of releasing striped bass was to learn something of their behavior in the upstream channel and within the facility.

Facility efficiency estimates covered all typical facility operations, and generally agree with other TFCF efficiency studies (Bates *et al*. 1960, Karp *et al*. 1995; Bowen *et al*. 2004, Bridges *et al*. In Draft). Only 3 fish (1.4% of Chinook salmon, 3.3% of steelhead) or 2.3% of all released salmonids were keyed as non-participants because it became apparent that fish had to be collected in hand to confirm this fate. All other fish that were potential non-participants were keyed as unknown fate. The high number of unknown fates, particularly for steelhead, influenced estimates of facility efficiency and pre-screen loss. These estimates would improve with development of reliable equipment and methods to determine predation events, as well as installation of additional acoustic equipment upstream of the trash boom.

Participation estimates generally increased with flow for both Chinook salmon and steelhead. In general, across both species tested, there tends to be an increase in facility efficiency as the number of JPP pumps in operation increases from 1 to 5. This trend is likely due to reduced predation rates resulting from decreased residence time within the facility with increased flows.

Primary channel louver efficiency estimates for Chinook salmon ranged from 71.4% to 100% and were greater than those described by Karp *et al.* 1995 (13–82%) for this species. The higher primary channel louver efficiency observed during this study was likely due to the use of acoustic tags which allowed for the exclusion of known non-participants and predation losses that occurred upstream of the primary louvers during analysis. Generally, primary channel louver efficiency for Chinook salmon did not appear dependent on the number of JPP pumps in operation and, due to low sample size and high variability in data, continued data collection efforts are necessary to determine the true relationship between Chinook salmon primary channel louver efficiency and the number of JPP pumps in operation. Primary channel louver efficiency estimates for steelhead ranged from 50% to 100%. However, it should be noted that the observed 50% primary channel louver efficiency was due to 1 incidence of reduced efficiency during 5 JPP pump operation in which 1 of 2 fish that encountered the primary louvers were lost. Other than this instance, steelhead primary louver efficiency was 100% for all pumping regimes. While this data may seem to suggest that primary louver efficiency remains consistently high during 1 and 3 JPP pump operation and then decreases during 5 JPP pump operation, due to low sample size and high variability, continued data collection efforts are necessary to determine the true relationship between steelhead primary channel louver efficiency and the number of JPP pumps in operation.

Secondary channel louver efficiency estimates were 75%, or greater, for both species across all pumping conditions and were comparable to those described for Chinook salmon in Karp *et al.* 1995 (72–100%), Bowen *et al.* 1998 (mean = 83%), and Bowen *et al.* 2004 (mean = 85.1%). However, louver efficiency for this component of the TFCF is not dependent on the number of pumps in operation at the JPP as water flow and velocity in the secondary channel are controlled by a separate array of pumps (*i.e.*, secondary channel velocity control pumps).

Travel time through the facility and predation rates generally decreased with increased flow for both salmonids. This, along with the increased participation and facility efficiency with increased pumping, suggests that low pumping conditions may be more detrimental to salvage of Chinook salmon and steelhead than increased pump operation. However, most statistical relationships suggesting this trend were weak due to low sample size, high variability, and the high number of fish that were assigned an unknown fate. Continued data collection efforts are necessary to elucidate if there is an optimal number of operating JPP pumps that promote maximum facility efficiency.

Determination of pre-screen loss was based on presumed predation losses and the low estimates (average of 17.8% for Chinook salmon, 8.8% for steelhead) were similar to the 15% pre-screen loss estimate for the TFCF cited by NMFS (2009). However, the high estimates, which assumed all fish with an unknown fate were lost to predation, were much higher (average of 31.6% for Chinook salmon, 76.3% for steelhead). Actual pre-screen losses to predation probably lie somewhere between the low and high estimates, and additional data would help to further refine these numbers. Pre-screen loss estimates for Chinook salmon and steelhead generally decreased with increased flow, which was likely due to reduced predation rates resulting from decreased residence times within the facility with increased flows. This relationship further supports the idea that operating the JPP at 1 pump may be more detrimental to salmonid salvage at the TFCF relative to higher pumping. However, these trends were also likely affected by low sample size and high number of fish assigned unknown fates.

The high rate of predation upstream of and within the facility, together with observed striped bass behavior and observations that many of the salvaged experimental salmonids were delayed by the trash rack (76%), suggest opening the trash rack (either by removing panels or adding space between adjacent slats) in the spring when striped bass become migratory, would allow “resident” striped bass to move upstream and leave, and allow entrained fish an easier path to the fish diversion/collection system. In winter/spring 2010, two of the five trash rack panels were removed during installation of a new cleaning rake (Appendix H). Salvage of Chinook salmon, steelhead, and striped bass per acre-foot of exported water all increased relative to other years

(Appendix I). This also supports the idea of opening the trash rack to allow greater movement of fish into and out of the facility as it is likely that smaller entrained fish and larger predator fish perceive the trash rack as a barrier. The fact that all of the striped bass that were released upstream of the trash rack eventually left the area, including the two fish that moved upstream through the trash rack is further support for the idea of allowing some exchange between the area upstream of the trash rack and the primary channel.

Conclusions

Acoustically tagged juvenile salmonids were released from the trash boom to better estimate facility efficiencies under typical flows and operations. Recovery of some of these fish allowed for the description of species specific behavior in the facility with 100% certainty. The use of acoustic tags allowed for the quantification of non-participation, losses to predation and louver passage, as well as the development of more refined pre-screen loss and facility efficiency estimates. A low level of non-participation was determined (1 Chinook salmon, 2 steelhead) based on fish that were salvaged after the experimental period. A higher number of non-participants was expected, but could not be confirmed. Consequently, there were high numbers of fish with unknown fates (23.2% Chinook salmon, 73.8% steelhead), which reduced the precision of the pre-screen loss and facility efficiency estimates. In the future, estimates of these facility parameters would improve with development of reliable equipment and methods to definitively determine predation events, as well as installation of additional receivers and hydrophones upstream of the trash boom to reduce the proportion of unknown fates.

All three acoustically tagged species exhibited both straight and looping movements in this study (see Figures 10–12). Most Chinook salmon moved relatively directly through the facility, particularly at higher flows. However, two low flow fish spent many hours in the upstream channel making numerous turns and loops. Some Chinook salmon remained for unexpectedly long periods in the bypass system at high flows. Juvenile steelhead exhibited more variable behavior but most steelhead did not participate in the experiments. Of the salvaged fish, some moved relatively quickly with flow, but most made looping turns similar to striped bass and the two low flow Chinook salmon. Most salvaged steelhead remained within the facility, particularly the bypasses, for long periods. This may be due in part to their ability to migrate or residualize, and to their predatory behavior. While it is recognized that the fish in this study may have been delayed due to a perception of the trash rack and louvers as barriers, the wide range in the amount of time each salmonid took to move between the trash boom and holding tanks (from about 7 min to over 24 h, significantly more than water flowing during the same hydraulic conditions) suggests that time between detections may not be a reliable parameter for assigning species identification in survival studies in the Delta where barriers and other impediments also exist (*e.g.*, Perry *et al*. 2010; Steel *et al*. 2012; Buchanan *et al*. 2013; CDWR 2015). The authors emphasize that the time estimates between detection points made in this study were entirely based on the 37 fish that were recovered in hand. Thus, there was 100% certainty of their specific identification.

The percentage of released Chinook salmon and steelhead noted as lost to predation was 24.6 and 8.2%, respectively, and occurred more so in the channel upstream of the trash rack than in the primary channel. More fish were lost at lower and intermediate flows than high flows (see Figure 9). This, along with the apparent improvements to Chinook salmon and steelhead salvage with increased pumping suggests low pumping conditions may be more detrimental to salvage of entrained salmonids than increased pump operation. However, most statistical relationships suggesting improvements to salvage with increased pumping were weak due to low sample size, high variability, and the high number of fish that were assigned an unknown fate. Continued data collection efforts are necessary to elucidate if there is an optimal number of operational JPP pumps that promotes maximum facility efficiency.

The TFCF has some inefficiencies including predation, louver losses, and trash rack delay. Several observations noted here (residency of striped bass in the primary channel, departure of striped bass from the channel upstream of the trash rack, high rate of predation upstream of and within the facility, and delay of many of the salvaged experimental salmonids by the trash rack, over 75%), suggests opening the trash rack (either by removing panels or adding space between adjacent slats) in the spring when striped bass become migratory, would allow “resident” striped bass to move upstream and leave, and allow entrained fish an easier path to the fish diversion/collection system.

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Appendix A. Summary of Hydraulic and Temperature Data

Table A-1. Summary of Hydraulic Data (Average and Range) During 3–Day Experiments in March and May 2013, Tracy Fish Collection Facility, Byron, California (JPP = Bill Jones Pumping Plant).

	# JPP Pumps	Primary Channel Flow (ft^3/s [m^3/s])	Primary Channel Velocity (ft/s [m/s])	Primary Channel Bypass Ratio	Secondary Channel Flow (ft^3/s [m^3/s])	Secondary Channel Velocity (ft/s [m/s])	Secondary Channel Bypass Ratio
March 21–22	5	4,211.0 (3,738–5,141 [119.2, 105.8–145.6])	2.9 (2.4–3.5 [0.9, 0.7–1.1])	1.1 (0.6–1.7)	108.0 (71.3–149 [3.1, 2.0–4.2])	2.5 (1.6–3.2 [0.8, 0.5–1.0])	1.4 (1.1–2.3)
March 22–23	3	2,924.8 (2,513–3,486 [82.8, 71.2–98.7])	1.9 (1.5–2.5 [0.6, 0.5–0.8])	1.7 (1.0–2.6)	115.5 (74.5–160.5 [3.3, 2.1–4.5])	2.6 (1.4–3.5 [0.8, 0.4–1.1])	1.4 (1.0–2.7)
March 23–24	1	946.8 (615–1,323 [26.8, 17.4–37.4])	0.6 (0.3–1.0 [0.2, 0.1–0.3])	6.1 (2.8–10.1)	118.9 (75.6–149.1 [3.4, 2.1–4.2])	2.7 (1.5–3.3 [0.8, 0.5–1.0])	1.3 (1.0–2.3)
May 2–3	5	4,235.0 (3,271–4,941 [119.9, 92.6–139.9])	2.9 (2.4–3.6 [0.9, 0.7–1.1])	1.1 (0.7–1.6)	115.4 (78–155.2 [3.3, 2.2–4.4])	2.5 (1.6–3.2 [0.8, 0.5–1.0])	1.2 (1.0–1.8)
May 3–4	3	2,607.0 (2,119–3,105 [73.8, 60.0–87.9])	1.7 (1.3–2.3 [0.5, 0.4–0.7])	2.2 (1.5–3.0)	131.6 (112.2–150.9 [3.7, 3.2–4.3])	2.9 (2.4–3.3 [0.9, 0.7–1.0])	1.2 (1.0–1.3)
May 4–5	1	859.6 (461–1,284 [24.3, 13.1–36.4])	0.5 (0.2–0.9 [0.2, 0.1–0.3])	8.6 (4.1–18.8)	139.0 (111.9–150.5 [3.9, 3.2–4.3])	2.8 (2.0–3.4 [0.9, 0.6–1.0])	1.2 (1.1–1.6)

Table A-2. Summary of Environmental Data (Average and Range) During 3–Day Experiments in March and May 2013, Tracy Fish Collection Facility, Byron, California (JPP = Bill Jones Pumping Plant).

	# JPP Pumps	**Water Temp (F° [C°])**	**Light (µmol/m²/s)**	**Turbidity (NTU)**
March 21–22	5	61.1 (59.9–62.9 [16.2, 15.5–17.2])	468.6 (0–1,681.7)	5.3 (3.0–8.9)
March 22–23	3	59.6 (58–60.5 [15.3, 14.4–15.8])	396.4 (0–1,572.8)	4.3 (2.4–8.4)
March 23–24	1	59.2 (58.2–60 [15.1, 14.6–15.6])	399.4 (0–1,592.3)	3.3 (2.3–4.6)
May 2–3	5	66.6 (64.3–68.5 [19.2, 17.9–20.3])	646.3 (0–1,870.4)	12.2 (7.7–21)
May 3–4	3	68.0 (64.4–70 [20.0, 18–21.1])	548.5 (0–1,770.1)	9.4 (6–20)
May 4–5	1	67.9 (65.8–9.4 [19.9, 18.8–20.8])	594.8 (0–1,847.7)	8.1 (6.1–9.8)

Appendix B. Summary of Assigned Fates

Table B-1. Summary of Assigned Fates of the 130 Released Chinook Salmon and Steelhead in March and May 2013, Tracy Fish Collection Facility, Byron, California.

	# JPP Pumps[1]	Salvage	Non-participation	Primary Channel Louver Loss	Secondary Channel Louver Loss	Predation	Unknown	Dead fish/tag	Total Released
Steelhead									
March 2013	1 JPP	1	0	0	0	1	6	4	8
	3 JPP	1	0	0	0	2	8	1	11
	5 JPP	1	2	1	0	0	8	0	12
May 2013	1 JPP	0	0	0	0	2	7	3	9
	3 JPP	1	0	0	0	0	8	3	9
	5 JPP	3	0	0	1	0	8	1	12
Chinook salmon									
March 2013	1 JPP	0	1	0	0	4	7	0	12
	3 JPP	6	0	0	0	2	4	1 (fish salvaged)	12
	5JPP	6	0	1	1	1	3	1 (fish salvaged)	12
May 2013	1 JPP	3	0	1	0	4	2	2	10
	3 JPP	5	0	2	0	4	0	1	11
	5 JPP	7	0	2	1	2	0	0	12

[1] JPP refers to number of Jones Pumping Plant pumps in operation: 1 JPP = low flow, 3 JPP = intermediate flow, 5 JPP = high flow.

Appendix C. Tracks of Salvaged Chinook Salmon and Steelhead

Figure C-1. Track of Chinook salmon 2091 (released at low flow, total time in system was over 10 h, mostly in upstream channel and along the upstream side of the trash rack).

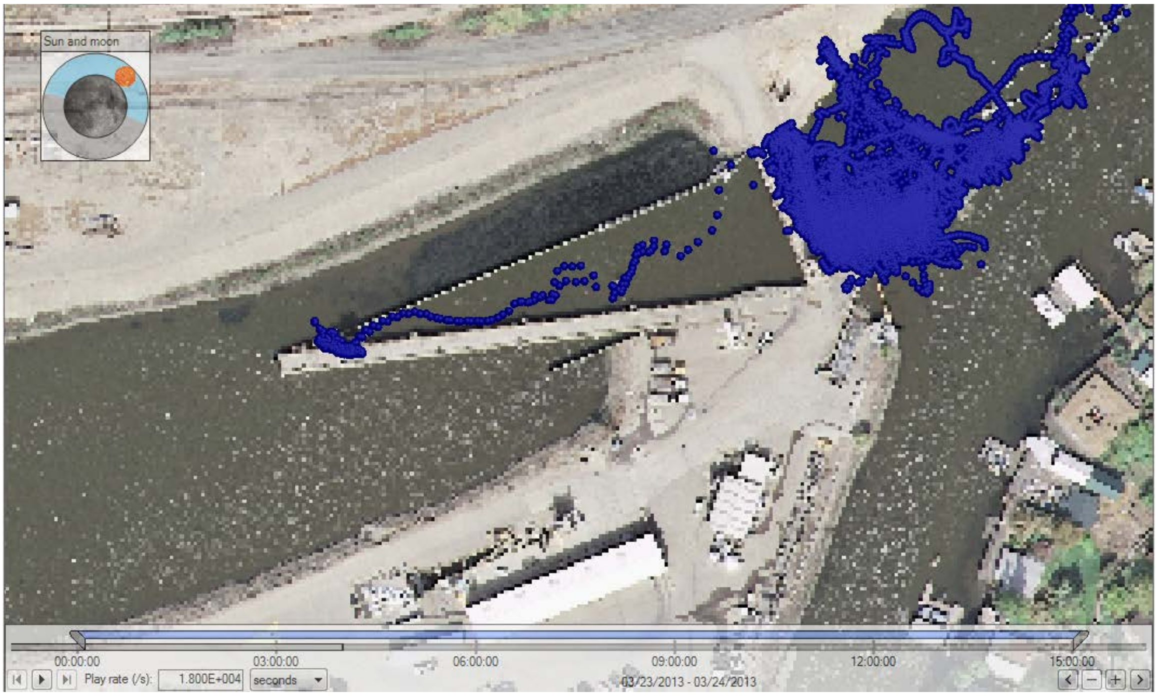

Figure C-2. Track of Chinook salmon 2315 (released at low flow, total time in system was 13.7 h: 10 min in the upstream channel, over 13 h along the upstream side of the trash rack, about 10 min in the primary channel, and 44 min in the bypass pipes/ secondary channel).

Figure C-3. Track of Chinook salmon 3239 (released at low flow, total time in system was 12 min: spent about 4 min in the upstream channel, < 1 min along upstream side of trash rack, 6 min in the primary channel, and 2 min in the bypass pipes/secondary channel).

Figure C-4. Track of Chinook salmon 3603 (released at low flow, total time in system was about 52 min, mostly in upstream channel).

Figure C-5. Track of Chinook salmon 2119 (released at intermediate flow, total time in system was about 7 min: spent about 2.5 min in the upstream channel, < 1 min along the upstream side of the trash rack, 1 min in the primary channel and 3 min moving through the bypass pipes/secondary channel).

Figure C-6. Track of Chinook salmon 2623 (released at intermediate flow, total time in system was about 31 min: spent 2 min moving toward the trash rack, about 23 min moving along upstream side of the trash rack, 3 min in the primary channel, and 3 min moving through the bypass pipes/secondary channel).

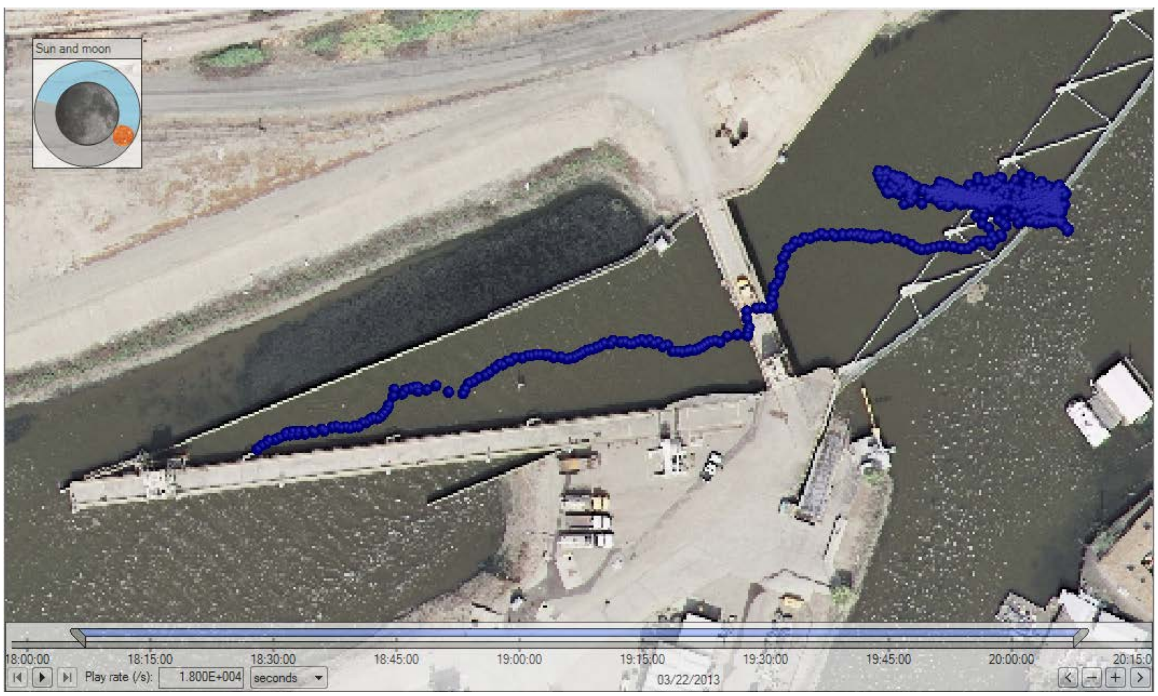

Figure C-7. Track of Chinook salmon 2735 (released at intermediate flow, total time in system was about 7 min: 2 min in the upstream channel, < 1 min along upstream side of the trash rack, 3 min in the primary channel, and 2 min in the bypass pipes/secondary channel).

Figure C-8. Track of Chinook salmon 3015 (released at intermediate flow, total time in system was about 16 min: 3 min in the upstream channel, < 1 min along upstream side of the trash rack, 10 min in the primary channel, and 3 min in the bypass pipes/secondary channel).

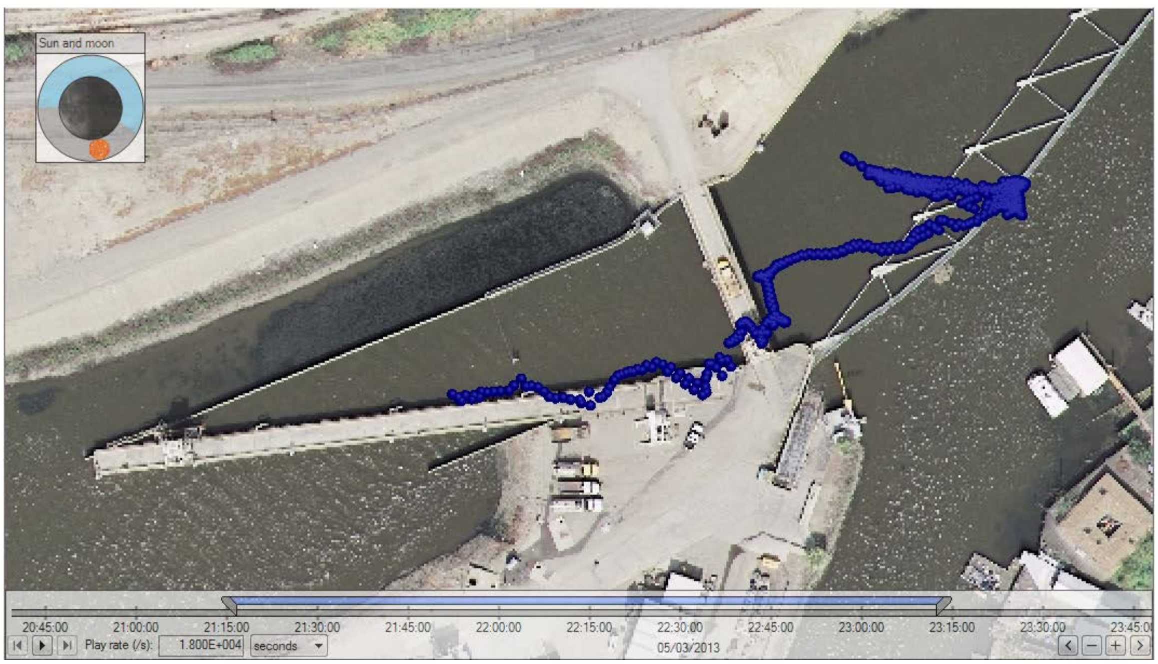

Figure C-9. Track of Chinook salmon 3631 (released at intermediate flow, total time in system was about 11 min: 4 min in the upstream channel, 2 min along the trash rack, 3 min in the primary channel, and 2.5 min moving through the bypass pipes and secondary channel).

Figure C-10. Track of Chinook salmon 3855 (released at intermediate flow, total time in system was about 8 min: 2 min in the upstream channel, < 1 min along upstream side of the trash rack, 3 min in the primary channel, and 3 min in the bypass pipes and secondary channel).

Figure C-11. Track of Chinook salmon 3883 (released at intermediate flow, total time in system was about 18 min: about 9 min in upstream channel, 2.4 min along the trash rack, 3.3 min in the primary channel, and 3.5 min moving through the bypass pipes and secondary channel).

Figure C-12. Track of Chinook salmon 3939 (released at intermediate flow, total time in system was about 29 min: 3 min in the upstream channel, 3 min along the trash rack, 4 min in the primary channel, and 19 min in the bypass pipes/secondary channel).

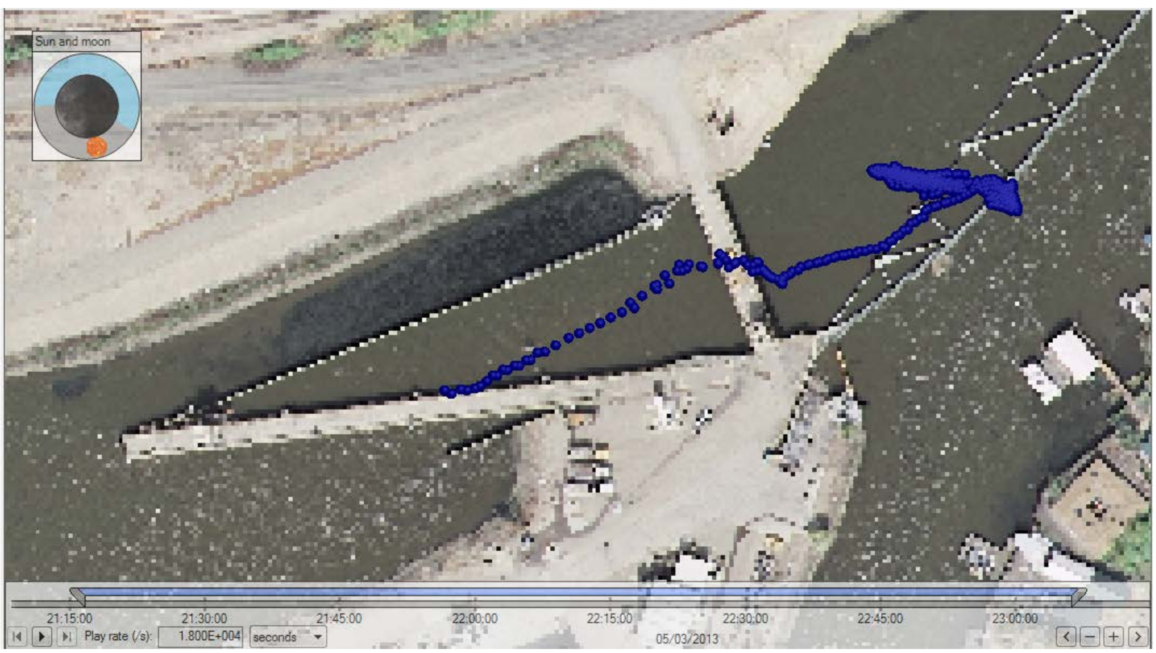

Figure C-13. Track of Chinook salmon 3967 (released at intermediate flow, total time in system was about 8 min: 4 min in the upstream channel, 1.7 min in the primary channel, and 2.8 min in the bypass pipes/secondary channel).

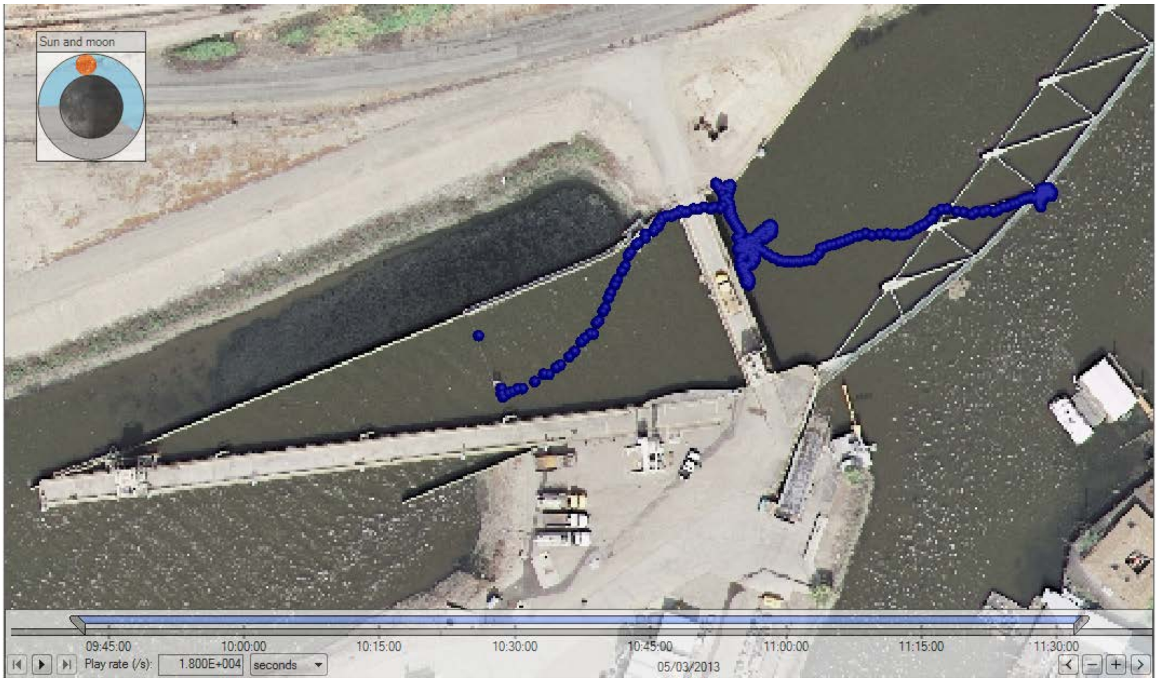

Figure C-14. Track of Chinook salmon 4247 (released at intermediate flow, total time in system was about 28 min: 3 min in the upstream channel, 21 min along the upstream side of the trash rack, 2 min in the primary channel, and 2 min moving through the bypass pipes/secondary channel).

Figure C-15. Track of Chinook salmon 2007 (released at high flow, total time in system was about 41 min: 2 min in upstream channel and along the trash rack, 2 min in the primary channel, and 36 min in the bypass pipes/secondary channel before moving into a holding tank).

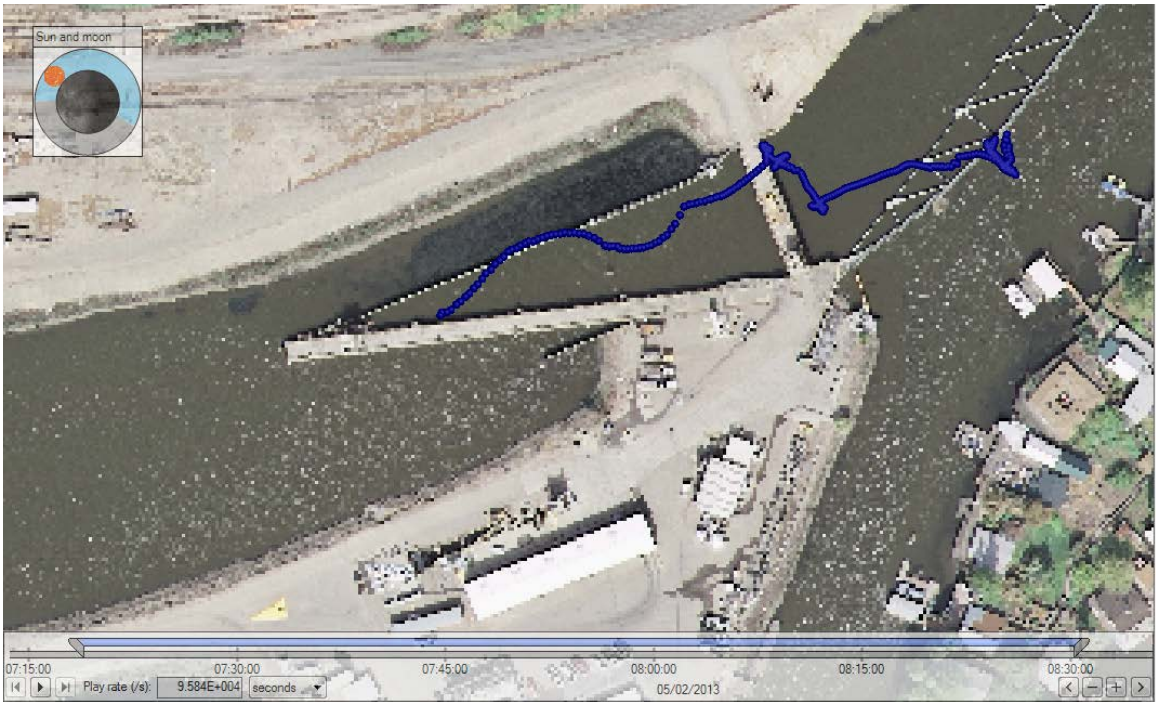

Figure C-16. Track of Chinook salmon 2063 (released at high flow, total time in system was about 25 min: 15 min in the upstream channel, 7 min along the trash rack, 3 min through the primary channel/bypass pipes/secondary channel into the holding tank).

Figure C-17. Track of Chinook salmon 2231 (released at high flow, total time in system was about 9 min: 3 min in the upstream channel, 3 min along the trash rack, and 3 min through the primary channel/bypass pipes/secondary channel into the holding tank).

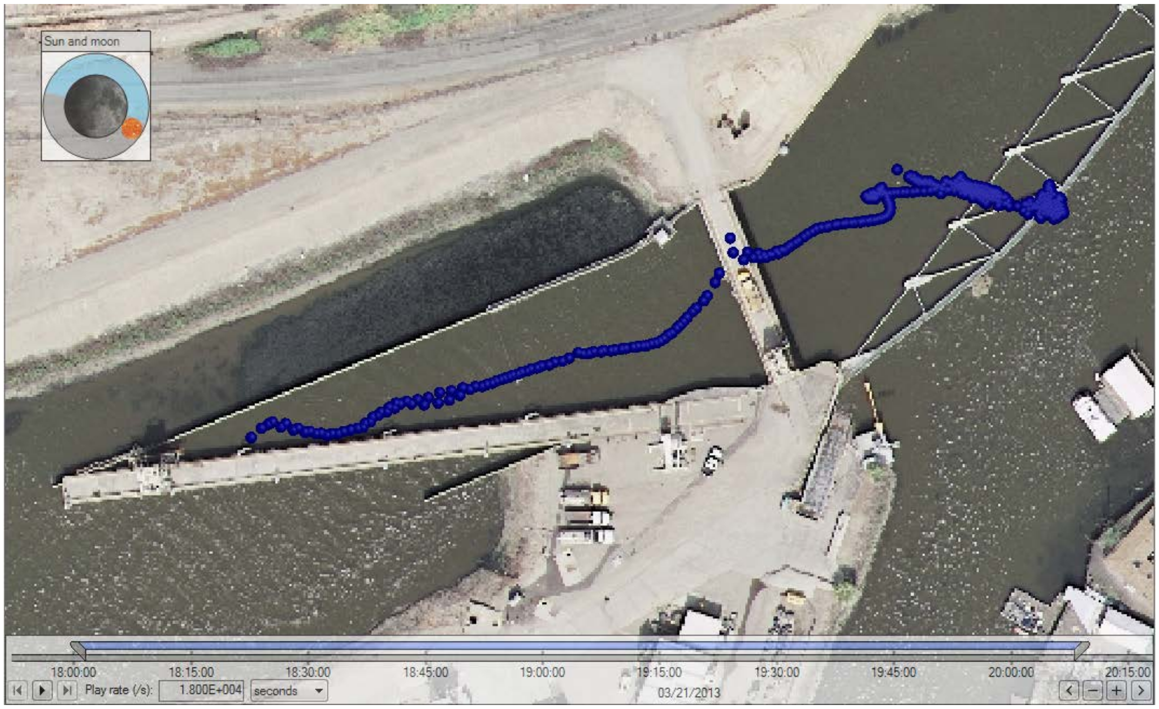

Figure C-18. Track of Chinook salmon 2343 (released at high flow, total time in system was about 13 min: 6 min in the upstream channel, < 1 min along upstream side of trash rack, 2 min in the primary channel, and 5 min moving through the bypass pipes/secondary channel into the holding tank).

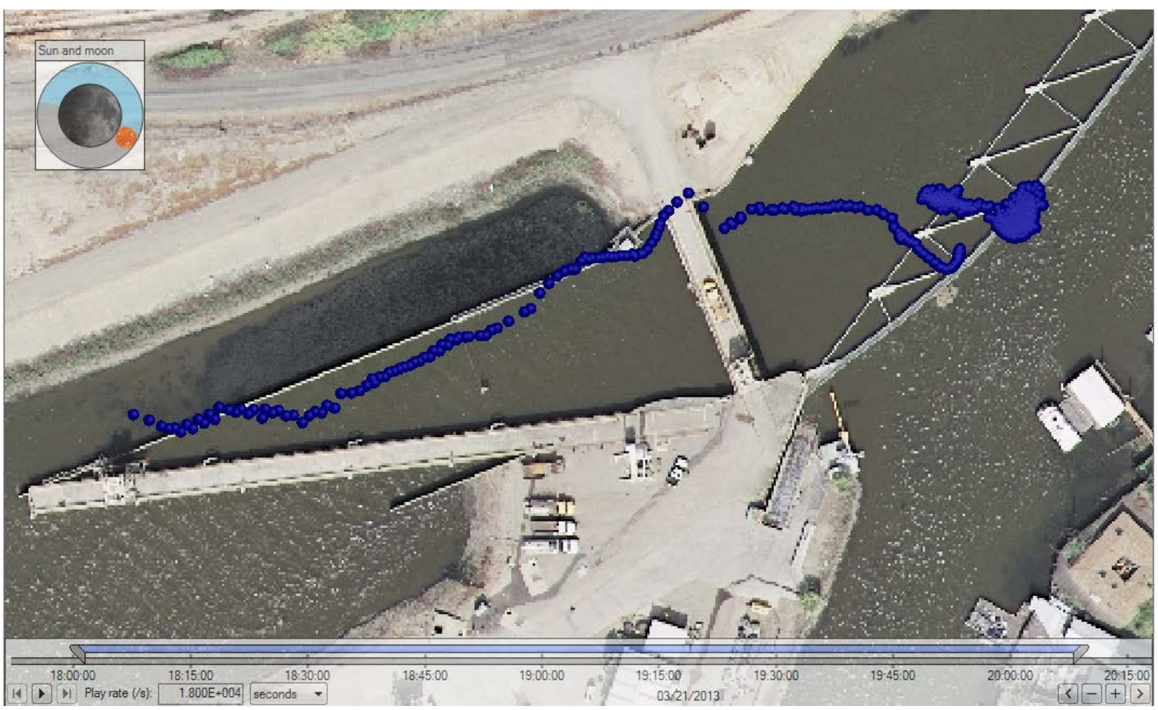

Figure C-19. Track of Chinook salmon 2539 (released at high flow, total time in system was about 12 min: 5 min in the upstream channel, 2 min along the trash rack, 2 min in the primary channel and 3 min through the bypass pipes/secondary channel to the holding tank).

Figure C-20. Track of Chinook salmon 2847 (released at high flow, total time in system was about 12 min: 5 min in the upstream channel, 2 min along the trash rack, 3 min in the primary channel and 2 min through the bypass pipes/secondary channel to the holding tank).

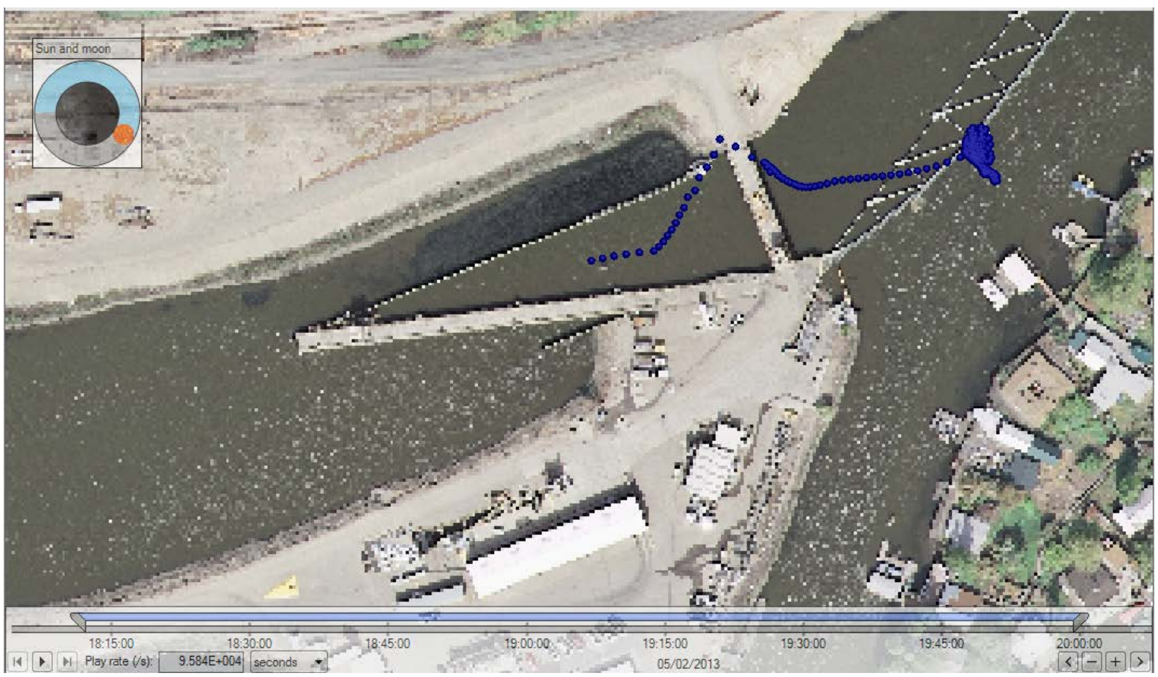

Figure C-21. Track of Chinook salmon 3071 (released at high flow, total time in system was about 7 min, mostly in the bypass pipes and secondary channel).

Figure C-22. Track of Chinook salmon 3211 (released at high flow, total time in system was about 40 min: 11 min in the upstream channel, 1 min along the trash rack, 2 min through the primary channel, and 26 min in the bypass pipes/secondary channel).

Figure C-23. Track of Chinook salmon 3267 (released at high flow, total time in system was about 29 min: 3 min in the upstream channel, 1 min along the trash rack, 1 min through the primary channel, and 25 min in the bypass pipes/secondary channel).

Figure C-24. Track of Chinook salmon 3295 (released at high flow, total time in system was about 20 min: 2 min in the upstream channel, 1 min along the trash rack, 13 min in the primary channel and 4 min in the bypass pipes/secondary channel).

Figure C-25. Track of Chinook salmon 3323 (released at high flow, total time in system was about 7 min: 2 min in the upstream channel, < 1 min along upstream side of trash rack, 2 min through the primary channel, and 2 min in the bypass pipes/secondary channel).

Figure C-26. Track of Chinook salmon 3379 (released at high flow, total time in system was about 10 min: 2 min in the upstream channel, 2 min along the trash rack, 1 min in the primary channel, and 5 min in the bypass pipes/secondary channel).

Figure C-27. Track of steelhead 2203 (released at low flow, total time in system was about 9 h: 17 min in the upstream channel, over 8 h in front of the trash rack, 11 min in the primary channel and 3 min in the bypass pipes/secondary channel).

Figure C-28. Track of steelhead 3127 (released at intermediate flow, total time in system was about 2.5 h: mostly along the upstream side of the trash rack).

Figure C-29. Track of steelhead 3883 (released at intermediate flow, total time in system was 20 min: 3 min in the upstream channel, 10 min along the trash rack, 3 min in the primary channel, and 4 min in the bypass pipes/secondary channel).

Figure C-30. Track of steelhead 2063 (released at high flow, total time in system was over 24 h: just over 1 h in the upstream channel, over 7 h in the primary channel and about 16 h in the bypass pipes/secondary channel).

Figure C-31. Track of steelhead 3407 (released at high flow, total time in system was about 2.5 h: 3 min in the upstream channel, 1 min along the trash rack, over 1 h in the primary channel, and almost 1 h in the bypass pipes/secondary channel).

Figure C-32. Track of steelhead 3211 (released at high flow, total time in system was over 11 h: 4 min in the upstream channel, 1.5 min along the trash rack, 3 min through the primary channel, and over 11 h in the bypass pipes/secondary channel).

Figure C-33. Track of steelhead 3827 (released at high flow, total time in system was about 11 h: 5 min in the upstream channel, 45 min along the trash rack, 25 min in the primary channel, and over 9 h in the primary channel bypasses/secondary channel).

Figure C-34. Track of steelhead 2455 (released at high flow, total time in system was about 2 h: 2 min in the upstream channel, 2 min along the trash rack, 1 min in the primary channel, and almost 2 h in the bypass pipes/secondary channel).

Figure C-35. Track of steelhead 2763 (released at high flow, total time in system was 0.6 h: 2 min in the upstream channel, 3 min along the trash rack, 2 min in the primary channel, and 28 min in the bypass pipes/secondary channel).

Appendix D. Summary of Travel Time for a Theoretical Particle and Salvaged Fish from the Trash Boom to Holding Tanks

Table D-1. Summary of travel time for a theoretical particle and salvaged fish from the trash boom to holding tanks, Tracy Fish Collection Facility, Byron, California.

Species	Tag Code	Jones Pumping Plant Pumps in Operation	Time theoretical particle moved from trash boom to holding tank (h)[1]	Time tagged fish moved from trash boom to holding tank (h)
Chinook salmon[2]	2847	5	0.1	0.2
	3323	5	0.1	0.1
	2343	5	0.1	0.2
	2539	5	0.1	0.2
	2007	5	0.1	0.7
	3295	5	0.1	0.3
	2063	5	0.1	0.4
	3211	5	0.1	0.7
	3071	5	0.1	0.1
	3267	5	0.1	0.5
	3379	5	0.1	0.2
	2231	5	0.1	0.2
	3855	3	0.1	0.1
	3015	3	0.1	0.3
	2735	3	0.1	0.2
	3883	3	0.1	0.3
	2119	3	0.1	0.1
	4247	3	0.1	0.5
	3939	3	0.2	0.5
	3631	3	0.1	0.2
	3967	3	0.1	0.1
	2623	3	0.2	0.5
	2315	1	0.3	13.7
	2091	1	0.2	10.3
	3603	1	0.3	0.9
	3239	1	0.3	0.2
Steelhead	2063	5	0.1	24.5
	3407	5	0.1	2.5
	3211	5	0.1	11.6
	3827	5	0.1	10.9
	2455	5	0.1	2.2
	2763	5	0.1	0.6
	3127	3	0.1	2.6
	3883	3	0.2	0.3
	2203	1	0.3	9.3

[1] Time was determined for a water molecule to move from the trash boom to the holding tank using water velocities, bypass and holding tank used by the associated fish.
[2] Times were not determined for 2 Chinook salmon whose acoustic tags had died after release.

Appendix E. Tracks of 3 Striped Bass Released into the Channel Upstream of the Trash Rack

Figure E-1. Tracks of 3 striped bass released into the channel upstream of the trash rack, upper fish released at low flow, middle fish released at intermediate flow, and lower fish released at high flow (all released just after 1600 h in May 2-4 and track shows movement until 0700 the following day).

Appendix F. Tracks of 2 Presumed Steelhead Assigned to Unknown Fate Category

Figure F-1. Upper: track of steelhead tag 2819 (released at low flow, salvaged almost 32 h after release) and lower: track of steelhead tag 2231 (released at intermediate flow, salvaged about 34 h after release); tracks believed to be steelhead based on passage through the primary channel but could not confirm as steelhead in the salvage (and thus, assigned to unknown fate category).

Appendix G. Tracks of 3 Presumed Consumed Chinook Salmon in the Channel Upstream of the Trash Rack

Figure G-1. Tracks of 3 presumed consumed Chinook salmon in the channel upstream of the trash rack showing a range of behavior by presumed predators.

Appendix H. Photograph of Trash Rack with 2 Panels Removed in Spring 2010

Figure H-1. Photograph of trash rack with 2 panels removed in spring 2010 (arrows indicate removed panels).

Appendix I. Numbers of Chinook Salmon, Steelhead, and Striped Bass Salvaged per Acre-Foot Water Exported

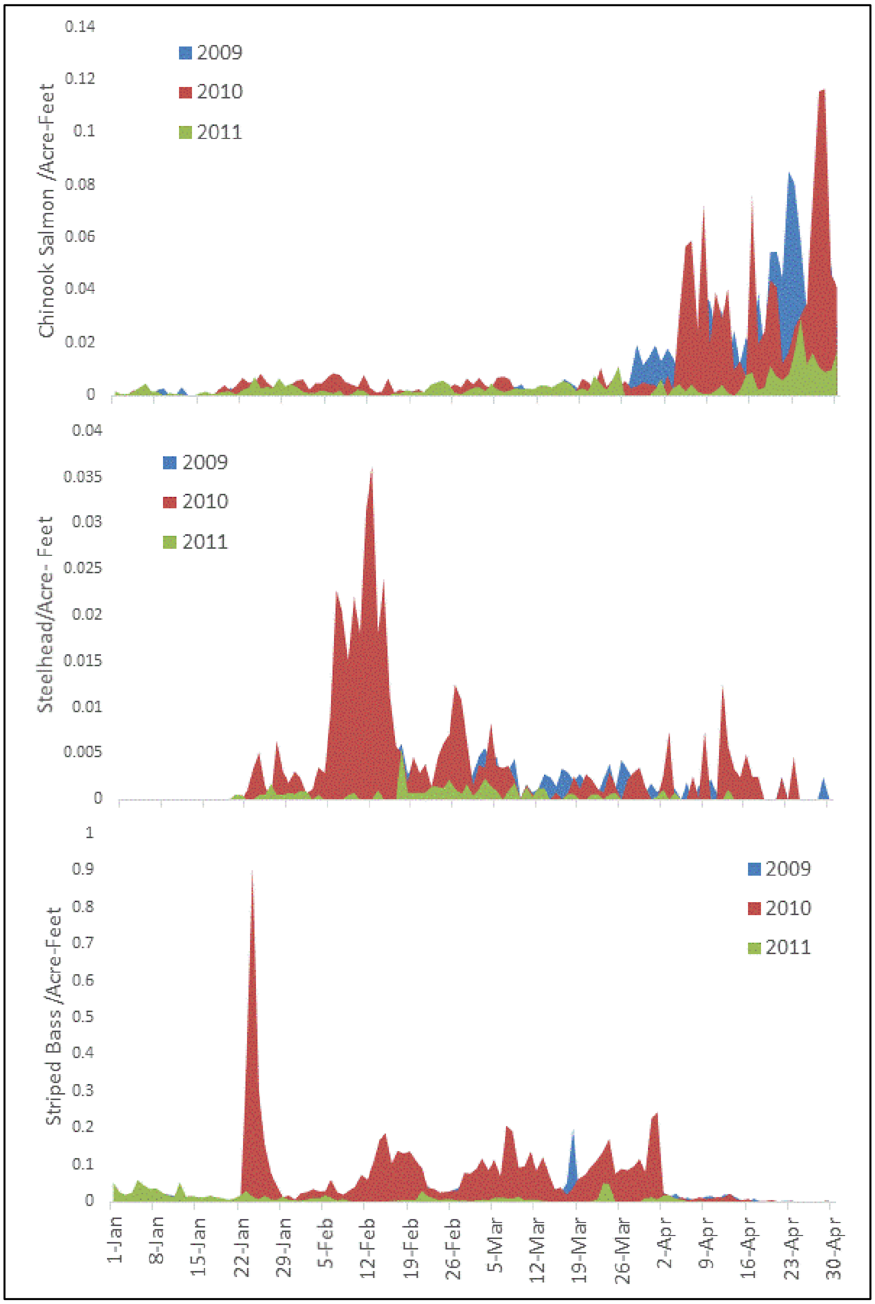

Figure I-1. Upper-middle, lower-middle, and lower figures: numbers of Chinook salmon, steelhead, and striped bass salvaged per acre-foot water exported, Tracy Fish Collection Facility, January 1 – April 30, 2009–2011.