

RECLAMATION

Managing Water in the West

Tracy Technical Bulletin 2019-2

Exploring Methods to Measure Fish Predation at Sacramento-San Joaquin Delta Release Sites



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Exploring Methods to Measure Fish Predation at Sacramento- San Joaquin Delta Release Sites

by

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Executive Summary

Operations at the Bureau of Reclamation's Tracy Fish Collection Facility and the California Department of Water Resources' John E. Skinner Delta Fish Protective Facility remove fish from water destined for federal and state water export pumping plants. Entrained fishes, including federally protected species, are collected (salvaged) and contained in holding tanks, then trucked daily to fixed release sites approximately 30 km north of the salvage facilities near the confluence of the Sacramento and San Joaquin Rivers. Salvaged fishes released in the Sacramento-San Joaquin River Delta (Delta) may experience high mortality because of predation by piscivorous fish and birds at or near the fixed release sites (NMFS 2009, Miranda et al. 2010). The goal of this project was to determine a methodology to measure changes in release site predation, and to collect pilot-level data to determine if cessation of fish releases for extended periods of time warrants further evaluation as an appropriate strategy to reduce release site predation.

In searching for a suitable tool for measuring release site predation, this study evaluated various acoustic tag technologies, including the use of traditional and predation detection acoustic transmitters. We held laboratory experiments to examine the trigger time of VEMCO V5 (Amirix Systems Inc., Bedford, Nova Scotia, Canada) predation detection acoustic tags (V5D) under a variety of temperature, meal size, and body placement scenarios. V5D transmitters emit a different coded signal after extended time in the low pH gut environment of a predator. VEMCO V5D tags were also used at the Curtis Landing Release Site to examine prey fish movement and fate in the Delta post-release, and to examine V5D trigger time in a natural setting using a Predation Event Recorder (PER).

In addition to field and laboratory testing of acoustic transmitters, computer simulations were run to examine the number of acoustic tags necessary to reduce our margin of error to acceptable levels in a mass-release acoustic tag survival study but found that such a study would require a large effort to provide even the modest level of confidence. Through field, lab, and modelling efforts we concluded that neither V5D nor traditional acoustic tags are good candidates for large-scale studies of release site predation, as these transmitters have highly variable trigger times (~3–60 hours) and are unable to measure predation in the near-field Delta area where piscivores are potentially highly mobile.

Predator movement around the Curtis Landing Release Site (CLRS) was monitored using acoustic tags and a receiver array. CLRS is one of four state and federal fish release sites in the Delta and was used to represent predator movement at all release sites because it is set up to allow access by both federal and state release trucks to release experimental fish. Though many tagged predators left the study area and were non-participants in our study, two tagged predators indicated that a modified salvage fish release scheme where a release cessation for 5+ days could reduce the willingness of certain predators to reside near the release pipe area. Since a modified release scheme is the most easily attainable solution to remedy release site predation, we suggest that further studies should elucidate the effects of a release cessation treatment on predation loss of salvaged fishes in the Delta. We recommend future studies examine predation directly using tools such as tethered prey monitoring to compare predation before and after a modified release scheme.

Introduction

The Bureau of Reclamation's (Reclamation) Tracy Fish Collection Facility (TFCF) and the California Department of Water Resources' (CDWR) John E. Skinner Delta Fish Protective Facility (SDFPF) remove fish from water destined for both state and federal water pumping plants. Both facilities are in the southern region of the Sacramento-San Joaquin River Delta (Delta). Salvaged fishes, included federally protected species, are removed (salvaged) upstream of the pumping plants, contained in holding tanks, and trucked daily to fixed release sites approximately 30 km north of the salvage facilities near the confluence of the Sacramento and San Joaquin Rivers (Figure 1). Salvaged fishes released in the Delta may experience high mortality because of predation by piscivorous fish and birds at or near the fixed release sites (Miranda et al. 2010). The goal of this project is to design a methodology to measure a predation rate reduction resulting from changes in the way fish are released at the fixed sites in the Delta (i.e., treatment effects).

The TFCF and SDFPF salvage millions of fish annually, including native, non-native, and federally protected fish species, all of which are released at four fixed release sites throughout the year (Figure 1). From 2003 to 2017, TFCF average annual salvage of Chinook Salmon, including those that are federally protected (winter and spring runs; Federal Register 70(123):37160-37204 June 28, 2005) was 12,017 fish (range: 106.5 fish in 2015 to 35,294.9 fish in 2006; Figure 2). The National Marine Fisheries Service's (NMFS) 2009 Biological Opinion (BO) determined the long-term state and federal fish salvage operations may be adversely affecting endangered winter-run and threatened Central Valley spring-run Chinook Salmon (NMFS 2009).

Quantifying release site predation rate is a driving research question for both state and federal operations. Survival of salvaged fish at Delta release sites is likely dependent on seasonal fish assemblages, diurnal behavioral, frequency of site-specific releases (e.g., number of releases per day), tides, river discharge, and total abundance of fish in each release. Miranda et al. 2010 conducted a release site predation study in 2007 – 2008, which concluded predation of salvaged fish does occur at state and federal release sites, and piscivorous fishes tend to remain near the release sites when the number of fish being released is consistently high. The study determined predation during releases could have a substantial effect on salvaged fish survival. However, they did not estimate rate of predation, a metric highly sought after by regulatory (NMFS) and operating agencies (Reclamation and CDWR).

Salvaged fishes are released from underwater pipes at the release sites. These end-of-pipe areas are deep, high-flow, and seasonally turbid. They also release fish into a large open water system, which makes many fisheries monitoring techniques (e.g., netting, biotelemetry) ill-equipped to provide accurate assessments of salvaged fish predation rates at a reasonable cost and effort. Concurrently, there have been few attempts to accurately describe the size of the predation area outside of release pipes. NMFS (2009) included a list of Reasonable and Prudent Alternatives (RPAs) regarding fish salvage operations, including a requirement to achieve an "end-of-pipe" predation rate reduction of 50%. To address this RPA, an interagency working group convened to design a study of release site predation to estimate release site predation loss (Appendix 1). Using the guidance provided by the interagency working group, we performed pilot-level

research to examine the applicability of various technologies to release site studies. This report includes results of two laboratory-based studies and a field experiment examining the utility of a novel fish predation transmitter, a field study monitoring predator behavior around the Delta release sites, and results from a computer modelling effort to better understand the funding and effort necessary to perform a survival study using traditional acoustic transmitters (Appendix 1).

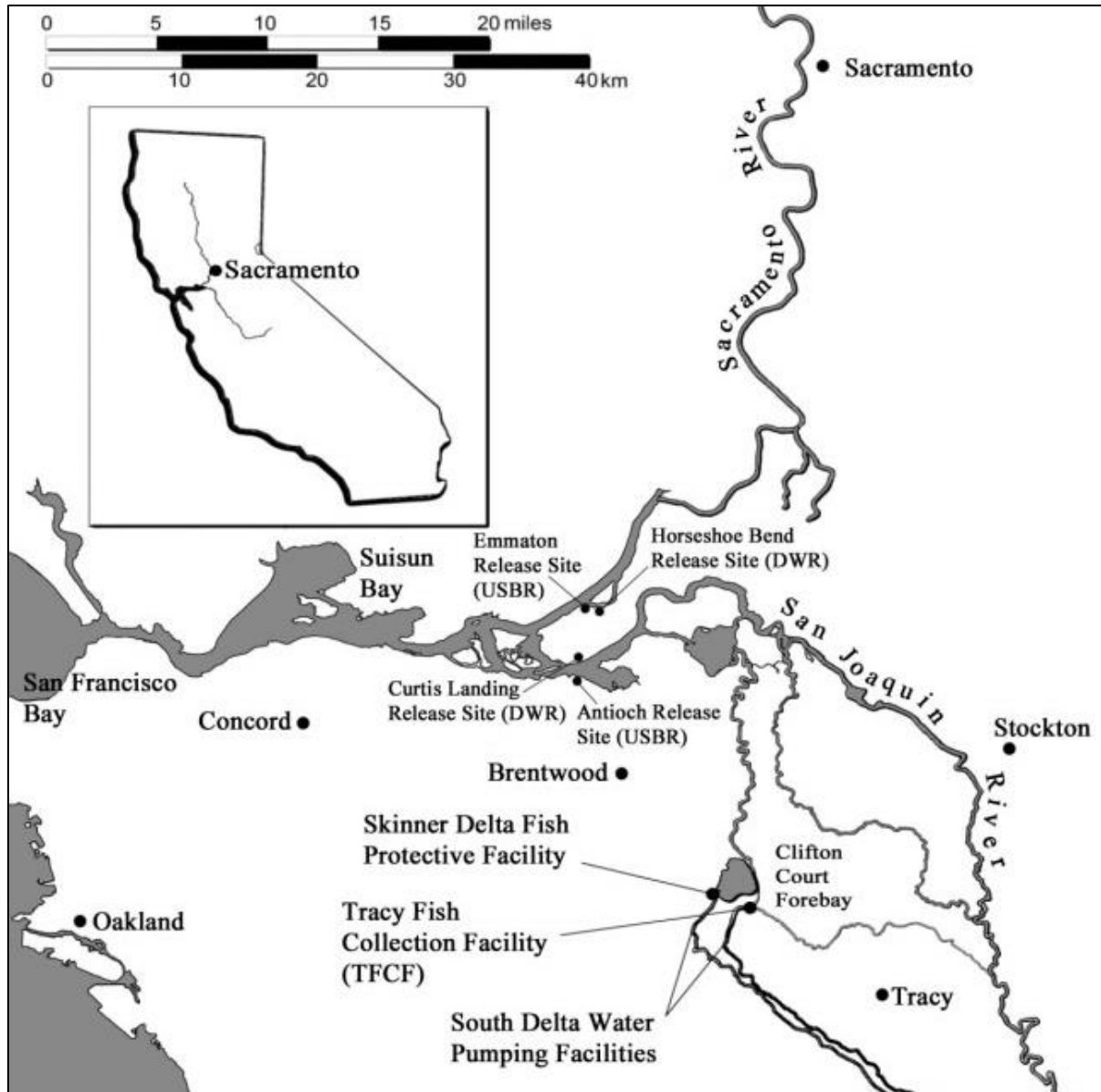


Figure 1.—Map of the Sacramento-San Joaquin Delta showing the location of the state and federal pumping facilities, fish salvage facilities, and fixed release sites located near the confluence of the Sacramento River and San Joaquin Rivers. Figure is from *Karp and Bridges (2016)*.

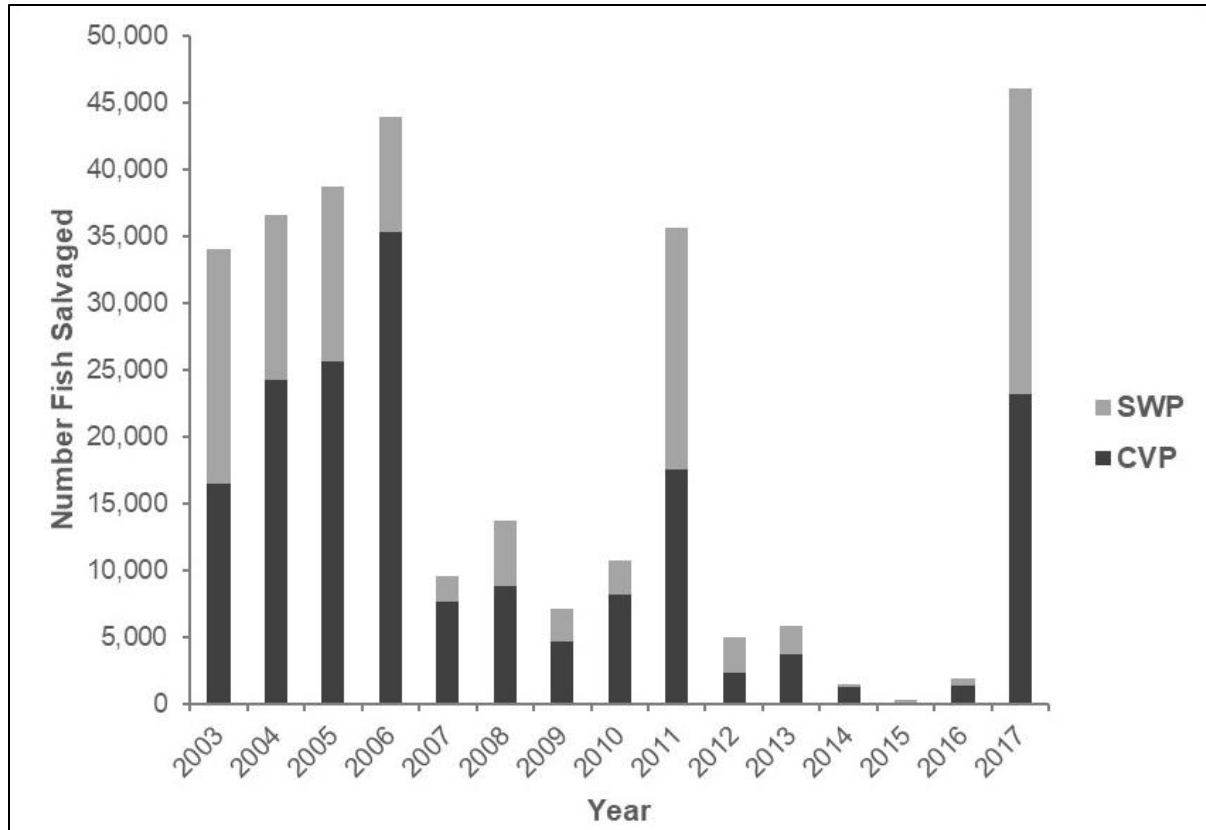


Figure 2.—Graph of total Chinook Salmon (*Oncorhynchus tshawytscha*; all runs and origins combined) salvage per year from 2003 to 2017, showing proportions of fish salvaged at the Tracy Fish Collection Facility (Central Valley Project; CVP) and John E. Skinner Delta Fish Protective Facility (State Water Project; SWP) in the Sacramento San Joaquin River Delta.

Methods

Internal Predation Detection Acoustic Tag Study

Acoustic Transmitters

The field of biotelemetry has been advancing at a rapid pace in recent years (Adams et al. 2012; Crossin et al. 2017). Among other things, acoustic telemetry systems now enable monitoring of fish movement, physiology, behavior, and predation status (Halfyard et al. 2017). The interagency working group identified the emerging use of predation-detection acoustic tags as a research tool that could be applicable to end-of-pipe, or near-field, predation studies. Predation detection acoustic tags became commercially available around the commencement of this project, however there was very limited research to provide insight into their efficacy for our intended use (near-field, short duration predation study). Through discussion with industry experts and a literature review, our interagency working group considered the use of three acoustic telemetry transmitters capable of sensing predation: (1) VEMCO Ltd. (Amirix Systems Inc., Bedford, Nova Scotia, Canada) V5 Predation Transmitters (V5D), (2) HTI-VEMCO USA (Amirix Systems Inc., Bedford, Nova Scotia, Canada) predation-detection acoustic (PDAT) transmitters, and (3) ATS (Advanced Telemetry Systems, Inc., Isanti, MN, USA) accelerometer-enabled SS400 acoustic transmitters (Table 1). We also considered the status of software and algorithms for filtering predation events from the behavior of traditional transmitters.

Table 1.—List of acoustic transmitters considered for release site predation monitoring. Model and manufacturer are listed, along with mechanism used to detect a predation event. Trigger lag is the time between predation event and tag detection of the predation event.

Manufacturer	Model	Predation-Detection Mechanism	Advertise Trigger Lag
VEMCO	V5D	Biopolymer	3-5 hr
HTI-VEMCO	PDAT	Biopolymer	60 hr
ATS	SS400	Accelerometer	Unknown

Our group deemed VEMCO transmitters to be the best option because the advertised 3–5 hour predation trigger time is the shortest currently available, and they do not require time-consuming and expensive data post-processing. In March 2017, 16 VEMCO 180 kHz V5D (25 – 35 second tag delay; Figure 3) were procured for prototype testing. VEMCO V5D transmitters provide 143 dB acoustic power output while weighing 0.68 g in air and are 12.7 mm long by 5.6 mm wide. Tag ID code switches one digit (e.g., code 504202 would change to 504203) after the biopolymer is digested in the low pH stomach environment.

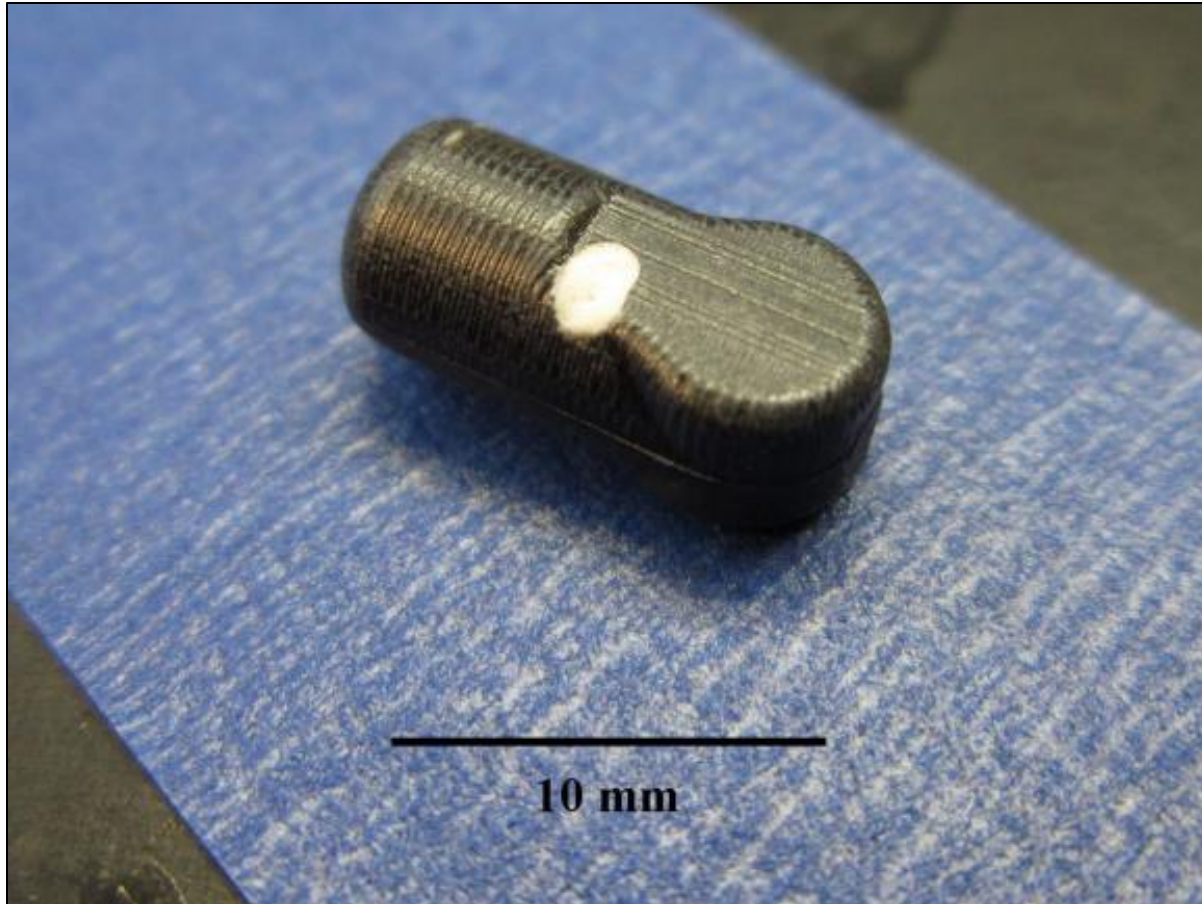


Figure 3.—VEMCO V5D Predation Transmitter tag. The digestible biopolymer (white pigment) is designed to dissolve in the stomach of a predator. The tag transmits a 143 dB signal at 180 kHz, weighs 0.68 g in air, and has dimensions of 12.7 x 4.3 x 5.6 mm. Picture from Halfyard et al. 2017.

Fish Source and Care

The internal tagging experiment was performed at the Reclamation Technical Service Center Fisheries Laboratory in Denver, Colorado (Denver Lab) in March and April 2017. Juvenile Rainbow Trout (*Oncorhynchus mykiss*) were used as prey fish, and Striped Bass (*Morone saxatilis*) were used as experimental predators. Rainbow trout were procured from the Colorado Bellvue-Watson State Fish Hatchery (Bellvue, Colorado), and Striped Bass were obtained from the TFCF and maintained on a pellet fish food diet in the Denver Lab since 2014.

Prior to the experiment, Rainbow Trout were held in a 950-L fiberglass tank and fed *ad libitum* with commercial fish food. Individual Rainbow Trout were euthanized in 100 mg/L of buffered tricaine methanesulfonate (MS-222) following the methods of Coyle et al. (2004), and surgically implanted with V5D transmitters (Brown et al. 2010, Liedtke et al. 2012). Since decomposition of gut contents is unlikely to differ between live or recently euthanized prey fish, we opted to use euthanized prey fish to ease in the force-feeding procedures. Transmitters were placed in the body cavity of the Rainbow Trout and secured with two sutures (Figure 4).



Figure 4.—Rainbow trout (*Oncorhynchus mykiss*) recently euthanized in MS-222 receiving a VEMCO V5D transmitter implantation. Transmitters were implanted following procedures of Brown et al. (2010). Two sutures were used to secure the tags internally. Fish were rinsed in fresh water and immediately fed to Striped Bass (*Morone saxatilis*) after tag implantation.

Feeding Experiments

Fourteen days prior to experimentation, Striped Bass were switched from pellet feed to live Rainbow Trout (mean FL 136 mm \pm 13 SD) to develop aggressive feeding behaviors and mimic wild predator gut conditions (gut flora, pH, etc.). Since most Striped Bass did not show aggressive behavior towards prey fish and would take them opportunistically rather than immediately after introduction, stomach injections of prey were used to ensure consistent meal size and accurate predation times (Ince and Thorpe 1976, Liedtke et al. 2012).

Striped Bass were mildly anaesthetized (~3-minute immersion in 150 mg/L buffered MS-222 or CO₂ sedation; Coyle et al. 2004) and prey fish were manually inserted into stomachs using a beveled 38 mm (1.5”) outer diameter schedule 40 PVC tube (Kapusinski et al. 2012) and a wooden dowel plunger to push fish through the tube into the stomach. To evaluate effects of gut fullness on trigger time, either 1 or 4 Rainbow Trout (mean mass = 32.2 g \pm 2.5 SD) were fed to each predator, 1 being low meal size and 4 being large meal size. For single fish feedings, the single fish contained the transmitter. For 4 prey feedings, the first of four fish fed contained the transmitter to reduce the risk of the transmitter-implanted fish being regurgitated (the assumption being that the last fish fed would be the first fish regurgitated). For large meal size category, all four fish were stacked in the PVC tube with the head facing towards the predator gut.

After feeding, Striped Bass were immediately returned to and maintained individually in 950-L fiberglass tanks (Figure 5) where they were closely monitored to ensure normal swimming behavior for 5 minutes and were monitored in 30 minute intervals for ~2 hours to check for regurgitation or abnormal behaviors. Since water temperature is a driver of digestion rate (Legler et al. 2010), four tanks were maintained at 14°C, and four at 21°C (using AquaLogic Titan[®] in-line heat pumps, San Diego, California) to evaluate effects of temperature on trigger time. These temperatures were selected to be representative of minimum and maximum

temperatures encountered during spring out-migration of Chinook Salmon smolts in the Delta. Temperature was recorded daily in each tank using digital thermometers. Each tank was outfitted with a VEMCO VR2W acoustic receiver to monitor tag transmissions. Striped Bass were not fed until tags were triggered.



Figure 5.—Experimental tanks used for the March 2017 laboratory experiment at the Reclamation Technical Service Center Fisheries Laboratory in Denver, Colorado. Foreground holding tanks were used to hold bait fish, the background two rows were used for this experiment. Filters, heat pumps, and water pumps are seen on the right side of the figure.

Data Analysis

Treatments were assigned randomly to each tank (Table 2). Predation experiments followed a two-way analysis of variance (ANOVA) design assessing influence of water temperature (two levels, 14 and 21°C) and meal size (two levels; low [1 fish] and high [4 fish]) on tag trigger time ($\alpha = 0.05$). All analyses were conducted using the `lm()` function in program R version 3.5.0 (The R Foundation for Statistical Computing, Vienna, Austria) and Minitab 15 Statistical Software (Minitab Inc., State College, Pennsylvania). Trigger time was log transformed to achieve normality (Anderson-Darling test for normality on residuals, $p = 0.2$).

Table 2.—Summary of experimental design for feeding experiments for each temperature level and meal category. SB are Striped Bass (*Morone saxatilis*), RT are Rainbow Trout (*Oncorhynchus mykiss*).

SB Mean Total Length (mm \pm SD)	Temperature (°C)	Meal Category	RT Per Meal	Meal Mass (g) Mean \pm SD	Sample Size
738 \pm 26	14	Low	1	34 \pm 2	4
738 \pm 26	14	High	4	101 \pm 13	4
739 \pm 40	21	Low	1	33 \pm 3	4
736 \pm 37	21	High	4	123 \pm 7	3

External Predation Detection Acoustic Tag Study

Acoustic Transmitters

A second lab study using VEMCO V5D transmitters was performed in November 2017 at the Reclamation Tracy Aquaculture Facility (TAF; Byron, CA) to examine differences in VEMCO

V5D transmitter trigger time between internal and external tag attachment methods (Table 3). External acoustic tags have been used in fisheries research (Adams et al. 2012), and specifically with juvenile salmonids (Brown et al. 2013). We hypothesized an external tag would reduce length and variability of trigger times compared to an internal tag because of the reduction in digestion needed to expose the biopolymer to a predator's stomach. Striped Bass were used as predators and juvenile Chinook Salmon as prey.

Fish Source and Care

Striped Bass were collected during predator removal operations and by hook and line collection at the Tracy Fish Collection Facility, held in outdoor tanks for 1 to 3 months, and fed a diet of live and dead fish. Eight Striped Bass were selected relocated individually to 711-liter individual indoor laboratory tanks which were salted to 4.0 ppt and held at 14°C, which is typical of temperatures encountered during salmon out-migration in the spring. Striped bass were acclimated to their individual tanks for one week and feed-restricted 48 h prior to the start of the experiment.

Feeding Experiments

Prey fish were euthanized prior to transmitter application, as described above. Transmitter-enabled prey fish were provided one acoustic tag via surgical implantation as described above, and they also were affixed with a second tag on their caudal peduncle using a single suture with a surgeon's knot (Figure 6). While likely not suitable for field testing, tag placement was not a concern for lab testing as we were not concerned longevity of attachment or effects on swimming performance. Caution was taken to ensure the biopolymer was positioned facing away from the body of the fish, so the body tissue did not block stomach acid from activating the transmitter. Prey fish were inserted into each predator's stomach using the plunger method described above. Transmitter-enabled prey fish were either the first or second fish inserted into the gut, with position alternated between replicates. All replicates were conducted at 14°C, with low (1 fish meal, n = 4) and high (4 fish meal, n = 4) meal categories. A single meal size was chosen to increase power to detect a significant difference between temperature regimes. Each tank was monitored using a VEMCO VR2W hydrophone receiver. Tanks were visually monitored regularly for meal regurgitation and tag defecation. Defecated tags were collected, disabled, and re-tooled by VEMCO for use in later field testing.

Table 3.—Summary of experimental design for internal vs external VEMCO V5d acoustic transmitter trigger time feeding experiments. Striped Bass (SB; *Morone saxatilis*) and Chinook Salmon (CS; *Oncorhynchus mykiss*) were used as predators and prey, respectively. Sample size used for analysis is provided, though target sample size for each treatment was 4 (regurgitation reduced sample sizes). All experiments were performed at 14°C.

SB Mean Total Length (mm ± SD)	Mean Meal Total Mass (g ± SD)	Fish Per Meal	Meal Category	Tag Application	Sample Size
654 ± 74	26 ± 1	1	Low	Internal	3
659 ± 40.1	112 ± 11	4	High	Internal	4
662 ± 88	28 ± 1	1	Low	External	3
659 ± 40.1	112 ± 11	4	High	External	3

Data Analysis

Predation experiments followed a two-way analysis of variance (ANOVA) design assessing influence of meal size (two levels; small [1 fish] and large [4 fish]) and tag location (internal or external) on V5D trigger time. Analyses were conducted using the `lm()` function in program R version 3.5.0 (The R Foundation for Statistical Computing) and Minitab 15 Statistical Software (Minitab Inc.).



Figure 6.—External attachment of a VEMCO V5D transmitter on a juvenile Chinook Salmon (*Oncorhynchus tshawytscha*). Experimental prey received external and internal tags, and trigger time was monitored using a VEMCO VR2W acoustic hydrophone receiver.

Field Assessment of Predation Detection Acoustic Tags

Field research was conducted in May 2017 to further test V5D tag performance by (1) evaluating salvaged fish movement and fate by releasing tagged juvenile Chinook Salmon ($n = 12$) from the Curtis Landing Release Site (CLRS), and (2) evaluate piscivore movements trigger time after consumption of a V5D tagged Chinook Salmon ($n = 4$) using a Predation Event Recorder (PER). CLRS is one of four state and federal fish release sites in the Delta and was used to represent predator movement at all release sites because it is set up to allow access by both federal and state release trucks to release experimental fish and is also the most logistically feasible site for boat-based monitoring.

Salvage Release Predation Detection Acoustic Tag Study

To better understand the fate of juvenile Chinook Salmon moving through the state and federal trucking and release process and observe the function of V5D transmitters after predation, we released three groups of four V5D tagged Chinook Salmon. We used 12 VEMCO V5D transmitters (estimated 35-day battery life, 8 – 12 second delay) for field testing at the CLRS. These tags were reused from the external predation detection acoustic tag study after they were reconfigured by VEMCO to enable another predation detection event.

Tags (weight = 0.68 g in air) were surgically implanted in the abdominal cavity of juvenile Chinook Salmon (mean FL = 121 mm; range: 111 mm to 130 mm) using the methods described in Brown et al. (2010). Newton et al. (2016) found evidence that smolt migration studies can deviate from the 2% rule (Adams et al. 2012) up to 12.7% for Atlantic Salmon (*Salmo salar*), which is well within the range of our tagging study (mean tag burden = 2.7%).

Tags were sterilized in 10% Povidone-Iodine (Equate, Bentonville, Arkansas) for 5 minutes prior to implantation. We used 70 mg/L MS-222, 70 mg/L sodium bicarbonate, and 10 ml of Seachem Prime[®] (Seachem[®], Madison, Georgia) water conditioner for anesthesia. Anesthesia and surgery were performed with UV sterilized well water at 18°C. After surgery, fish were held individually in outdoor tanks containing 18°C well water. Fish were fully acclimated to 100% treated Delta water over a 3-day period. Treatment of Delta water included ozone application and bead/sand filtration. All tags were verified to be on and transmitting after implantation.

The 12 V5D tagged fish were added to fish salvage release trucks leaving the TFCF on 5/15/2017, 5/16/2017, and 5/17/2017. Fish were tracked using stationary receivers (VEMCO VR2W 180kHz) and manual boat-based tracking (VEMCO VR100, 180kHz directional hydrophone). VEMCO receivers detect and store transmissions, and data recovery requires removal from the field and download via Bluetooth connection. During this time, there were two daily salvaged fish deliveries to the CLRS.

Predation Event Recorder Experiment

Four V5D tagged Chinook Salmon (FL = 121, 118, 112, and 124 mm) were attached to a PER (Figure 7) to determine transmitter trigger time after consumption by wild predators. Fish were deployed on the PER one at a time, one deployment on 5/15/2017, two deployments on 5/16/2017, and a final deployment on 5/17/2017. Each trial was performed within 3 hours following fish salvage release.

Chinook Salmon were attached to the PER using a 50 cm length of 8 lb breaking strength monofilament fishing line. Fish were attached to the distal end of the fishing line by tying a loop through the mouth and operculum (hook-less tether; Demetras et al. 2016). A seven-gram split shot lead weight was placed 10 cm above the fish on the monofilament line to keep the prey fish away from the PER and reduce entanglement. The PER was equipped with a predation trigger mechanism which recorded predation time (via reed switch activated timer), and a GoPro camera (GoPro, Inc., San Mateo, CA, USA), recorded video for visual identification of the predator.

The PER was deployed and fished 100 m upstream or downstream of the CLRS, and 0–30 m from shore. Water depth ranged from 1–10 m in the fishing zone. Effective fishing depth for the PER was 0.6 m to 1 m, depending on the position of the prey fish relative to the end of the PER (tethered prey are free-swimming and can move up and down in the water column). The PER was deployed near the release pipe and allowed to float through the release pipe area until (1) entanglement occurred, or (2) a positive predation event occurred. Entanglements in submerged aquatic vegetation, or straying ~150 m upstream or downstream of the release pipe resulted in retrieval and re-deployment. Video (GoPro video camera, 1280x720 resolution at 60 frames per second) was examined in the laboratory after the tethering trials to assess predator identification.

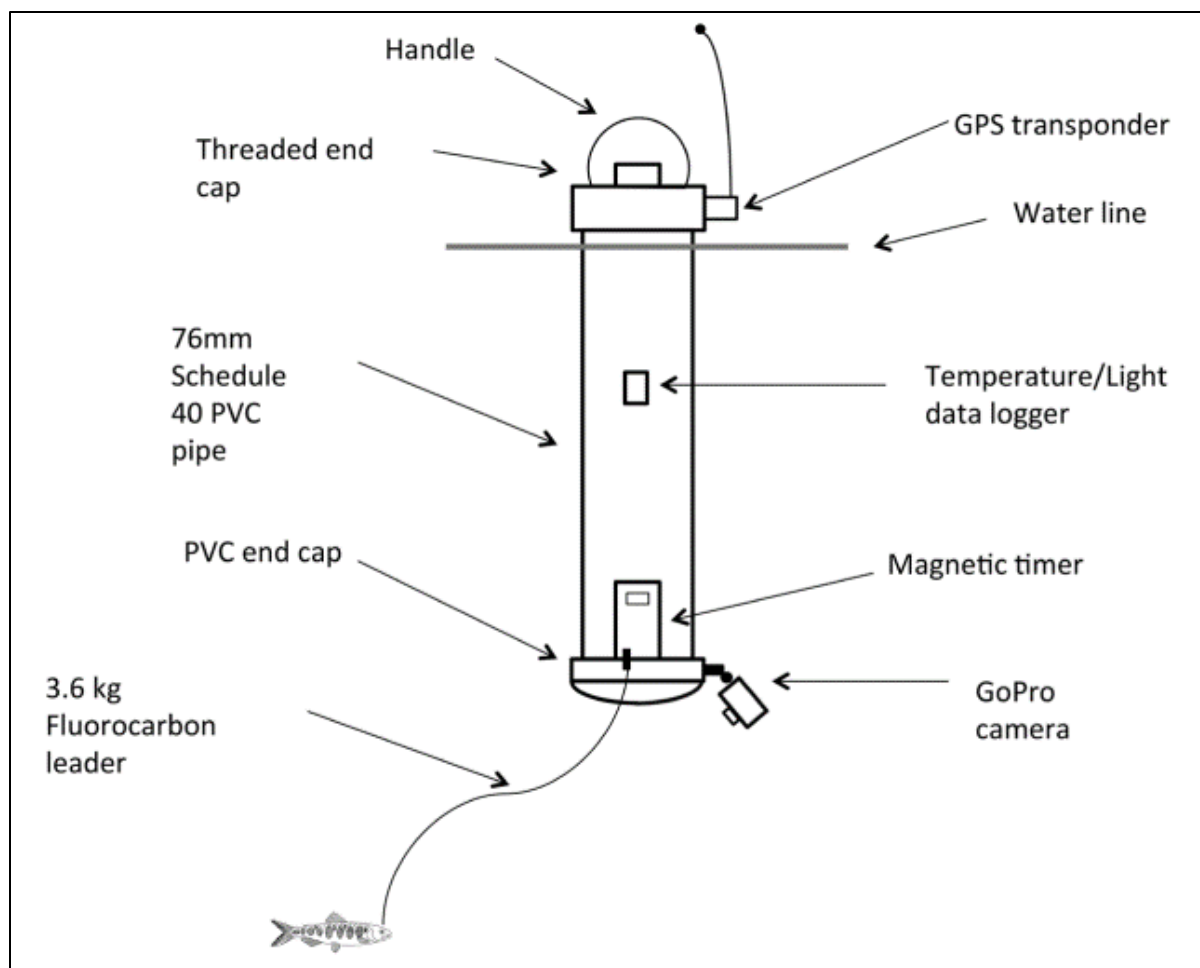


Figure 7.—Schematic of a predation-event recorder (PER) with attached bait. PERs were used to evaluate VEMCO V5D acoustic transmitters at the Curtis Landing Release Site near Sherman Island, California in May 2017.

Predator Monitoring

Predator monitoring occurred during spring 2017 to coincide with the period when wild salmon are most often collected in state and federal salvage (California Department of Fish and Wildlife 2018). Our goal was to better understand movements and residence time of acoustically tagged piscivores captured and released near the CLRS, as these predators may be responsible for predation of listed salmonids and other salvaged fishes at the CLRS and other releases sites (Miranda et al. 2010).

Modified Release Schedule

During monitoring in 2017, salvaged fish releases at CLRS were stopped shortly after predators were tagged with acoustic transmitters. From 4/13/2017 to 4/21/2017 and 5/18/2017 to 5/26/2017, there were no salvage fish releases at CLRS. This release site stoppage was designed to test whether predators dispersed once releases stopped, and if so, what is the effective release

cessation time necessary to affect residence time of predators. This would help inform whether a change to a rotational release schedule where specific release sites are used only periodically could reduce release site salvaged fish predation.

Predator Tagging

Acoustic telemetry data was used to determine if tagged predators remained at the release site (i.e., exhibited site fidelity) or moved away from the release site during periods of no releases. Only predators captured in good condition with no sores, hemorrhages, or badly frayed fins were selected for acoustic tagging.

On 4/10/2017 to 4/12/2017, we captured and tagged 11 Striped Bass with VEMCO V5 (180kHz, 25 – 35 second delay) transmitters (Figure 8). These are the traditional, i.e., non-predation detection transmitters offered by VEMCO. Striped Bass were captured by hook and line using live and artificial baits and were taken within a 50 m radius of the CLRS. Barbs were pinched on baited hooks to reduce the chances of injury or hooking mortality (Boyd et al. 2010) and reduce impacts to release site predator behavior (Adams et al. 2012).

On 5/14/2017, 10 predators (9 Striped Bass, 1 Sacramento Pikeminnow [*Ptychocheilus grandis*]) were captured and tagged within a 50 m radius of the CLRS using hook and line methods previously mentioned. These predators were externally tagged with new VEMCO V13 transmitters (69 kHz, 10–30 second delay; Figure 9) and monitored with a separate receiver array with VEMCO VR2W 69 kHz hydrophones. These transmitters had reliable batteries (183 day estimated tag life), so tags which left the receiver array were interpreted as departures from the study area.

Prior to receiving an externally-mounted transmitter, each fish was held onboard the boat and was measured for length (mm) and weighed to the nearest 0.5 lb. increment using a BogaGrip® Model 130 (Eastaboga Tackle, Eastaboga, Alabama). Both V5 and V13 transmitters were externally attached to predators using a 25 cm (10 in) piece of galvanized steel wire (0.41 mm diameter) affixed to the transmitter using polyolefin heat shrink tubing for V13 transmitters and attached with plastic ties for V5 transmitters. Securing the transmitter to the fish was performed in a similar manner to the method described by Miranda et al. (2010). Hypodermic needles were inserted through the muscle tissue inferior to the dorsal fin, the steel wire affixed to the transmitter was threaded through the needles, and the needles were pulled from the fish leaving the wire through the body of the fish. The two ends of the wire were pulled tightly, twisted several times, cut, and the excess pushed posteriorly against the fish. During the tagging process, the fish was secured in a cradle and water was pumped across its gills. Once tagging was complete, the fish was released to the water. No anesthesia was used, as the procedure was performed quickly and we intended to minimize effects to fish behavior by reducing handling time and eliminating time spent in anesthesia. Fish recovered in the live well for <1 minute and observed for abnormal behaviors before release to the Delta.



Figure 8.—A Striped Bass (*Morone saxatilis*) captured via hook and line sampling near the Curtis Landing Release Site in the Delta with an externally mounted VEMCO V5 acoustic transmitter. V5 acoustic transmitters were applied to 11 Striped Bass (*Morone saxatilis*). Movements were monitored using fixed and mobile hydrophones in the Sacramento-San Joaquin River Delta in April–May 2017.



Figure 9.—A Striped Bass (*Morone saxatilis*) captured via hook and line sampling near the Curtis Landing Release Site in the Delta with an externally mounted VEMCO V13 acoustic transmitter. V13 acoustic transmitters were applied to 9 Striped Bass (*Morone saxatilis*) and one Sacramento Pikeminnow (*Ptychocheilus grandis*). Movement of predators with V13 tags was monitored using fixed and mobile hydrophones in the Sacramento San Joaquin River Delta in May 2017.

Results and Discussion

Internal Predation Detection Acoustic Tag Study

Successful prey retention occurred for 15 of the 16 Striped Bass feeding replicates, with trigger times varying between 6.4 to 33.2 hours (Figure 10). One Striped Bass (high meal category, 21°C did not recover from anesthesia and was removed from the study. Three of the 4 low meal category 14°C Striped Bass replicates regurgitated one of the four Rainbow Trout they were force fed, resulting in smaller average weight for this factor level. Though there was a significant difference between the mean weight of 3 vs 4 fish meals ($p = 0.011$), we maintained either 3 or 4 fish meals as categorical (i.e., high feeding level) for this analysis as either 3 or 4 fish meals had significantly more mass than a single fish meal.

Water temperature had a significant ($\alpha = 0.05$) effect on trigger time ($p = 0.003$), but there was no significant effect of meal size ($p = 0.131$) or interaction effect between water temperature and meal size on trigger time ($F(1,11) = 0.31$, $p = 0.590$). Statistical power was low (power = 0.31 where sample size = 4, maximum difference = 3 hours [minimum trigger time as advertised by VEMCO], $SD = 1.96$, 4 levels) mainly driven by the small sample size so our ability to detect a significant difference was low. Results would be improved with a larger sample size. Target temperatures were 14°C and 21°C. Actual temperatures for 21°C ranged from 20°C to 20.4°C. Actual temperatures for 14°C ranged from 13.7°C to 13.8°C.

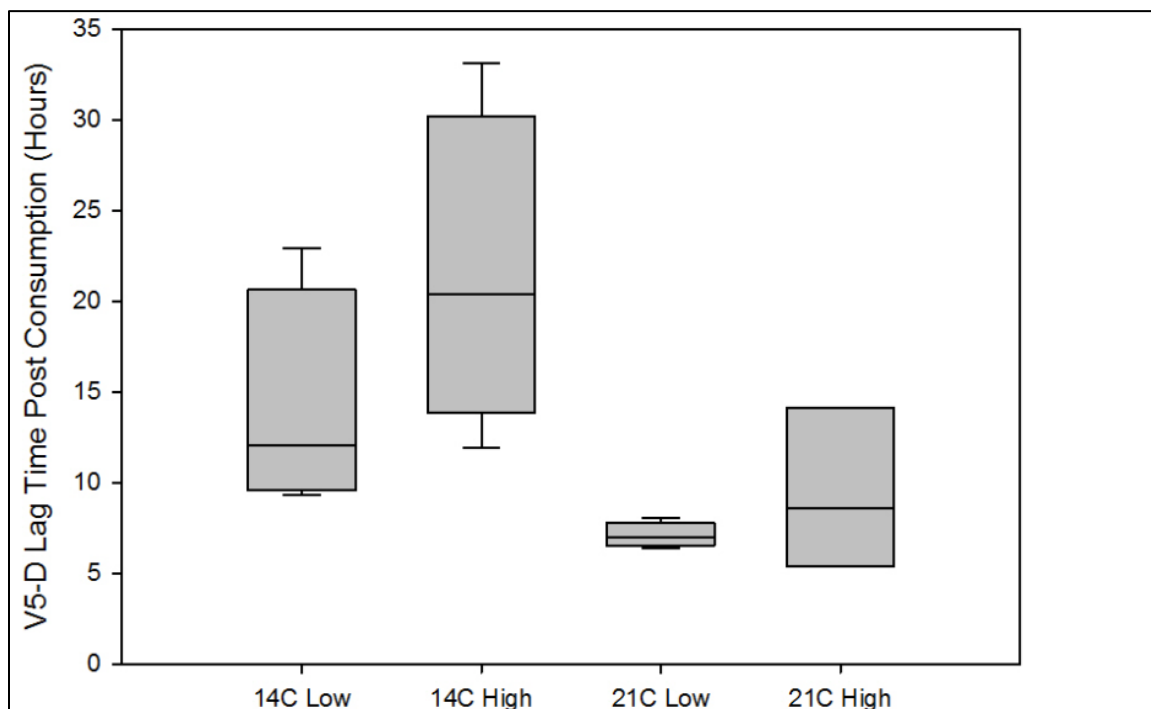


Figure 10.—Boxplot of trigger lag time of VEMCO V5D Predation Transmitters post-consumption of Rainbow Trout (*Oncorhynchus mykiss*) in adult Striped Bass (*Morone saxatilis*). Two temperature regimes were used (14°C and 21°C) and two feeding levels were tested. Boxplots represent the 25th and 75th percentiles and the median lag time is indicated by a horizontal line inside box.

External Predation Detection Acoustic Tag Study

Successful feeding events occurred for 13 of the 16 replicates. In one replicate, a Striped Bass regurgitated the entirety of its meal, including both V5D transmitters. These tags were removed from the analysis. Another tag did not trigger and was later found in the untriggered state on the bottom of the holding tank. For the 13 successful replicates, trigger times for internal and external tags varied from 3.0–23.2 hours (Figure 11). Internal trigger time ranged from 9.0–23.2 hours. External trigger time ranged from 3.0–6.5 hours.

Residuals passed the assumption of normality (Anderson-Darling, $p = 0.582$). There was no significant interaction effect found between tag location and meal size on trigger time, $F(1,11) = 2.79$, $p = 0.129$. Tag location had a significant effect on trigger time ($p < 0.001$), but there was no significant effect of meal size on trigger time ($p = 0.109$).

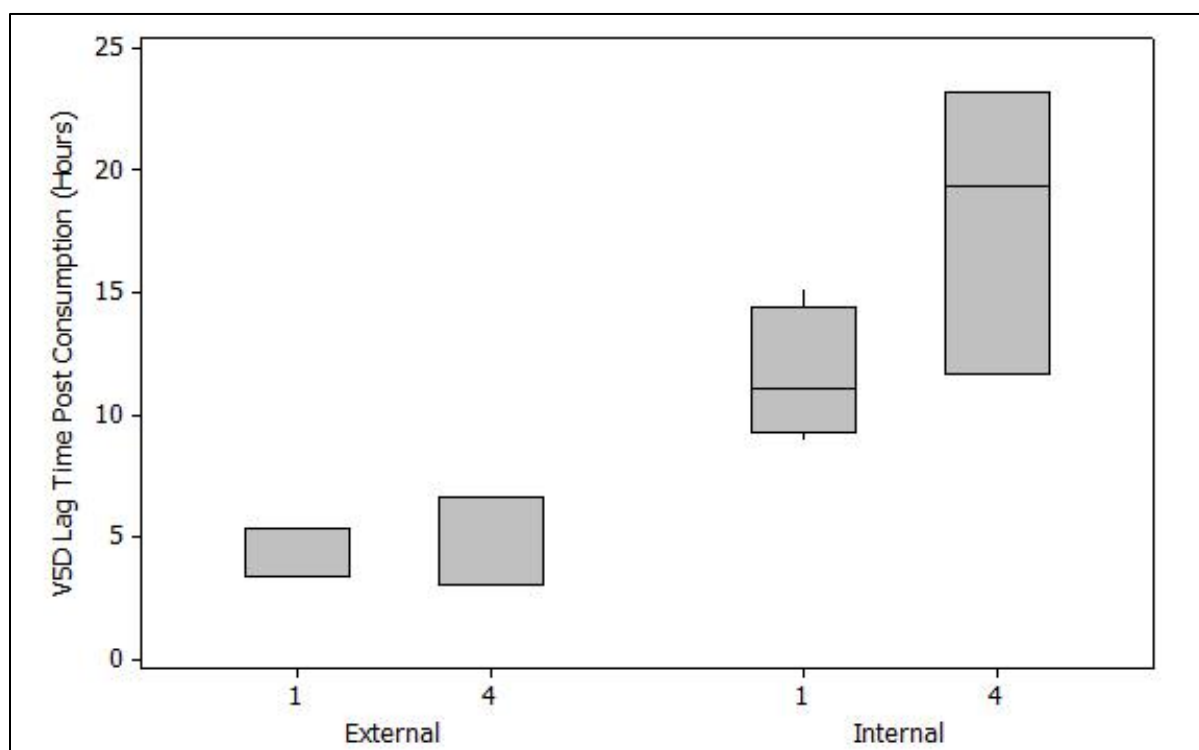


Figure 11.—Boxplot of trigger lag time of VEMCO Predation Transmitters (V5D) post-consumption of juvenile Chinook Salmon (*Oncorhynchus tshawytscha*) in adult Striped Bass (*Morone saxatilis*). External and internal tagging implantations were compared alongside two feeding levels. Boxplots represent the 25th and 75th percentiles, the median (horizontal line inside box). Median lines for both external 1 and 4 fish meal sizes are overlapping with the bottom 25th percentile line.

Because there was some indication of meal size affecting trigger time in earlier analysis, we examined the combined laboratory data for internally-implanted V5D transmitters tested at 14°C ($n = 15$) from both spring and fall experiments. We felt that Rainbow Trout and Chinook Salmon were similar enough taxonomically and in body size to combine their results. We used

least-squared regression analysis to examine the meal size as a continuous variable. There was a significant positive correlation ($p = 0.039$), with meal weight explaining some ($R^2 = 0.29$) of the variability in trigger time of V5D transmitters (Figure 12).

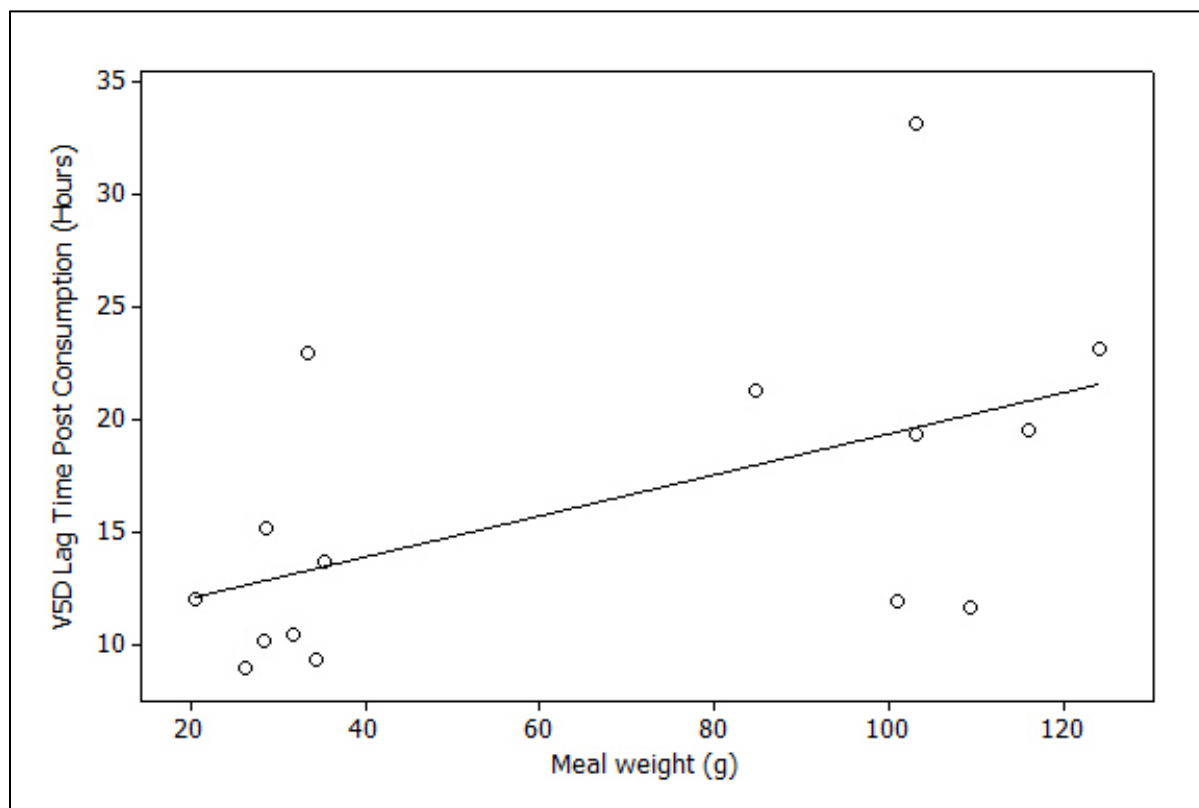


Figure 12.—Scatterplot of total meal weight (g; juvenile Rainbow Trout [*Oncorhynchus mykiss*] and Chinook Salmon [*Oncorhynchus tshawytscha*]) and V5D transmitter trigger (lag) time after feeding to adult Striped Bass [*Morone saxatilis*]. This analysis uses data combined for all 14°C, internally tagged fish from both experiments. The solid regression line is significant at $p = 0.039$, $R^2 = 0.29$.

Field Assessment of Predation Detection Acoustic Tags

Predation Event Recorder Experiments

Three of the four Chinook Salmon implanted with VEMCO V5D transmitters and tethered to a PER were consumed and revealed predation events. One tethered fish became entangled in submerged aquatic vegetation, broke free of the PER, and was lost to the experiment. The lost transmitter remained untriggered near the release site for the duration of hydrophone monitoring most likely wrapped around vegetation inhibiting the ability of the salmon to swim.

Trigger times for the three tags were 13.0, 31.7, and 60.7 hours. We were able to determine predator identification based on video images for two of three predation events (Figure 13), both of which were Striped Bass. Size and stomach fullness for predators was unknown and likely contributed to trigger time for V5D transmitters. Predation events occurred within 10 m of the release pipes in < 15 ft of water. One triggered tag remained in the release pipe vicinity from predation event until receiver removal.



Figure 13.—Underwater image of predator striking a Chinook Salmon (*Oncorhynchus tshawytscha*) tethered to a PER as captured via GoPro footage in the Sacramento San Joaquin River Delta at the Curtis Landing Release Site. The predator is clearly visible, but the prey fish is not. The Chinook Salmon was tagged with a VEMCO V5D predation detection transmitter. Professional opinion was that this predator was a Striped Bass (*Morone saxatilis*). Frame-by-frame analysis showed a large-bodied fish with horizontal stripes (shown here), characteristic of Striped Bass. Striped Bass are known predators in the area and are in high seasonal abundance at the release sites (Miranda et al. 2010).

Salvage Release Predation Detection Acoustic Tag Study

Of the 12 Chinook Salmon implanted with V5D transmitters and released with the daily fish salvage release at CLRS, seven transmitters recorded predation events (58%) after a period of residency at the release pipe area. Two of the predation-triggered transmitters remained in the release pipe array for the duration of monitoring, one remained in the release pipe array for all but a single four-hour period during the release cessation. Tags remained either because the predator remained stationary or the tags were defecated and continued transmitting from the bottom of the Delta (Schultz et al. 2015 reported mean tag evacuation time for adult Striped Bass and juvenile salmonids at 1.2 to 2.7 days). The other four predation-triggered transmitters stayed within the receiver array for 2 to 3 days before disappearing from the array moving in a downstream ($n = 3$) or upstream ($n = 1$) direction. Tag results are summarized in Table 4.

The five remaining tags were untriggered for the duration of monitoring. All untriggered fish migrated downstream to or past the Antioch Bridge (1.4 km from release pipe), with two fish (one released on 5/16/2017 and another released on 5/17/2017) reaching the Benicia Bridge (35.4 km downstream of release pipe) receiver array managed by University of California at

Davis on 5/17/2017 and 5/18/2017, respectively. Two tagged Chinook Salmon were manually tracked downstream to Antioch Marina (7.7 km downstream from release pipe) and Dow Wetlands (7.9 km from release pipe). The single fish which did not move downstream further than Antioch Bridge disappeared from our receiver array on 5/17/2017, two days after deployment. Because of the lengthy time required to activate the predation detection mechanism in VEMCO V5D transmitters, we are unable to discern whether these untriggered tags were salmon swimming on their volition, or whether tags were in the stomachs of predators.

Table 4.—Fate of VEMCO V5D transmitters deployed in 2017. Four transmitters were released via Predation Event Recorder (PER) and twelve were released as part of a salvage fish release at the Curtis Landing Release Site. All tags were surgically implanted in Chinook Salmon (*Oncorhynchus tshawytscha*), and fork length (FL) is reported. Fate is reported as triggered (Trig.) or untriggered (Untrig.) for individuals, triggered meaning the predation mechanism was activated. Trigger time in hours is reported for those fish released via PER only, as predation event time is unknown for pipe released fish.

Tag ID	Salmon FL	Weight (g)	Tag Use	Fate	Trigger Time (hours)	Release Date	Last Detection	Last Known Location
46054	121	21.4	PER	Trig.	60.72	5/15	5/26	Release pipe
46056	118	21.6	PER	Trig.	31.68	5/15	5/26	Release pipe
46058	112	17.7	PER	Lost	-	5/15	5/26	Release pipe
46060	124	26.5	PER	Trig.	12.96	5/16	5/26/	Release pipe
46062	126	26.9	Release	Trig.	-	5/15	5/26	Release pipe
46064	123	23.9	Release	Trig.	-	5/15	5/26	Release pipe
46066	130	28.3	Release	Trig.	-	5/15	5/26	Release pipe
46068	124	22.9	Release	Untrig.	-	5/15	5/17	Antioch Bridge
46070	121	22.6	Release	Trig.	-	5/16	5/19	Antioch Bridge
46072	123	25.5	Release	Untrig.	-	5/16	5/17	Benicia Bridge
46074	122	22.9	Release	Untrig.	-	5/16	5/17	Antioch Marina
46076	111	16.8	Release	Trig.	-	5/16	5/18	Antioch Bridge
46078	119	20.9	Release	Trig.	-	5/17	5/19	Antioch Bridge
46080	117	21.0	Release	Untrig.	-	5/17	5/17	Dow Wetlands
46082	125	25.2	Release	Trig.	-	5/17	5/19	1km Upstream
46084	127	28.5	Release	Untrig.	-	5/17	5/18	Benicia Bridge

Predator Monitoring

All predators were detected after transmitter application. Average Striped Bass fork length was 391 mm (range: 240 to 515 mm) for both April and May tagging events. Transmitter tag life study did not accurately predict remaining battery life for V5 tags used in April 2017. We used transmitters from batches with the highest predicted battery life, and discarded others because some transmitters from batches with estimated remaining battery life of 25+ days did not activate. Predator departure from the study area therefore cannot be interpreted from our data, however we were able to get a coarse idea of predator movement around the release site from the 11 transmitters that were successfully deployed.

April 2017 V5 Tagging

The predator group tagged on 4/10/2017 to 4/12/2017 were detected until 5/7/2017, after which time all tags either died or predators left the area (Table 5). Delta water temperature averaged 14.6°C during monitoring. The cessation in CLRS salvage releases occurred between 4/13/2017 and 4/21/2017, with daily releases resuming on 4/22/2017. Four of the 11 tagged Striped Bass either had battery failure (batteries in V5 tags were used and were later deemed unreliable) or left the study area within ~24hrs of release and were either never detected again, or only detected after releases resumed. One fish reappeared after the cessation of releases for a single day and then disappeared.

Six fish were present at the beginning of cessation of CLRS salvage releases (4/13) and were considered experimental participants. One fish never left the area during the release cessation. Five fish may have reacted to the cessation based on their behavior. Behavior of the participating fish is described below:

- One fish was last detected at a downstream receiver on 4/17/2017, mid-way through the release cessation. This fish either left the area during the release cessation or experienced battery failure.
- One fish left the array during the release cessation from 4/15/2017 to 4/17/2017, returning and residing in the study area during the second half of the release cessation.
- One fish left on the release cessation and returned afterwards on 4/24/2017.
- One fish left on the last day of release cessation on 4/21/2017 and returned on 5/2/2017.
- One fish left the array on 4/13 two days after release cessation but returned 4/19/2017 mid-way through the release cessation and resided until 5/7/2017.
- One fish was detected continuously throughout the experiment and did not react to the release cessation.

There is some evidence showing predators willing to leave the release pipe array during release cessation, as overall tag detections dropped substantially mid-way through the release cessation (Figure 14).

Table 5.—Summary of Striped Bass (*Morone saxatilis*) with external VEMCO V5 transmitters tagged during April 2017 predator monitoring. V5 transmitters had uncertain battery life. Transmitter duration in array ranged from 0–26 days. Residency hours represent the time between transmitter application and last detection, not total hours in the detection array. There was a cessation in Curtis Landing salvage releases between 4/13/2017 and 4/21/2017. D2 = downstream receiver 2, RP = release pipe receiver, U1 = upstream receiver 1. Participant (N = no, Y = yes) indicates whether a fish was actively moving in or out of the array during the release cessation.

FL (mm)	Participant (?)	Tag Date	Last Detection Date	Residence Hours	Last Location	Predator History
311	N	4/12	4/12	0.9	D2	Left area or tag died immediately.
375	N	4/11	4/11	4.4	D2	Left area or tag died immediately.
360	N	4/12	4/12	0.2	RP	Left area or tag died immediately.
240	N	4/11	4/12	28.3	D2	Left area or tag died.
355	N	4/10	4/16	125.1	U1	Missing 4/11 – 4/14, then missing on 4/16.
393	Y	4/12	4/17	120.2	D2	Detected continuously, missing after 4/17.
435	Y	4/10	4/30	424.3	D2	Missing 4/15 to 4/17, then present until 4/30.
450	Y	4/10	4/30	479.6	D2	Left first day, returned 4/24.
310	Y	4/10	5/4	577.6	RP	Left 4/21, returned 5/2.
373	Y	4/12	5/7	588.8	RP	Left 4/13 – 4/19, then present.
420	Y	4/10	4/6	616.6	U1	Detected continuously.

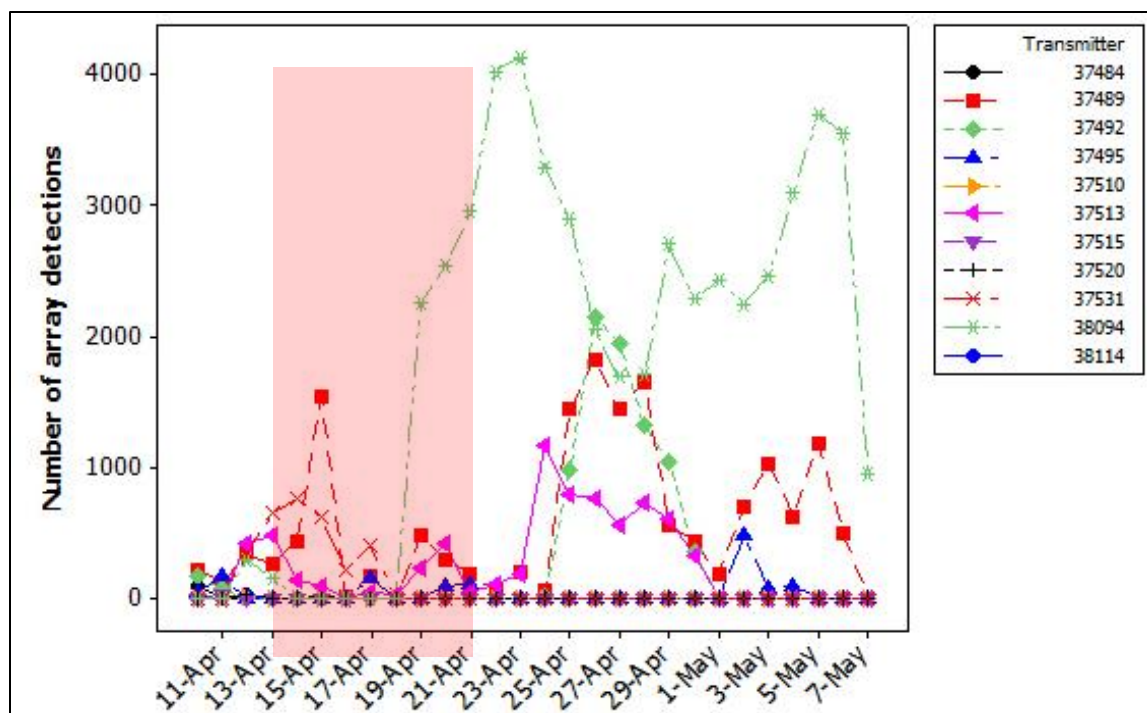


Figure 14.—Total number of whole-array detections per VEMCO V5 transmitter. The cessation in Curtis Landing salvage releases occurred between 4/13 and 4/21 (highlighted in pink). Flatlined detections at 0 indicate a predator left the release site receiver array or the tag died.

May 2017 V13 Tagging

Releases were ceased at Curtis Landing Release Site between 5/18/2017 to 5/26/2017. The predator group was tagged and immediately released back to the Delta on 5/14/2017 and 5/15/2017 and were detected until 5/26/2017 when the receiver array was removed from the study area. Transmitter battery life well exceeded monitoring time, so we were able to make assumptions about predator residency behavior with this data set. Total residence time in the receiver array was substantially higher for the Sacramento Pikeminnow than any of the Striped Bass (Figure 15). Most detections occurred at the receiver nearest the release pipe, or at the downstream-most receiver (Figure 16). The Sacramento Pikeminnow was present until 5/24/2017, over five days after cessation of releases, but left the array during the release break (Figure 17).

Seven Striped Bass left the receiver array within one to two days after tagging and did not participate in the release cessation experiment. One Striped Bass left the area within 24 hours of tagging and did not return until 5/26/2017; during that time this fish's whereabouts are unknown. Only one Striped Bass (FL 389mm) stayed within the receiver array for the start and early duration of the release cessation (Figure 18). This fish was last detected on 5/22, four days into the cessation of salvage fish releases at the CLRS. This transmitter was last detected at the downstream receiver, indicating a downstream departure. Detections were monitored until 5/26/2017.

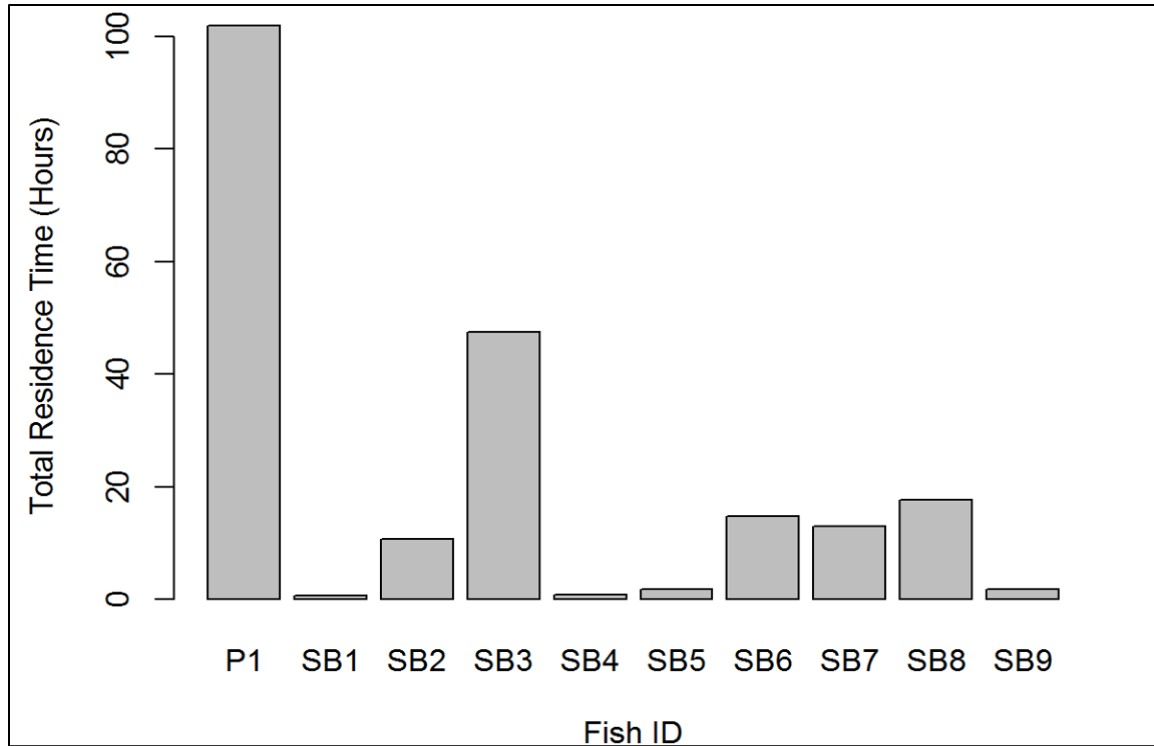


Figure 15.—Total residence time of Sacramento Pikeminnow (*Ptychocheilus grandis*; P1) and Striped Bass (*Morone saxatilis*; SB1 – SB9) affixed with VEMCO V13 acoustic transmitters. All hydrophones were grouped together to evaluate the residence time in the area around the Curtis Landing Release Site. This area covered about 4 linear kilometers of the north (river right) margin of the San Joaquin River encompassing the Curtis Landing Release Site pipe. These data suggest that Sacramento Pikeminnow may be more stationary in the area and Striped Bass may be more mobile.

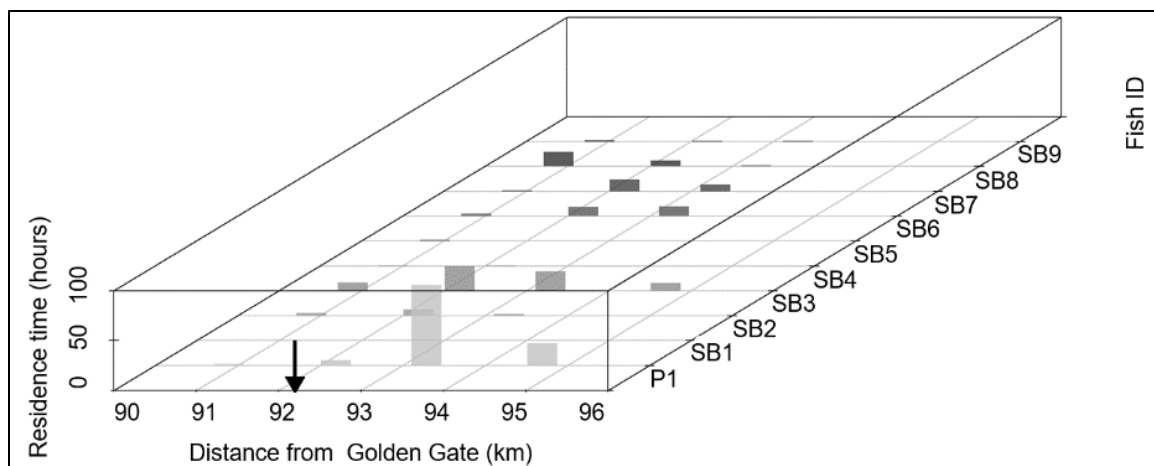


Figure 16.—Residence time (hours) for the ten predators affixed with VEMCO V13 acoustic transmitters in May 2017. P1 is the Sacramento Pikeminnow (*Ptychocheilus grandis*) and SB1 – SB9 are the nine Striped Bass (*Morone saxatilis*) monitored during this study. The black arrow indicates the location of the Curtis Landing Release Site. Receivers were located upstream and downstream of the release site and residence time for each fish at each receiver is indicated with a vertical bar. All Striped Bass left the receiver array moving downstream. The Sacramento Pikeminnow was last detected at the upstream most receiver.

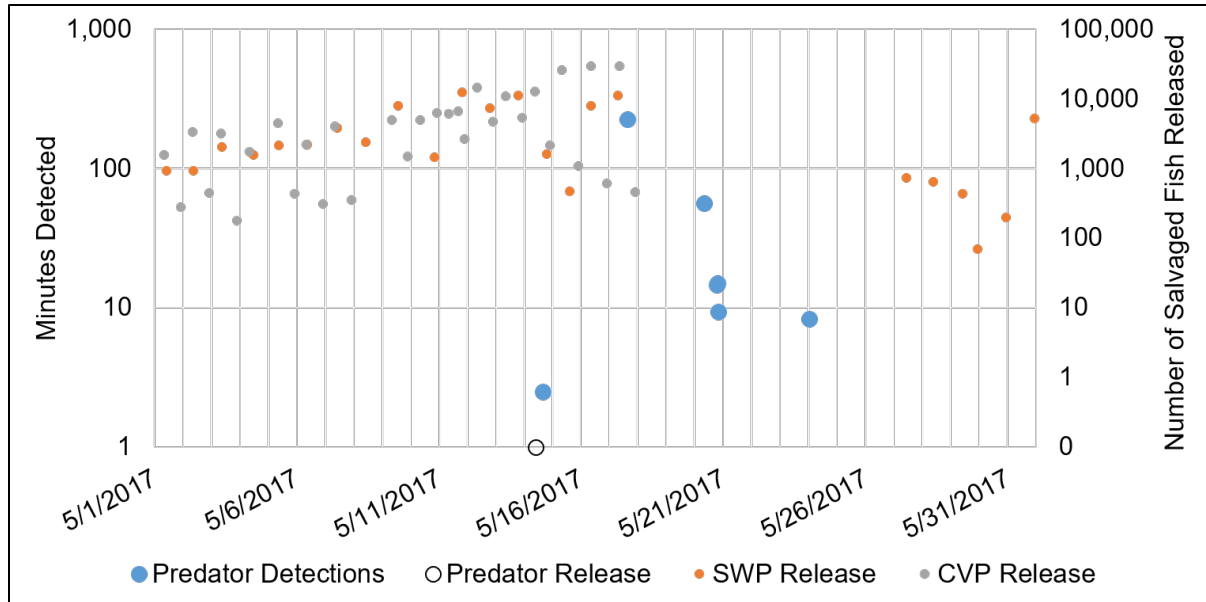


Figure 17.—One Sacramento Pikeminnow was tagged on 5/14/2017 with a VEMCO V13 acoustic transmitter. This fish stayed at the Curtis Landing Release Site receiver array longer than five days after salvage releases were ceased. Detections were monitored until 5/26/2017. SWP and CVP dots indicate salvage origin from the State Water Project and Central Valley Project, respectively.

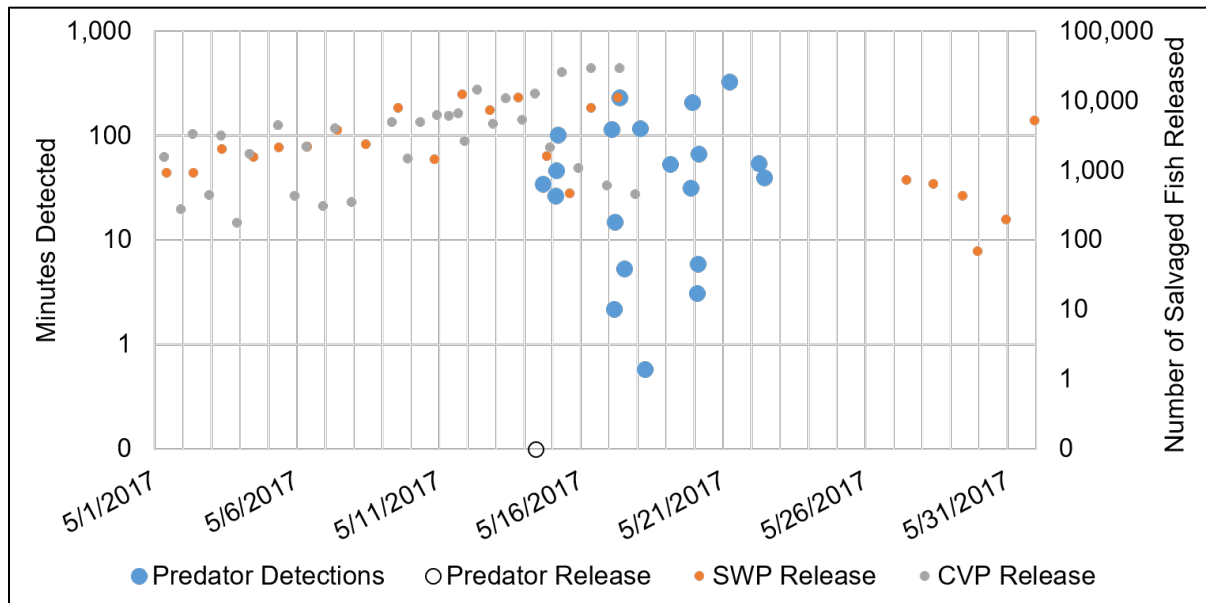


Figure 18.—One of nine Striped Bass (*Morone saxatilis*) affixed with a VEMCO V13 acoustic transmitter, tagged on 5/14/2017 (white circle). This fish was last detected on 5/22, four days into the cessation of salvage fish releases at Curtis Landing Release Site. This transmitter was last detected at the downstream receiver, indicating a downstream departure for this predator. Detections were monitored until 5/26/2017. SWP and CVP dots indicate salvage origin from the State Water Project and Central Valley Project, respectively.

Conclusions and Recommendations

Mean trigger time (i.e., time from feeding until time at code switch) for all internal V5D transmitters was significantly higher (6.4 to 33.2 hours) than advertised by VEMCO (3 to 5 hours). The advertised trigger time for VEMCO V5D transmitters is 3-5 hours, based on laboratory studies using acidic aqueous solutions to dissolve the biopolymer. Trigger time was lower at the warmer temperature regime than the cooler temperature regime (Figure 10). Temperature had a noticeable, but not statistically significant effect on trigger time, likely due to the small sample sizes of these experiments. A low sample size for our experiment was deemed acceptable to gain some perspective on the effects of both temperature and meal size, and meal size and tag location, rather than limiting ourselves to a single factor for analysis. Though a significant interaction effect of meal size on trigger time was not evident in the ANOVA analysis, there was evidence of meal size effect in regression analysis of combined spring and fall lab experiments. Further investigation into larger meal sizes may reveal a stronger effect on transmitter trigger time, and experiments with larger sample sizes would be better at elucidating such effects.

High costs of acoustic tag survival studies and uncertainty of treatment efficacy will prevent future studies using VEMCO V5D predation detection transmitter for monitoring near-field changes in release site predation. In periods of low ambient predation loss at a release site area, measuring changes in predation loss based on a management action (e.g., rotational release schedule) would make detecting changes with acoustic tag survival studies even more difficult. Such an approach provides little promise of elucidating treatment effects from any management action, especially compared to other methodologies which are cheaper and more precise (i.e., tethered predation studies). The interagency working group provided us with new direction for release site predation studies, which use tethered prey and hook timers to detect predation events. This tethered prey hook timer methodology is more temporally and spatially accurate than acoustic transmitter survival studies.

April 2017 predator monitoring with V5 transmitters resulted in interesting data despite transmitter loss via fish departure or battery loss. It is difficult to distinguish a pattern of behavior for the Striped Bass we tagged in April, as we recorded some predators exhibiting nomadic behavior, some showing site fidelity, and others showing a willingness to leave the area during the release cessation.

Predator monitoring in May 2017 using VEMCO V13 transmitters further revealed a lack of site fidelity by Striped Bass. Only one of nine tagged Striped Bass stayed within the area for more than 48 hours after transmitter application. The single Striped Bass that did stay for the start of the release cessation experiment left the area 4 days after the last release. Additionally, the Sacramento Pikeminnow that showed high site fidelity left the release pipe area during the release cessation. These two participants indicate that a modified salvage fish release scheme where a release “break” happens for 5+ days could reduce the willingness of certain predators to reside near the release pipe area, though the high rate of non-participant tagged fish makes us unwilling to draw any solid conclusions from these data. A longer duration study that includes

more resident predators (e.g., Largemouth Bass [*Micropterus salmoides*], Sacramento Pikeminnow) may be more revealing, especially since those predators may be present year-round during the salmon out-migration season, when Striped Bass are less abundant.

Since a modified release scheme is the most easily attainable solution for lowering release site predation rate, we suggest that further studies be performed to elucidate effects of reduced release frequency on predation loss of salvaged fishes in the Delta. We documented some evidence of predators leaving the study area for multiple consecutive days after release cessation. We recommend future studies examine predation directly using tools such as trot lines or a modified PER (Appendix A) and compare predation before and after a modified release scheme is implemented, as VEMCO V5D transmitters are unlikely to provide accurate estimates of near-field predation around the Delta release sites because of potential movement for highly mobile predators.

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References

- Adams, N.S., J.W. Beeman, and J.H. Eiler. 2012. *Telemetry Techniques: A User Guide for Fisheries Research*. American Fisheries Society, Bethesda, Maryland.
- Boyd, J.W., C.S. Guy, T.B. Horton, and S.A. Leathe. 2010. Effects of Catch-and-Release Angling on Salmonids at Elevated Water Temperatures. *North American Journal of Fisheries Management* 30:4, pages 898-907.
- Brown, R.S., S.J. Cooke, G.N. Wagner, and M.B. Eppard. 2010. *Methods for surgical implantation of acoustic transmitters in juvenile salmonids*. U.S. Army Corps of Engineers.
- Brown, R.S., Z.D. Deng, K.V. Cook, B.D. Pflugrath, X. Li, T. Fu, J.J. Martinez, H. Li, B.A. Trumbo, M.L. Ahmann, and A.G. Seaburg. 2013. *A field evaluation of an external and neutrally buoyant acoustic transmitter for juvenile salmon: implications for estimating hydroturbine passage survival*. *PLoS One*, 8(10):e77744. doi:10.1371/journal.pone.0077744.
- California Department of Fish and Game. 2018. *Salvage Monitoring*. www.dfg.ca.gov/delta/apps/salvage. Accessed November 2018.
- Crossin, G.T., M.R. Heupel, C.M. Holbrook, N.E. Hussey, S.K. Lowerre-Barbieri, V.M. Nguyen, G.D. Raby, and S.J. Cooke. 2017. *Acoustic telemetry and fisheries management*. *Ecological Applications* 27(4), pp.1031-1049.
- Coyle, D.C., R.M. Durborow, and J.H. Tidwell. 2004. *Anesthetics in Aquaculture*. Southern Regional Aquaculture Center SRAC Publication No. 3900.
- Demetras, N.J., D.D. Huff, C.J. Michel, J.M. Smith, G.R. Cutter, S.A. Hayes, and S.T. Lindley. 2016. *Development of underwater recorders to quantify predation of juvenile Chinook Salmon (Oncorhynchus tshawytscha) in a river environment*. *Fishery Bulletin of the National Marine Fisheries Service* 114:197-185.
- Halfyard, E.A., D. Webber, J. Del Papa, T. Leadley, S.T. Kessel, S.F. Colborne, and A.T. Fisk. 2017. *Evaluation of an acoustic telemetry transmitter designed to identify predation events*. *Methods Ecological Evolution*, doi:10.1111/2041-210X.12726.
- Ince, B.W. and A. Thorpe. 1976. *The effects of starvation and force-feeding on the metabolism of the northern pike, Esox Lucius L.* *Journal of Fish Biology* 8:79-88.
- Kapuscinski, K.L., J.M. Farrell, and B.A. Murry. 2012. *Feeding Strategies and Diets of Young-of-the-Year Muskellunge from Two Large River Ecosystems*. *North American Journal of Fisheries Management*, 32:4, 635-647.

- Karp, C. and B. Bridges. 2016. *A review of fish release methods at the Tracy Fish Collection Facility with recommendations for future operations*. Tracy Fish Collection Facilities Studies. Tracy Technical Bulletin 2016-1. U.S. Bureau of Reclamation, Mid-Pacific Region and Denver Technical Service Center, 33 p.
- Legler, N.D, T.B. Johnson, D.D. Heath, and S.A. Ludsin. 2010. *Water Temperature and Prey Size Effects on the Rate of Digestion of Larval and Early Juvenile Fish*. Transactions of the American Fisheries Society, 139:3, 868-875, doi:10.1577/T09-212.1.
- Liedtke, T.L., J.W. Beeman, and L.P. Gee. 2012. *A standard operating procedure for the surgical implantation of transmitters in juvenile salmonids*. U.S. Geological Survey Open-File Report 2012-1267, 50 p.
- Miranda, J., R. Padilla, J. Morinaka, J. DuBois, and M. Horn. 2010. *Release site predation study*. California Department of Water Resources, California Natural Resources Agency, California.
- National Marine Fisheries Service (NMFS). 2009. *Biological Opinion and Conference Opinion of the Proposed Long term operations of the Central Valley Project and State Water Project*. U.S. Department of Commerce, National Marine Fisheries Service. June 4, 2009.
- Newton, M., J. Barry, J.A. Dodd, M.C. Lucas, P. Boylan, and C.E. Adams. 2016. *Does size matter? A test of size-specific mortality in Atlantic salmon (Salmo salar) smolts tagged with acoustic transmitters*. Journal of fish biology 89, no. 3: 1641-1650.
- Schultz, A.A., K.K. Kumagai, and B.B. Bridges. 2015. *Methods to evaluate gut evacuation rates and predation using acoustic telemetry in the Tracy Fish Collection Facility primary channel*. Animal Biotelemetry, 3(1), 13.

Appendix A.—Interagency Working Group

To examine the multitude of research avenues which can provide for the assessment of release site predation, Reclamation biologists consulted with Delta biotelemetry and fisheries experts. A group of these biologists convened on a semi-regular basis to discuss and debate the most appropriate ways in which to (1) define “end-of-pipe” zones, and (2) design an experiment in which to measure predation loss of salvaged fish in the end-of-pipe zones.

Beginning in August of 2016, email correspondence commenced with a core group of biologists from federal, state, and private organizations (Table A-1). The group ended teleconference and group email dialogue in June 2017 after a pilot-level project was proposed for FY2018. Communication took place via group email (137 emails) and teleconference (3), along with various meetings in California as time permitted. The group discussed various research paths to measure and reduce release site predation, including survival studies using current and future generations of acoustic tags, predation-detection acoustic tags, photonically tagged fish releases paired with predator capture and gut content analysis, and statistical design.

Table A-1.—List of interagency working group members and consulting biologists. All listed were involved in vetting experimental designs to evaluate release site predation loss. Core group members are listed as “members” and those consulted on an irregular basis are listed as “advisors.”

Name	Agency	Status
Clarence Fullard	U.S. Bureau of Reclamation	Member
Zachary Sutphin	U.S. Bureau of Reclamation	Member
Catherine Karp	U.S. Bureau of Reclamation	Member
Michael Horn	U.S. Bureau of Reclamation	Member
Brandon Wu	U.S. Bureau of Reclamation	Member
René Reyes	U.S. Bureau of Reclamation	Member
Javier Miranda	California Department of Water Resources	Member
Pat Brandes	U.S. Fish and Wildlife Service	Member
Jerry Morinaka	California Department of Fish and Wildlife	Member
Bob Fujimura	California Department of Fish and Wildlife	Member
Bruce Oppenheim	National Marine Fisheries Service	Member
Jeffrey Stuart	National Marine Fisheries Service	Member
Andrew Hein	National Marine Fisheries Service	Member
Steve Lindley	National Marine Fisheries Service	Member
Mark Bowen	Environmental Science Associates (ESA)	Member
Jon Bura	United States Geological Service	Advisor
Chris Vallee	United States Geological Service	Advisor
Brad Cavallo	Cramer Fish Sciences	Advisor
Steve Zeug	Cramer Fish Sciences	Advisor

The interagency working group expanded in membership from fall 2016 to summer 2017, and became inclusive of other groups such as USGS, NMFS regional biologists, and included consultation with various consulting firms (Environmental Science Associates [ESA], Cramer

Fish Sciences). The group consensus was Delta survival (and predation) studies are innately difficult because the Delta is a dynamic system with migratory predators. The Delta also has a multitude of compounding variables that influence predation loss, making it difficult to measure changes in a near-field area using a large-scale acoustic array. The team suggested running statistical simulations based on through-Delta survival estimates and desirable confidence intervals to ensure our proposed methodology has the statistical power to detect the changes we expect to see and determine the potential cost for sample sizes required to reveal changes based on a treatment methodology (target predation reduction = 50%).

Cramer Fish Sciences was consulted to perform simulations based on recent Delta survival numbers for Chinook Salmon near the Delta release sites (56% to 84%; Cramer Fish Sciences, unpublished data). Simulations were performed in program SampleSize 3.1.1 (Columbia Basin Research, University of Washington, Seattle, WA) to estimate the sample sizes required to obtain an acceptable margin of error. Though we expect a single management action to reduce release site predation, there is much uncertainty in the efficacy of any single treatment. Therefore, if a treatment is successful in reducing release site near-field predation loss, but only reduces it by 10-20%, and the margin of error of our survival estimates to a downstream receiver array is high (> 10%), we may not be able to elucidate treatment effects from environmental variability which could result in a considerable waste of time and taxpayer funds.

Based on a theoretical paired acoustic transmitter release study from the release site and a control site, assuming a downstream hydrophone receiver array at Chipps Island (most logical physical array location), simulations revealed very high requirements for the number of transmitters (Figure A-1) which would need to be released to achieve confidence intervals small enough to elucidate a reduction in release site predation. Models indicated a high uncertainty in estimates associated with a single release of a small number of tags (~20) per release (which we originally considered feasible), and any treatment effect could easily be hidden within the margin of error of such a low sample size. Cost estimates revealed a range of \$26,250 to \$52,500+ in tags (75–150+ transmitters, \$350 each) per release could be necessary to reduce confidence intervals to a level even moderately acceptable considering the uncertainty in treatment efficacy and accuracy of modeling output. The total cost of the project could be prohibitive in transmitter expense with high sample sizes. These estimates are not inclusive of labor, monitoring systems, or other costs. Various factors contribute to the uncertainty inherent in an acoustic release survival study examining effects of an operational change at Delta release sites:

1. The greatest probability of detecting a change in survival to Chipps Island will occur when release pipe mortality is relatively high (> 10%) and strongly affected by the treatment;
2. When values of release site mortality and/or survival to Chipps Island are low, a change in survival (i.e., change in predation loss) will be difficult to detect regardless of how strongly the treatment influences release pipe mortality; and
3. When other sources of mortality are high and/or variable, detection of changes in survival to Chipps Island resulting from a treatment will be obscured.

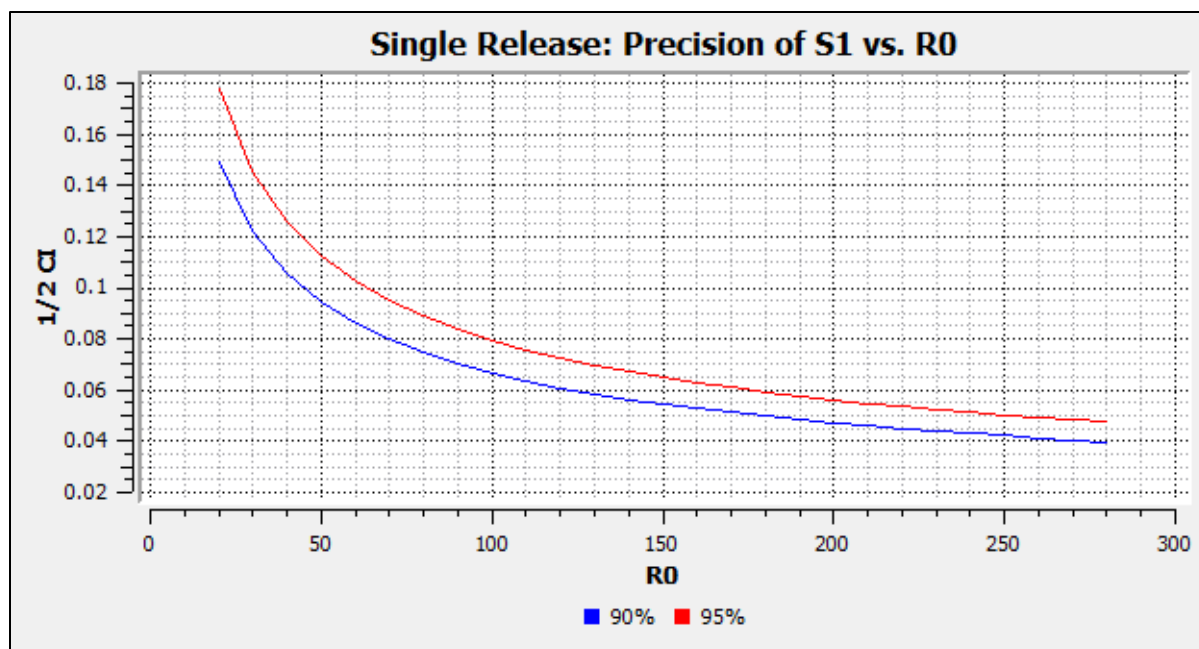


Figure A-1.—Precision of survival estimates (half confidence intervals (CI)) between the release site and Chipps Island, assuming a survival value of 56%. Other survival rates were simulated as well. Simulation was performed in SampleSize3.1.1. S1 is survival from the release pipe to the Chipps Island receiver array. R0 is the number of acoustic transmitters released from the release pipe.

The interagency working group and lab research team concluded that the 3+ hour variability (best-case scenario) inherent in VEMCO V5D transmitters will present real and unresolvable uncertainty in the analysis of predation loss at the release site. Because predators may be mobile, and because of the high lag time between predation event and predation trigger in the transmitters, predation events not related to conditions at state and federal release sites could be falsely attributed to near-field predation. In addition, near-field predation events could be missed if the predator leaves the area before the tag is triggered. Essentially, predation events occurring within the first 3-6 hours (best case scenario) post-release will result in unresolvable data analysis questions, and these specialty transmitters provide us little resolution to discern changes in near field predation loss based on operational changes (treatments). Based on group discussion and lab and field results, we opted to defer consideration of this technology until further refinement and testing has occurred.

The group also considered estimating predation loss using stomach evacuation rates of photonically tagged juvenile Chinook Salmon. Preparation was made to undergo a pilot level effort to assess this methodology. This design would use mass releases of photonically tagged salmon, which would be added to salvage release trucks and released during normal operations. After predator-prey interaction time has passed (0.5–2 hours) trammel nets would be soaked to capture predators residing in the near-field zone around the release pipe. Predators would undergo gastric lavage (Kapusinski et al. 2012) and any photonically marked Chinook Salmon would be noted, and predators would be released back to the near-field area of the release pipe. Ratios of prey recovered via lavage to total prey released would be indicative of true predation rate. Logistical hurdles (endangered species concerns, permitting, marine mammal entanglement

in nets, effectiveness of trammel nets at capturing all predators) prevented the trial of this methodology, and further discussion and brainstorming led us to a more targeted methodology, such as tethered prey studies.

The preferred methodology that resulted from working group discussions was tethered prey trials. Discussions with fisheries biologists at Cramer Fish Sciences and USGS led us to propose future studies which 1) evaluate the applicability of tethered fish trails, and 2) use tethered prey studies to assess release site predation and treatment effects on release site predation. Modified fish tethers were tested in the field in May 2017, using a 20 m length of 30 lb. monofilament fishing line with ten Golden Shiners (*Notemigonus crysoleucas*) connected via loop knot and distributed vertically. The bottom was weighted with a 4 oz lead pyramid weight, and the top buoyed with an orange net float. The tethers were float-fished for 10 minutes in the near-field area of the release pipe during May 2017 when predation levels were relatively high. At the end of the ten-minute set, five fish were missing from the tether line, providing support for this methodology as a way to measure near-field release site predation loss. A proposal was submitted to the Tracy Fish Facility Improvement Program in May 2017 to further refine this tool and prepare a full-scale research design.

REFERENCES

- Cavallo, B. 2018. Cramer Fish Sciences. Auburn, CA. Personal communication.
- Kapuscinski, K.L, J.M. Farrell, and B.A. Murry. 2012. *Feeding Strategies and Diets of Young-of-the-Year Muskellunge from Two Large River Ecosystems*. North American Journal of Fisheries Management, 32:4, 635-647.