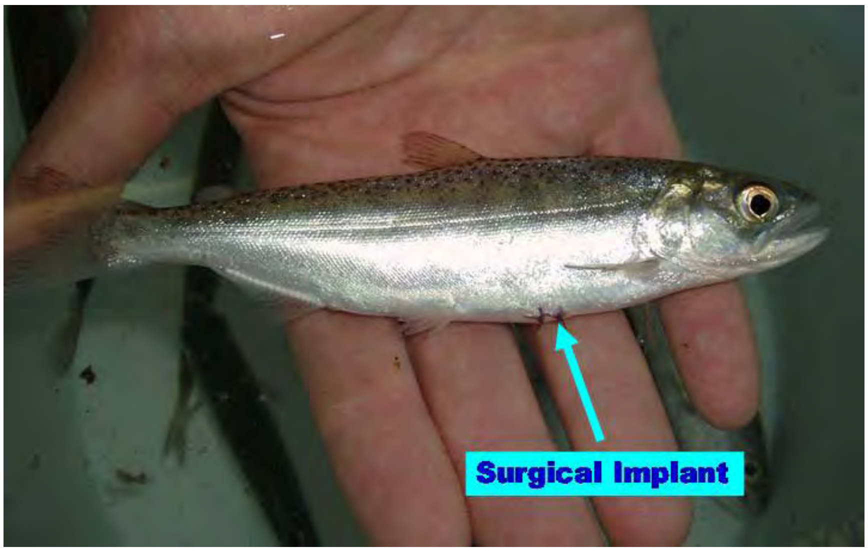
Evaluation of Acoustic-Tagged Juvenile Chinook Salmon Movements in the Sacramento – San Joaquin Delta during the 2009 Vernalis Adaptive Management Program



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"The great tragedy of science - the slaying of a beautiful hypothesis by an ugly fact."
Thomas Henry Huxley, English biologist (1825-1895)

Evaluation of Acoustic-Tagged Juvenile Chinook Salmon Movements in the Sacramento – San Joaquin Delta during the 2009 Vernalis Adaptive Management Program

Executive Summary

The spring of 2009 was the fourth year of experiments evaluating the movements of acoustic-tagged juvenile Chinook salmon (*Oncorhynchus tshawytscha*) released in the San Joaquin River during the Vernalis Adaptive Management Program (VAMP). It was hypothesized that the study may provide salmon survival estimates in some key reaches of the Delta and fish route "selection" probabilities at critical flow splits (i.e., head of Old River and Turner Cut). This plan was also intended to become adaptive by continuing the testing of the acoustic receiver network and equipment, refining logistical approaches to field implementation, and assessing other potential improvements should a study of this nature continue in future years. The project was considered to be an ongoing effort to determine the efficacy of using this technology for Delta fish studies.

A total of 933 acoustic-tagged salmon was released in the lower San Joaquin River at Durham Ferry during seven separate releases in late April and early May 2009. Passage of those fish at 19 acoustic receivers strategically positioned in various Delta channels was monitored from the time of first fish release until early June. Additionally, mobile telemetry was used in some of the key fish migration channels to potentially locate areas of high salmon mortality and where predatory fish may have defecated smolt tags. To improve our understanding of how potential effects of non-native fish predation may influence survival results and interpretation of smolt telemetry data, small numbers of predatory fish were also tagged with transmitters to monitor trends in behavior and movements within the VAMP acoustic telemetry array.

We employed elaborate, painstaking techniques to evaluate the extensive acoustic telemetry data and spatiotemporal history of each tagged fish acquired during the VAMP study. We chose this approach because simple reporting of fish tag presence/absence information may cause widespread misinterpretation and negate the potential for scientifically sound results. These highly detailed assessments of acoustic tag movements included: 1) a near-field environment within the fish transmitter detection range of each of the 19 acoustic hydrophones, 2) medium-field observations of tag movements in a fine-time scale between receivers in close proximity, and 3) far-field examinations of movements of transmitters throughout the study-wide telemetry array. Manual processing of the acoustic telemetry data, although time consuming, provided critically important information on fish behavior to assist in interpreting the 2009 study results.

All of the fish telemetry data were integrated with: 1) flow measurements recorded in relevant Delta channels; 2) site-specific characteristics in fish migration corridors; and 3) knowledge acquired from numerous prior juvenile salmon telemetry studies conducted in the Delta. Furthermore, the analyses included results of a concurrent independent evaluation of acoustic tag movements at a two-dimensional acoustic receiver with four hydrophones positioned at the head

of Old River and a dual-frequency identification sonar camera to study a potential fish behavioral barrier (“bubble curtain”). This latter study provided a means to develop a separate independent method to estimate predation on VAMP study fish and compare with our analyses.

It appears that we were frequently tracking dead salmon (or the transmitters) inside predatory fish during the 2009 VAMP study, not live salmon. Although reasonably accurate numerical estimates of salmon smolt survival were not feasible, fish survival as observed from all seven releases of acoustic-tagged salmon was extremely low. Both independent methods of data evaluation, although not definitive, suggest that there was a very high level of predation on acoustic-tagged salmon. Mobile telemetry surveys found a total of 173 acoustic tags believed to be dead acoustic-tagged salmon or tags defecated by predatory fish in the reaches surveyed (approximately 19% of those fish released at Durham Ferry).

Although the proximal cause of the fish mortality appeared to be a result of predation, the circumstances causing predation remain unknown and warrant further study. While remaining speculative, some of the conditions enhancing predation on salmon are hypothesized to be a result of one or more of the following: 1) flow and/or water quality (including temperature) conditions; 2) in-channel artificial structures (e.g., bridge piers, pump stations, docks); 3) channel geometry (e.g., scour holes) providing favorable habitat conditions for predatory fish; and/or 4) the possible substandard condition of tagged salmon.

Acoustic-tagged striped bass frequently moved throughout the telemetry array and empirical evidence corroborating assumptions of predation on acoustic-tagged salmon was observed. These complex circumstances significantly affect how juvenile salmon telemetry data can be interpreted. Due to a large number of acoustic-tagged salmon possibly being eaten by non-native predatory fish in the Delta, the ability to accurately estimate salmon survival is likely severely compromised because of incorrect assumptions on tag detections (i.e., live salmon versus dead salmon). Differentiating between live acoustic-tagged salmon and predatory fish that had eaten acoustic-tagged salmon makes it very difficult to estimate overall salmon survival, salmon survival by reach, and fish route selection at key flow splits, all of which were (and continue to be) key objectives of the VAMP study.

Acoustic telemetry technology has been amply demonstrated to be a powerful analytical tool to study juvenile salmon movements in the Delta, but only if it is appropriately implemented and the results are properly analyzed and understood. Information developed from the 2009 VAMP study indicates that attempts to accurately estimate salmon survival in the Delta using acoustic telemetry will require a new approach, perhaps by seeking changes in the technology to determine predation. In the absence of a technological breakthrough, highly detailed data on the behavior of predatory fish movements as compared to juvenile salmon movements is critically necessary.

Most importantly, because of the well-documented low salmon smolt survival in the lower San Joaquin River and Delta, efforts should focus on determining site-specific causes of mortality with the objectives of developing and implementing remedial actions to increase fish survival. This report contains numerous recommendations to improve the execution and scientific integrity of future acoustic telemetry studies in the Delta.

Table of Contents

List of Figures

List of Figures (continued)

List of Figures (continued)

List of Figures (continued)

List of Tables

Introduction

The spring of 2009 was the fourth year of experiments evaluating the movements of acoustic-tagged juvenile Chinook salmon (*Oncorhynchus tshawytscha*) released in the San Joaquin River during the Vernalis Adaptive Management Program (VAMP). The use of acoustic telemetry had been previously recommended as a useful analytical technique to acquire detailed biological data that was not possible with the more-traditional coded-wire tagging studies historically used for the VAMP program (Vogel 2005a). In the fall and winter of 2008-2009, the VAMP Biology Committee formulated a plan for the 2009 fish study similar to 2008 using a network of acoustic receivers[1] deployed in the Delta to detect passage of acoustic-tagged juvenile salmon released in the San Joaquin River and potentially estimate fish survival through the Delta to Chipps/Mallard Islands. The 2008 and 2009 studies were expanded from initial pilot acoustic-telemetry studies conducted in 2006 (Vogel 2006a) and 2007 (SJRGA 2008) where fewer acoustic receivers were deployed and fish samples were smaller. In 2008, Natural Resource Scientists, Inc. was responsible for installing and troubleshooting the single-port acoustic receivers (data loggers) in the interior Delta channels and the U.S. Geological Survey (USGS) installed and maintained the dual-array four-port acoustic receivers near Chipps/Mallard Islands and Jersey Point (Figure 1). During the winter of 2008-2009, the VAMP Biology Committee worked on preparations to continue the same study in April and May of 2009. However, in early January 2009, USGS announced that their staff would be unable to duplicate their effort from 2008. Without acoustic receivers at the Chipps/Mallard Island and Jersey Point locations, overall survival for fish released in the lower San Joaquin at Durham Ferry (downstream of the Stanislaus River confluence) to Chipps/Mallards Island could not be estimated.

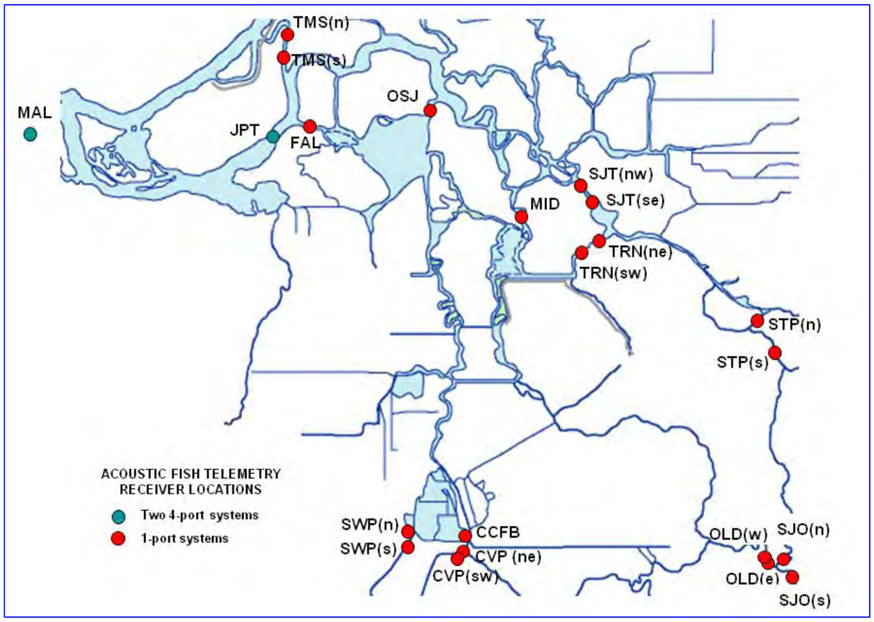

Figure 1. Placement of acoustic receivers in the Delta during the 2008 VAMP study. The fish release site (not on map) was on the San Joaquin River at Durham Ferry (just downstream of the Stanislaus River confluence).

[1] The acoustic telemetry equipment used for the VAMP study was obtained from Hydroacoustic Technology, Inc. (HTI), Seattle, Washington.

Therefore, on January 18, 2009, Natural Resource Scientists, Inc. developed an alternative plan for 2009 which was subsequently adopted by the VAMP Biology Committee with some minor modifications. These included incorporating receiver sites that the California Department of Water Resources (DWR) had planned to install as part of a pilot study to evaluate south Delta barriers and eliminating the sites in the vicinity of the Skinner Fish Facilities at the west side of Clifton Court Forebay. Also, a four-port acoustic receiver was positioned at the head of Old River to evaluate a potential fish behavioral barrier using bubbles, sound, and lights (referred to as the "bubble curtain" in this report). Slight changes were also made in positioning and numbers of receivers following field reconnaissance to determine the most appropriate locations.

The final telemetry array for the 2009 VAMP fish study is shown in Figure 2. Although this alternative plan would not provide estimates of overall fish survival to Chipps/Mallard Islands, it was hypothesized that it may provide results in some key reaches of the Delta and help determine fish route "selection" probabilities at critical flow splits (i.e., head of Old River and Turner Cut). Also, this plan would enable continued testing of the acoustic receiver network and equipment, refining logistical approaches to field implementation, and evaluating other potential improvements (e.g., determining appropriate fish sample sizes) should a study of this nature continue in future years.

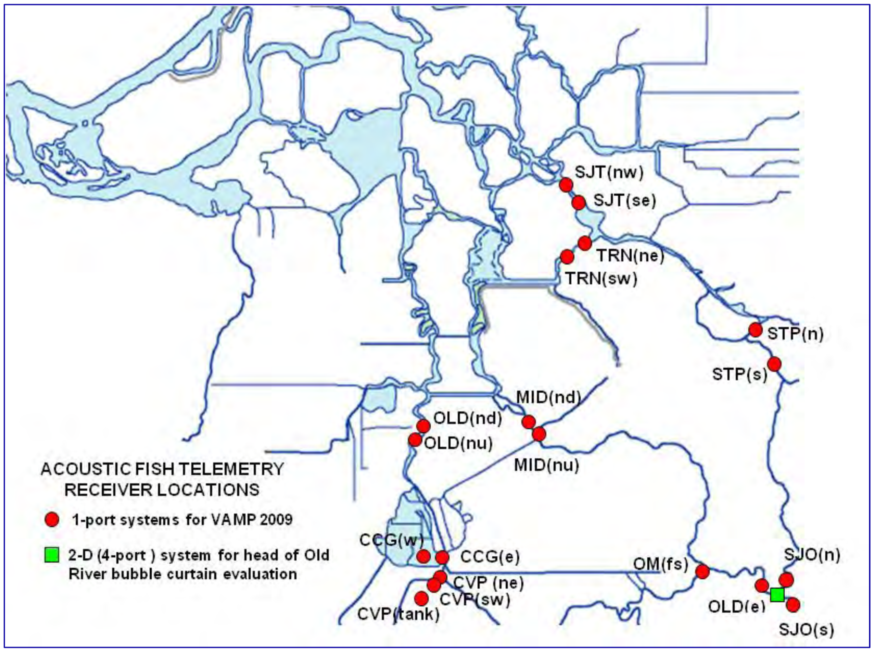

Figure 2. Approximate placement of acoustic receivers in the Delta during the 2009 VAMP fish study. The fish release site (not on map) was on the San Joaquin River at Durham Ferry (just downstream of the Stanislaus River confluence). Refer to Table 1 for nomenclature.

Nineteen acoustic receivers were utilized for the 2009 VAMP study, including those receivers DWR used for their south Delta barriers pilot study. Table 1 provides the receiver locations and nomenclature for each receiver shown in Figure 2 and used throughout this report.

Table 1. Site name and location of acoustic receivers deployed for the 2009 acoustic telemetry fish study (refer to Figure 1).	
Site Name	**Location**
SJO(s)	San Joaquin River at Mossdale bridges
SJO(n)	San Joaquin River just downstream of the head of Old River at the DWR gage station
STP(s)	San Joaquin River in Stockton at the USGS gage station upstream of the waste water treatment plant
STP(n)	San Joaquin River in Stockton at Navy Bridge
SJT(se)	San Joaquin River at the Stockton Deep Water Ship Channel marker red 18
SJT(nw)	San Joaquin River at the Stockton Deep Water Ship Channel marker red 16
TRN(ne)	Turner Cut approximately 1 mile from the San Joaquin River
TRN(sw)	Turner Cut at Turner Cut Resort
OLD(e)	Old River just downstream of the head of Old River flow split
OM(fs)	Old River at the Middle River flow split
MID(nu)	Middle River just upstream of the Highway 4 bridge
MID(nd)	Middle River just downstream of the Highway 4 bridge
CVP(ne)	Tracy Fish Facilities just upstream of the trash racks
CVP(sw)	Tracy Fish Facilities just downstream of the trash racks
CVP(tank)	Tracy Fish Facilities inside the fish salvage holding tank
CCG(e)	Clifton Court Forebay gates just outside (east) of the gates
CCG(w)	Clifton Court Forebay gates just inside (west) of the gates
OLD(nu)	Old River just upstream of the Highway 4 bridge
OLD(nd)	Old River just downstream of the Highway 4 bridge

Methods

Juvenile Salmon Tagging and Release

Juvenile fall-run Chinook salmon used in the 2009 VAMP acoustic telemetry study were surgically implanted with individually identifiable transmitters programmed prior to insertion. A small incision was made on the ventral side of the fish (under anesthesia) and the sterilized transmitter was inserted into the peritoneal cavity. The incision was closed with several sutures (Figure 3) and the fish was allowed to recover from surgery for at least a day prior to release. Details on the fish tagging and release procedures are provided in the 2008 VAMP annual report (SJRGA 2009). Study fish for the project were obtained from the Department of Fish and Game’s (DFG) Feather River Hatchery and the tagging was performed at the federal Tracy Fish Facilities in the south Delta. The fish tagging and subsequent releases were performed by FishBio, U.S. Fish and Wildlife Service (FWS), DFG, and Hanson Environmental staff. Development of the acoustic tag coding scheme for all three studies (VAMP, bubble curtain, and DWR) was developed by HTI.

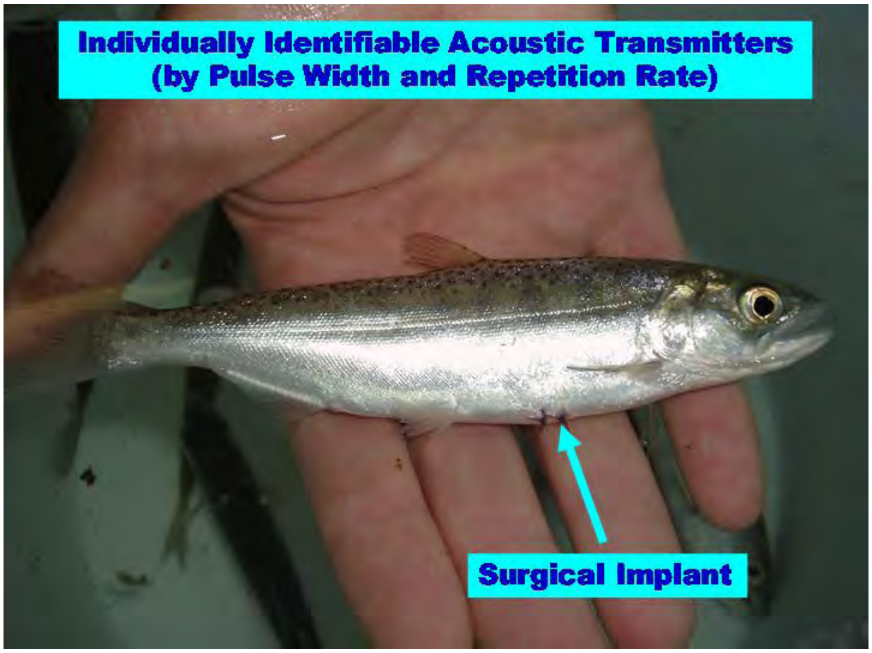

Figure 3. A juvenile Chinook salmon after surgical implant of an acoustic transmitter.

Fish releases were made at Durham Ferry on the mainstem San Joaquin River downstream of the Stanislaus River confluence after the acoustic-tagged salmon had acclimated to local water quality conditions. Seven releases consisting of approximately 130-135 fish each were made during late afternoon or evening hours.

Acoustic Receiver Deployment

Once the VAMP Biology Committee agreed upon the basic deployment locations for the fixed-station acoustic receivers, Natural Resource Scientists, Inc. programmed and installed the electronic equipment at strategic sites in the Delta. This required a significant amount of field reconnaissance and testing at each site to ensure optimal coverage across the channels so that passing acoustic-tagged fish were detected.

Acoustic background noise generated in Delta waters from irrigation pumps, marinas, boat traffic, boat depth sounders, and DWR and USGS flow station Acoustic Doppler Current Profilers (ADCP) (depending on sound frequencies) always makes this a challenge. In some instances, placement of receivers at "noisy" locations was unavoidable and required some "fine-tuning" during programming to minimize interference. Additionally, cross-sectional depth profiles were measured at each site to ensure that riverbed topography did not obscure direct passage of acoustic signals from transmitters to the hydrophones. Continuously pinging "beacon" tags were programmed and anchored underwater near each site throughout the study period in order to verify that each receiver was operating properly. When the various field crews periodically communicated with each receiver via their field laptop computers, they would see the signal and instantly confirm that everything was functioning properly.

Some equipment installation areas were secure at DWR or USGS gaging stations or at the federal or State water export facilities. In the wider Stockton Deep Water Ship Channel, Natural

Resource Scientists, Inc. requested and received approval from the U.S. Coast Guard to place the electronic equipment on top of channel markers. In some cases, sites chosen for receiver placement were not secure and required private landowner or Reclamation District approvals. These latter instances required that the equipment be housed in tamperproof metal job boxes and anchored to large riprap using concrete anchor bolts. Figure 4 shows a diagram of how the equipment was placed in the channels of the Delta.

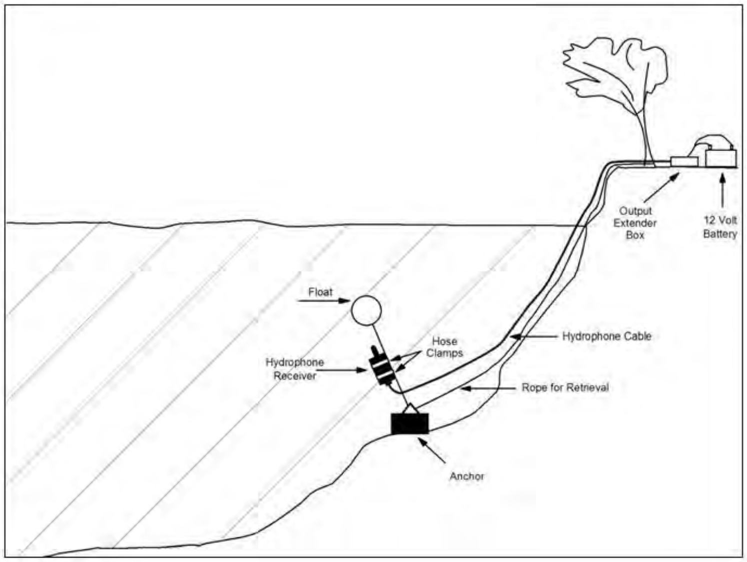

Figure 4. Deployment of an internal hydrophone, single-port acoustic receiver (data logger) from a levee in the Delta.

Although not part of the original study design, Natural Resource Scientists, Inc. decided to place a receiver at the fish salvage/holding tank at the Tracy Fish Facilities. After discussions with on-site U.S. Bureau of Reclamation (USBR) staff, they were willing to temporarily alter their normal operations to accumulate salvaged fish using one tank instead of alternating between two tanks thereby facilitating the potential detection of acoustic-tagged fish using a hydrophone placed in the single tank by USBR personnel. Of the four VAMP acoustic telemetry field studies Natural Resource Scientists, Inc. conducted in the Delta since 2006, this was the first year a receiver was placed in the fish salvage tank.

The acoustic receivers used for the 2009 VAMP study were purchased by USBR and DWR with specifications provided by USGS for use in an earlier north Delta study. Of the two types of single-port receivers available from HTI (internal and external hydrophone), all new receivers purchased for the north Delta study were of the external hydrophone type. At the time the equipment was ordered, USGS staff was not aware that the external hydrophone receiver electronics were designed to be continuously submerged underwater (as are the internal hydrophone receivers) and purchased a 5-ft communication cable to connect between each above-water receiver and input/output box to allow housing the units inside secure, tamperproof job boxes on Delta levees. Initial experiments using this setup during a winter-time pilot study in the north Delta demonstrated that the equipment worked satisfactorily (Vogel 2008). However, during the May 2008 VAMP study, ambient air temperatures were very warm and some of the receivers housed in metal job boxes had data collection problems which the manufacturer believed was caused by the receivers overheating. The 2007 VAMP study also demonstrated several of the symptomatic problems, but the reasons were unknown at that time (SJRGA 2008). All of the receivers used during the 2006 VAMP pilot study did not experience this problem because all had internal hydrophones and were continuously submerged (Vogel 2006a).

For the 2009 VAMP study, insufficient time was available to purchase numerous hydrophone cables and re-configure the receivers to be continuously submerged. To help alleviate this problem, Natural Resource Scientists, Inc. modified the job boxes purchased by the San Joaquin River Group Authority (SJRGA) to house the electronic units. Three techniques were employed to avoid potential spring-time temperature problems: 1) incorporating a water bath inside the job boxes, 2) cutting ventilation holes in the bottom and top for convection cooling, and 3) painting the exterior of the metal boxes with a ceramic paint (Figure 5). Based on evaluation of the acoustic receivers' performance during the study, one or more of these remedial actions appeared to have fixed the problem.

Figure 5. Modifications to the acoustic receiver boxes for the 2009 VAMP study. Left picture: plasma cutting ventilation holes. Right picture: inside of the modified job box showing the water bath compartment and drainage pipe on the right and the dry compartment on the left for housing the data logger and ventilation hole.

Acoustic Receiver Maintenance

Maintenance of the acoustic receivers after deployment required regular visits to the sites to exchange the 12-VDC batteries and download data. Unlike the prior three years of the VAMP acoustic telemetry studies where data were written to USB drives, the SJRGA purchased laptops in 2009 so field crews could download the data files directly from the data logger hard drives. Battery swaps and data downloads occurred every Monday, Wednesday, and Friday during the study. At their earliest opportunity, field crews uploaded the receiver data to the Natural Resource Scientists, Inc. file transfer protocol (ftp) server. Some of the field crews visited the sites more frequently to ensure the equipment was operating properly. During the initial phase of the study, we discovered that at sites where receivers were connected to shore AC power, background noise interference compromised the data files and were subsequently switched back to DC power. Personnel from multiple agencies (FWS, DFG, DWR, USBR, FishBio) provided us with invaluable assistance during this year's study through regular battery replacements, data downloads and uploads to the ftp site. This procedure was a significant improvement over the last three years which required use of USB drives for data storage. It also improved implementation of remedial actions to fix problems.

Mobile Telemetry Monitoring

In 2009, mobile telemetry was performed in channels within the acoustic receiver array after equipment was installed and fish were released. The technique was developed from prior juvenile salmon telemetry studies in the Delta (e.g., Vogel 2007a, 2008). The process generally involved anchoring a boat with a suspended hydrophone and cable approximately every ¼ mile in each reach or in the vicinity of potential predatory fish habitat. Operating the receiver for about 5 to 10 minutes at a fixed location helped to obtain a sufficient recording of any transmitters within detection range. GPS coordinates were noted for later data processing to document receiver positioning. Implementing the surveys with a moving boat is of little value because very few “pings” from acoustic tags in the vicinity would be recorded on the acoustic receiver making post-processing very difficult and greatly reducing the ability to identify individual transmitters. Additionally, boat motor and depth sounder noise further inhibits the value of the data.

Priority was placed on two specific river reaches: Between Durham Ferry and the Deep-Water Ship Channel and in Old River to the south Delta water export facilities. Natural Resource Scientists, Inc. periodically surveyed the reach between the head of Old River and the ship channel and FishBio surveyed the reach between Durham Ferry to the head of Old River and in Old River and Grant Line Canal (Figure 6).

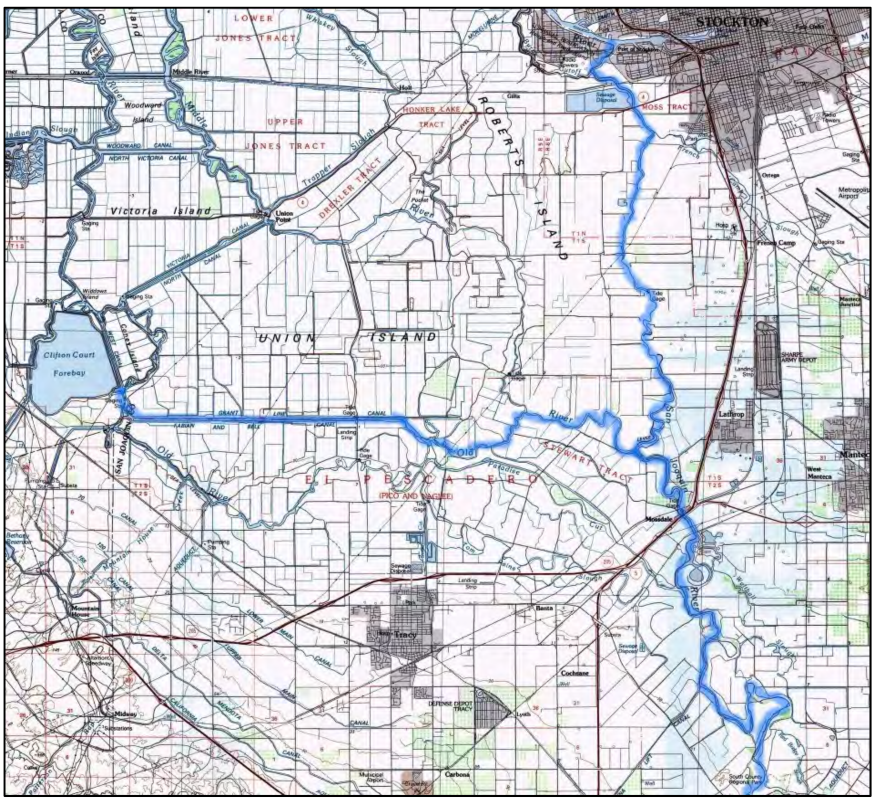

Figure 6. Areas surveyed (shaded blue) using mobile acoustic receivers during the 2009 VAMP study.

Predatory Fish Tagging

Because of the critically important issue of how predation may cause misinterpretation of study results (discussed later in this report), predatory fish were tagged during the 2009 VAMP study with acoustic transmitters to monitor fish movements and behavior. Striped bass (*Morone saxatilis*) and black bass (*Micropterus salmoides*) were captured by hook and line angling, externally tagged, and released at the capture site in a variety of locations in the lower San Joaquin River and interior Delta. Sites included scour holes, near structures, and in front of the trash racks at the federal Tracy Fish Facilities. The acoustic transmitters were similar but larger (13 grams) than the 0.65-gram transmitters implanted in salmon smolts released during the VAMP study. The bass transmitter batteries lasted for the duration of the one-month study. Each transmitter was individually identifiable and did not overlap with the smolt transmitters. Movements of tagged striped bass were monitored and recorded using the same fixed-station acoustic receiver network.

Data Processing

The acoustic telemetry receivers generate hourly raw acoustic tag data files (.rat files). These files alone do not provide useful data for analyses and, instead, are processed using the vendor's proprietary software program (*MarkTags®)* to view and evaluate collected data. There are two techniques to process the hourly files: auto tracking and manual processing. Each procedure has its advantages and disadvantages. Auto tracking is advantageous when processing large numbers of files and large numbers of study fish have been released. But this approach can be problematic in the Delta region when incorrect acoustic signals from boat traffic, water pumps, etc. are misinterpreted as representing tagged fish (a "false positive" detection). USGS utilized auto-tracking to process the data from the 2008 VAMP study. USGS is working on software programming methods to significantly reduce this problem (J. Burau, USGS, pers. comm., January 14, 2010). Although tedious, manual processing is currently advantageous for Delta studies because it minimizes false positive detections and provides greater reliability in the results. As reported below, substantial data can be derived and are extremely useful for biological evaluations in the Delta that would otherwise not be utilized under the auto tracking scenario. Therefore, we employed the manual processing method for all data from the 2009 VAMP study to maximize data quality and increase reliability in the results.

Results and Discussion

Acoustic-Tagged Juvenile Salmon Releases

For the 2009 VAMP study, 933 acoustic-tagged juvenile salmon were released in seven separate groups at Durham Ferry in the lower San Joaquin River. Table 2 provides the numbers of fish released in each group and the date/times of release. These numbers do not include initial incidental mortalities (e.g., latent fish tagging and fish transport mortalities) which were eliminated from analyses of fish movements through the Delta. A tag life study conducted by FishBio indicated that 100% of the representative tags were still functioning 21 days after activation (Andrea Fuller, pers. comm.., September 1, 2009) which was assumed to be a sufficient period for acoustic-tagged smolts to move though the VAMP acoustic telemetry array.

Table 2. Numbers of fish and dates/times of release for the seven groups of acoustic-tagged salmon released at Durham Ferry on the San Joaquin River during the 2009 VAMP study.

Release Group:	1	2	3	4	5	6	7
Date/Time:	4-22-09 1705 hrs.	4-25-09 2150 hrs.	4-29-09 2145 hrs.	5-2-09 1737 hrs.	5-6-09 2138 hrs.	5-9-09 1739 hrs.	5-13-09 2138 hrs.
No. Fish Released:	133	134	134	134	132	133	133

Tag Detections at Downstream Locations for Fish Releases 1 – 7

Total tag detections at one or more receivers downstream of the release site for each release group varied from 51% to 85% and averaged 70% for all seven fish releases (Table 3).

Table 3. Numbers of fish detected at one or more downstream receivers for each of the seven groups of acoustic-tagged salmon released at Durham Ferry on the San Joaquin River during the 2009 VAMP study.

Release Group:	1	2	3	4	5	6	7	Overall
No. Fish Released:	133	134	134	134	132	133	133	933
No. Tags Detected at One or More Downstream Receivers[1]:	74 (56%)	106 (79%)	114 (85%)	82 (61%)	106 (80%)	68 (51%)	103 (77%)	653 (70%)

[1] Includes detections at the four-port receiver at the bubble curtain at the head of Old River.

There were periods when the acoustic receivers failed to properly operate during the study, primarily due to AC grounding issues, which reduced detection probabilities at some receivers particularly early in the study (Table 4).

Table 4. Periods of non-operation of acoustic receivers during the 2009 VAMP study. Refer to Figure 2 for receiver locations.

Site Name	Receiver Location	Start Down Time	End Down Time
SJO(s)	Mossdale	4/22/09 1000 hrs.	4/28/09 1000 hrs.
SJO(n)	Lathrop gage	5/15/09 0200 hrs.	5/15/09 0600 hrs.
		5/15/09 0800 hrs.	5/15/09 1300 hrs.
		5/15/09 1500 hrs.	5/15/09 1900 hrs.
		5/15/09 2100 hrs.	5/18/09 1200 hrs.
OLD(e)	Head of Old River	5/4/09 1300 hrs.	5/6/09 1200 hrs.
STP(s)	Stockton USGS gage	4/22/09 1000 hrs.	4/28/09 1200 hrs.
		5/1/09 1200 hrs.	5/3/09 1400 hrs.
		5/12/09 0800 hrs.	5/18/09 1200 hrs.
STP(n)	Navy Bridge	5/24/09 2300 hrs.	5/25/09 0900 hrs.
		5/26/09 1300 hrs.	5/27/09 0200 hrs.
SJT(se)	Shipping Channel red 18	5/1/09 1100 hrs.	5/2/09 0500 hrs.
SJT(nw)	Shipping Channel red 16	5/1/09 1000 hrs.	5/2/09 0800 hrs.
		5/25/09 0800 hrs.	5/26/09 0900 hrs.
CVP(sw)	Tracy FF inside trash racks	5/15/09 1300 hrs.	5/18/09 1000 hrs.
OLD(nd)	Old River upstream of Hwy 4	5/4/09 0900 hrs.	5/11/09 0900 hrs.

To account for these down times, we assumed that acoustic tags passing an inoperative site but subsequently detected at a site further downstream (including the four-port receiver at the head of Old River) would have been detected at the upstream site if the receiver had been working. However, in those instances, the date/time of actual passage towards a downstream receiver or ending at the non-functioning site is unknown.

Passage of Acoustic-Tagged Fish through the VAMP Telemetry Array

Table 5 provides the information for passage of acoustic-tagged fish from each release within the acoustic receiver array downstream of the fish release site at Durham Ferry.

Table 5. Passage of acoustic-tagged fish through the 2009 VAMP acoustic telemetry array downstream of the Durham Ferry release site.[1]

Receiver Location	Fish Release Number (Numbers of fish released in parentheses)							
	1 (N=133)	2 (N=134)	3 (N=134)	4 (N=134)	5 (N=132)	6 (N=133)	7 (N=133)	Overall (N=933)
SJO(s)	74	106	114	82	106	68	103	653
SJO(n)	18	33	52	26	47	22	37	235
STP(s)	9	20	41	21	33	14	25	163
STP(n)	9	19	41	20	29	14	22	154
SJT(se)	3	0	7	8	0	0	0	18
SJT(nw)	3	0	6	7	0	0	0	16
TRN(ne)	0	0	1	0	0	0	0	1
TRN(sw)	0	0	1	0	0	0	0	1
OLD(e)	52	65	54	46	43	31	38	329
OM(fs)	48	58	48	42	36	31	37	300
MID(nu)	0	0	0	0	0	0	0	0
MID(nd)	0	0	0	0	0	0	0	0
CVP(ne&sw)	11	25	26	19	8	4	20	113
CVP(tank)	3	3	6	1	0	2	4	19
CCG(e)	26	22	26	29	21	13	16	153
CCG(w)	7	7	7	13	4	6	3	47
OLD(nu&nd)	6	3	2	1	3	4	0	19

[1] Includes those tags passing a site undetected but subsequently detected at a site further downstream.

Overall, of the 933 tagged fish released at Durham Ferry, approximately 70% were estimated to have reached Mossdale. The actual percentage was likely higher because the receiver at Mossdale was down during most of the time those fish from releases 1 and 2 would have reached Mossdale. Although tags detected at sites further downstream were included in the estimates, some tags could have reached Mossdale during the receiver down times, but were not subsequently detected at any other sites. Of that 70%, for the reach between Mossdale and the receivers placed near the head of Old River [Old(e) and SJO(n), combined], an estimated 86% of the fish migrated that distance. This estimate is likely lower for the foregoing reasons. An estimated 69% of the fish migrated from the Lathrop gage [SJO(n)] to the Stockton gage [STP(s)]. Of those tags reaching the Stockton gage, a surprisingly low 12% of the tags were detected at the Turner Cut or Deep Water Ship Channel receivers (positioned downstream of Turner Cut) (all four stations combined). For the reach from the head of Old River [Old(e)] to all the receivers positioned in fish migration routes to the west and northwest combined, approximately 87% of the fish were estimated to have migrated those distances. However, for reasons described later in this report, these estimates likely do not accurately reflect actual salmon smolt survival by reach.

Fish Migration (Transit) Timing

Because acoustic-tagged salmon were individually identifiable at the time of release and detection times were recorded when fish passed receivers positioned downstream of the release site, individual migration timing for each fish for specific reaches could be determined. The first fish migration reach was from Durham Ferry to the receiver positioned at the Mossdale bridges. Most fish from all releases, except releases 1 and 2 which could not be determined due to the AC grounding problem, migrated this distance of approximately 13 miles within less than a day (Figure 7 and Table 6) (approximately 0.6 MPH). A more-complete record of downstream receiver detections for all seven fish releases was available from the four-port receiver positioned 2.8 miles downstream of Mossdale at the head of Old River. For this latter reach, most fish from all releases moved from Durham Ferry to the head of Old River, a distance of approximately 15.8 miles, in an average time of 27 hours (Figure 8 and Table 7) (approximately 0.6 MPH). Some fish in all releases exhibited long transit times over several days which may have been dead acoustic-tagged salmon (or the transmitters) inside predatory fish. For example, some fish took approximately a week to migrate from Durham Ferry to the first downstream detection sites. Fish travel times for the short reach between Mossdale and the head of Old River averaged approximately 6 hours (Figure 9 and Table 8) (approximately 0.5 MPH).

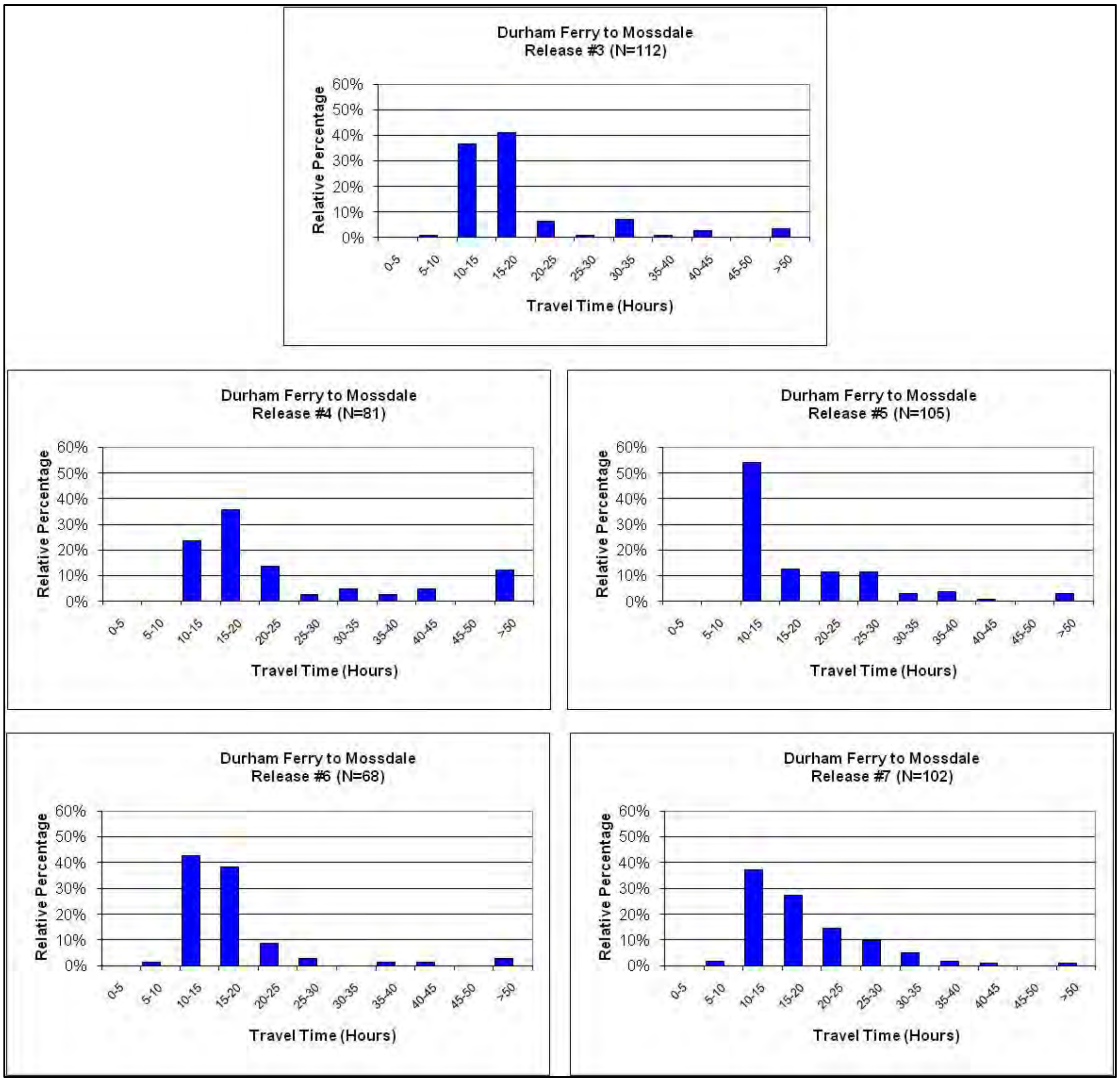

Figure 7. Travel time in hours for acoustic-tagged fish to move between the release site at Durham Ferry and the Mossdale bridges.

Table 6. Fish transit time (in hours) from Durham Ferry (fish release site) to Mossdale.

Fish Release Number	Minimum	Maximum	Average	Std Dev	Median
3 (N=112)	9.8	143.9	20.2	16.2	15.8
4 (N=81)	10.0	210.5	30.3	32.1	18.8
5 (N=105)	11.1	90.1	20.0	12.5	14.7
6 (N=68)	9.7	120.3	18.7	15.1	16.1
7 (N=102)	9.5	79.9	19.0	9.2	16.7
Overall (N=468)	9.5	210.5	21.4	18.5	16.3

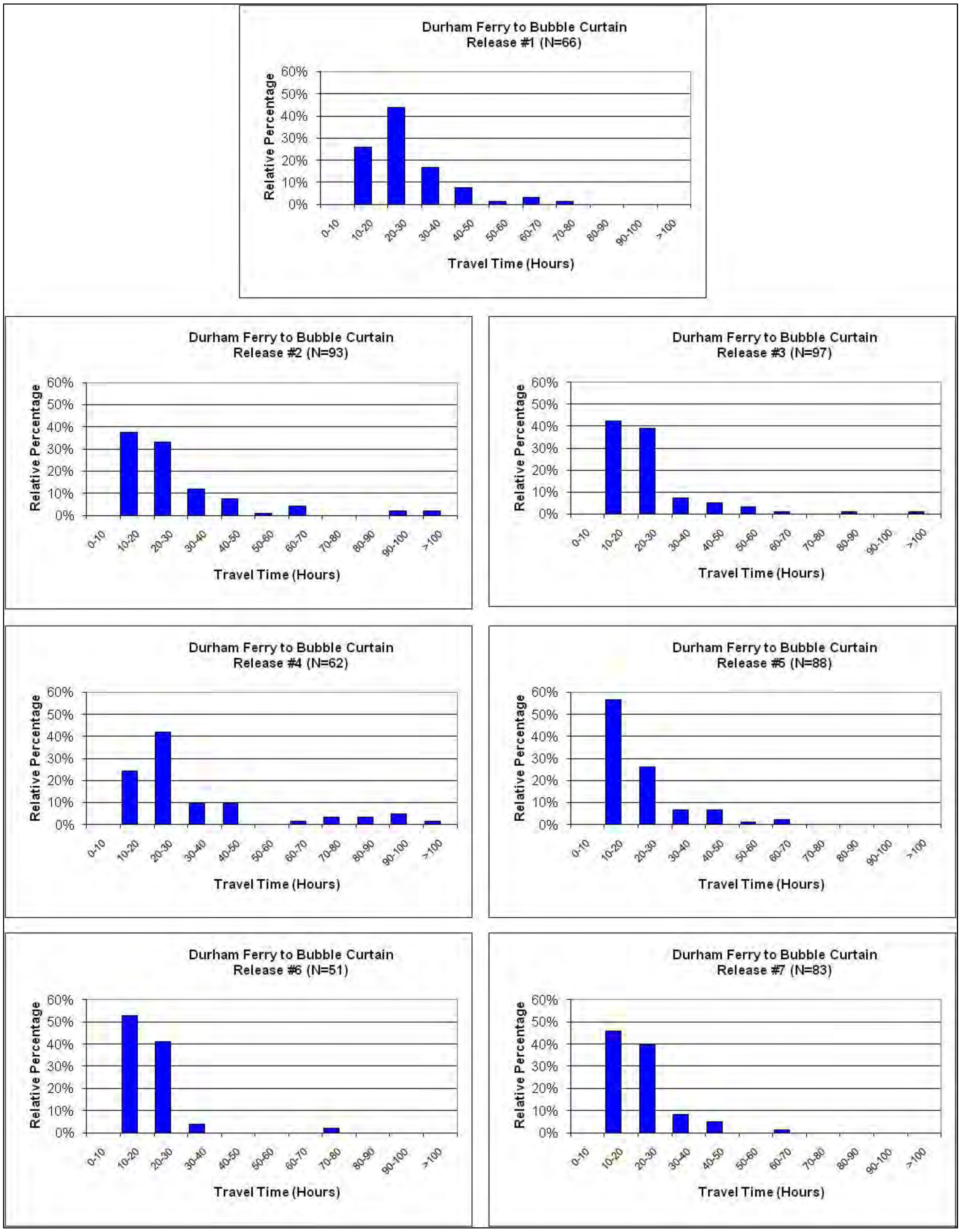

Figure 8. Travel time in hours for acoustic-tagged fish to move between the release site at Durham Ferry and the bubble curtain at the head of Old River.

Table 7. Fish transit time (in hours) from Durham Ferry (fish release site) to the bubble curtain at the head of Old River.					
Fish Release Number	**Minimum**	**Maximum**	**Average**	**Std Dev**	**Median**
1 (N=66)	15.9	77.6	28.1	12.5	23.9
2 (N=93)	14.2	167.5	31.1	24.5	22.4
3 (N=97)	15.9	154.3	26.0	17.5	20.4
4 (N=62)	14.8	212.3	37.0	31.1	27.3
5 (N=88)	13.5	65.0	23.3	11.1	17.7
6 (N=51)	15.5	71.5	21.9	8.2	19.7
7 (N=83)	13.9	61.5	23.1	8.1	20.7
Overall (N=540)	13.5	212.3	27.1	18.5	21.5

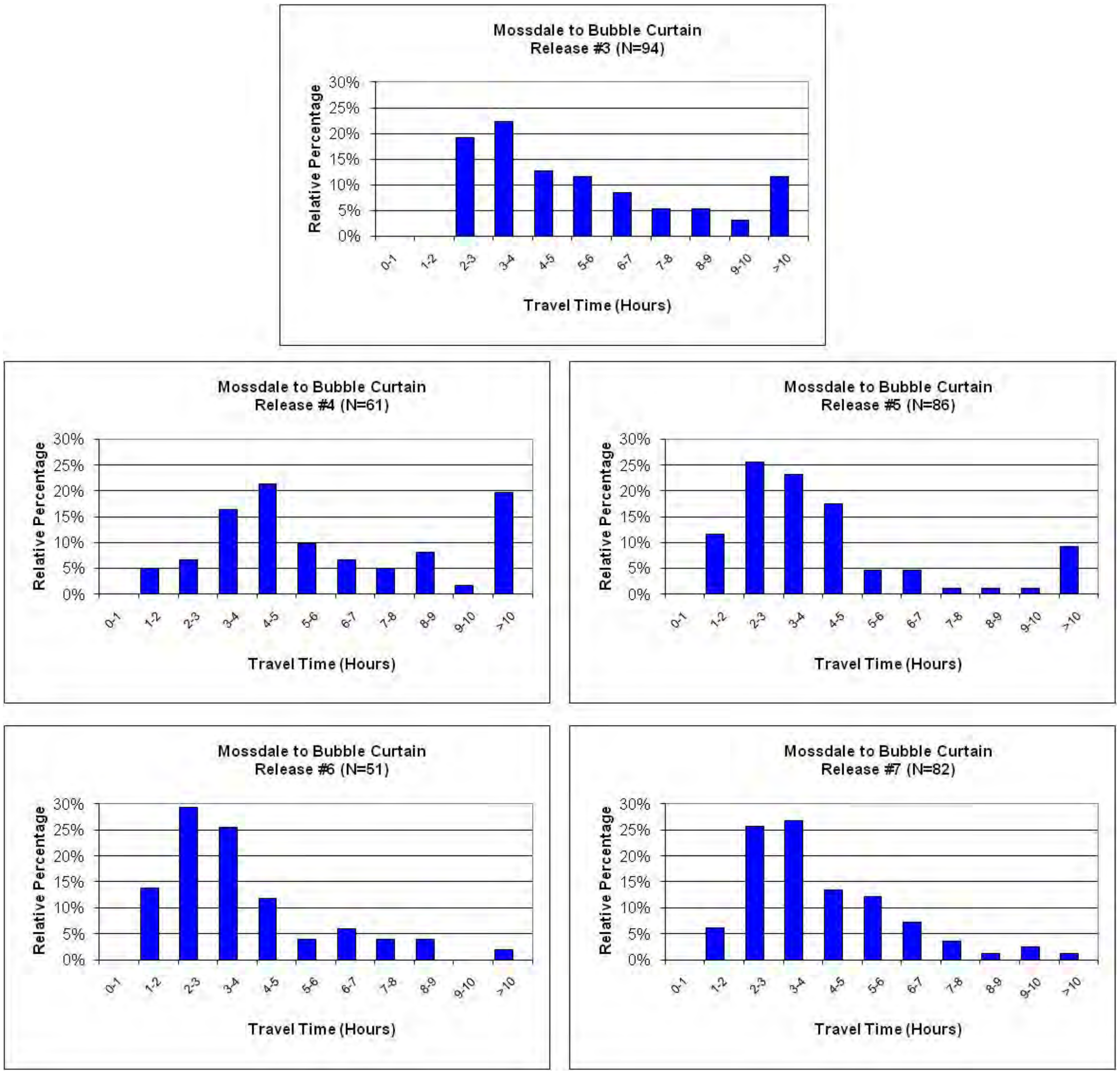

Figure 9. Travel time in hours for acoustic-tagged fish to move between the Mossdale bridges and the bubble curtain at the head of Old River.

Table 8. Fish transit time (in hours) from Mossdale to the bubble curtain at the head of Old River.					
Fish Release Number	**Minimum**	**Maximum**	**Average**	**Std Dev**	**Median**
3 (N=94)	2.0	50.1	7.0	8.1	4.7
4 (N=61)	1.6	81.6	8.8	12.3	5.1
5 (N=86)	1.6	19.2	4.4	3.1	3.4
6 (N=51)	1.3	14.5	3.9	2.4	3.4
7 (N=82)	1.8	13.1	4.2	2.1	3.6
Overall (N=374)	1.3	81.6	5.7	6.9	3.9

The remaining reaches where sufficient numbers of tags were detected at downstream receivers for meaningful comparative purposes were: 1) on the San Joaquin River from the DWR Lathrop gage [SJO(n)] to the receiver positioned at the USGS gage in Stockton [STP(s)]; and 2) from the receiver positioned at the Middle River flow split off Old River [OM(fs)] to the receivers placed at the Tracy Fish Facilities and the Clifton Court Forebay gates [CVP(ne), CVP(sw), CCG(e), combined] (refer to Figure 2 for locations). Fish transit times from Lathrop to Stockton (a distance of 11.4 river miles) averaged approximately 48 hours (approximately 0.2 MPH) with some fish migrating in unusually rapid or long times (Figure 10 and Table 9), the latter of which may have actually been predatory fish which had eaten the acoustic-tagged salmon. Notably, that river reach was under strong tidal influence during the study period which would be expected to result in slower downstream net fish movement. Fish movements from the receiver in eastern Old River to the entrance of the Tracy Fish Facilities and Clifton Court Forebay (a distance of 11.8 miles) averaged a little over a day (Figure 11 and Table 10) (approximately 0.4 MPH). Based on flow records from the DWR flow station in eastern Old River, this reach experienced positive (westerly) flow conditions during the study period. Again, some fish migrated the distance through Old River and Grant Line Canal in both very rapid and very long times (Table 10) which may have been tags inside predators.

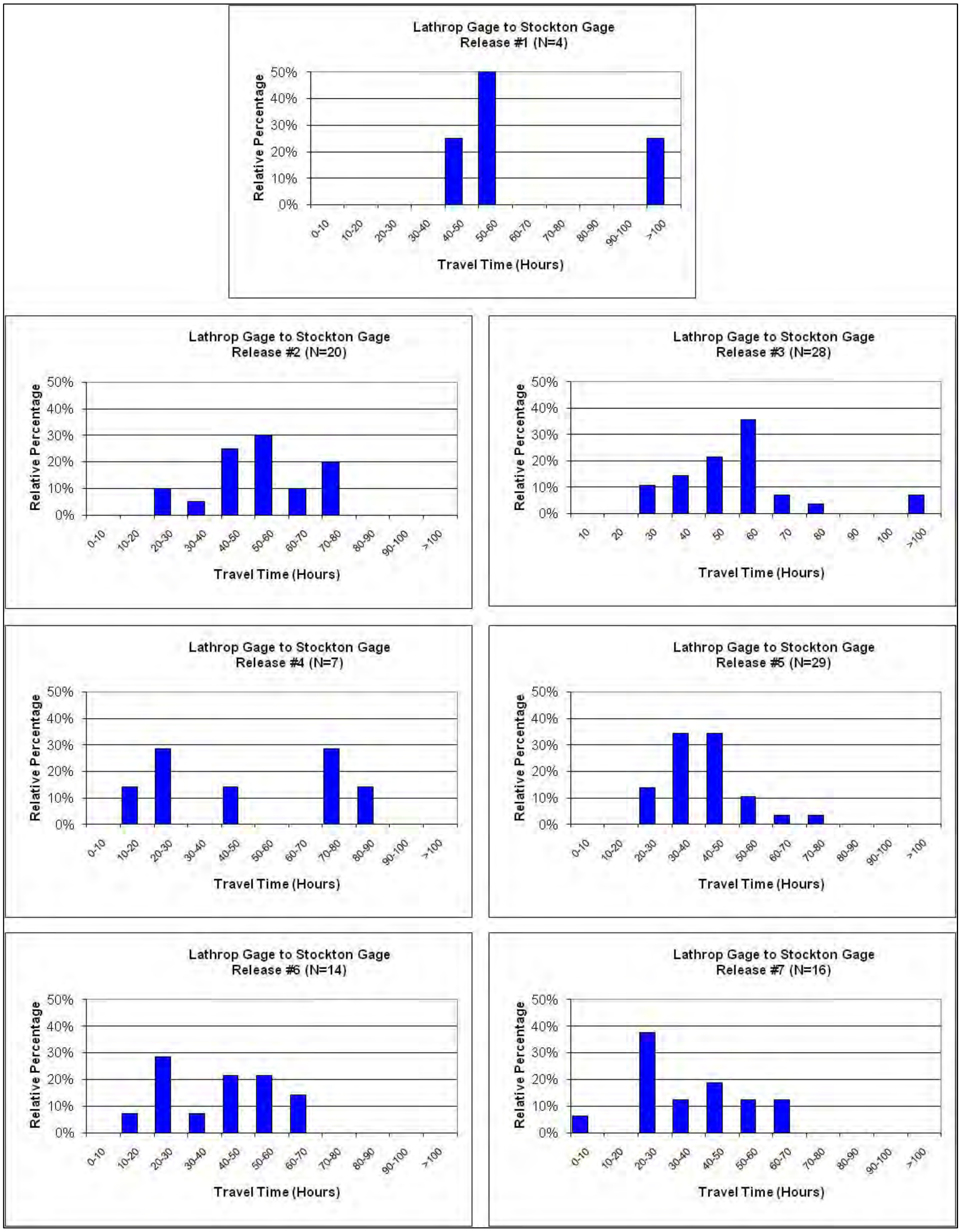

Figure 10. Travel time in hours for acoustic-tagged fish to move between the Lathrop gage [SJO(n)] and the Stockton gage [STP(s)] on the mainstem San Joaquin River.

Table 9. Fish transit time (in hours) from the Lathrop gage [SJO(n)] to the Stockton gage [STP(s)].					
Fish Release Number	**Minimum**	**Maximum**	**Average**	**Std Dev**	**Median**
1 (N=4)	47.0	179.0	82.6	64.3	52.3
2 (N=20)	24.0	79.8	52.7	15.7	51.2
3 (N=28)	28.9	125.0	52.8	22.9	50.2
4 (N=7)	10.2	85.7	48.7	29.9	40.8
5 (N=29)	22.5	70.3	41.9	11.8	41.3
6 (N=14)	11.1	64.0	41.6	15.3	47.0
7 (N=16)	9.7	64.0	38.3	14.6	37.9
Overall (N=118)	9.7	179.0	47.6	21.8	47.8

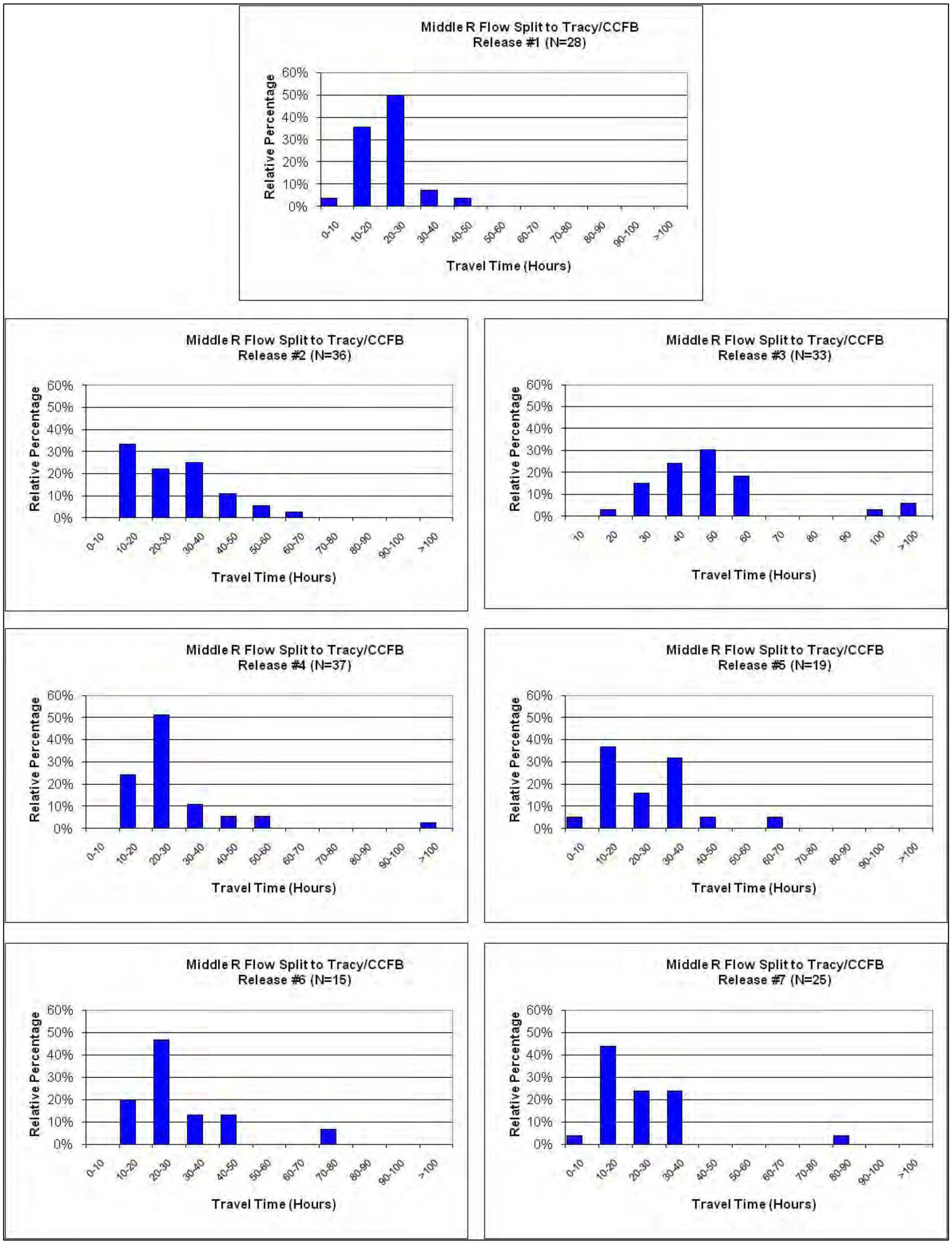

Figure 11. Travel time in hours for acoustic-tagged fish to move between the Middle River/Old River flow split [OM(fs)] to the receivers placed at the Tracy Fish Facilities trash racks [CVP(ne) and CVP(sw)] and near the entrance to the Clifton Court Forebay gates [CCG(e)] (combined).

Table 10. Fish transit time (in hours) from the Middle River flow split [OM(fs)]to Tracy FF/CCFB [CVP(ne), CVP(sw), CCG(e) (combined)].					
Fish Release Number	**Minimum**	**Maximum**	**Average**	**Std Dev**	**Median**
1 (N=28)	9.3	41.2	21.7	6.9	21.2
2 (N=36)	14.7	64.9	30.4	13.3	28.1
3 (N=33)	19.1	110.6	46.1	21.1	41.1
4 (N=37)	13.6	170.4	30.0	25.7	24.2
5 (N=19)	7.1	65.5	27.7	14.3	28.6
6 (N=15)	17.7	72.6	29.6	14.8	22.6
7 (N=25)	9.3	86.7	25.2	15.6	20.5
Overall (N=193)	7.1	170.4	30.7	19.0	26.1

Problems with Sole Reliance on Tag Detections

Unlike survival studies in rivers where unidirectional flow is the norm, there are several scenarios in the Delta where sole use of assumed tag detections at the acoustic receivers would result in erroneous conclusions on estimated fish survival, fish route selection at key Delta flow splits, and fish transit timing; all have potentially serious consequences on study results. One circumstance can arise when an acoustic signal is recorded on the receiver and is assumed, during data processing, to be a specific tag code from an acoustic-tagged smolt but, instead, is an incorrect tag code. In the Delta, with the large amount of highly variable and abundant background acoustic noises, much of that interference can be recorded within the detection range of an acoustic receiver. In particular, if the background noise is within the general acoustic frequency of the acoustic tags used for the study, the noise may result in misidentification of a tag code detected at a receiver. According to HTI, many of the commonly used boat depth sounders and electronic “fish finders” use frequencies in ranges relatively close to the fish transmitter frequency.

Another scenario occurs during manual data processing where there may be instances of a valid tag recorded on a receiver, but the tag code is misinterpreted as a different tag code than the true tag code. This situation can occur when two tags have very close repetition rates (e.g., within one millisecond such as repetition rates of 5,016 milliseconds versus 5,017 milliseconds). Querying sub-codes in the *MarkTags®* program during data processing is used to verify the true tag codes to eliminate a false positive detection. After manual data processing, a QA/QC exercise is used to examine sequential occurrences of specific tag detections between receivers deployed throughout the Delta to help identify those instances where some tag codes have been misidentified. This procedure requires examining the tag history recorded at all receivers detecting specific tags which may reveal improbable results of an acoustic-tagged fish moving unlikely distances over unrealistic times. An example would be a tag observed moving sequentially past upstream to downstream receivers, then suddenly being detected minutes later at an upstream receiver dozens of miles from the previous downstream receiver.

The last and probably most serious, common problem arises when a true valid tag code is detected by a receiver, but the tag is emanating from a dead acoustic-tagged salmon smolt (or the transmitter) inside a predator and not from a live smolt. Perhaps most importantly for the VAMP study, manual processing allows better ability to evaluate fish behavior and fish movements within range of the hydrophone (near-field observations) using the *MarkTags*® graphical page view format. Through detailed analyses, this technique may help to see if the tagged salmon has been preyed upon. This circumstance has become increasingly important in the Delta acoustic telemetry studies where small test fish may be subsequently preyed upon and telemetry data can be misinterpreted.

Evaluation of Assumed Predation on Acoustic-Tagged Salmon

It is a challenge to differentiate a live acoustic-tagged salmon versus a dead acoustic-tagged salmon inside a predatory fish (e.g., striped bass). In both instances, the acoustic signal gets recorded by the data loggers, but the equipment cannot discriminate between the two scenarios. If a tagged salmon is consumed by a predatory fish, then swims past a data logger, this will bias salmon survival estimates high because, at present, we have no way of knowing that the signal was not transmitting from inside a live salmon. This is a technical concern that Natural Resource Scientists, Inc. has frequently described to the VAMP Biology Committee since conducting the first VAMP acoustic telemetry study in 2006. Given the present limited technological capabilities, recent data suggest that resolving this problem will be complex and difficult to accurately estimate salmon survival and avoid biased estimates.

A unique exception to this problem occurs when a predator consumes more than one acoustic-tagged salmon and all the acoustic signals from the predator's stomach are recorded as the predator swims past the data logger(s). However, this phenomenon is not easy to detect using solely the single-hydrophone receivers deployed for the VAMP study. It was first discovered during experiments Natural Resource Scientists, Inc. conducted on the Sacramento River in 2005 (Vogel 2006b). In a study to determine juvenile salmon migration rates, we released individually identifiable acoustic-tagged juvenile salmon at different times and locations. In these experiments, we used a very rapid repetition or "ping" rate of around once per second but with slightly different pulse rates so each fish could be logged separately on the downstream acoustic receivers. During manual post-processing we noticed that three salmon, released at different times and locations, arrived at the downstream data logger at the same time (to the nearest second). Based on the high precision observed in changes in amplitude and voltage of each transmitter during data processing, we determined that it was impossible for the three salmon to move in perfect unison for long periods and, therefore, it was obvious all three salmon were inside a predator (probably a striped bass). Subsequently, all the data were re-examined and we found that among 16 acoustic-tagged salmon released, all had been preyed upon. In one instance, five acoustic-tagged salmon were detected inside one predator (again, probably a striped bass). Initially, we had presumed 100% fish survival based solely on detections by the acoustic receivers, whereas in reality, it was 100% mortality (Vogel 2006b). HTI considered this discovery of detecting multiple predation events groundbreaking (Bruce Ransom, HTI, pers. comm., November 4, 2005). Normally, this phenomenon would not be detected during data processing because confirmed detection of each tag is determined from separate, unrelated computer screen views; it was only because we were studying fish transit time to the nearest second that prompted further detailed examination of the data. We therefore determined that, under certain circumstances, a unique feature of the acoustic telemetry technology allowed detection of predation events (Vogel 2006c, 2007a).

This problem with predation in interpreting juvenile salmon telemetry results was also observed during radio-tag studies of juvenile salmon in the Delta. Over the course of numerous studies conducted in the north, central, and south Delta, certain "behavior" patterns emerged indicating that some of the radio-tagged salmon (tracked using boat-mounted mobile receivers) were likely inside predators. Some of the indicators of probable predation included: abrupt change (decline) in radio tag transmission signal strength, signal remaining consistently attenuated, a sudden change in behavior in comparison to prior observations of the same tag or other radio-tagged fish (e.g., moving with strong currents then abruptly moving for extended distances against the current), or a radio tag remaining in the exact same location where a juvenile salmon would not be expected to maintain position for such a long duration (e.g., mid San Joaquin River Deep Water Shipping Channel) (Vogel 2004). However, for an acoustic-tagged salmon eaten by a predator, the signal does not change or attenuate (at least with the present capabilities in data processing). Abrupt changes in behavior and stationary positioning for extended periods have been observed during recent acoustic-telemetry studies, but are not as easily detected with the fixed-station receivers used during the VAMP studies. Exceptions occur when the initial predator activity or tag detection occurs within the detection range of the receiver and graphical displays of tag movements provide insights into changes in fish behavior (near-field observations).

This problem is not significant in the Columbia River where acoustic telemetry studies to estimate juvenile salmon survival are commonly conducted. In that riverine environment, flow is unidirectional and the predators are more stationary in their local habitats, unlike the Delta with complex, multi-directional flows and highly migratory and very abundant predators such as striped bass. For example, during the 2008-2009 north Delta acoustic telemetry study, one of the striped bass Natural Resource Scientists, Inc. tagged with an acoustic transmitter in northern Cache Slough near Miner Slough was later caught by an angler in the Napa River. This acoustic-tagged striped bass had migrated downstream a distance of more than 50 miles through the Delta. Additionally, during the 2008 VAMP study, a striped bass we tagged with an acoustic transmitter in the south Delta was later detected more than 20 miles further north in Three-Mile Slough. Additional examples are provided later in this report.

During initial examination of the data obtained from the VAMP acoustic receivers deployed in 2009, it became apparent, in numerous instances, that we were likely recording and tracking dead acoustic-tagged salmon, or the transmitters, inside predatory fish. Evidence of this same phenomenon, using evaluations of two-dimensional fish movements, occurred during the study at the head of Old River bubble curtain (Bowen *et al*. 2009). We had the unique opportunity to utilize the results of the evaluation of the fish behavior barrier at the head of Old River to assist in interpreting results of the VAMP study (discussed below).

Evidence of Predation at the Bubble Curtain at the Head of Old River

Concurrent with the 2009 VAMP experiment, a simultaneous evaluation of the non-physical fish behavioral barrier at the head of Old River was conducted. The original concept for a potential fish behavioral barrier at this location was proposed as a bubble curtain positioned diagonally across the Old River flow split (Vogel 2009) just upstream from where a prior physical barrier was seasonally installed. The proposal was subsequently modified to include the use of bubble, lights, and sound as a potential behavioral fish barrier. The original proposed method of evaluating the effectiveness of the barrier was to utilize the single-hydrophone, fixed-station receivers positioned downstream of the Old River flow split in Old River and the San Joaquin River for the VAMP experiments, and adding another single-hydrophone receiver positioned just upstream of the barrier to detect passage of acoustic-tagged smolts released for the VAMP study. Upon further review, Natural Resource Scientists, Inc. recommended installation of a four-port acoustic receiver in the vicinity of the barrier which would allow detailed observations of acoustic-tagged fish movements in a two-dimensional (2-D) perspective, as well as determination of fish route selection. This proposal was accepted by the VAMP Biology Committee and Natural Resource Scientists, Inc. and HTI staff subsequently installed the four-port unit at the head of Old River on April 20, 2009. DWR was responsible for installation and removal of the barrier and USBR was responsible for the evaluation of the barrier. A report on the effectiveness of the barrier is provided by Bowen *et al*. (2009).

During the evaluation of the behavioral barrier using the four-port acoustic receiver, certain behavior patterns of acoustic-tagged fish movements convinced researchers that some fish were not live acoustic-tagged salmon, but instead, dead acoustic-tagged salmon inside a predatory fish's stomach. A description of these patterns is provided in Bowen *et al*. 2009. In addition to use of the 2-D tracking of fish movements, USBR researchers concurrently employed the use of a dual-frequency identification sonar (DIDSON®) camera to monitor fish movements in the vicinity of the barrier. The combination of these two techniques provided the ability to study differences in juvenile salmon and predatory fish movements and behavior. USBR contracted with the acoustic equipment vendor, HTI, to assist in evaluating the results. They provided those data to Natural Resource Scientists, Inc. and we used the information to assist in interpretation of the VAMP data.

Of those VAMP tags detected at the fish behavioral barrier, Table 11 provides the numbers of tags believed to be live smolts, dead smolts (or the transmitters) inside predators, or the fate of the fish could not be estimated (unknown category) for all seven VAMP fish releases. Based on these evaluations, predation on the VAMP acoustic-tagged salmon was severe (nearly 50%). However, it could not be determined where the acoustic-tagged salmon had been preyed upon.

Table 11. Acoustic tag detections with the four-port receiver at the bubble curtain at the head of Old River. Data provided by Mark Bowen, USBR.				
Fish Release No.	**No. of fish believed to be live salmon**	**No. of fish believed to have been preyed upon**	**Status of fish could not be estimated**	**Total**
1	31 (44%)	16 (23%)	24 (34%)	71
2	27 (28%)	49 (50%)	22 (22%)	98
3	17 (16%)	59 (55%)	31 (29%)	107
4	11 (15%)	40 (55%)	22 (30%)	73
5	17 (19%)	49 (54%)	25 (27%)	91
6	19 (37%)	19 (37%)	14 (27%)	52
7	18 (21%)	47 (56%)	19 (23%)	84
Total	140 (24%)	279 (48%)	157 (27%)	576

We used these data, in part, to subsequently estimate whether or not a tag detection at a VAMP receiver, *after detection at the barrier four-port receiver*, was a dead salmon (or the transmitter) in a predator. In other words, if the tag was assumed to be preyed upon based on the four-hydrophone receiver, 2-D fish tracking evaluations, and then later detected at a VAMP receiver, it was also assumed to have been preyed upon. This was one method used in the analyses.

Evidence of Predation from Evaluation of VAMP Fixed-Station Acoustic Receiver Data

Using "Near-Field" Observations

During manual data processing, we had the exceptional ability to examine subtle movements of acoustic-tagged fish in detection range of all the fixed-station receivers we deployed throughout the Delta. These "near-field" observations were used to study the movements of acoustic-tagged fish within detection range of each hydrophone. Whereas the classical use of detections to determine potential fish survival estimates uses basic tag presence/absence among acoustic receiver arrays, we utilized an enormous amount of additional detailed data on acoustic tag movements at each receiver in the VAMP array.

All detectable coded acoustic signals emanating from an acoustic tag within range of a fixed-station receiver (Figure 12) are recorded in electronic files for subsequent detailed processing and analyses. Besides simple presence/absence data, the files also record several parameters important for evaluating fish behavior in the vicinity of the submerged hydrophone. For example, detailed analysis during manual data processing can show a Doppler-type effect with fish movement from an upstream to downstream direction (Vogel 2006d). With sustained movement of the acoustic-tagged salmon approaching the receiver, it takes less time for the sound pulses (pings) to reach the receiver as compared to immediately prior upstream locations. After the fish moves past the site, it takes a longer time for the sound pulses to reach the receiver. This phenomenon results in the inverted "V" appearance on the software display with the peak signifying the closest proximity of the acoustic tag to the hydrophone (Figure 13). Additionally, the software display not only shows readily apparent changes in amplitude, but also specific changes in voltage via a color gradation with the highest voltage signifying the tag's closest proximity to the hydrophone (Figure 13). As described below, use of these detailed data, with proper processing and analyses, can reveal subtle or dramatic movements of acoustic-tagged fish within detection range of each acoustic receiver.

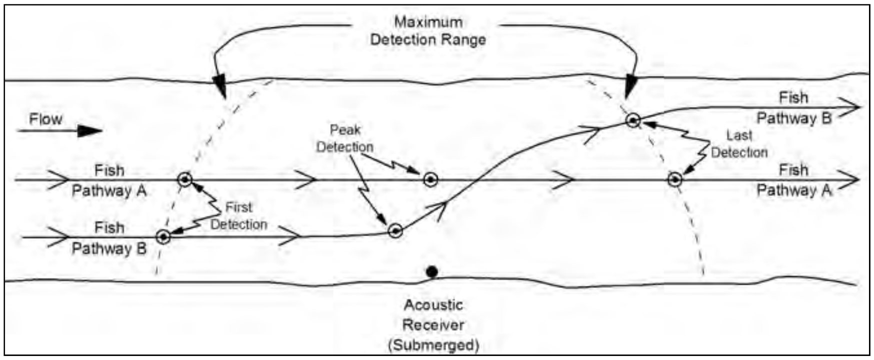

Figure 12. Plan-view schematic of two hypothetical fish migration pathways showing maximum and peak detection ranges (Figure from Vogel 2006d).

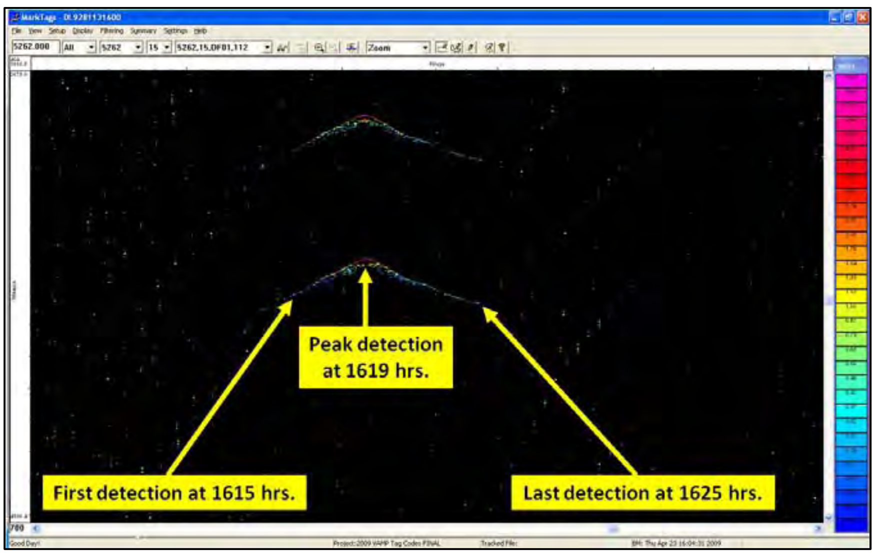

Figure 13. Magnified data processing display of the movement of acoustic tag no. 5262.15 past the acoustic receiver placed in Old River just downstream of the San Joaquin River flow split and identification of times of first detection, peak detection (closest proximity to the receiver's hydrophone), and last detection on April 23, 2009. Display shows Doppler-type fish movements from an upstream to downstream direction and changes in magnitude of voltage. The second, nearly identical inverted "V" is the programmed double pulse (sub-code) emitted from the tag.

The following provides examples of the types of telemetry data we evaluated and characterization of acoustic tag pulses acquired by the receivers. We provided training and insights to DWR staff on how to similarly process the data manually for their south Delta barriers pilot acoustic telemetry study.

This first example (classified as "code 1") shows detection data for an acoustic tag passing a receiver with a relatively uniform rate of speed from an upstream to downstream direction (Figure 14). The tag passage exhibits the Doppler-type signature past the hydrophone previously described. Using the time-stamp feature of the software, the detected movement past the hydrophone is generally less than 30 minutes from time of first to last detection. This type of movement is commonly displayed from acoustic-tagged salmon smolts passing through the Delta moving in the direction of flow (positive downstream movement with the ebb tide or river flow or reverse upstream movement with the flood tide).

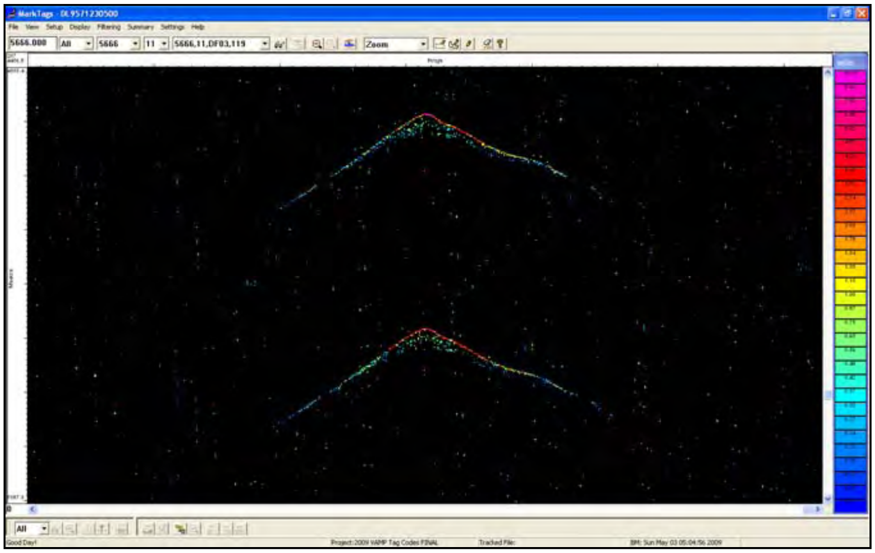

Figure 14. Magnified data processing display of the movement of an acoustic tag passing an acoustic receiver's hydrophone exhibiting relatively rapid, uniform movement. Time increments in seconds are left to right on the X axis.

The second example shows an acoustic tag exhibiting the classic, uniform movement past a receiver's hydrophone, but differs from code 1 only due to slower (but still relatively uniform) movement past the hydrophone (Figure 15). Such a phenomenon would be expected from a salmon smolt moving past a hydrophone under slower water velocities than a smolt exhibiting movements for code 1. This example was designated "code 2" if detected for more than 30 minutes from time of first to last detection within range of a receiver.

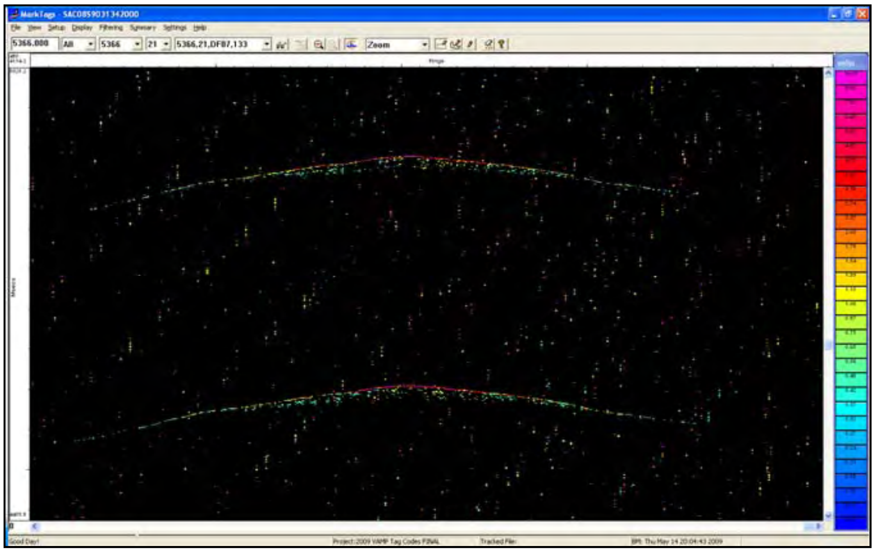

Figure 15. Magnified data processing display of the movement of an acoustic tag past an acoustic receiver's hydrophone exhibiting relatively slow, uniform movement.

Example 3 shows an acoustic tag movement considerably more complex than the first two examples. In this instance, classified as "code 3", the acoustic tag exhibits more erratic, non-uniform movements such as moving closer to, away from, then back toward the hydrophone over an extended period of time (Figure 16). There were many variations of this pattern observed among the acoustic telemetry data collected during the study. This type of fish behavior would generally be considered to be uncharacteristic for a salmon smolt in a location where strong positive flow conditions are present. The behavior could indicate a predator had eaten the acoustic-tagged salmon depending on the duration of erratic movements in relation to localized flow conditions and other factors. Alternatively, if the hydrophone was placed in the vicinity of good juvenile salmon rearing habitat, this behavior could signify a salmon taking up temporary residency (rearing behavior) in the area of the hydrophone. However, the VAMP study design assumes that the tagged fish are smolts and instinctively migrate downstream to the estuary and ocean. It must be emphasized that a code 3 would not necessarily signify predation because of the many variations observed during data processing. There are other critical issues to consider beyond just the "acoustic signature" of the data display to estimate predation discussed later in this report (e.g., evaluation of site-specific biological and hydrodynamic factors). There were many instances, after detailed analyses, a code 3 was not assumed to represent predation.

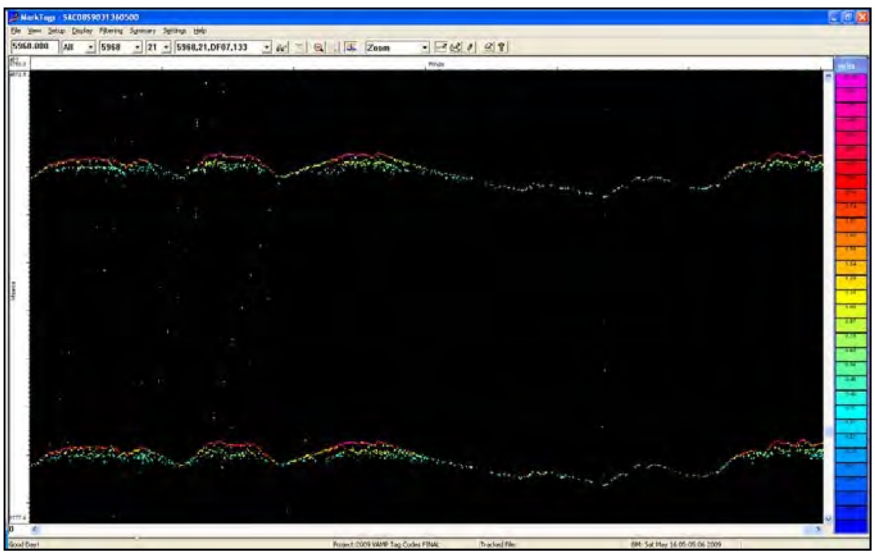

Figure 16. Magnified data processing display of the movement of an acoustic tag and exhibiting relatively erratic movements within detection range of an acoustic receiver's hydrophone.

The last example, termed a "code 4", shows a definitive pattern of no tag movement at all (Figure 17). In this instance, the pattern signifies one of three possible scenarios: 1) the acoustic-tagged fish is dead and immobile, 2) an acoustic-tag salmon had been eaten by a predator and the tag was subsequently defecated, or 3) the tag is inside a predator which remains motionless for an extended period [e.g., white catfish (*Ameiurus catus*)]. Natural Resource Scientists, Inc. used this latter characteristic display of non-movement of an acoustic tag (code 4) to discover 116 motionless tags in the lower San Joaquin River near Stockton during the 2007 VAMP study (Vogel 2007b).

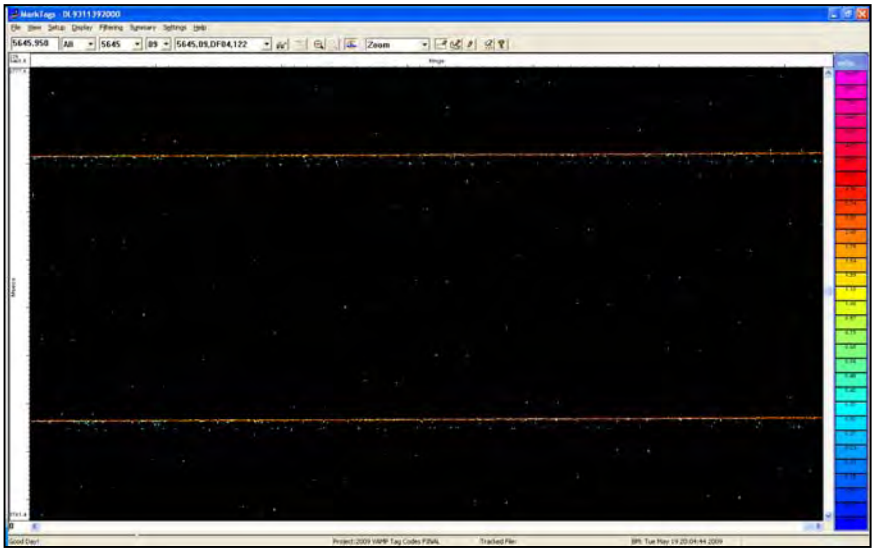

Figure 17. Magnified data processing display of the movement of an acoustic tag exhibiting no movements within detection range of an acoustic receiver's hydrophone.

This process was meticulous and time consuming. There were more than *five million* direct visual examinations of the "page-view" displays during data post-processing to begin the evaluation of "near-field" observations of acoustic tag movements near each hydrophone. In addition to detailed analyses of the detection patterns recorded at each receiver, we kept track of the time an acoustic-tagged salmon remained within the detection range of a receiver for up to a six-hour continual duration to assist in interpretation of fish behavior for near-field observations. If there were breaks in the continuity of detection and the tag subsequently reappeared within the hydrophones detection range, the process repeated for up to another continuous six hours, and so on.

<u>Using "Medium-Field" Observations</u>

However, and very importantly, localized flow conditions (magnitude and direction) can rapidly change over time in the tidally-dominated Delta and can result in significant changes in fish movements. The comparison of juvenile salmon telemetered movements on a micro- and macro-scale with detailed flow data has provided valuable insights on fish behavior in other studies in the Delta (e.g., Vogel 2003a, 2003b, 2005b). Therefore, we also examined the detailed acoustic tag movements at the fixed-station receivers in relation to fine-scale flow measurements at nearby DWR or USGS flow gaging stations. Table 12 provides the Delta flow stations used to evaluate fish movements in nearest proximity to the VAMP receivers. Because the acoustic receivers provide a time stamp of acoustic tag detections and our data analyses provided the time to the nearest minute when each identifiable acoustic tag was in closest proximity to the receivers' hydrophones, we were able to relate the passage to the nearest 15-minute flow value for comparisons.

Table 12. Delta flow stations used to analyze fish behavior during the 2009 VAMP acoustic-telemetry study.			
Flow Station	**Station ID**	**Operator**	**Location (Latitude/Longitude)**
San Joaquin River at Mossdale Bridge	MSD	California Department of Water Resources	37.7860°N, -121.3060°W
Old River at Head	OH1	California Department of Water Resources	37.8080°N, -121.3290°W
San Joaquin River below Old River near Lathrop	SJL	California Department of Water Resources	37.8100°N, - 121.3230°W
San Joaquin River at Garwood Bridge	SJG	U.S. Geological Survey	37.9350°N, - 121.3290°W
Turner Cut near Holt	TRN	U.S. Geological Survey	37.9928°N, - 121.4542°W
San Joaquin River at Prisoners Point near Terminous	PRI	U.S. Geological Survey	38.0594°N, - 121.5572°W
Old River at Highway 4	OH4	U.S. Geological Survey	37.8911°N, -121.5692°W

An initial comparison was made of fish movements between the first two detection sites in very close proximity (head of Old River four-port receiver) to both Old(e) (2,000 feet) and SJO(n) (1,500 feet) to compare fish migration rates with the nearest 15-minute increment of an index of channel velocity (medium-field observations). Although these channel index velocities measured at each flow station are unlikely to accurately reflect ambient water velocities at specific fish positions in the water column, those data provide an indication of the localized flow conditions the fish encounter when present near the stations. For example, fish migration rates between the head of Old River and SJO(n) indicated generally slower movement than index channel water velocities (Figure 18). Similarly, earlier studies in the north Delta suggested that juvenile salmon may move slightly slower than ambient water velocities (Vogel 2003b) as did a study of juvenile salmon movements in the south Delta (Vogel 2002a). However, no clear pattern for fish migration rates was evident between the head of Old River and the receiver placed at Old(e) (Figure 19). Several circumstances may account for these phenomena. Fish moving from the head of Old River to SJO(n) encounter a complexity of flow conditions in the deep scour hole and unnatural sharp river bend which may affect their migration rate, whereas fish moving down Old River encounter more-uniform flow conditions. Additionally, many of the fish migration rates estimated for each reach may have actually been predatory fish that had consumed acoustic-tagged salmon. The complex predator/prey and fish/flow interactions at this site warrant further examination for future studies.

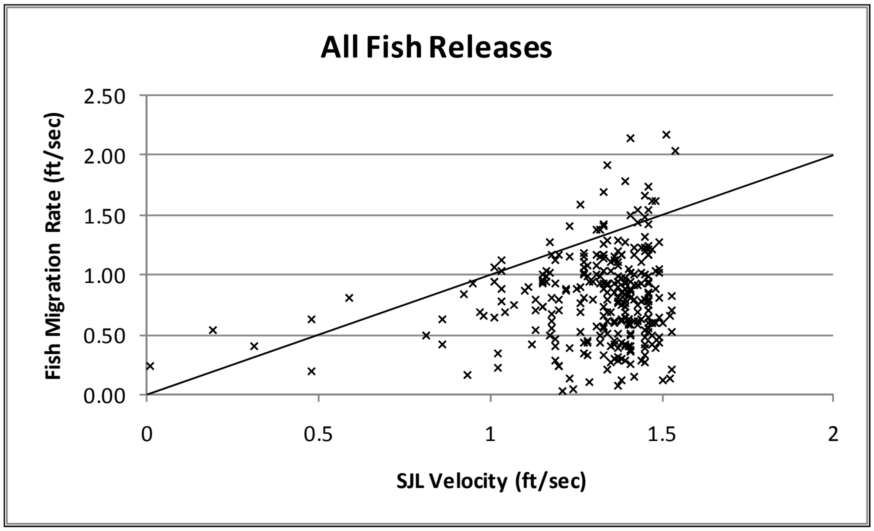

Figure 18. Comparison of fish migration rates (ft/s) between the head of Old River and the receiver positioned in the San Joaquin River [SJO(n)] 1,500 feet downstream of the head of Old River with channel index water velocities (ft/s) measured at the DWR Lathrop gage (SJL). Only data of positive downstream flow conditions were used for the comparisons to eliminate effects of tide reversals. Diagonal line shows equal values.

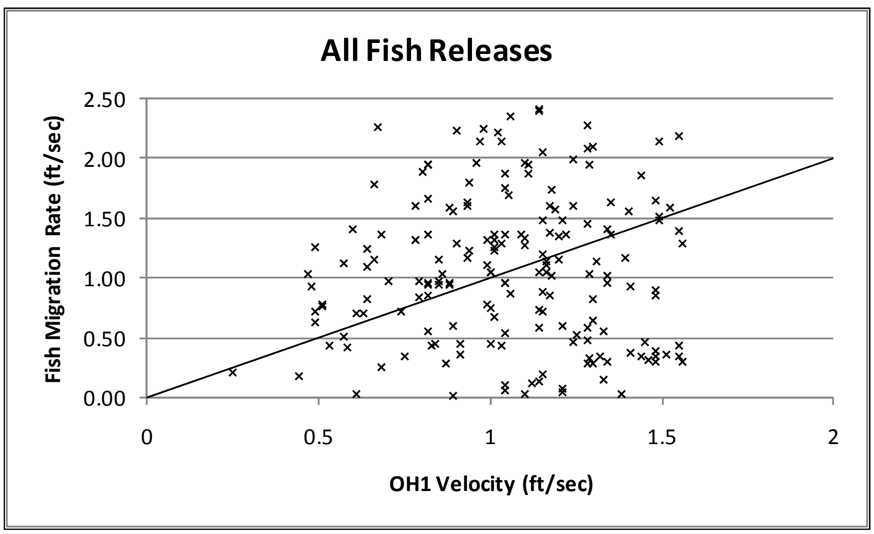

Figure 19. Comparison of fish migration rates (ft/s) between the head of Old River and the receiver positioned in Old River 2,000 feet downstream of the head of Old River [OLD(e)] with channel index water velocities (ft/s) measured at the DWR Old River gage (OH1). Only data of positive downstream flow conditions were used. Diagonal line shows equal values.

Using "Far-Field" Observations

We also integrated detailed analyses of individual transit times of acoustic tags between receiver locations throughout the VAMP acoustic telemetry array to evaluate fish behavior (far-field observations). For this portion of the analyses, we developed an exhaustive, spatiotemporal history for each tagged fish and included analyses of flow conditions in relation to fish transit timing. Those far-field data also provided information on potentially aberrant fish movements.

The analytical techniques utilizing near-field, medium-field, and far-field observations were elaborate, time-consuming, and painstaking, but yielded a large amount of useful biological information that would have not otherwise been developed. Additionally, knowledge acquired from hundreds of observations made during prior acoustic telemetry studies in the Delta and Sacramento River (e.g., Vogel 2008, 2006a, 2006b, 2006d) and radio-tagged salmon studies in the Delta were incorporated into the analyses of fish behavior. This combination was ultimately used to estimate if the acoustic tags were in live salmon smolts, acoustic tags inside predators (originating from acoustic-tagged salmon), or immobile transmitters. The following were commonly observed characteristics where it was believed acoustic-tagged salmon had been preyed on by predatory fish.

- Tags moving against the localized flow conditions (e.g., moving upstream against an outgoing tide or opposite direction from the positive river flow (near-field and medium-field observations).
- Tags moving erratically for sustained periods (e.g., hours) in a channel with strong positive flow (near-field observations).
- Tags moving erratically for extended periods (e.g., hours or days) at locations known to harbor large numbers of predatory fish and in locations of unfavorable juvenile salmon habitat (e.g., in the vicinity of the Mossdale bridge piers and in front of the trash racks at the Tracy Fish Facilities) (near-field observations).
- Long tag transit times between receivers positioned in very close proximity (medium-field observations).
- Tags moving in and out of range of receivers, but remaining in a general location for extended periods (e.g., days near the receivers near the Stockton Waste Water treatment plant and Navy Bridge) (medium-field observations).
- Tags exhibiting movement patterns very similar to those observed from acoustic-tagged predatory fish (e.g., striped bass) (near-field and medium-field observations).
- Tags moving sequentially in the direction of flow, then abruptly changing direction and moving against the flow (medium-field and far-field observations).
- Tags moving over long distances very rapidly or very slowly compared to the majority of other tag detections (far-field observations).

Table 13 provides a comparison of the two independent techniques to estimate predation among the detections within the VAMP acoustic telemetry array:

1) Incorporating estimates of predation from the evaluations conducted at the bubble curtain at the head of Old River using the four-port (2-D receiver); and

2) Evaluation of near-, medium- and far-field observations of acoustic tag movements from the single-port receivers for the VAMP study to evaluate fish behavior.

Table 13. Numbers of acoustic-tagged salmon believed to have been preyed upon during the 2009 VAMP study using two independent methods described in the report. Estimated numbers of salmon preyed upon (red and blue numbers) are compared to total numbers of VAMP tags detected at each receiver site[1] throughout the Delta. Method A[2] (red numbers): Evaluation of the bubble curtain at the head of Old River using the four-port (2-D) receiver and Method B (blue numbers): near-, medium-, and far-field observations from the VAMP single-port fixed station receivers deployed throughout the Delta. Refer to Figure 2 for receiver locations.

Receiver Location	Release 1			Release 2			Release 3			Release 4			Release 5			Release 6			Release 7			Overall		
	Tags	A	B	Tags	A	B	Tags	A	B	Tags	A	B	Tags	A	B	Tags	A	B	Tags	A	B	Tags	A	B
SJO(s)	74		3	106		6	114		34	82		15	106		24	68		33	103		43	653		158 (24%)
SJO(n)	18	6	2	33	20	7	52	38	27	26	21	8	47	37	8	22	12	8	37	28	19	235	162 (69%)	79 (34%)
STP(s)	9	4	2	20	11	4	41	30	24	21	17	9	33	28	9	14	8	8	25	20	14	163	118 (72%)	70 (43%)
STP(n)	9	4	2	19	10	5	41	30	27	20	16	12	29	26	9	14	8	10	22	17	15	154	111 (72%)	80 (52%)
SJT(se)	3	1	2	0	0	0	7	4	4	8	7	4	0	0	0	0	0	0	0	0	0	18	12 (67%)	10 (56%)
SJT(nw)	3	1	2	0	0	0	6	4	4	7	6	5	0	0	0	0	0	0	0	0	0	16	11 (69%)	11 (69%)
TRN(ne)	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1 (100%)	1 (100%)
TRN(sw)	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1 (100%)	1 (100%)
OLD(e)	52	10	10	65	29	25	54	20	24	46	19	12	43	12	15	31	7	17	38	15	15	329	112 (34%)	118 (36%)
OM(fs)	48	9	14	58	26	26	48	18	23	42	18	12	36	10	16	31	7	19	37	15	17	300	103 (34%)	127 (42%)
MID(nu)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MID(nd)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CVP(ne&sw)	11	2	8	25	13	21	26	10	20	19	8	17	8	3	7	4	1	2	20	10	16	113	47 (42%)	91 (81%)
CVP(tank)	3	2	0	3	1	0	6	3	0	1	0	0	0	0	0	2	0	0	4	3	0	19	9 (47%)	0 (0%)
CCG(e)	26	5	14	22	9	10	26	8	13	29	15	16	21	6	8	13	1	8	16	9	7	153	53 (35%)	76 (50%)
CCG(w)	7	2	6	7	2	5	7	1	7	13	5	13	4	0	4	6	0	6	3	2	3	47	12 (26%)	44 (94%)
OLD(nu&nd)	6	1	5	3	2	3	2	1	2	1	1	1	3	1	3	4	1	2	0	0	0	19	7 (37%)	16 (84%)

[1] Includes those tags passing a site undetected but subsequently detected at a site further downstream.
[2] Method A assumes that once fish were believed to be preyed upon at the head of Old River, those same acoustic tags later detected at other downstream sites were also preyed upon salmon (i.e, the transmitters were inside a predatory fish swimming past the receiver).

The two independent methods differed in estimating where predation had already occurred. For example, in method "A", the four-port receiver evaluations estimated if an acoustic-tagged salmon had already been preyed upon at the time detailed observations were made at the head of Old River. In contrast, method "B" estimated predation using near-, medium-, and far-field observations based on fixed-station receivers throughout the VAMP telemetry array. In some instances, detections at multiple fixed-station receivers were required before there was sufficient confidence that an acoustic-tagged salmon had been preyed upon. Therefore, as expected, an increasing number of fish assumed to be preyed upon using method "B" was generally evident the further downstream from the head of Old River tags were detected in the VAMP array (particularly for fish entering Old River and moving in a westerly direction). This occurrence would be expected due to: 1) a longer time with more observations necessary to estimate predation and, 2) greater distances of fish movement and, therefore, greater opportunities for predation. If the two methods were combined, the estimated total numbers of salmon preyed upon would be larger for most VAMP receiver sites.

Both independent methods of analyses suggest that there was a very high level of predation on acoustic-tagged salmon during the VAMP program. These results are obviously not definitive, but provide compelling evidence of the magnitude of predation on acoustic-tagged salmon. The apparent very low survival is not surprising from the perspective of the estimated very high rate of predation on acoustic-tagged salmon. For example, earlier VAMP studies using coded-wire tagging on juvenile salmon showed extremely low recoveries of tagged fish in the western Delta (Table 14), but the reasons for the low survival were unexplained.

Table 14. Recovery information for coded-wire tagged Chinook salmon released during the 2004 VAMP study (SJRGA 2005) (Table from Vogel 2005a).

Release Site in the San Joaquin River	Number of Tagged Salmon Released	Number of Tagged Salmon Recovered at Antioch	Number of Tagged Salmon Recovered at Chipps Island
Durham Ferry	23,440	1	0
Durham Ferry	21,714	1	1
Durham Ferry	23,327	0	1
Durham Ferry	23,783	0	1
Mossdale	25,320	1	0
Mossdale	23,586	0	1
Mossdale	24,803	0	2

The 2009 study results also strongly indicate significant problems with the ability to accurately quantify salmon smolt survival rates through the Delta. Sole reliance on assumed passage of salmon past the VAMP receivers using simple presence/absence of acoustic tag transmissions could have resulted in incorrect conclusions on assumed fish survival and fish route selections. It also indicates that these issues must be adequately addressed before management decisions are made based on Delta juvenile salmon acoustic telemetry studies using solely presence/absence detection data.

Recommendations are provided at the end of this report on measures to improve the scientific integrity of future juvenile salmon telemetry studies in the Delta.

The Mossdale Bridges

It is apparent that a high level of salmon smolt mortality occurred in the general vicinity of the Mossdale Bridges and/or that a high level of smolt mortality occurred somewhere upstream of the bridges; predatory fish, having presumably consumed the tagged smolts, subsequently lingered in the vicinity of the bridges while the transmitters were still in the predators' stomachs. Detailed near-field observations of acoustic tag movements revealed that many fish remained within the detection range of the hydrophone for many hours under strong positive (downstream) flow conditions exhibiting the "code 3" pattern. Many of those fish ultimately moving further downstream and detected by either the four-port receiver at the head of Old River, the two fixed-station receivers just downstream in Old River, or at the Lathrop gage were believed to have been preyed-upon salmon. The combination of artificial structures in the river channel at Mossdale from the numerous bridge piers and nearby docks is probably one of the highest concentrations of structures in the Delta for such a confined area. Prior DIDSON® sonar camera footage taken by Natural Resource Scientists, Inc. in that locality also revealed a substantial amount of submerged false bridge work remaining on the riverbed and high concentrations of large fish believed to be striped bass or other predators near the artificial structures. The position of the hydrophone at the bridges did not provide complete coverage under all the bridge piers and could not detect tags approaching the bridges from upstream areas (Figure 20). As recommended later in this report, an additional receiver placed just upstream of the bridges would provide valuable data to evaluate fish behavior and potential predation in the vicinity of the bridge piers.

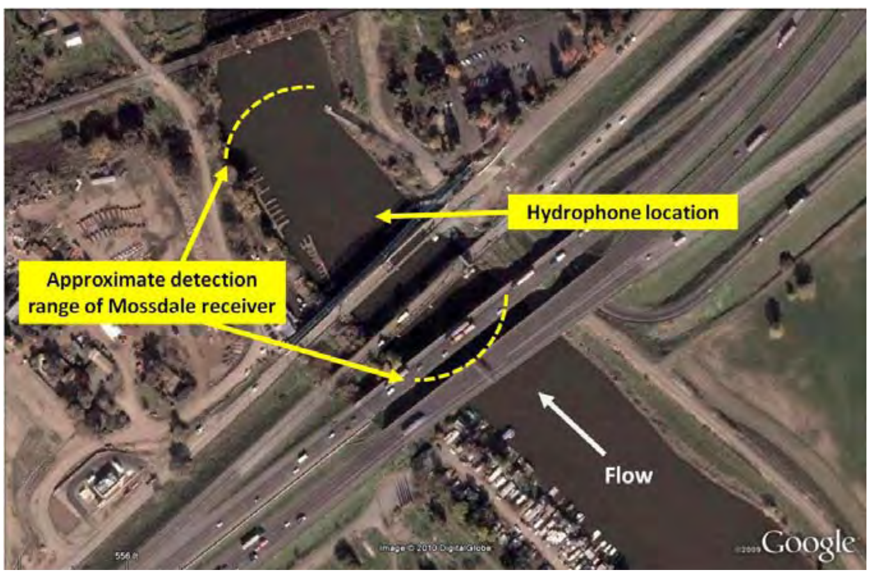

Figure 20. Aerial photograph of the San Joaquin River at the Mossdale bridges showing location of submerged hydrophone [SJO(s)] and estimated detection range of the acoustic receiver.

The Head of Old River

At the time Natural Resource Scientists, Inc. had proposed the installation and evaluation of a bubble curtain at the head of Old River (Vogel 2009), the projected flow conditions during the VAMP study period were unknown. It was assumed that flows in both Old River and the San Joaquin River downstream of Old River would be continuously positive in a downstream direction. However, this did not occur during the spring of 2009. Instead, tidally-induced reverse flow conditions in the San Joaquin River downstream of the Old River flow split were recorded, whereas the flow into Old River always remained positive during the VAMP study period (Figure 21).

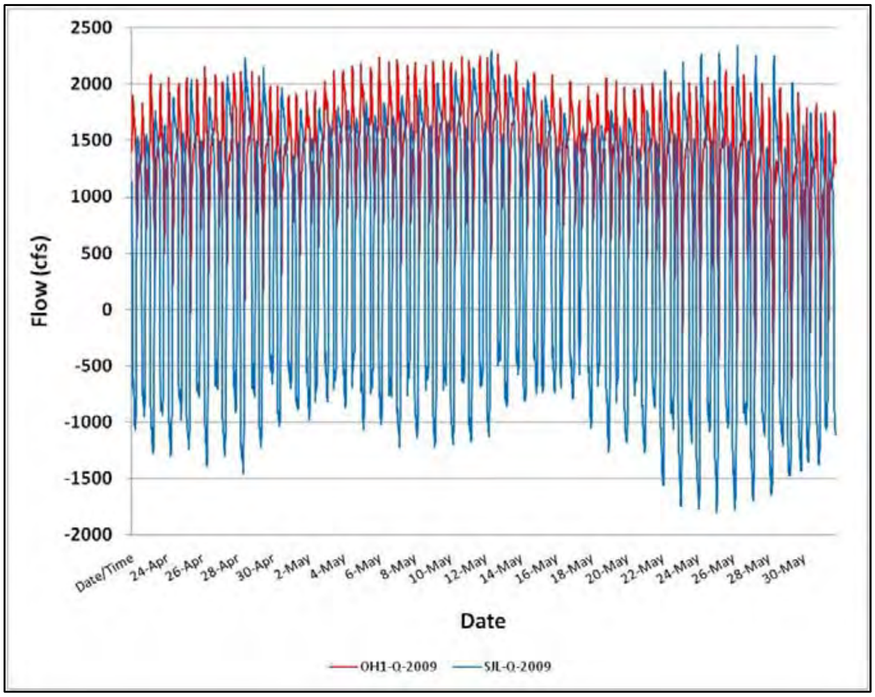

Figure 21. Flow (cfs) in 15-minute increments measured at the DWR flow stations at the head of Old River (OH1) and in the San Joaquin River just downstream of the Old River flow split (SJL), April 22 – June 1, 2009.

This type of flow condition did not occur during the 2007 VAMP study when the positive, rock barrier was installed at the head of Old River and San Joaquin River flow was higher (Figures 22 and 23). In 2007, during the period when the rock barrier was in place, the proportion of flow entering Old River was substantially less than observed in 2009 without the positive barrier and flow in the San Joaquin River downstream of the flow split remained positive under both ebb and flood tide conditions.

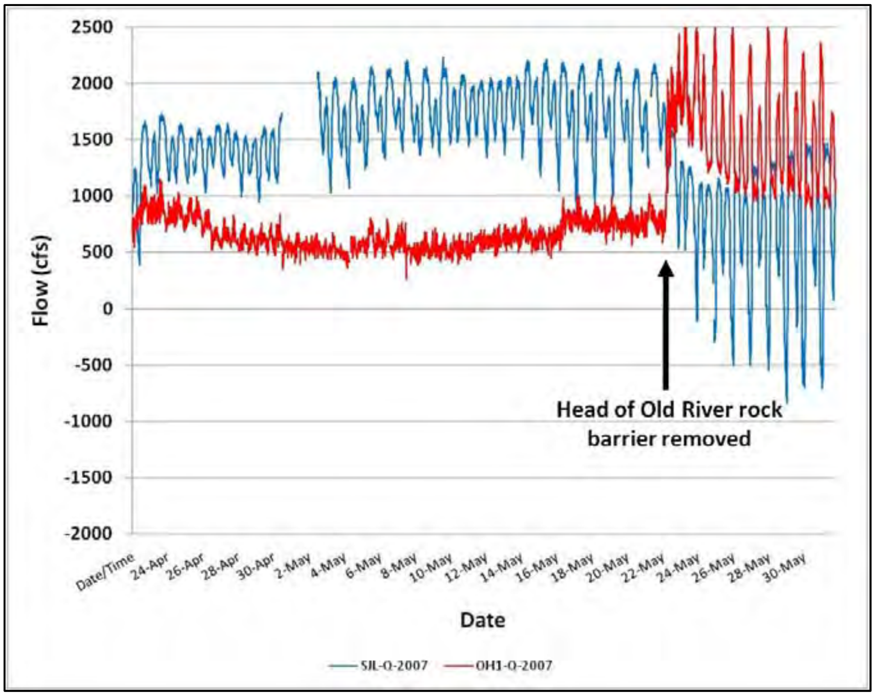

Figure 22. Flow (cfs) in 15-minute increments measured at the DWR flow stations at the head of Old River (OH1) and in the San Joaquin River just downstream of the Old River flow split (SJL), April 22 – June 1, 2007.

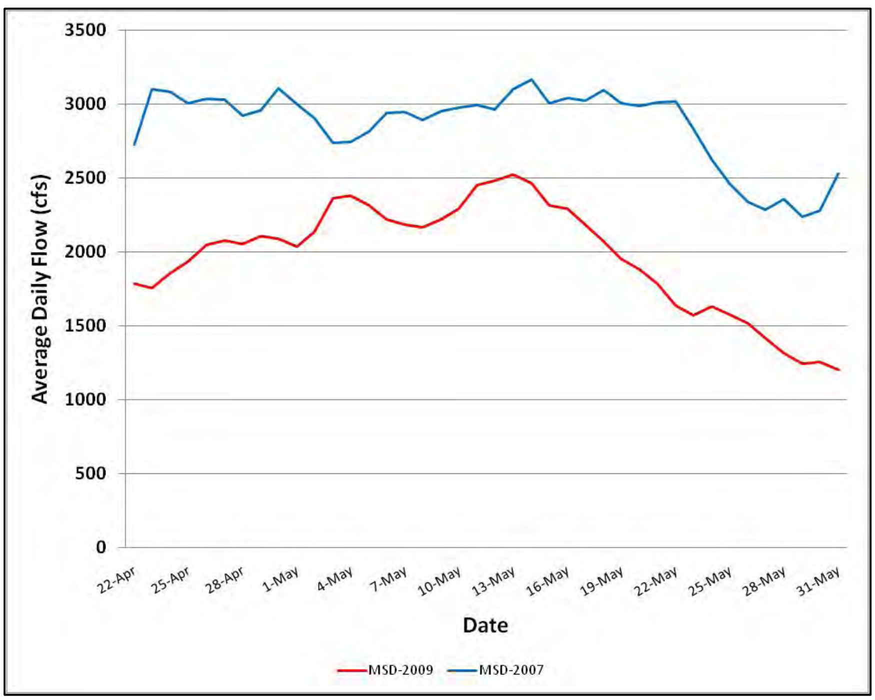

Figure 23. Average daily flow (cfs) measured at the DWR Mossdale flow station (MSD), April 22 - June 1, 2007 and April 22 - June 1, 2009.

The flow reversals frequently resulted in acoustic tags being detected moving past the receiver positioned at the DWR Lathrop gage site [SJO(n)] during ebb tides, but were subsequently volitionally or non-volitionally advected back upstream during flood tides (Figure 24). In many instances, the tags were then later detected moving past the receiver positioned just downstream of the head of Old River [OLD(e)]. Overall, an estimated 29% of those tags initially moving past Old River down the San Joaquin eventually changed direction and moved back up and entered Old River (Table 15). Based on observational data at the four-port receiver at the head of Old River and the observations made with the fixed-station receivers, those tags were frequently believed to be inside predators. Accounting for fish changing routes after initial route selection, 59% of the VAMP study fish reaching the flow split ultimately went down Old River but ranged from 48% to 74% among the seven fish release groups (Table 16).

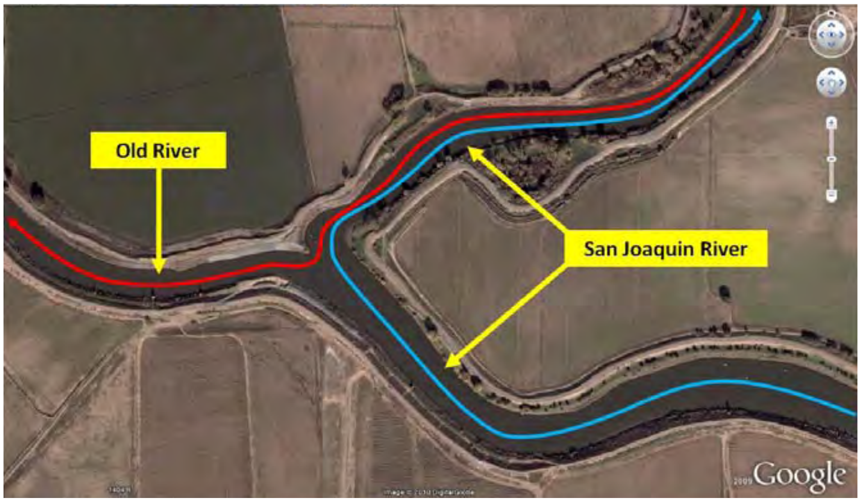

Figure 24. Depiction of a migration route for an acoustic-tagged fish migrating past the head of Old River during an ebb tide, remaining in the mainstem San Joaquin River (blue line) but subsequently, many hours later, returning back upstream and migrating into Old River (red line).

Table 15. Acoustic-tagged fish changing route selection back to Old River after initially selecting the mainstem San Joaquin River downstream of the head of Old River. Numbers of fish with percentages in parentheses.

Fish Route Selection	Fish Release Number							Overall
	1	2	3	4	5	6	7	
Total Fish Initially Detected at SJO(n)	34	54	62	38	61	29	34	312
Fish Ultimately Moving back from SJO(n) to Old(e)	16 (47%)	21 (39%)	10 (16%)	12 (32 %)	14 (23%)	7 (24%)	7 (21%)	87 (29%)

Table 16. Acoustic-tagged fish route selection at the head of Old River on the San Joaquin River. Numbers of fish with percentages in parentheses.

Route Selection	Fish Release Number							Overall
	1	2	3	4	5	6	7	
Old River	52 (74%)	65 (66%)	55 (52%)	46 (64%)	43 (48%)	31 (58%)	38 (51%)	330 (59%)
San Joaquin	18 (26%)	33 (34%)	51 (48%)	26 (36%)	47 (52%)	22 (42%)	37 (49%)	234 (41%)

The flow conditions in the vicinity of the Old River flow split and the presence or absence of the positive barrier can have significant biological effects on salmon smolts passing the site. It has been generally accepted that salmon migrating down the San Joaquin River will have a survival rate higher than those salmon migrating down Old River. Assuming that the scour hole just downstream of the head of Old River harbors large numbers of predatory fish (Vogel 2006a), these reverse flow conditions doubles the opportunity for predatory fish to prey on juvenile salmon as compared to only one opportunity with continuously positive flows.

Lower San Joaquin River near Stockton

Based on detections of acoustic tags reaching the receivers placed at Stockton in the lower San Joaquin River, it initially appeared that salmon survival was relatively high (compared to other reaches during this study). However, the two independent analyses suggested that many of those tag detections were actually preyed-upon salmon smolts. Close examination of the spatiotemporal history of those tags (medium-field observations) revealed movement back and forth between the USGS Stockton gage ([STP(s)] and Navy Bridge [STP(n)] for long periods which was initially believed to be solely attributable to tidal seiching. Additionally, observations of some of the tags when in detection range of the hydrophones were considered uncharacteristic movements for salmon smolts (near-field observations). Using the combination of near- and medium-field observations, and the independent analyses from the four-port receiver, it appears that many of those tags were probably in predators. This particular region is known to harbor relatively high concentrations of predatory fish based on: 1) anglers familiar with the area; 2) DIDSON® sonar camera footage taken by Natural Resource Scientists, Inc.; and 3) predator tagging conducted near the Stockton Waste Water Treatment Plant outfall. It was noted by the Natural Resource Scientists, Inc. crews at the site that many of the fish caught by angling were small striped bass. Sonar camera footage taken at the outfall (Figure 25) revealed dozens of large- to medium-size fish and hundreds of small-size fish. This particular region in the lower San Joaquin continues to warrant further scrutiny as to potential sources of high salmon mortality.

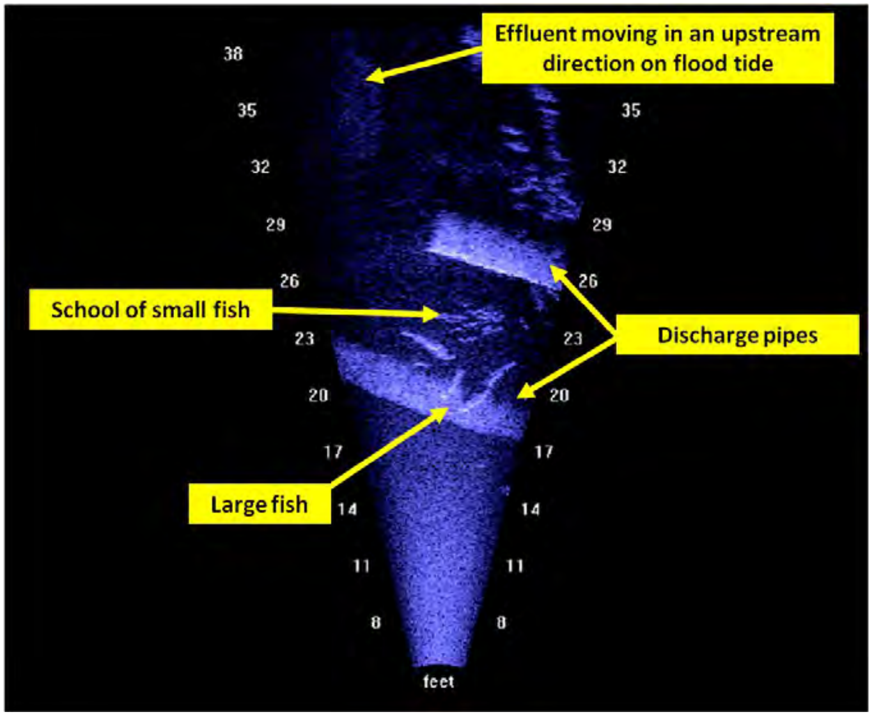

Figure 25. DIDSON® sonar camera still image looking down on the two submerged Stockton waste water treatment plant effluent pipes in the San Joaquin River and large and small fish near the pipes.

Tracy Fish Facilities

Study results also indicated an extremely high rate of predation among acoustic tags detected in the vicinity of the receivers positioned at the trash racks in front of the Tracy Fish Facilities (Tracy FF) and near the Clifton Court Forebay gates. For example, Figure 26 shows the computer display of a one-hour raw acoustic-tag file where the receiver in front of the Tracy FF trash racks recorded 41 individually-identifiable transmitters (taking 55 minutes to mark each fish in the file). Using the two different methods of assessing potential predation on salmon, 81% -90% of the VAMP study fish (or the transmitters) reaching that location were believed to be inside predators or had been defecated at the site.

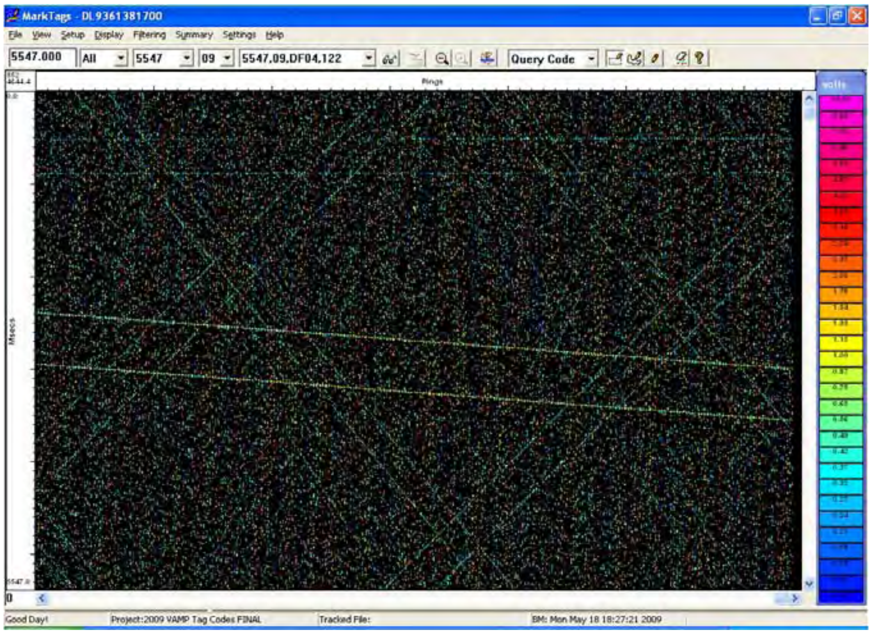

Figure 26. Data processing display screen showing 41 individually identifiable (after processing) acoustic tags detected at the trash racks at the Tracy Fish Facilities (35 tags from the VAMP study and 6 from the DWR study). The color dots are "pings" recorded from each transmitter. This one-hour raw acoustic tag file was 4.3 megabytes in size and took 55 minutes to process.

This locality has been known for many years to harbor very high concentrations of striped bass in the areas immediately upstream and downstream of the trash racks. The area just upstream of the debris deflector boom is also an area popular with anglers for catching striped bass; in fact, two anglers caught two of our acoustic-tagged striped bass at that location.

Interestingly, large numbers of striped bass reside in the area between the trash racks and the entrance to the Tracy Fish Facilities, an area where one would initially not believe possible due to spacing of the trash racks. USBR personnel at the site believe the striped bass in this location originate from two sources: 1) small striped bass which are entrained through the trash racks and rear in the downstream area; and 2) large striped bass rearing further downstream in the Delta-Mendota Canal moving upstream into the area when the downstream fish louvers are pulled up and cleaned (Brent Bridges, USBR, pers. comm., December 8, 2009). USBR frequently removes high numbers of striped bass in the area between the upstream trash racks and the fish facilities using a variety of techniques (e.g., gill nets and CO_2). During the VAMP study, USBR personnel removed large numbers of striped bass in this area with gill nets.

Nineteen of the VAMP juvenile salmon acoustic transmitters were detected inside the Tracy Fish Facilities fish salvage tank which represented only 17% of those tags detected at the receivers positioned at the upstream trash racks (Table 13). Those results also demonstrated an extremely high mortality among the VAMP study fish. However, nine of those tags detected in the fish salvage tank were assumed to have been preyed-upon salmon based on evaluations derived from the four-port receiver. These results would initially suggest that at least some of the assumptions on predation may have been incorrect. Presumably, striped bass or other predators would be unable to fit through the trash racks and reach the fish salvage tank at the Tracy Fish Facilities. These upstream trash racks are bolted to the concrete bottom and are not removed (Brent

Bridges, USBR, pers. comm., December 8, 2009). It is conceivable that some acoustic transmitters could have been defecated from predators upstream of the trash racks and been swept by currents along the smooth concrete floor and into the fish salvage tank. Although possible, this scenario appears unlikely because export pumping was low during the VAMP study period (thereby creating low sweeping water velocities) and the cross-sectional area for a tag to reach the tanks is a very small portion of the total channel width (Brent Bridges, pers. comm., December 8, 2009). However, small striped bass or other predatory fish could be entrained through the trash racks which have a 2.25-inch opening. Some of the striped bass we tagged with transmitters were small enough to fit through the trash racks. Also, there may be larger openings in the trash racks that have not been detected. Because this area continues to demonstrate a very high level of fish mortality, more effort should be focused on remedial actions to fix the problems. USBR is examining several design features to reduce the predation problem.

Clifton Court Forebay Gates

As observed from prior VAMP acoustic-telemetry studies, the 2009 study results also indicated a very high level of detections of VAMP smolt transmitters believed to be inside predatory fish residing in behind the Clifton Court Forebay gates. Using the two methods to estimate predation, 94% to 98% of the salmon smolt transmitters detected behind the gates [CCG(w)] were believed to be inside predatory fish (Table 13). It was difficult to use the receiver positioned outside the Forebay east of the gates [CCG(e)] to quantify detections and estimate predation because the hydrophone could detect transmitters further to the east from the gates in the main channel. Based on near-field observations, some of the transmitters detected out in the main channel frequently moved north and south, but did not necessarily enter the region in close proximity to the gates. However, the combined detections from these two receivers indicated that some smolt transmitters moved in and out of the Forebay, as was also observed for some of the striped bass we tagged with transmitters (discussed below). This site continues to demonstrate a serious problem area for juvenile salmon survival.

Predatory Fish Tagging

Acoustic-tagging of predatory fish was anticipated to provide information on striped bass and black bass movements within the study area and possible affinity of those species to specific locales. During the study, 23 striped bass and one large-mouth bass were tagged with individually identifiable acoustic transmitters and released at the fish capture locations. Instead of having the field crews focus solely on large predators, they were instructed to also include smaller predatory fish, but only those sufficiently large to eat a salmon smolt. Table 17 provides the information on the tagged predatory fish.

Table 17. Predatory fish tagged with acoustic transmitters during the 2009 VAMP study.			
Fish Species	**Fork Length (mm)**	**Date/Time of Release**	**Location of Release**
Striped Bass	690	4/29/09 1400 hrs.	Upstream of Tracy Fish Facilities trash racks
Striped Bass	550	4/29/09 1400 hrs.	Upstream of Tracy Fish Facilities trash racks
Striped Bass	520	4/29/09 1400 hrs.	Upstream of Tracy Fish Facilities trash racks
Striped Bass	665	4/29/09 1400 hrs.	Upstream of Tracy Fish Facilities trash racks
Striped Bass	550	4/29/09 1400 hrs.	Upstream of Tracy Fish Facilities trash racks
Striped Bass	585	4/29/09 1400 hrs.	Upstream of Tracy Fish Facilities trash racks
Striped Bass	570	4/29/09 1400 hrs.	Upstream of Tracy Fish Facilities trash racks
Striped Bass	655	4/29/09 1400 hrs.	Upstream of Tracy Fish Facilities trash racks
Striped Bass	635	4/29/09 1400 hrs.	Upstream of Tracy Fish Facilities trash racks
Striped Bass	680	4/29/09 1400 hrs.	Upstream of Tracy Fish Facilities trash racks
Striped Bass	460	5/4/09 1340 hrs.	San Joaquin River ½ mile downstream of Dos Reis
Largemouth Bass	315	5/6/09 1500 hrs.	San Joaquin River at head of Old River
Striped Bass	370	5/7/09 1500 hrs.	San Joaquin River at Burns Cut
Striped Bass	370	5/12/09 1820 hrs.	San Joaquin River at head of Old River
Striped Bass	450	5/12/09 1900 hrs.	San Joaquin River at Burns Cut
Striped Bass	420	5/13/09 1420 hrs.	San Joaquin River ½ mile downstream of Dos Reis
Striped Bass	425	5/24/09 1510 hrs.	San Joaquin River at Stockton waste water treatment plant
Striped Bass	470	5/24/09 1610 hrs.	San Joaquin River at Stockton waste water treatment plant
Striped Bass	390	5/24/09 1630 hrs.	San Joaquin River at Stockton waste water treatment plant
Striped Bass	490	5/24/09 1730 hrs.	San Joaquin River at Stockton waste water treatment plant
Striped Bass	410	5/24/09 1820 hrs.	San Joaquin River at Stockton waste water treatment plant
Striped Bass	400	5/27/09 1640 hrs.	San Joaquin River at Stockton waste water treatment plant
Striped Bass	360	5/27/09 1720 hrs.	San Joaquin River at Stockton waste water treatment plant
Striped Bass	370	5/27/09 1940 hrs.	San Joaquin River at Stockton waste water treatment plant

Although sample sizes were limited because low numbers of fish were tagged (mostly not until well into the study period), some near-field observational data were obtained for those tagged predators within detection range of the VAMP receivers. For example, Figure 27 shows the movements of a striped bass tagged and released near the Tracy Fish Facilities, but subsequently detected by the hydrophone positioned behind the gate inside Clifton Court Forebay. These movements depict the code 3 display previously discussed. However, there were also instances where the predatory fish movements (based on graphical post-processing displays) looked very similar to movements of salmon smolts.

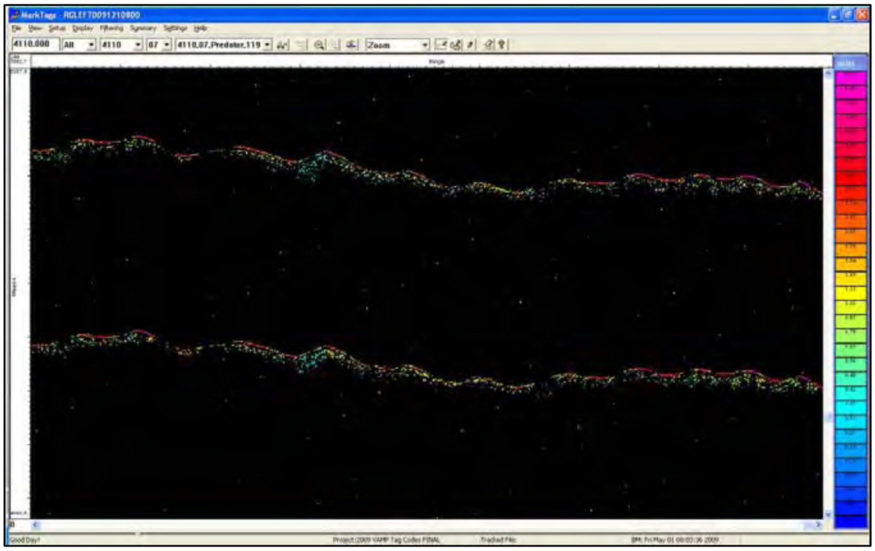

Figure 27. Movements of an acoustic-tagged striped bass released in front of the Tracy Fish Facilities trash rack and later detected behind the Clifton Court Forebay gates.

We frequently observed acoustic-tagged predators moving against the local flow conditions (medium-field observations), but also observed the predators moving with the flow. Sample size was very low so no definitive conclusions based on comparisons between known predator movements and assumed acoustic-tagged salmon movements could be made. More research on the issue is warranted using larger sample sizes.

The far-field observations of predatory fish movements were particularly interesting. The following Figures 28 - 39 show some of the more prominent and complex movements of acoustic-tagged predators during the 2009 VAMP study.

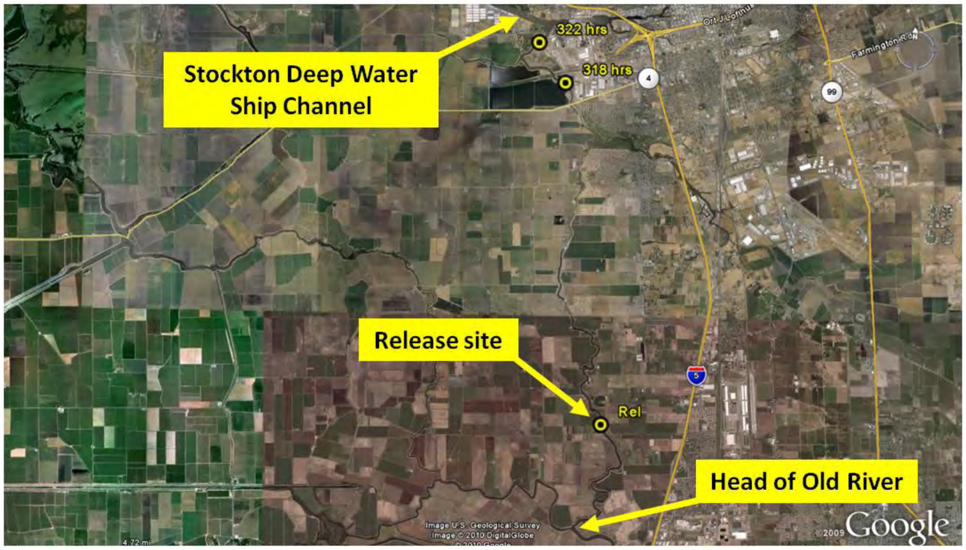

Figure 28. Movements of a 460-mm FL striped bass tagged with transmitter 4138.07 near Dos Reis on the lower San Joaquin River. Nearly two weeks after release, the bass was detected passing two downstream receivers positioned in Stockton just upstream of the Deep Water Ship Channel.

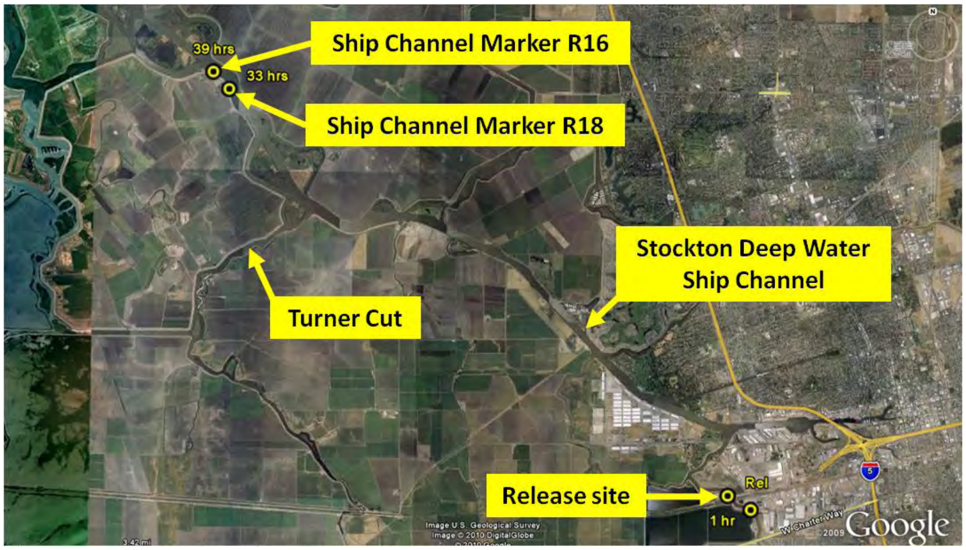

Figure 29. Movements of a 470-mm FL striped bass tagged with transmitter 4236.07 near the Stockton Waste Water Treatment Plant on the lower San Joaquin River. Later, the bass moved downstream in the Deep Water Ship Channel and was detected at the Ship Channel Markers R18 and R16.

Figure 30. Movements of a 390-mm FL striped bass tagged with transmitter 4264.07 near the Stockton Waste Water Treatment Plant on the lower San Joaquin River. The bass was detected in the general vicinity nearly a week after release.

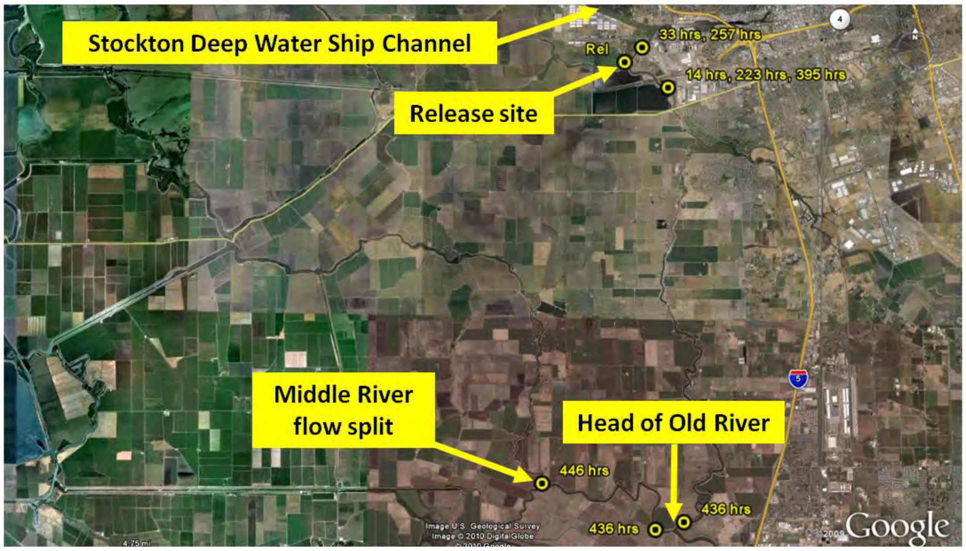

Figure 31. Movements of a 370-mm FL striped bass tagged with transmitter 4054.07 near Burns Cut on the lower San Joaquin River. The bass was detected in the general vicinity of release after more than two weeks then subsequently swam upstream and entered Old River; last detected moving west in Old River passing the Middle River flow split.

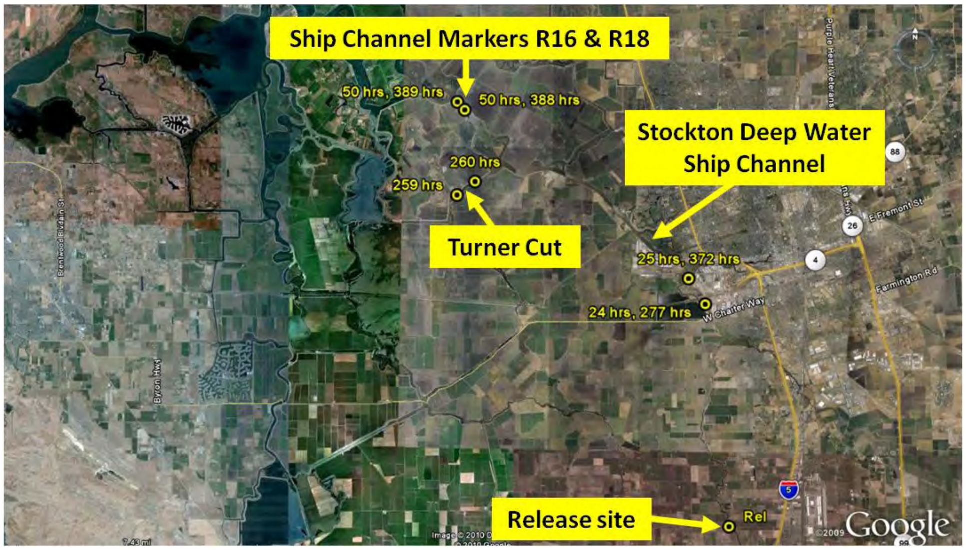

Figure 32. Movements of a 420-mm FL striped bass tagged with transmitter 4082.07 near Dos Reis on the lower San Joaquin River. The bass was detected a day later passing the two downstream receivers at Stockton, migrated past the receivers positioned at the Deep Water Ship Channel Markers (R18 and R16), apparently migrated into a further downstream channel leading into the interior Delta, was detected moving northeast through Turner Cut, back upstream to the receiver at Navy Bridge in Stockton, then was last detected moving downstream past the R18 and R16 Ship Channel receivers.

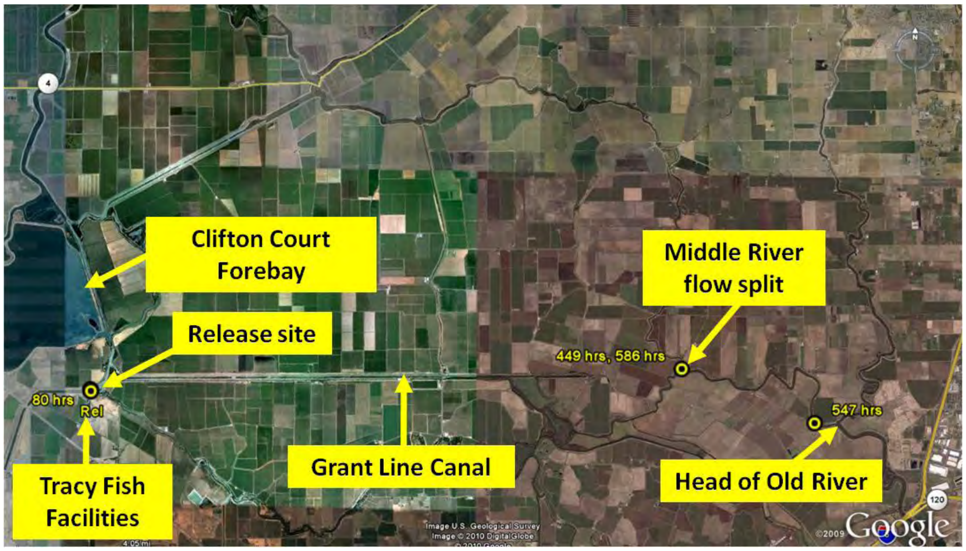

Figure 33. Movements of a 520-mm FL striped bass tagged with transmitter 4012.07 near the Tracy Fish Facilities. The bass was detected to have moved east passing the Old/Middle River flow split, reaching detection range of the receiver positioned just downstream of the head of Old River, then last detected to have moved west in Old River at the Middle River flow split.

Figure 34. Movements of a 550-mm FL striped bass tagged with transmitter 4026.07 near the Tracy Fish Facilities. The bass was detected to have moved north near the entrance to Clifton Court Forebay, then south back to the Tracy Fish Facilities, then back up to and entered the gates into Clifton Court Forebay. The location east of the gates was moved further east than the hydrophone location due to the inability to accurately determine fish position.

Figure 35. Movements of a 585-mm FL striped bass tagged with transmitter 4096.07 near the Tracy Fish Facilities. The bass was detected to have moved north near the entrance to Clifton Court Forebay, then south back to the Tracy Fish Facilities nearly two days after release. The location east of the gates was moved further east than the hydrophone location due to the inability to accurately determine fish position.

Figure 36. Movements of a 550-mm FL striped bass tagged with transmitter 4124.07 near the Tracy Fish Facilities. The bass was detected to have moved north near the entrance to Clifton Court Forebay, then last detected migrating past the receivers positioned at the Highway 4 bridge over Old River.

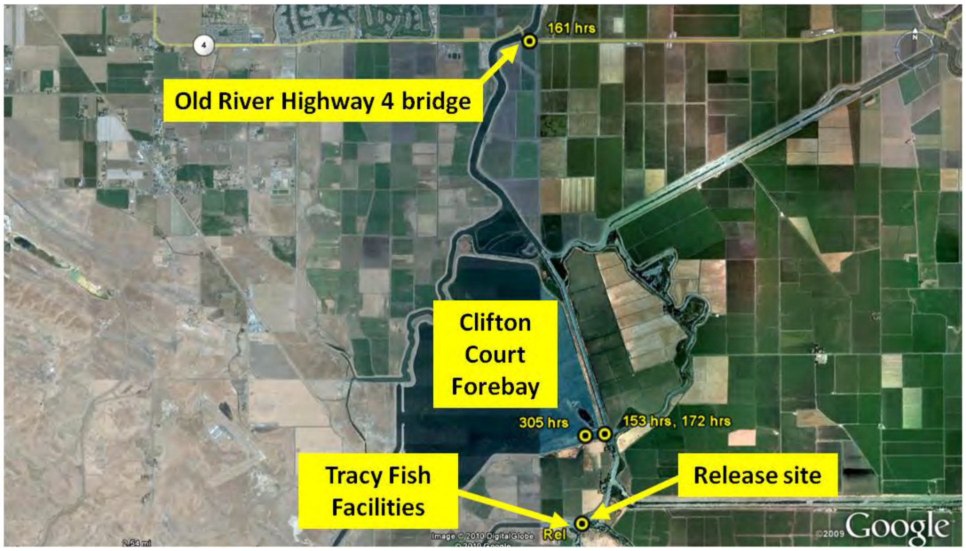

Figure 37. Movements of a 635-mm FL striped bass tagged with transmitter 4152.07 near the Tracy Fish Facilities. The bass was detected to have moved north to the Highway 4 bridge over Old River, then back south near the entrance to Clifton Court Forebay and last detected inside the Forebay approximately 13 days after release.

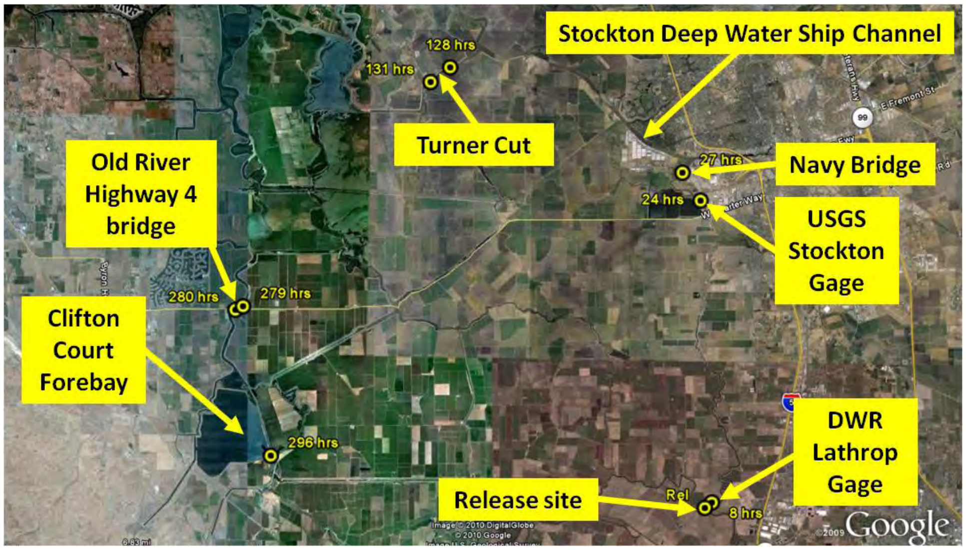

Figure 38. Movements of a 370-mm FL striped bass tagged with transmitter 4222.07 at the scour hole near Old River, migrating downstream and detected passing the two receivers near Stockton, passing the two receivers in Turner Cut, passing the receivers at the Highway 4 bridge in Old River and last detected near the entrance to Clifton Court Forebay.

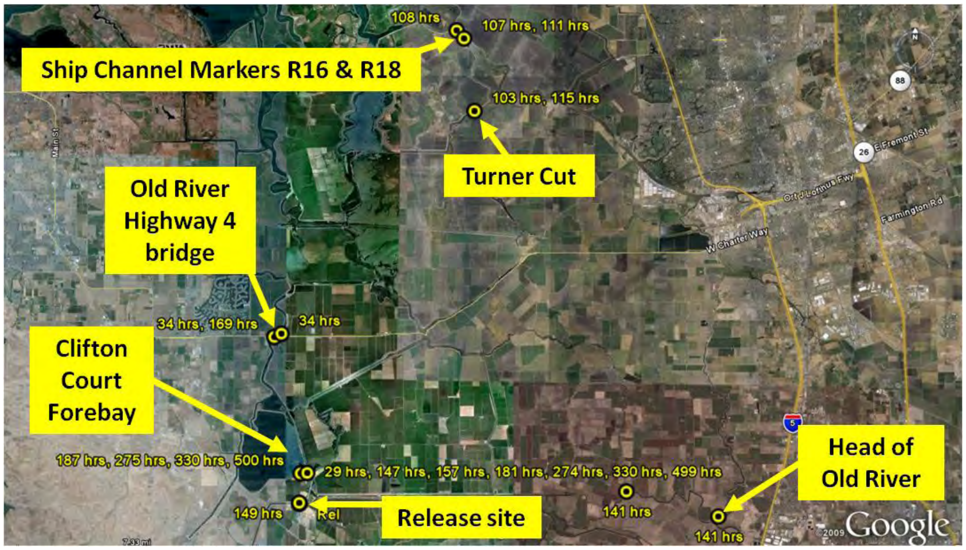

Figure 39. Movements of a 680-mm FL striped bass tagged with transmitter 4208.07 at the Tracy Fish Facilities, moved north in Old River, migrated into Turner Cut, detected moving downstream (northwest) at the two Deep Water Ship Channel markers, then back upstream (southeast) entering Turner Cut, passing the receivers in southeastern Old River then detected at the Tracy Fish Facilities, back up to the Old River Highway 4 bridge (with subsequent detections both inside and outside Clifton Court Forebay), and last detected inside the Forebay.

The other tagged striped bass, in addition to the one tagged largemouth bass, lingered in the general vicinity of their release location. Several of the striped bass tagged and released at the Tracy Fish Facilities moved in and out of Clifton Court Forebay. Two of the tagged striped bass were caught by sport fishermen suggesting that our tag and release procedures may not have adversely affected the bass feeding abilities.

As evident from the telemetry data, there were examples of striped bass moving long distances through the Delta (both downstream and upstream) during the VAMP study. In a juvenile salmon acoustic telemetry study conducted on the Sacramento River in the north Delta, Perry and Skalski (2009) found that approximately 10% of acoustic-tagged salmon moved upstream long distances against the flow suggesting those salmon had been eaten by predators. For the VAMP study, striped bass frequently moved back and forth with the flow and migrated throughout the telemetry array, in some instances, similar to that expected for salmon smolts. These complex circumstances significantly affect how juvenile salmon telemetry data can be interpreted.

Mobile Telemetry

Mobile telemetry is a useful technique to complement fixed-station telemetry for interpreting fish behavior and confirming fish mortality between fixed stations (Vogel 2008). Results of the 2009 mobile surveys were used to determine where fish “disappear” in reaches between fixed stations. Additionally, pinpointing locations where numerous motionless transmitters have accumulated provide an indication where a high mortality of juvenile salmon may have occurred. Three such sites where this phenomenon has been previously noted were at the deep scour hole near the head of Old River, near a railroad bridge in Stockton, and in front of the

Tracy FF trash racks. As a caveat, this technique cannot precisely determine where the mortality occurred, only where the motionless transmitter was located. For example, a predator could undoubtedly consume an acoustic-tagged salmon, swim to another location, and then defecate the tag.

During the VAMP study, mobile telemetry surveys found a total of 173 acoustic tags believed to be dead acoustic-tagged salmon or tags defecated by predatory fish in the reaches surveyed (Figure 40) (approximately 19% of those fish released at Durham Ferry). It is important to note that there was not complete coverage of the channels during these surveys. Additionally, if a tag was defecated and the negatively-buoyant transmitter settled into the riverbed in silt or in a location where the acoustic signals were muffled, the mobile telemetry surveys would not have detected those tag codes.

Forty-seven transmitters were found in the reach surveyed between Durham Ferry and Mossdale (Figure 41). The reach between Mossdale was not surveyed frequently enough to ascertain if tags were present for extended periods. Relatively high numbers of transmitters were found downstream of the release site long after release suggesting that some fish may have died shortly after release from unknown causes (Figure 42). Possible causes could have been predation, latent mortality from fish tagging/transport, or indirect effects of tagging/transport causing salmon to be more prone to predation.

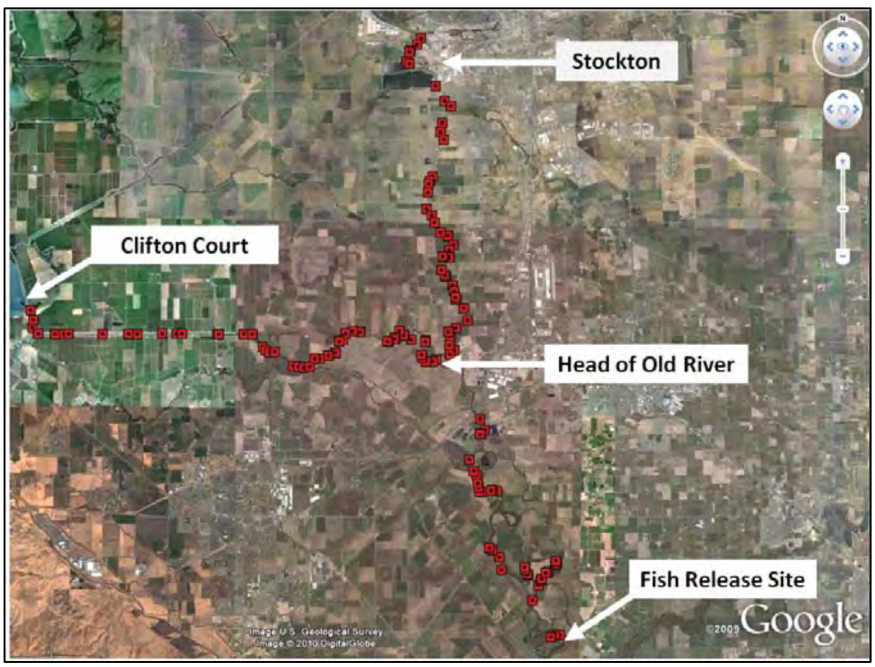

Figure 40. Location of 173 acoustic tags detected during the 2009 VAMP study believed to be dead acoustic-tagged salmon or tags defecated by predatory fish. Specific tag locations are approximate and represent the general vicinity of the tag.

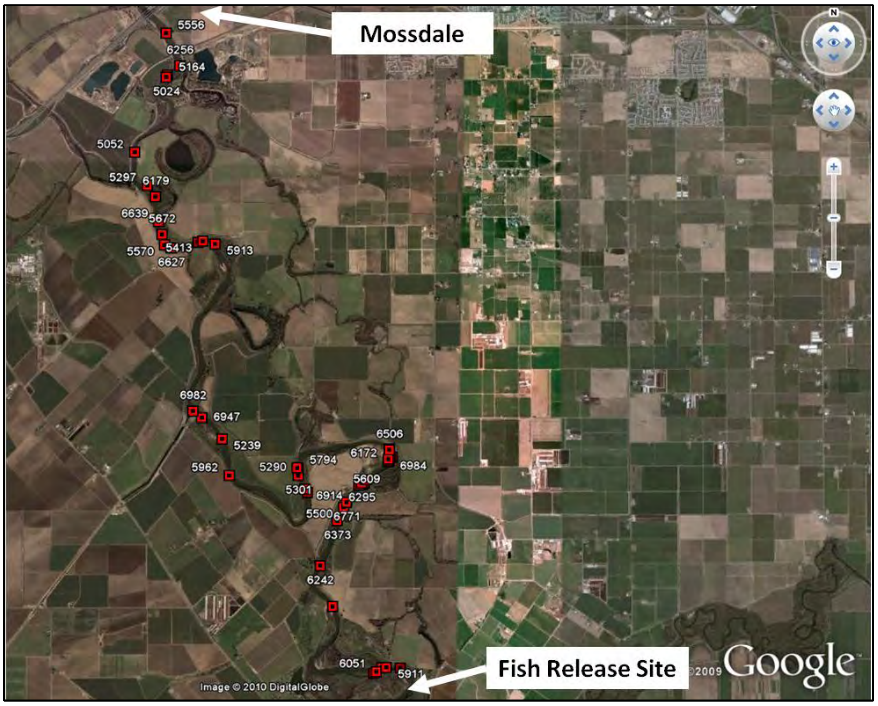

Figure 41. Location of 47 acoustic tags (showing designated transmitter codes) detected in the San Joaquin River between the fish release site at Durham Ferry and Mossdale during the 2009 VAMP study believed to be dead acoustic-tagged salmon or tags defecated by predatory fish. Specific tag locations are approximate and represent the general vicinity of the tag.

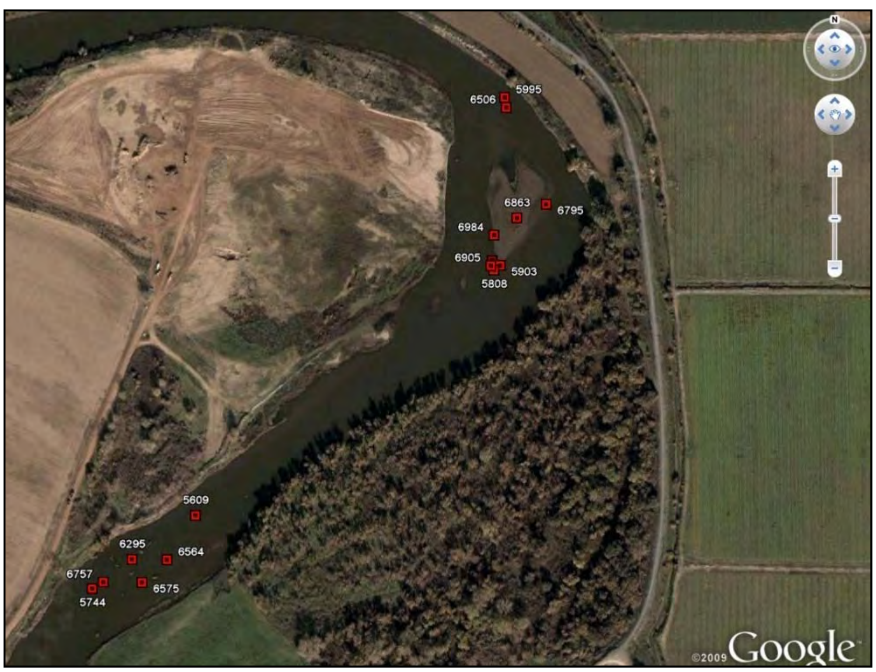

Figure 42. Location of acoustic tags (showing designated transmitter codes) detected in the San Joaquin River approximately 3.5 to 4 river miles downstream of the fish release site at Durham Ferry during the 2009 VAMP study believed to be dead acoustic-tagged salmon or tags defecated by predatory fish. Specific tag locations are approximate and represent the general vicinity of the tag.

Fifty-seven transmitters were found in the reach between the head of Old River and the Stockton Deep Water Ship Channel (Figure 43). Some areas where relatively high numbers of transmitters were located tended to be in the vicinity of channel bends/scour holes and near pump stations (Figures 44 and 45). There was no occurrence of large numbers of transmitters found near the Stockton Waste Water Treatment Plant (Figure 46) as was the case during the 2007 VAMP study (Vogel 2007b). Unlike prior years' surveys, only one tag was located in the scour hole just downstream of the head of Old River, but mobile telemetry coverage in the area was infrequent during the study. Although substantial predatory fish activity and acoustic-tagged salmon (or the transmitters) inside predators was believed to occur in this area, the results suggest that predatory fish did not reside in the scour hole for sufficient periods to defecate tags at the site or that defecated tags escaped detection by settling into the riverbed. Based on presumed predators frequently passing the receivers placed in Old River [Old(e)] and the San Joaquin River at the Lathrop gage [SJO(n)], it is likely predators defecated the tags elsewhere.

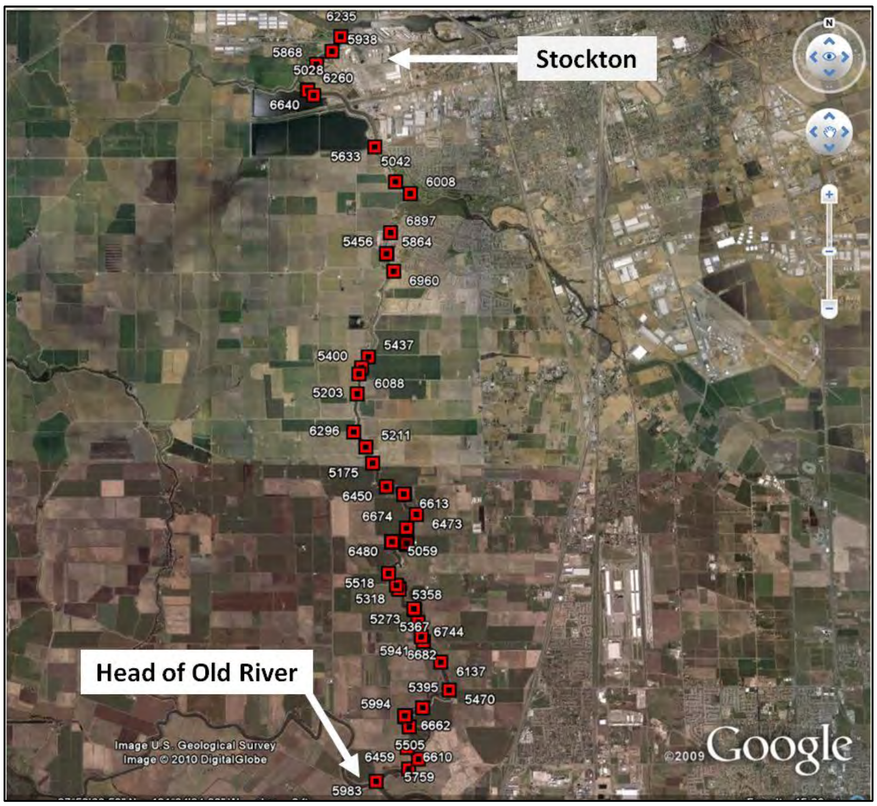

Figure 43. Location of 57 acoustic tags (showing designated transmitter codes) detected in the San Joaquin River between the head of Old River and Stockton during the 2009 VAMP study believed to be dead acoustic-tagged salmon or tags defecated by predatory fish. Specific tag locations are approximate and represent the general vicinity of the tag.

Figure 44. Location of acoustic tags (showing designated transmitter codes) detected in the San Joaquin River approximately 1.75 river miles downstream of the head of Old River during the 2009 VAMP study believed to be dead acoustic-tagged salmon or tags defecated by predatory fish. Specific tag locations are approximate and represent the general vicinity of the tag.

Figure 45. Location of acoustic tags (showing designated transmitter codes) detected in the San Joaquin River approximately 5 river miles downstream of the head of Old River during the 2009 VAMP study believed to be dead acoustic-tagged salmon or tags defecated by predatory fish. Specific tag locations are approximate and represent the general vicinity of the tag.

Figure 46. Location of acoustic tags (showing designated transmitter codes) detected in the San Joaquin River near the city of Stockton during the 2009 VAMP study believed to be dead acoustic-tagged salmon or tags defecated by predatory fish. Specific tag locations are approximate and represent the general vicinity of the tag.

Sixty-nine transmitters were found in the reach between the head of Old River and the south Delta water export facilities (Figures 47 - 49). Transmitters located near the Tracy Fish Facilities were not included in these numbers but are reported elsewhere in this report. There were occurrences of tags located in the sinuous portion of Old River near channel bends as noted in the reaches surveyed in the San Joaquin River. In the relatively featureless, straight Grant Line Canal, there were no obvious habitat features suggesting why tags were found in most locations. If the Canal served primarily as a migratory route for predatory fish, the tags may have simply been defecated from predators moving from one location to another. However, five transmitters were located near one of the south Delta barriers just east of the South Tracy Boulevard bridge suggesting predation on salmon at that location.

Figure 47. Location of 69 acoustic tags (showing designated transmitter codes) detected in the reach between the head of Old River and Clifton Court Forebay during the 2009 VAMP study believed to be dead acoustic-tagged salmon or tags defecated by predatory fish. Specific tag locations are approximate and represent the general vicinity of the tag.

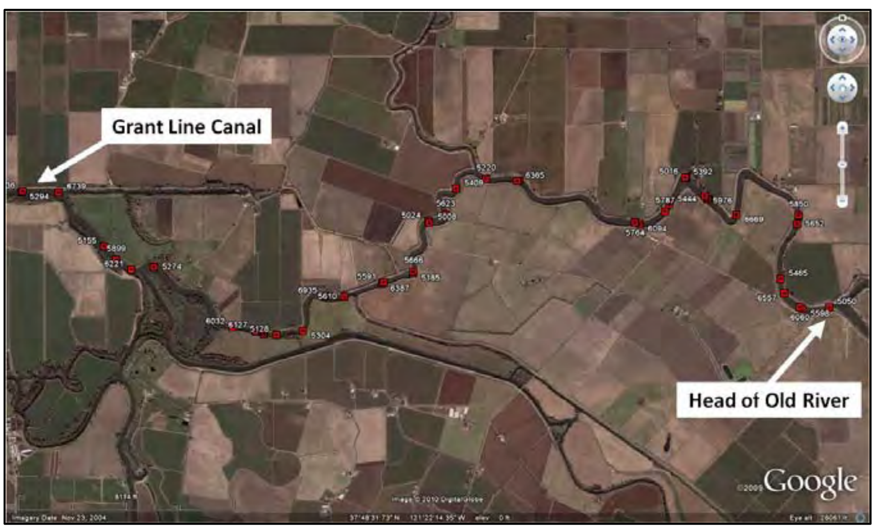

Figure 48. Location of acoustic tags (showing designated transmitter codes) detected in the reach between the head of Old River and Grant Line Canal during the 2009 VAMP study believed to be dead acoustic-tagged salmon or tags defecated by predatory fish. Specific tag locations are approximate and represent the general vicinity of the tag.

Figure 49. Location of acoustic tags (showing designated transmitter codes) detected in Grant Line Canal during the 2009 VAMP study believed to be dead acoustic-tagged salmon or tags defecated by predatory fish. Specific tag locations are approximate and represent the general vicinity of the tag.

Conclusions

Juvenile salmon smolt survival as observed from all seven releases of acoustic-tagged salmon at Durham Ferry for the 2009 VAMP study was extremely low. It appears that we were frequently tracking dead salmon (or the transmitters) inside predatory fish during the 2009 VAMP study, not live salmon. There is a complex problem with differentiating between live acoustic-tagged salmon and predatory fish that had eaten acoustic-tagged salmon making it very difficult to accurately estimate overall salmon survival, salmon survival by reach, and fish route selection at key flow splits, all of which were (and continue to be) key objectives of the VAMP study. This will be a challenging problem to solve but must be addressed.

The evaluative techniques used in this study in combination with a concurrent, independent study at the behavioral barrier at the head of Old River demonstrated compelling evidence of a high degree of predation on acoustic-tagged juvenile salmon. Although the proximal cause of the fish mortality appeared to be a result of predation, the circumstances causing predation remain unknown. While remaining speculative, some of the conditions enhancing predation on salmon are hypothesized to be a result of one or more of the following: 1) flow and/or water quality (including temperature) conditions; 2) in-channel artificial structures (e.g., bridge piers, pump stations, docks); 3) channel geometry (e.g., scour holes) providing favorable habitat conditions for predatory fish; and/or 4) the possible substandard condition of tagged salmon.

Acoustic telemetry technology continues to be demonstrated as a powerful analytical tool to study juvenile salmon movements in the Delta, but only if it is appropriately implemented and the results are properly analyzed and understood. Information developed from the 2009 VAMP study indicates that if we attempt to accurately estimate salmon survival in the Delta using acoustic telemetry, a new approach should be used by perhaps seeking changes in the technology to determine predation. One such idea Natural Resource Scientists, Inc. suggested to the telemetry vendor is the creation of a tag that changes detection characteristics after the tag has been exposed to a predatory fish's stomach acid. It also demonstrates that, in the absence of a technological breakthrough, we need to acquire highly detailed data on the behavior of predatory fish movements as compared to juvenile salmon movements. If acoustic-tagged salmon are consumed by an untagged predator and the predator swims past a receiver prior to tag defecation (undoubtedly a common occurrence in the Delta), data collected by the receivers would be misinterpreted as live salmon passing fixed stations. Therefore, data are needed on predator movements to assist in interpretation of study results.

Most importantly, because of the well-documented low salmon smolt survival in the lower San Joaquin River and Delta, efforts should focus on determining site-specific causes of mortality with the objectives of developing and implementing remedial actions to increase fish survival.

Recommendations

The following are recommendations by Natural Resource Scientists, Inc. based on observations made as a result of implementing the VAMP acoustic-telemetry field studies in 2006, 2007, 2008, and 2009.

Study Experimental Design

- The 2009 VAMP acoustic telemetry fish study and concurrent acoustic telemetry studies at the head of Old River and south Delta region provided compelling evidence of predation on acoustic-tagged juvenile salmon. Because of the comprehensive data processing techniques and subsequent highly detailed data interpretation for the 2009 VAMP study, we determined that the sole reliance of "traditional" use of presence/absence detection data within the Delta telemetry array would result in misinterpretation of results. The key study objectives of estimating overall salmon survival in the Delta, salmon survival in specific reaches, and fish route selection at flow splits would have resulted in erroneous conclusions using just presence/absence telemetry data. This circumstance is attributable to the difficulty in accurately differentiating live acoustic-tagged smolts from predatory fish that had eaten acoustic-tagged smolts. Future studies should be specifically designed to account for this critically important issue.

- The 2009 VAMP study and the VAMP acoustic telemetry studies conducted in 2006, 2007, and 2008 provided indications of site-specific sources of juvenile salmon mortality. Because of the high level of fish mortality in the Delta, future studies should be specially designed to account for this serious problem and not focus solely on Delta-wide "global" fish mortality caused by unknown factors. Future studies should be designed to yield results leading to site-specific, proactive, remedial actions to increase salmon survival.

- A technological advancement in acoustic transmitters should be actively pursued to provide empirical evidence of when an acoustic-tagged salmon is eaten by a predator.

Acoustic Receiver Deployments

- The receiver placed just downstream of the Mossdale bridges provided invaluable data for the 2009 study through “near-field” observations of fish movements within detection range of the receiver. It is evident that large numbers of acoustic-tagged smolts were either preyed upon at the bridges, between the release site at Durham Ferry and the bridges (with predators subsequently migrating downstream and taking up temporary residency near the bridge piers), or a combination of these scenarios. However, that site alone cannot provide data for acoustic tags approaching the bridges from the upstream direction. An additional receiver should be placed a short distance upstream of the bridges to acquire the needed data on fish behavior and potential site-specific sources of mortality. These types of “medium-field” telemetry observations between receivers in close proximity have proven to be invaluable (discussed below). This type of deployment would be similar to that used to monitor potential fish mortality in the vicinity of the Stockton Waste Water Treatment Plant [i.e., SJT(s) and SJT(n)].

- The receivers positioned just downstream of the head of Old River flow split [Old(e) and SJO(n)] are critically important to the study. If the receivers fail to function properly for temporary periods, valuable data can be lost. Therefore, redundant receivers at those two sites should be deployed to minimize or avoid the problem. However, the redundant receiver hydrophones should be separated by a short distance (e.g., 500 – 1,000 feet) to acquire highly useful data on fish movements in those areas which can subsequently be used to assess potential predation on acoustic-tagged salmon. These “medium-field” telemetry observations have proven to be invaluable based on telemetry data evaluated from receivers positioned in close proximity during the 2009 VAMP study. Placing receivers in such an array allows much better evaluations of tag movements with flow and helps to detect anomalous fish behavior that can indicate predation. Additionally, the separation of receivers would provide an accurate determination of the longitudinal direction of fish movement. Sole reliance of receivers placed many miles apart (“far-field” telemetry) would be of limited and questionable value due to the problems in differentiating predatory fish from salmon smolts. The combination of “medium-field” and “far-field” telemetry arrays will maximize the usefulness of study data.

- Some of the receiver sites continue to have a large amount of background acoustic noise generated from various sources rendering data processing very difficult and likely resulting in missed tag detections due to the interference. The following sites should be relocated to avoid those problems: eastern Old River just downstream of the San Joaquin River flow split [OLD(e)], DWR Lathrop gage [SJO(n)], and USGS Stockton gage [SJT(s)]. Additionally, the site at Turner Cut Resort [TRN(sw)] should be relocated to avoid tag reception problems in that area caused by marina background noise interference and channel geometry and riverbed topography issues reducing the ability to adequately detect acoustic tags.

- The use of modified job boxes during VAMP 2009 to house the acoustic receivers appeared to resolve the problems caused by overheating of the electronics. All telemetry sites exposed to outdoor ambient conditions should utilize the modified boxes.

- Consideration should be given to placing a receiver a short distance upstream of the fish release site(s) to determine if acoustic-tagged salmon or predators on those salmon move upstream out of detection range of the downstream telemetry arrays. This potentially serious problem was discovered during studies at the Delta Cross Channel in the northern Delta (Vogel 2002b).

- Installation of the four-port receiver (2-D) at the head of Old River in 2009 provided invaluable data for the VAMP study. Deployment of a four-port receiver at that location should continue regardless if the bubble curtain is installed. Because of the importance of fish route selection and predation at the site, the use of a 3-D system in that area should also be seriously considered to acquire additional detailed data on fish behavior in relation to localized flow dynamics and predatory fish effects on juvenile salmon.

- During the 2009 VAMP study, the receiver positioned at the entrance to the CCF gates provided limited data. This circumstance was attributable to the difficulty in detecting passage of acoustic tags out in the main channel. The receiver should be either repositioned or programmed with different gain settings to acquire better information of fish movements to minimize the problem with interpretation of fish detections near the gates versus the channel further east from the gates.

- The use of AC trickle chargers to maintain the 12-VDC batteries should not be used on the receivers unless the grounding and acoustic noise interference problems can be resolved.

- Depending on availability and funding, consideration should be given to placing some acoustic receivers near artificial structures in the Delta channels (e.g., pump stations, bridge piers) to determine potential point sources of juvenile salmon mortality. Alternatively, incremental recordation using DIDSON® sonar camera technology at those sites can be implemented to possibly verify high concentrations of predatory fish.

Predatory Fish Evaluations

- Due to a large number of acoustic-tagged salmon possibly being eaten by non-native predatory fish in the Delta, the ability to accurately estimate salmon survival is severely compromised because of incorrect assumptions on tag detections (i.e., live salmon versus dead salmon). To address this key issue, more predators should be tagged with acoustic transmitters for reasons similar to that recommended for an earlier north Delta study (CALFED 2008). This information is critical to acquire data on predator behavior and movements throughout the acoustic telemetry array deployed in the Delta (i.e., near-field, medium-field, and far-field observations) and minimize misinterpretation of salmon telemetry data. Predator tagging should take place prior to release of acoustic-tagged salmon, with predators released over a broader region throughout the Delta (but within the acoustic telemetry array) to maximize predatory fish detections during the VAMP study period.

- Consideration should be given to evaluating if the acoustic-tagged salmon are in "sub-standard condition" resulting from surgery and transport causing increased vulnerability to predation compared to untagged salmon. It is possible that the high degree of predation on salmon during the 2009 VAMP study could be attributable to tagged fish being more susceptible to predation. Predator avoidance tests could be conducted on representative tagged salmon using some of the general study protocols and experimental designs as described by Mesa (1994) and Vogel and Marine (1995, 1997). Without this information, the validity of study results may be in question.

- Mobile telemetry continues to provide useful information for the VAMP acoustic telemetry study. This method of acquiring data should continue approximately one time each week during the study period. However, the mobile telemetry should only be conducted after approximately one week has passed following the first fish release to increase the probability of detecting dead salmon. In order to efficiently collect viable data, mobile telemetry should be conducted with the hydrophone temporarily immobile for <u>at least</u> 10 minutes at each site to detect motionless transmitters (indicating dead acoustic-tagged salmon). Consequently, if the boat and hydrophone are in motion during the surveys, the identical process must be repeated in the same reaches approximately one week later to determine if the tags remain in the same vicinity as determined from the prior week's survey.

- An acoustic tag defecation study should be conducted on predatory fish to determine how long transmitters originating from preyed-on acoustic-tagged salmon remain in the stomachs of predatory fish. These data would be valuable to improve our estimates of the degree of predation on salmon and the ability to avoid false positive detection of transmitters assumed to be emanating from salmon versus predators that had preyed on salmon.

- A more-rapid acoustic tag repetition rate (e.g., 1 to 2 seconds) should be used for predators to allow better tracking of predatory fish with the fixed-station acoustic telemetry array and mobile telemetry monitoring. Predatory fish such as striped bass can swim faster than juvenile salmon over longer distances and long repetition rates for predator tags could compromise the ability to detect the correct tag codes.

Data Processing

Manual processing of the acoustic telemetry data, although time consuming, proved critically important in interpreting the 2009 study results. Future processing should include techniques to provide information of fish behavior within the detection range of each receiver's hydrophone (near-field observations), as was accomplished for the 2009 study. Data processing yielding only presence/absence information can cause widespread misinterpretation and negate the potential for scientifically sound results.

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