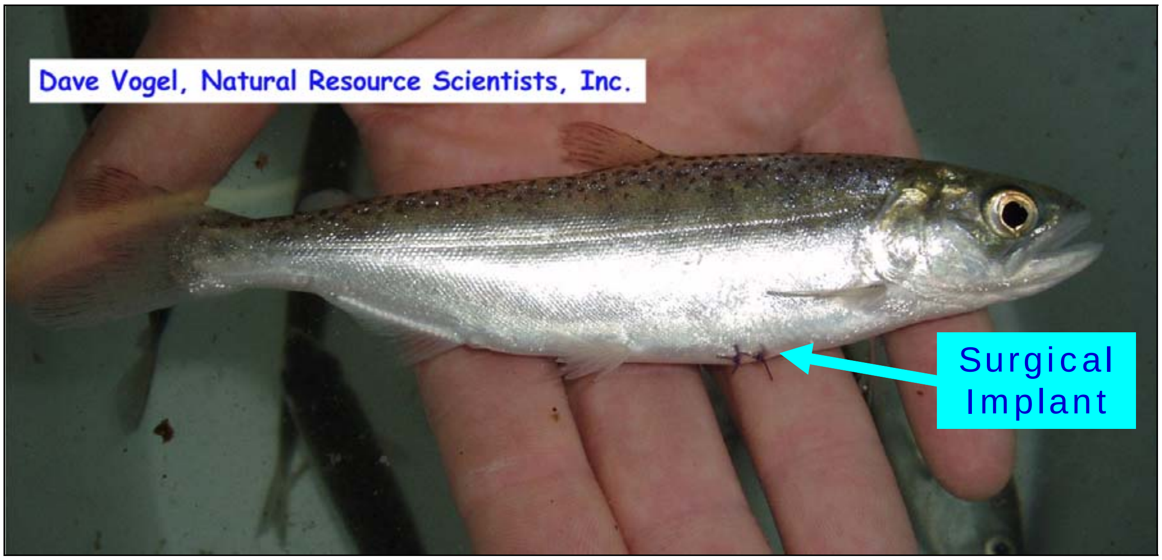
Pilot Study to Evaluate Acoustic-Tagged Juvenile Chinook Salmon Smolt Migration in the Northern Sacramento – San Joaquin Delta 2006 - 2007



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Introduction

The Sacramento-San Joaquin Delta (Delta) in California (Figure 1), which has been extensively modified both structurally and hydrodynamically, is used by juvenile Chinook salmon (*Oncorhynchus tshawytscha*) to migrate from Central Valley rivers to the Pacific Ocean. A number of programs are underway and planned that endeavor to improve water quality and conveyance in the Delta while simultaneously restore ecosystem attributes and protect native fish populations such as Chinook salmon. These programs are complex and uncertain. There is limited understanding of how juvenile salmon migrate through the Delta which possesses multiple channels, diverse shoreline and channel habitats, and complex hydrodynamics of river flow, water diversions, and tides. There is a need to better understand the basic biology characterizing the migratory behavior of juvenile Chinook in the Delta to enable restoration efforts to succeed (Vogel 2004). For example, there is presently a shortage of detailed data and technical understanding on:

- specific migration pathways used by juvenile salmon
- reach-specific salmon mortality (or survival)
- point-source mortality sites ("hot spots")
- salmon migration rates in different regions of the Delta
- salmon behavior compared to local hydrodynamic conditions at flow splits
- salmon movements (migration) and mortality compared to representative hydrologic conditions

Most importantly, information is limited pertaining to how salmon and other species will be impacted by future anthropogenic alterations to the Delta.

The use of telemetry to evaluate the movements of juvenile Chinook salmon smolts in the Delta has provided valuable information, previously unavailable, on fish behavior, migration pathways, and fish survival. The first use of radio telemetry on juvenile salmon in the Delta was conducted in the lower Mokelumne River and San Joaquin River in 1995 (Vogel 1998). Miniature individually-identifiable radio transmitters were attached to juvenile Mokelumne River Chinook fall-run salmon, released in the lower Mokelumne River upstream of flow splits, and tracked using mobile and fixed-station data loggers. In 1999, the use of the technique was employed for a U.S. Fish and Wildlife Service (USFWS) study in a much-larger Delta region when radio-tagged late-fall run Chinook salmon were released in the northern Delta to evaluate fish movements in the lower Sacramento and Georgiana Slough, Mokelumne River, and lower San Joaquin River (Vogel 2001). Because of the success of that project, radio-tagged salmon were released and tracked in the southern Delta in another USFWS study to evaluate juvenile salmon movements in proximity to the south Delta water export facilities (Vogel 2002). Subsequently, additional juvenile salmon telemetry studies were conducted for CALFED in wider regions throughout the Delta (Vogel 2003a, 2004) and in the vicinity of the Delta Cross Channel (DCC) (Vogel 2003b). Notably, these research results provided the first empirical evidence of how salmon smolts move with the tides in the Delta and determined specific migration pathways used by fish during emigration.

Ancillary findings demonstrated how juvenile salmon can be advected over long distances (i.e., miles) into regions with large tidal prisms, where mortality was higher than other channels (e.g. Georgiana Slough), and provided evidence of predation (Vogel 2003a).

Recent advances in acoustic telemetry (e.g., miniaturization of transmitters) has allowed use of the technology to monitor and study juvenile Chinook salmon in the Delta and is anticipated to improve our knowledge of the interaction between fish movements and survival with environmental parameters (Vogel 2006a, Vogel 2007). These techniques build upon the information derived from earlier research projects. An advantage in use of telemetry, although equipment- and somewhat labor-intensive, is the ability to estimate fish mortality of closed populations while simultaneously evaluating fish movements and other behavioral characteristics (Miranda and Bettoli 2007). Newly developed single-hydrophone acoustic receivers permit fixed-station monitoring of acoustic-tagged salmon smolts passing strategic sites within Delta channels as well as mobile, real-time telemetry monitoring. This equipment can also be used in conjunction with studies using three-dimensional (3-D) fish positioning telemetry hardware for cost-effective use of acoustic-tagged salmon for multiple study purposes.

Because of these significant breakthroughs in evaluating juvenile salmon migration and survival, the U.S. Geological Survey (USGS), the California Department of Water Resources (DWR), and Natural Resource Scientists, Inc. conducted a pilot study in the northern Sacramento-San Joaquin Delta during the winter of 2006 - 2007 to evaluate characteristics of juvenile salmon migration using acoustic telemetry. A parallel, complementary study was conducted by USGS at Clarksburg Bend on the lower Sacramento River (Figure 1) to evaluate movements of juvenile salmon in relation to channel geometry and flow structure using the 3-D acoustic telemetry equipment. Results of the Clarksburg Bend 3-D hydrodynamic study and statistical modeling of salmon survival and route selection probabilities using the single-hydrophone units are addressed in separate reports by USGS. This report provides methods and results of the field investigation on characteristics of juvenile salmon migration in the various channels of the northern Delta.

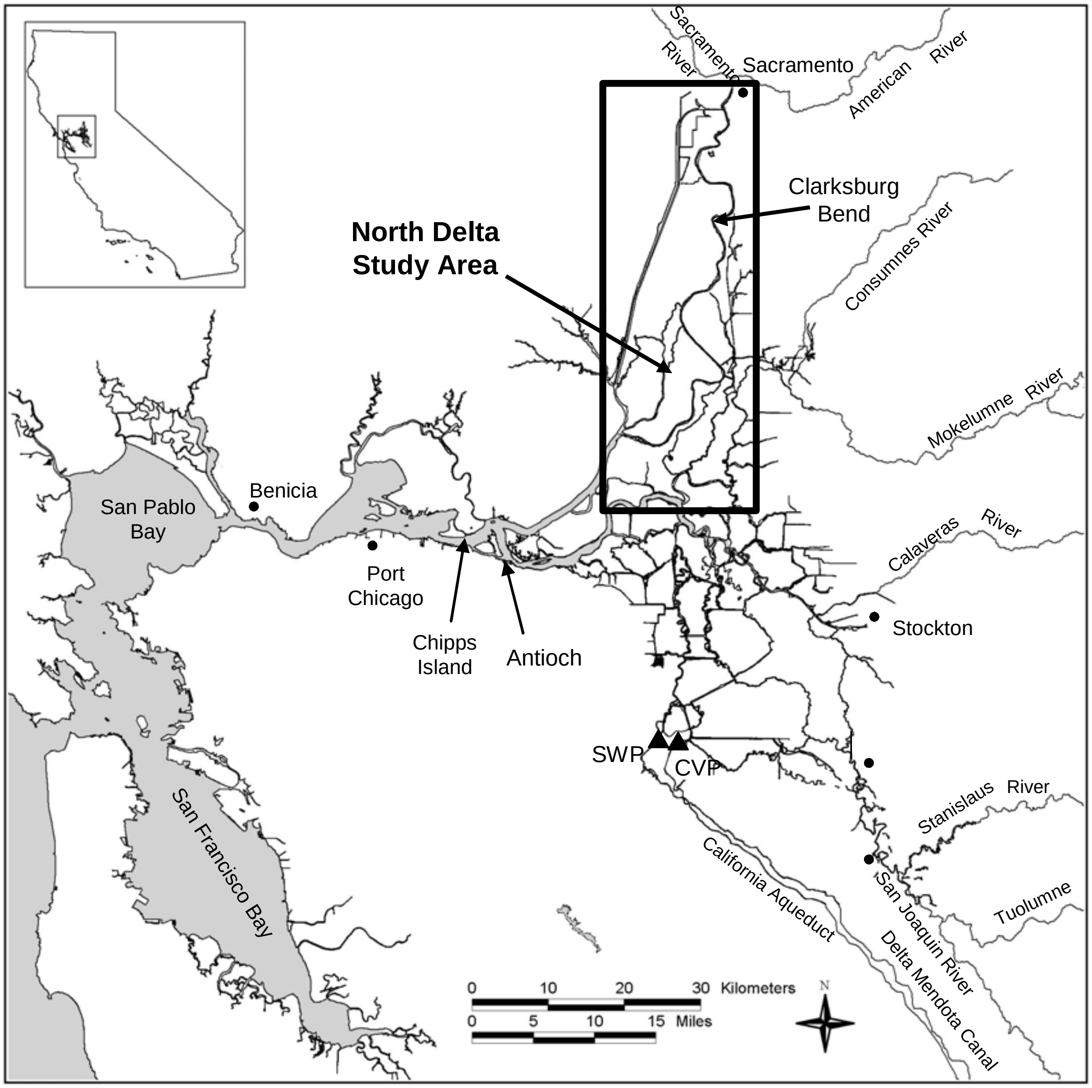

Figure 1. The Sacramento – San Joaquin Bay/Delta and the north Delta study area.

Materials and Methods

Basic Study Design

The overall study design had two primary purposes:

1) Collect data to indicate how salmon smolts migrate through a bend in the lower Sacramento River (Clarksburg Bend) in relation to channel geometry and flow structure and,

2) Collect data to indicate characteristics of juvenile salmon emigration through the north Delta including routes used by migrating smolts and smolt survival/mortality in those areas.

Results on study purpose no. 1 (Clarksburg Bend study) are covered in a separate report by USGS. Results for study purpose no. 2 are addressed in this report; statistical modeling of these results is reported by USGS.

Juvenile late-fall run Chinook salmon were surgically implanted with individually-identifiable HTI[1] acoustic transmitters and released in the Sacramento River at West Sacramento during December 2006 and January 2007 when the DCC gates were opened and closed, respectively. Fish were subsequently monitored by strategically-positioned, fixed-station data loggers (acoustic receivers) in downstream reaches at approximate locations shown in Figures 2 and 3. Exact locations of each receiver are provided in Appendix A. Positioning the downstream-most receivers for each reach in close proximity (dual arrays) allow for statistical computations of survival and probability of route selection (R. Perry, USGS, pers. comm.).

[1] Hydroacoustic Technology, Inc.

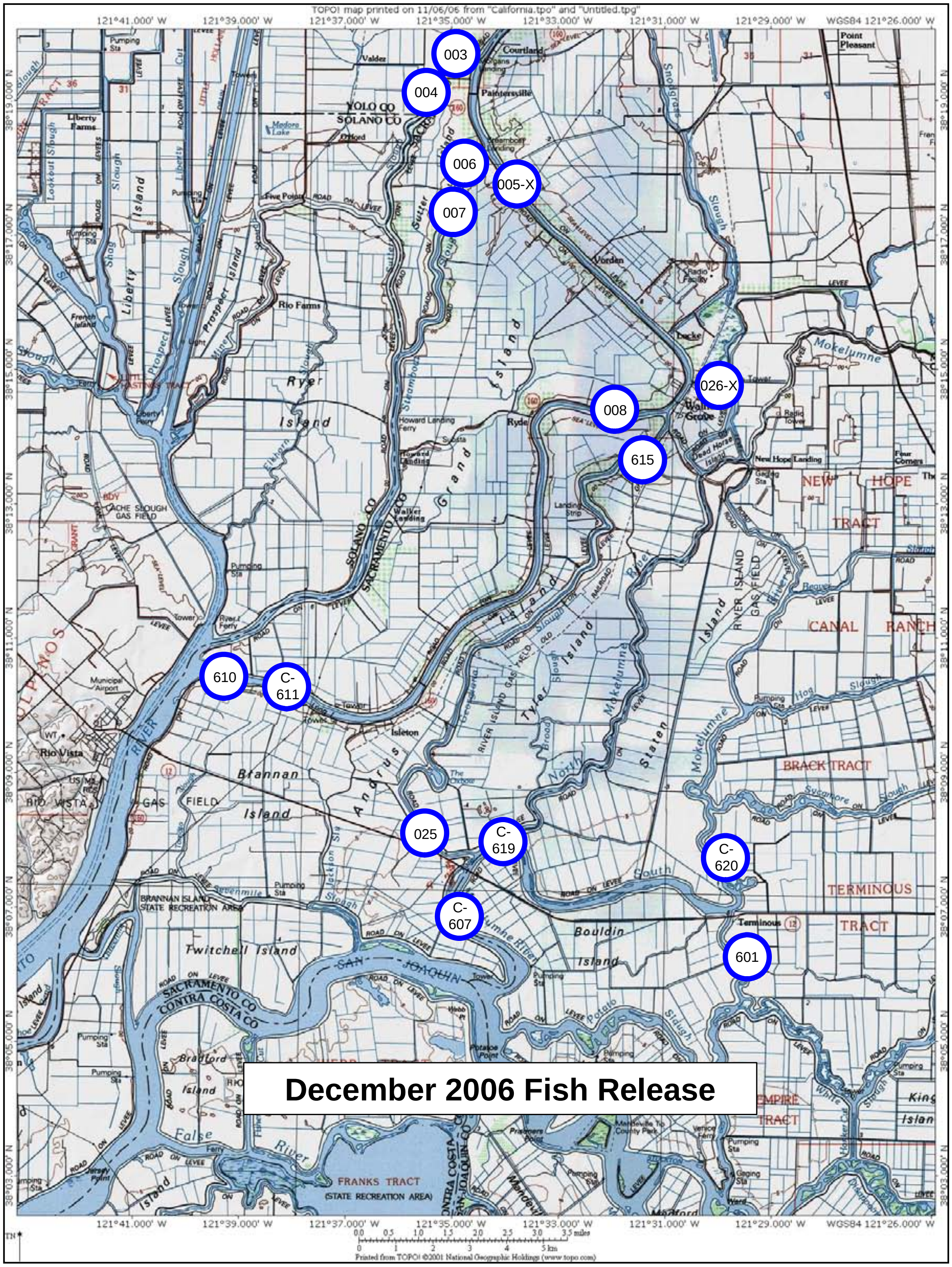

Figure 2. Approximate locations of acoustic receivers positioned in Delta reaches downstream of acoustic-tagged juvenile salmon released during December in the Sacramento River at West Sacramento with the DCC gates open. Numbers inside the blue circles are the last three digits of the serial number for each receiver.

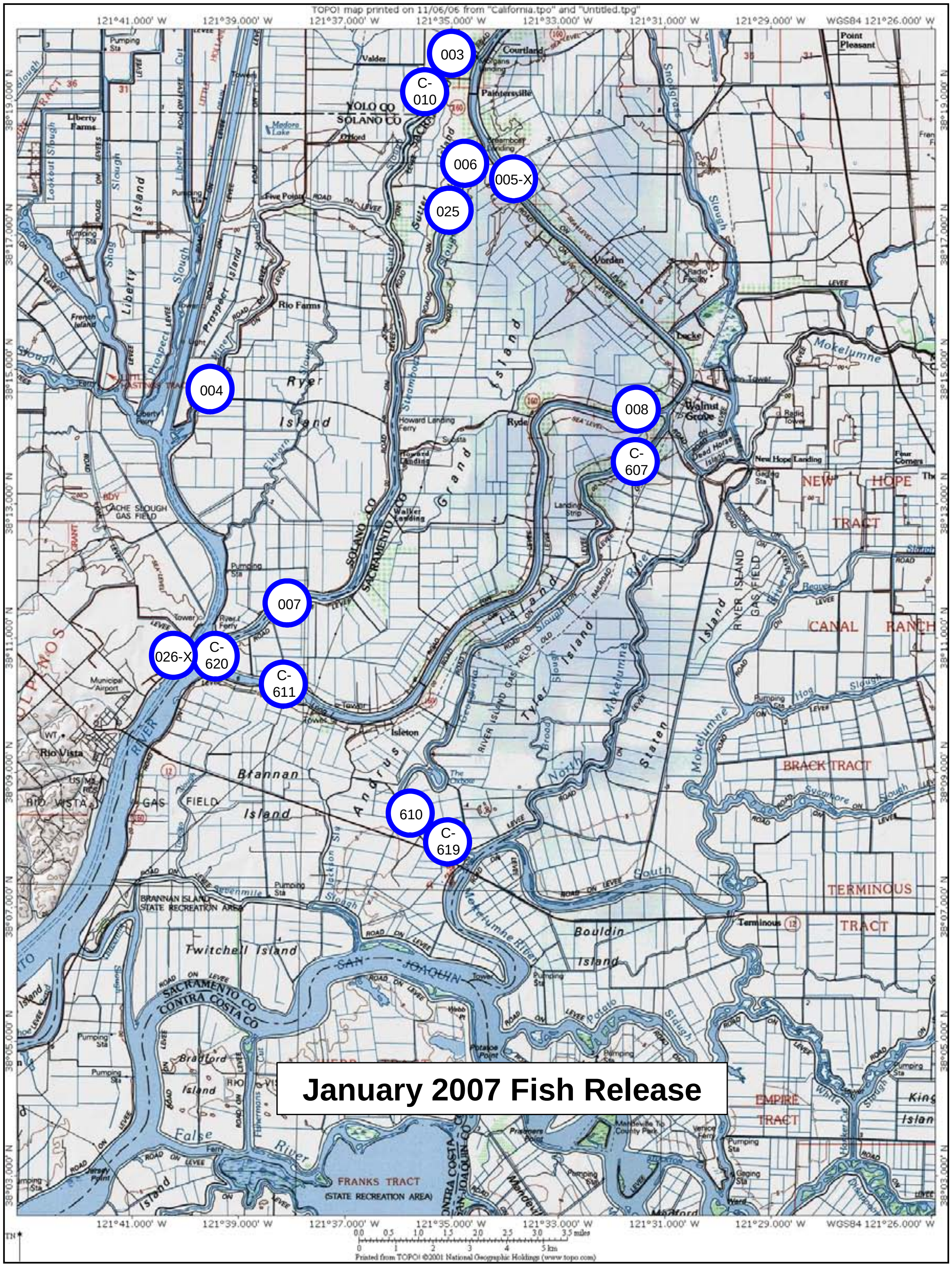

Figure 3. Approximate locations of acoustic receivers positioned in Delta reaches downstream of acoustic-tagged juvenile salmon released during January in the Sacramento River at West Sacramento with the DCC gates closed. Numbers inside the blue circles are the last three digits of the serial number for each receiver.

Surgical Implantation of Acoustic Transmitters

Juvenile late-fall Chinook salmon used for the north Delta study were obtained from Coleman National Fish Hatchery near Anderson, California. Salmon exhibiting external characteristics of smoltification were surgically implanted with 0.75-gram miniature acoustic transmitters (Figure 4). The transmitters measured approximately 6 mm in diameter and 16 mm long. Fish were anesthetized in aerated solutions of hatchery water containing 100 mg/liter 2,2,2 tricaine methanesulfonate, 5 ml of PolyAqua®, and about 7 g/liter sodium chloride. Water temperature of the anesthetic solution was monitored and maintained within 1^{o}C of the fish holding tanks at the hatchery. Upon sedation, the fish was placed dorsal side down in a foam tagging cradle covered with perforated plastic which supported the entire body and was saturated with a solution containing hatchery water, PolyAqua®, and 0.9% sodium chloride. All surgical equipment was disinfected with Nolvasan® and rinsed with physiological saline before surgery. The buccal cavity (mouth and gills) was continuously irrigated with the anesthetic solution (using a flexible plastic tube fed by gravity from a head bucket) throughout the implantation procedure.

An incision approximately 7 mm long was made about 3 mm adjacent and parallel to the ventral line and about 6 mm in front of the pelvic girdle. The transmitter was then gently pushed through the incision and placed inside the body cavity with the transducer facing forward. A passive integrated transponder (PIT) tag[2] was inserted into the body cavity by hand. The assumption was made that the PIT tag has negligible effects on juvenile salmon (Prentice et al. 1990). Addition of the PIT tag allowed for subsequent rapid discrimination of individual activated acoustic tags at the time of release. Antiseptic (oxytetracycline) was injected into the body cavity using a micro-pipette prior to closure of the incision; the amount was based on fish length. The incision was closed with two sutures placed equidistant apart (Figure 4).

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[2] “The PIT tag consists of an antenna coil that has about 1,200 wraps of a specially coated copper wire 0.0254 mm in diameter. The antenna coil is bonded to a pad and an integrated circuit chip. The electronic components of the tag are encapsulated in a glass tube 12.0 mm long by 2.1 mm in diameter.” (Prentice et al. 1990)

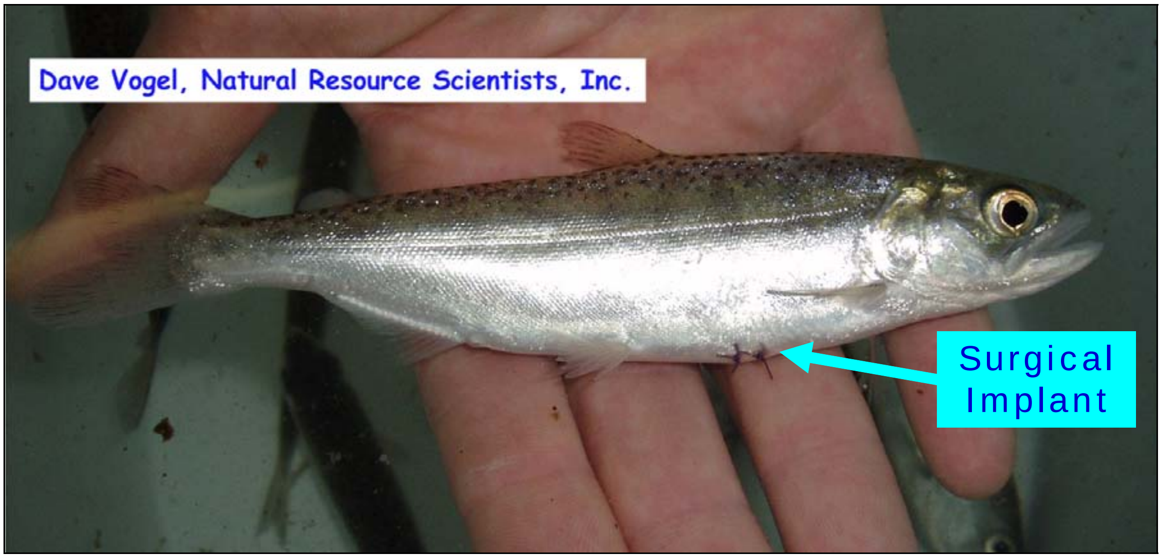

Figure 4. A juvenile Chinook salmon smolt after surgical implantation of a 0.75-gram acoustic transmitter.

After tagging, the fish was placed in a 20-liter recovery bucket containing an aerated solution of hatchery water, 5 ml PolyAqua® and about 5 to 7 g/liter sodium chloride. The entire tagging procedure from removal of the fish from the anesthetic solution to placement in the recovery solution took approximately two minutes. After visible recovery from anesthesia (fish was swimming upright), the fish was placed in a circular holding tank at the hatchery.

Control fish were tagged and handled in the same manner as test fish except the fish were surgically implanted with non-functional transmitters ("dummy" tags) of the same size as functional transmitters. Control fish were held in a circular tank at the hatchery for the duration of time test fish were monitored in the Delta. Fish were implanted with dummy tags only during January due to the unavailability of dummy tags during December.

Programming of Acoustic Transmitters

An HTI acoustic tag *in situ* programmer was used in conjunction with a laptop computer and HTI's software, *AcousticTag*®, to program and activate the acoustic tags inside the fish. Anesthetized fish were placed in a water-filled acrylic tube surrounded by a magnetic coil that was activated to program the transmitters inside the fish. Each tag was programmed with a different code (tag pulse transmission repetition rate) to allow subsequent discrimination between fish. A tag pulse width of 3 milliseconds (ms) was chosen for this study to ensure adequate reception by the 3-D hydrophone arrays deployed at Clarksburg Bend and the single-hydrophone receivers placed in downstream reaches. This pulse width provided an estimated battery life of approximately 11 to 13 days which was assumed to be sufficient for study purposes. A longer pulse width provides greater range of tag detection but less battery life (Figure 5). Longer repetition rates provide longer battery life but lower probability of detection as fish move past the receivers. Acoustic transmitters were programmed for different repetition rates ranging from 3,000 ms to 3,693 ms with 7 ms separation between codes for the December fish release and 3,006 ms to 5,890 ms with 14 ms separation between codes for the January fish release (Appendices B and C).

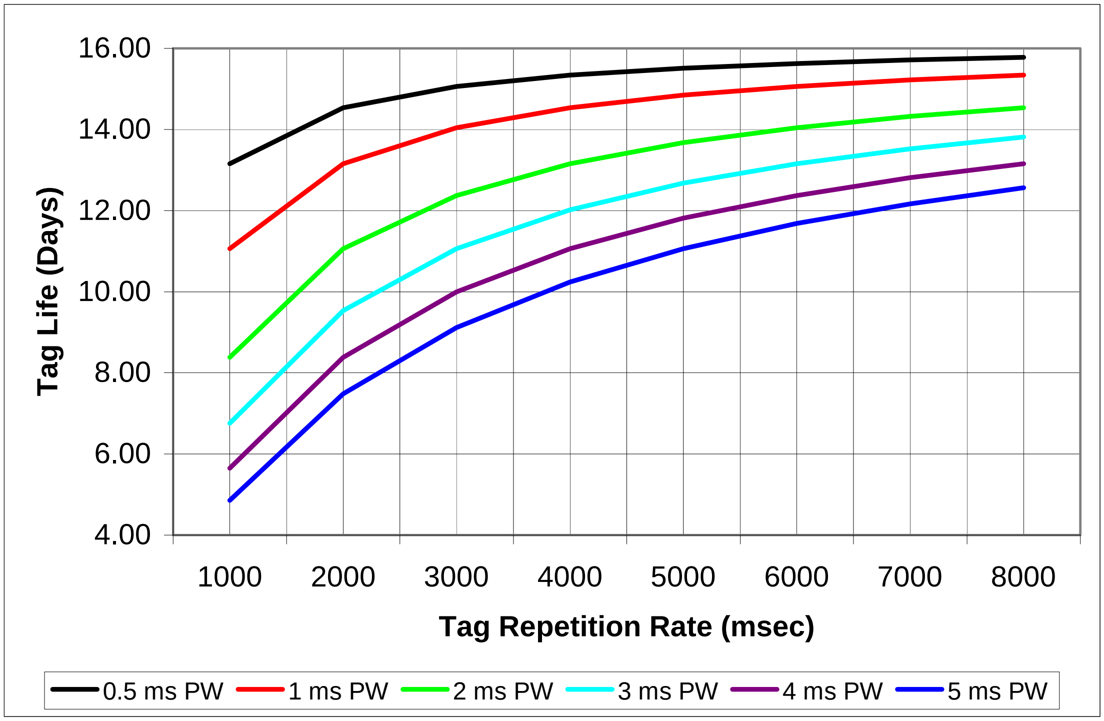

Figure 5. Estimated life of 0.75-gram acoustic tags based on pulse width (PW) and pulse repetition (data from HTI).

Fish Transport

Tagged salmon were allowed to recover from surgery for two or more days prior to transport to the release site. Fish were transported in an insulated, 110-liter fish-hauling tank with bottled oxygen aeration (1.5 - 3.0 liters/minute). The transport tank was filled with hatchery water and prepared by adding approximately 5 g/liter sodium chloride to minimize osmotic stress during handling and transport (Carmichael and Tomasso 1988, Long et al. 1977, Wedemeyer 1992) and 30 ml PolyAqua®. After transport to the lower Sacramento River at West Sacramento, fish were acclimated to river water through water exchanges providing for no more than about 1^{o}C temperature change every 10 minutes. When the holding water for fish in the transport tank was within 1^{o}C of river water, fish were transferred to a holding pen (3-ft x 3-ft x 5-ft live pen covered with 1/4-inch-mesh galvanized hardware cloth). Fish were held in the live pen for acclimation to ambient conditions overnight (or longer) prior to release (Figure 6).

Figure 6. Acclimation and holding pen used for the Delta fish tests.

Fish Releases

All fish releases were made at the same location in the lower Sacramento River at West Sacramento. The fish were released approximately 15.5 river miles upstream of Clarksburg Bend to allow fish acclimation time to recover from handling associated with the release and adjustment to natural riverine conditions. Just prior to release, 12 – 15 fish were netted from the live pen and each fish was individually scanned with an AVID® PIT tag reader to determine its corresponding acoustic tag code. Fish were subsequently transferred to 20-liter net-lid-covered buckets with aerated water, transported, and released in mid-channel from a boat. Fish were released mid-channel instead directly off the dock to avoid potential problems of predation by predators residing under or near the dock. Specific release times were based on predicted tidal phases developed by USGS. The fish release strategy was to introduce fish into the river during different tidal phases over one tidal cycle in December and two tidal cycles in January. The intent was to encompass a range of tidal flow variations to more closely reflect conditions that wild fish experience during outmigration.

Monitoring of Fish Migration

Acoustic Telemetry Equipment

Fish were monitored with the use of single-hydrophone acoustic receivers positioned off the river banks (Figure 7), from USGS flow-monitoring station platforms, or shipping channel markers. Approximate locations for each receiver during December and January are shown in Figures 2 and 3. The receivers were positioned in locations where there was an unobstructed direct line across the channel to allow acoustic tag detection if tagged fish passed those sites (Figure 8).

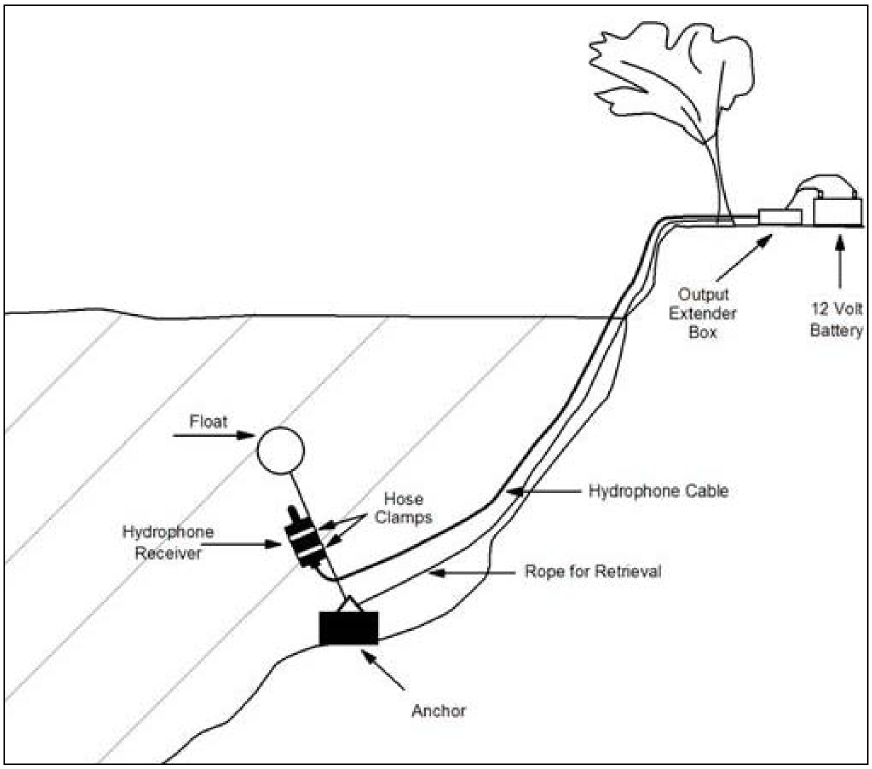

Figure 7. Deployment of an acoustic receiver from a Delta levee (from Vogel 2006b).

During receiver deployment and prior to fish releases, each receiver was tested by placing an activated acoustic transmitter on the opposite side of the channel from the receiver. A laptop computer was connected to the receiver to program the telemetry equipment for optimal tag reception (e.g., gain, signal-to-noise ratio, noise threshold) (Figure 9). The laptop computer was disconnected and removed during unattended field operations. Additional details on operation of the HTI telemetry equipment and software are provided in Vogel (2006b). Receivers were activated just prior to the fish releases. During the study, the USB drives (which store telemetry data) and the 12-VDC batteries were exchanged every two to three days.

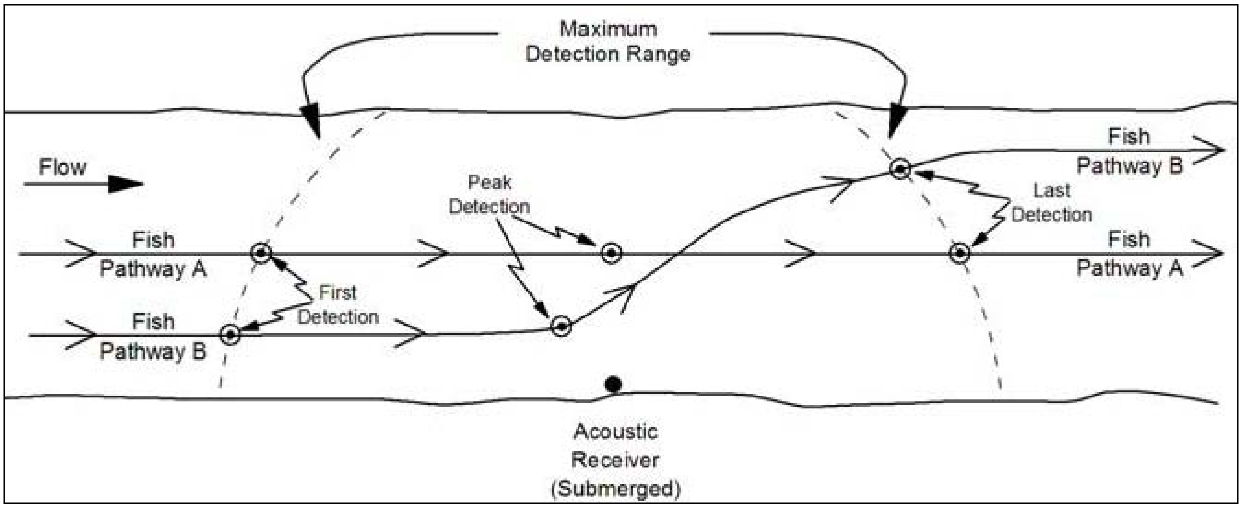

Figure 8. Plan-view schematic of two hypothetical fish migration pathways showing maximum and peak detection ranges (from Vogel 2006b).

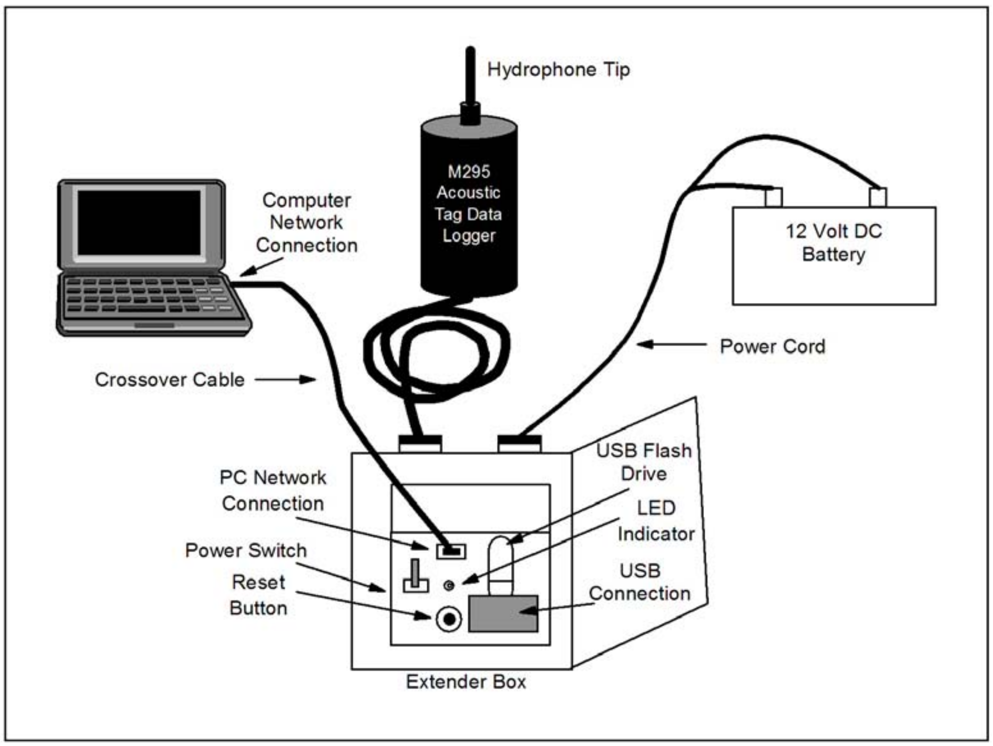

Figure 9. Setup of equipment for deployment of acoustic receivers in the field (not to scale) (from Vogel 2006b and adapted from HTI 2005b).

When acoustic-tagged fish pass each receiver, tag transmissions are recorded from the time of first detection until last detection; post processing displays peak detection (e.g., Figure 10). For this study, we used peak detection as the relative indicator of acoustic-tagged fish proximity near the receiver because it is a better approximation of location than that depicted by first or last detection.

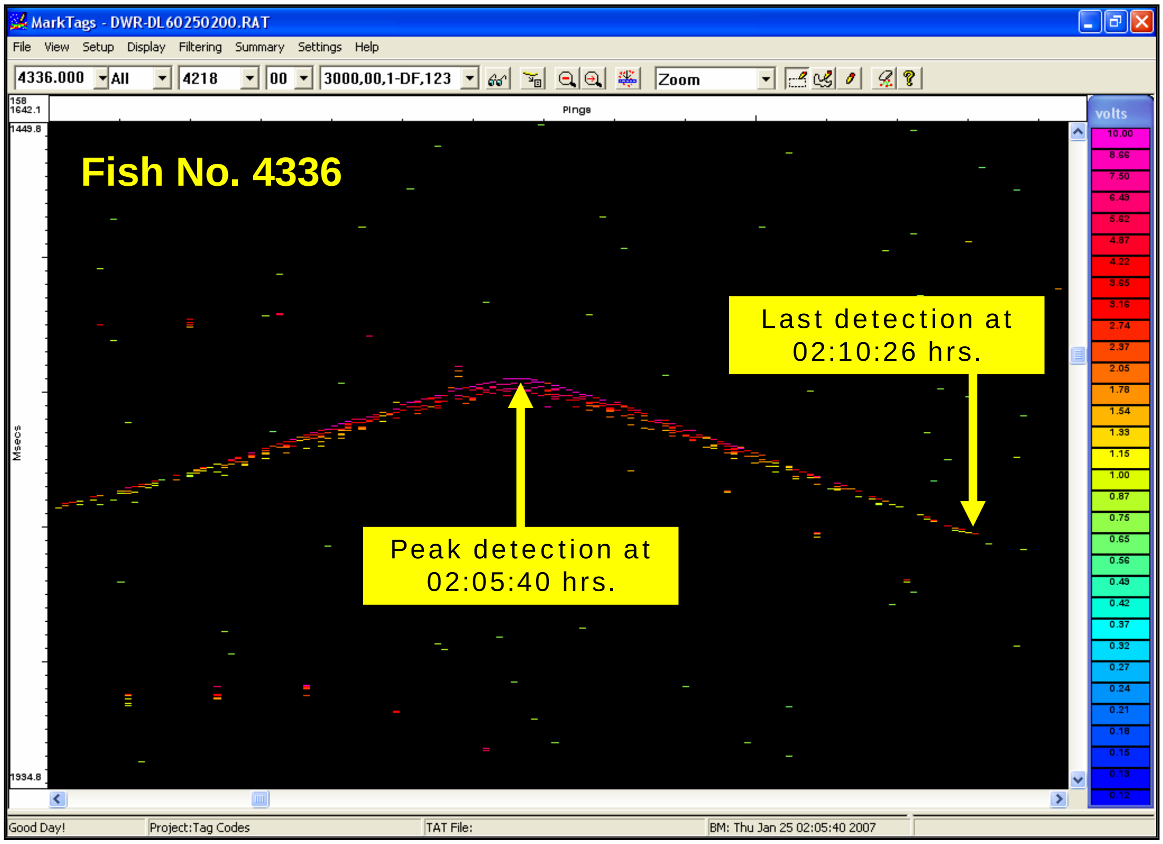

Figure 10. Post-processing display of the movements of fish no. 4336 on January 25, 2007 migrating past the fixed-station acoustic receiver positioned in upper Steamboat Slough. Note the change in amplitude and voltage strength as the fish approaches and passes the acoustic receiver.

Mobile telemetry was conducted by towing a hydrophone behind a jet boat with an inboard engine moving approximately 4 mph and recording data on an acoustic receiver. A GPS unit (Garmin® III+) was used concurrently with mobile acoustic receiver operation for post-processing purposes to determine locations where acoustic tags were detected.

Results and Discussion

December Fish Releases

One hundred juvenile salmon were surgically implanted with acoustic transmitters at Coleman National Fish Hatchery on December 2 and 3, 2006. Fish were allowed to recover from surgery at the hatchery for six to seven days prior to activating and programming tags using the *in-situ* programmer on December 9, 2006. Four tags did not activate. The 96 fish with active transmitters ranged in size from 107 mm to 181 mm fork length (FL) (mean of 140 mm FL, S.D.=15 mm). Each fish was examined during *in-situ* tag programming. All incisions had healed with the fish appearing in very healthy condition. All fish displayed external characteristics of smoltification and were actively feeding during the week after tag implantation. The 96 salmon with active transmitters were transported to the lower Sacramento River on December 10, 2006, acclimated to within 1^{o}C of receiving water temperatures, and placed in the live pen in the Sacramento River for holding and additional acclimation prior to release.

Fish releases began on December 11, 2006 and continued through December 12, 2006. Releases of four groups of 24 tagged and approximately a dozen untagged fish in each group occurred at 1955 hrs. on Dec. 11th and 0025 hrs., 0917 hrs., and 1515 hrs. on Dec. 12th (approximately 10 days after initial fish surgery). The four groups were released during approximate mean tides over a complete tidal cycle (Table 1). Appendix B provides each tag code for each fish release. No mortalities were observed and all fish appeared healthy and vigorous. No fish died from the time of surgery through the time of release in the river.

Table 1. Number of fish detected at downstream acoustic receivers for each group of acoustic-tagged juvenile salmon released in the Sacramento River at West Sacramento during December 2006.

Release Group:	**1**	**2**	**3**	**4**
Date/Time:	12-12-06 1955 hrs.	12-12-06 0025 hrs.	12-12-06 0917 hrs.	12-12-06 1515 hrs.
Tide Phase (Approx):	Mean tide during transition from high to low tide	Mean tide during transition from low to high tide	Mean tide during transition from high to low tide	Mean tide during transition from low to high tide
No. Fish Released:	24	24	24	24
No. Fish Detected at Downstream Receivers:	21 (88%)	22 (92%)	17 (71%)	21 (88%)

An acoustic receiver was positioned just downstream of the fish release site to record fish movements immediately upon release. All 96 tagged salmon exhibited normal smolt migration behavior moving rapidly downstream immediately after release. No fish moved in an upstream direction and there was no evidence of predation on tagged fish in the area from the release site to downstream of the Tower Bridge. No lingering of fish at the release site was observed; fish moved from the release site (mid-channel upstream of the live pen) to downstream of the Tower Bridge in approximately 7 - 8 minutes. A cross-check of all hand-recorded tag release codes and release times was conducted using receiver data; all data were determined to be accurate based on acoustic detections for each of the 96 fish by the single-hydrophone receiver.

Of the 96 acoustic-tagged salmon released in December, 81 fish (84%) were detected at the downstream single-hydrophone receivers; the remaining 15 fish (16%) presumably died in the reach upstream of receivers for unknown reasons (e.g., predation) or escaped detection at downstream receivers. Figure 11 shows the numbers of fish detected at the single-hydrophone receivers and Table 1 provides the numbers of fish from each release group detected during December. For those 81 fish reaching the general location of Sutter and Steamboat sloughs, 22% of the fish were detected entering Sutter Slough, 4% entering Steamboat Slough, and 74% remained in the Sacramento River (Figure 12).

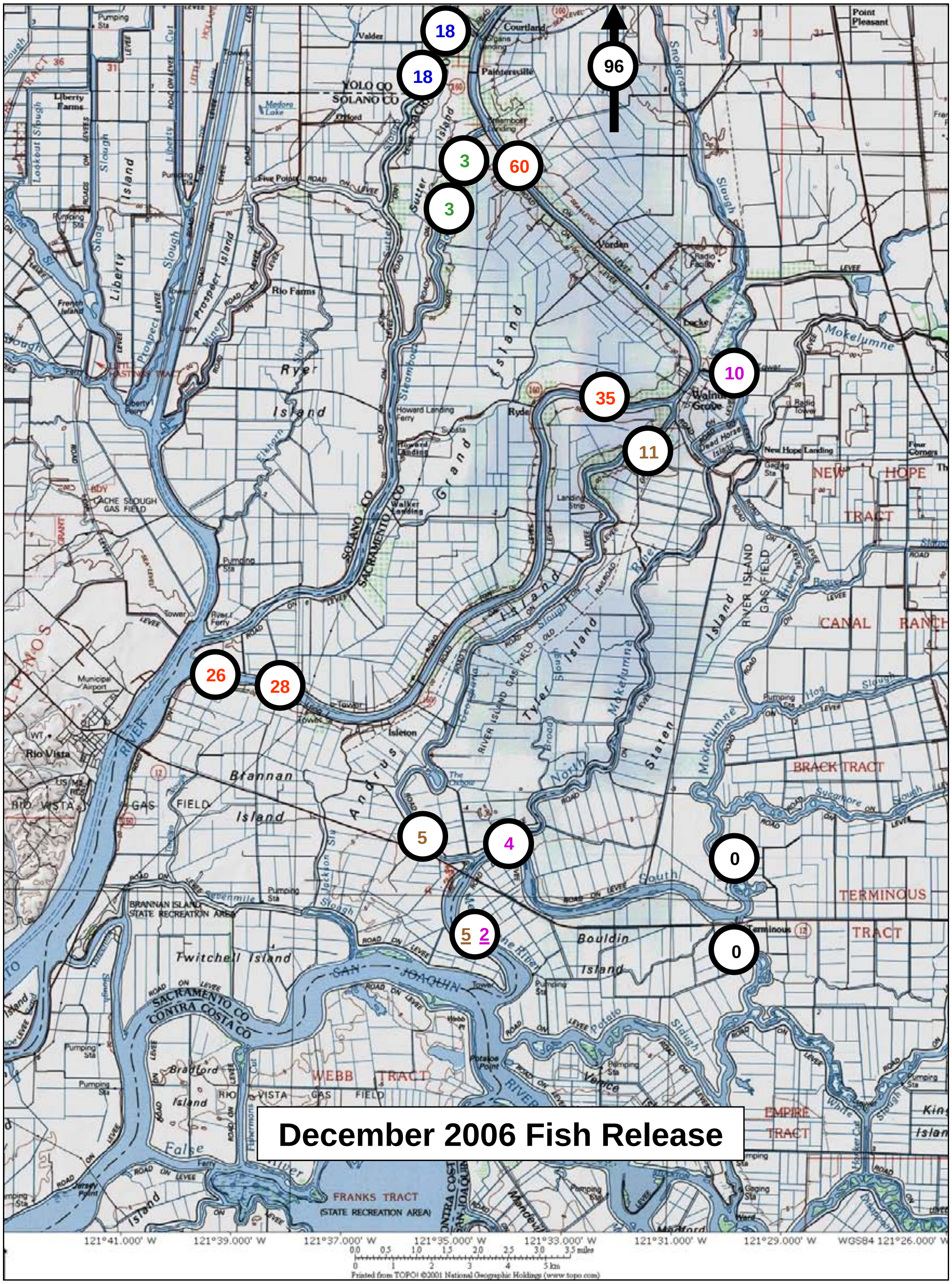

Figure 11. Detections of acoustic-tagged salmon at single-hydrophone acoustic receivers positioned in Delta channels downstream of the fish release site in West Sacramento during December 2006. Numbers are color-coded to show subsequent detections at downstream receivers.

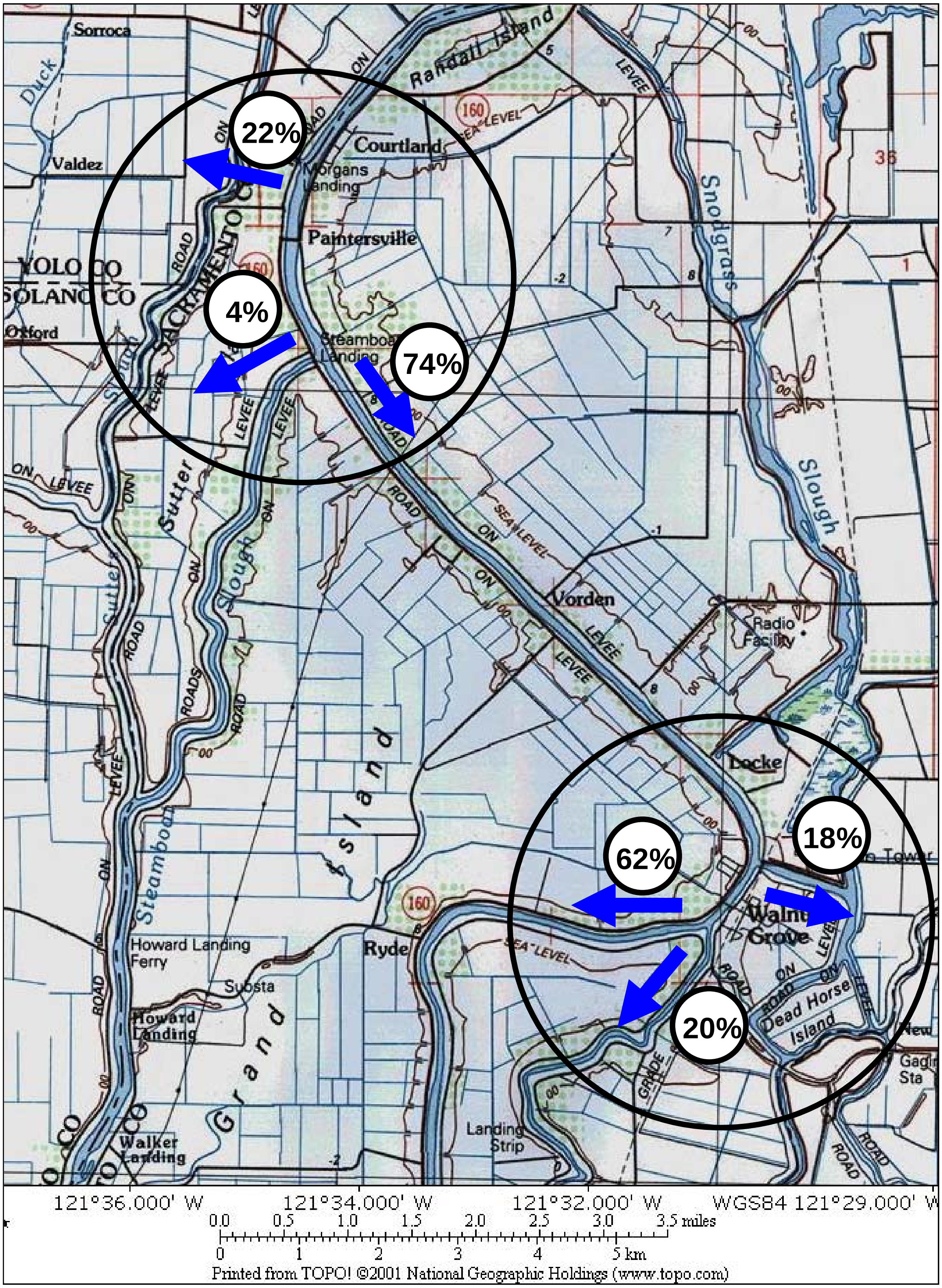

Figure 12. Proportional distribution of acoustic-tagged juvenile salmon entering channels at flow splits near the Sutter/Steamboat Slough region and the DCC/Georgiana Slough region in December.

A relatively high proportion of acoustic-tagged salmon entered Sutter Slough. Based on flow data provided by USGS, approximately 22% percent of the flow from the Sacramento River entered Sutter Slough during the time period between fish release at West Sacramento and the last detection of fish entering Sutter Slough. Although a substantial, but lesser, volume of Sacramento River flow enters Steamboat Slough as compared to Sutter Slough, a much smaller proportion of acoustic-tagged salmon entered Steamboat Slough. The reasons for the large discrepancy between proportions of fish diverted off the mainstem at the two locations may be a function of local channel geometries and hydrodynamic conditions at each site.

Further downstream, for the 56 fish reaching the general location of the DCC and Georgiana Slough, 18% were detected entering the DCC, 20% entering Georgiana Slough, and 62% remaining in the Sacramento River (Figure 12). No fish were detected in the lower South Fork Mokelumne River or Little Potato Slough suggesting high fish mortality in this region. However, we experienced some hardware problems with receivers in this area so, conceivably, some fish may have passed the sites undetected. Among those fish remaining in the Sacramento River downstream of the Georgiana Slough flow split, 74% were detected reaching the Cache Slough confluence. Two fish reaching the second receiver positioned just upstream of the Cache Slough confluence may have been eaten by predatory fish based on aberrant tag movements depicted in the data logged by that receiver.

Detections by acoustic receivers were compromised by malfunctions on some of those units. This was particularly evident for some receivers placed in the Mokelumne River system when some receivers were not operational and acoustic-tagged salmon may have passed those sites undetected (Table 2).

Table 2. Periods of non-operation of acoustic receivers during December 2006.[1]

Receiver No.	Location[2]	Start Down Time	End Down Time
006	Steamboat Slough	12/17/06 0200 hrs.	12/17/06 0900 hrs.
007	Steamboat Slough	12/17/06 0800 hrs.	12/17/06 0900 hrs.
005-X	Sacramento River	12/17/06 0800 hrs.	12/17/06 0900 hrs.
026-X	Delta Cross Channel	12/15/06 0800 hrs.	12/15/06 1000 hrs.[3]
615	N. Georgiana Slough	12/19/06 2300 hrs.	12/20/06 1200 hrs.
025	S. Georgiana Slough	12/12/06 1200 hrs.	12/14/06 1800 hrs.
C-619	Lower Mokelumne River	12/18/06 1700 hrs.	12/20/06 1200 hrs.
C-607	Lower Mokelumne River	12/12/06 1200 hrs.	12/16/06 1400 hrs.

[1] The acoustic receivers in the Mokelumne River system and the two receivers in the lower Sacramento River were removed during the afternoon of December 20, 2006 and the remaining receivers on the Sacramento River system were removed during December 21, 2006.
[2] Refer to Figure 2 for receiver locations.
[3] Time when the DCC gates were closed.

January Fish Releases

One hundred-fifty juvenile salmon to be used for the Delta experiments (test fish) were surgically implanted with acoustic transmitters at Coleman National Fish Hatchery on

January 13, 14, and 15, 2007. Additionally, dummy tags were surgically implanted in 53 salmon and held in a circular tank at the hatchery until February 4, 2007. One recently-dead dummy-tagged salmon was found in the tank on February 4th indicating that all dummy-tagged salmon survived for the duration of fish monitoring in the Delta. Test fish for the Delta experiments were allowed to recover from surgery at the hatchery for five to seven days prior to activating and programming tags using the *in-situ* programmer on January 20, 2007. The 150 fish with active transmitters ranged in size from 119 mm to 197 mm FL (mean of 159 mm FL, S.D. = 15 mm). Each fish was examined during *in-situ* tag programming. All incisions had healed with the fish appearing in very healthy condition. All fish displayed external characteristics of smoltification and were actively feeding during the week after tag implantation. The 150 salmon with active transmitters were transported to the lower Sacramento River on January 21, 2007, acclimated to within 1°C of receiving water temperatures, and placed in the live pen in the Sacramento River for holding and additional acclimation prior to release.

Fish releases began on January 22, 2007 and continued through January 23, 2007. Releases of eight groups of 17 to 20 fish per group occurred on the dates and times provided in Table 3 (approximately 7 - 10 days after initial fish surgery). The eight fish groups were released during various tide conditions ranging from low to high tide (Table 2). Appendix C provides each tag code for each fish release. No mortalities were observed and all fish appeared healthy and vigorous. No fish died from the time of surgery through the time of release in the river. The acoustic receiver with an external hydrophone placed near the release site was removed just prior to the fish release to replace a damaged hydrophone in the 3-D array at Clarksburg Bend. That receiver was replaced with a receiver with an internal hydrophone but had insufficient channel coverage to detect acoustic-tagged salmon upon release. Therefore, no data on fish behavior immediately after release was recorded for the January releases.

Table 3. Number of fish detected at downstream acoustic receivers for each group of acoustic-tagged juvenile salmon released in the Sacramento River at West Sacramento during January 2007.

Release Group:	1	2	3	4	5	6	7	8
Date/Time:	1-22-07 1603 hrs.	1-22-07 1908 hrs.	1-22-07 2154 hrs.	1-23-07 0155 hrs.	1-23-07 0448 hrs.	1-23-07 0806 hrs.	1-23-07 1105 hrs.	1-23-07 1500 hrs.
Tide Phase (Approx.):	Mean tide during transition from high to low tide	Low tide	Mean tide during transition from low to high tide	High tide	Mean tide during transition from high to low tide	Low tide	Mean tide during transition from low to high	High tide
No. Fish Released:	17	18	20	20	20	19	18	18
No. Fish Detected at Downstream Receivers:	8 (47%)	14 (78%)	13 (65%)	15 (75%)	13 (65%)	7 (37%)	13 (72%)	14 (78%)

Of the 150 acoustic-tagged salmon released in January when the DCC gates were closed, 97 fish (65%) were detected at the downstream single-hydrophone receivers; the remaining 53 fish (35%) presumably died in the reach upstream of the receivers for unknown reasons (e.g., predation) or escaped detection at downstream receivers. Figure 13 shows the numbers of fish detected at the single-hydrophone receivers and Table 3 provides the numbers of fish from each release group detected during January. For those 97 fish reaching the general location of Sutter and Steamboat sloughs, 30% of the fish were detected entering Sutter Slough, 7% entering Steamboat Slough, and 63% remaining in the Sacramento River (Figure 14). Further downstream, for the 52 fish reaching the Georgiana Slough flow split, 29% were detected entering Georgiana Slough and 71% remained in the Sacramento River (Figure 14). An operational receiver was not placed in northern Georgiana Slough until January 24, 2007 due to changing hydrophones for the 3-D arrays in Clarksburg Bend so some fish may have entered the Slough prior to that time. Nevertheless, a high number of fish entered Georgiana Slough which was similarly observed in a prior study of radio-tagged salmon at the entrance to the Slough (Vogel 2003b). For those fish remaining in the Sacramento River, 64% were detected reaching the Cache Slough confluence. Of those fish detected entering Georgiana Slough, only 27% were detected in lower Georgiana Slough. Of those fish entering Sutter Slough, 59% were detected in lower Miner Slough and lower Steamboat Slough. Among those fish detected entering Steamboat Slough, 57% were detected exiting Steamboat Slough.

As observed during the December fish releases, a relatively high proportion of acoustic-tagged salmon entered Sutter Slough during the January fish releases. Based on flow data provided by USGS, approximately 25% percent of the flow from the Sacramento River entered Sutter Slough during the period between time of fish release at West Sacramento and the last fish was detected entering Sutter Slough. Also as noted in December, a substantial, but lesser, volume of Sacramento River flow enters Steamboat Slough as compared to Sutter Slough but a much smaller proportion of acoustic-tagged salmon entered Steamboat Slough.

All receivers were removed from the Delta on February 4 and 5, 2007. The performance of acoustic receivers during the January fish releases was improved compared to December because the hardware was returned to the vendor for repair after the December experiments.

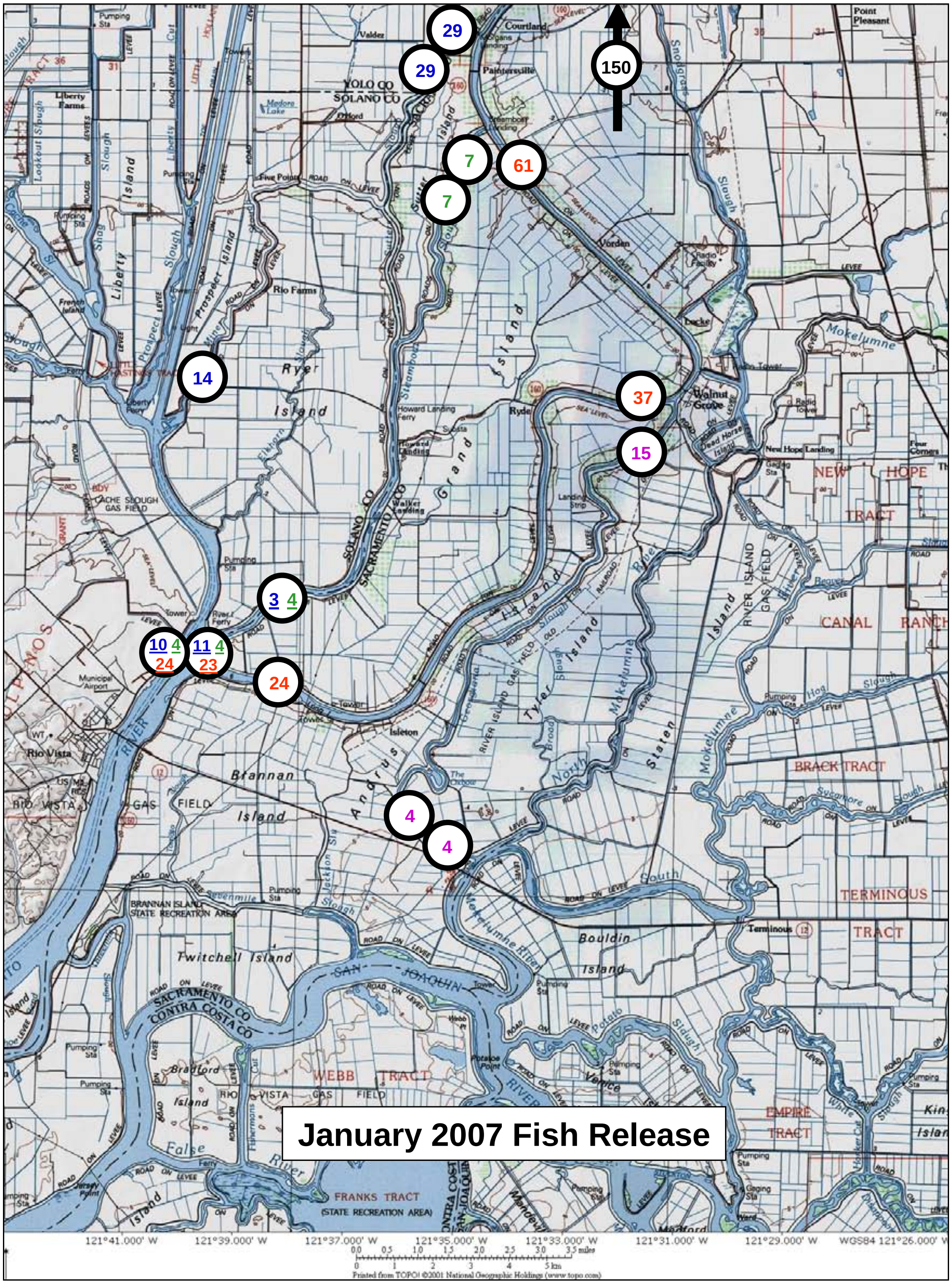

Figure 13. Detections of acoustic-tagged salmon at single-hydrophone acoustic receivers positioned in Delta channels downstream of the fish release site in West Sacramento during January 2007. Numbers are color-coded to show subsequent detections at downstream receivers.

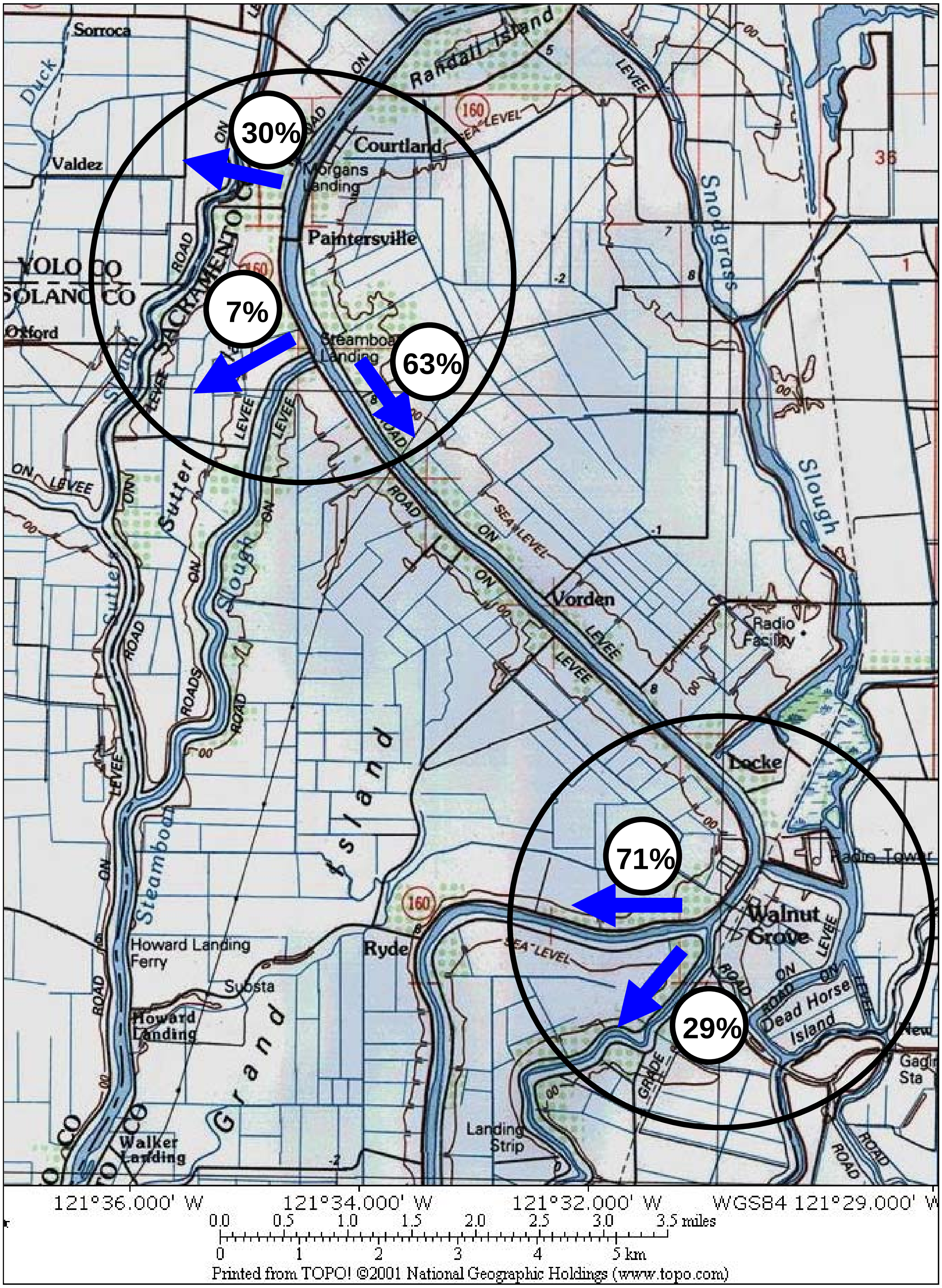

Figure 14. Proportional distribution of acoustic-tagged juvenile salmon entering channels at flow splits near the Sutter/Steamboat Slough region and the Georgiana Slough region (DCC gates were closed) in January.

The reasons for the apparent lower fish survival[3] in January compared to December are unknown. Flow was lower in January than December but flow, by itself, would not be a proximal cause of fish mortality. Although control fish held at the hatchery did not die during the period fish were monitored in the Delta (suggesting latent mortality due to surgery did not occur), there were no control fish held in the Delta during the study period. The use of the *in situ* tag programmer was conducted approximately one week after surgery providing an extended period for the fish to recover and heal from the surgical implantation of tags. Latent mortality due to transport and handling stress could have been a variable affecting subsequent fish survival after release but this was unlikely because of considerable care in fish handling. Fish handling stress just prior to release may have made the fish more vulnerable to predation after release. Although there was some indication that fish released during daylight may have experienced higher mortality as compared to fish released at night (Tables 1 and 3) (presumably making the fish more prone to predation), there was sufficient variability among releases to question that hypothesis. Water temperatures were optimal for juvenile salmon during both months and would not have caused chronically stressful conditions. Additionally, because the study was conducted during the winter, or the non-irrigation season, potential losses at unscreened water diversions should have been negligible. Although water quality conditions were not evaluated during the study period, chronically or acutely toxic conditions were assumed to be implausible due to high dilution flows and lack of any reports of dead fish. Turbidity generally increases with winter-time flows and the higher flows during December were more turbid than January based on synoptic observations. The lower-flow, lower-turbidity conditions in January may have made the acoustic-tagged salmon more vulnerable to sight-feeding predatory fish such as striped bass. Also, the seasonal distribution of predatory fish within the study area may have been substantially different between months. For both months, relative survival of fish migrating through Georgiana Slough was lower than fish migrating down the lower Sacramento River from the Georgiana Slough flow split. However, those data should be used with caution due to problems with the receivers placed in lower Georgiana Slough. However, a similar pattern of lower fish survival within Georgiana Slough was observed from prior releases of radio-tagged juvenile salmon; the source of mortality in those studies was attributed to predation (Vogel 2001, 2004). Juvenile salmon migration rates during January were slower than observed in December (discussed below) which presumably would have increased the duration of salmon exposure to predators within the study reaches.

Migration Rates

Because acoustic-tagged salmon were individually identifiable at time of release and detection times were recorded at receivers positioned downstream of the release site, individual migration rates for each fish could be determined. Sutter Slough was the location of first detection by a downstream single-hydrophone receiver[4] (a distance of

[3] Statistical estimates of fish survival by reach and 95% confidence intervals for those estimates are provided in a separate report by USGS.
[4] The 3-D hydrophone arrays at Clarksburg Bend were positioned upstream of Sutter Slough and is the site of first detection; those results are presented in a separate report by USGS.

25.2 river miles). Although sample sizes were small, there did not appear to be significant differences in fish migration rates based on different times of release during different tidal cycles among releases during December or January (Table 4). However, in comparing the two periods of study, differences in average migration rates did occur for those fish released in December (0.67 mph) and January (0.47 mph). The average river flow (as measured at Freeport[5], CA) during the period when fish were migrating[6] during December and January was 19,814 cfs and 11,613 cfs, respectively. The faster fish migration rates were associated with the higher flows.

Table 4. Migration rates (mph) for acoustic-tagged juvenile salmon released during December and January in the Sacramento River at West Sacramento to upper Sutter Slough (a distance of 25.2 river miles).

Fish ID	Release Date/Time	Detection Date/Time	Migration Rate (mph)	Average (mph)	S.D.
3056	12/11/2006 19:55	12/13 03:36	0.80		
3140	12/11/2006 19:55	12/13 02:56	0.81	0.80	0.01
3084	12/12/2006 0:25	12/15 06:38	0.32		
3098	12/12/2006 0:25	12/17 00:56	0.21		
3287	12/12/2006 0:25	12/13 05:39	0.86		
3329	12/12/2006 0:25	12/13 02:12	0.98		
3343	12/12/2006 0:25	12/17 00:54	0.21		
3511	12/12/2006 0:25	12/13 05:50	0.86		
3581	12/12/2006 0:25	12/13 03:15	0.94		
3651	12/12/2006 0:25	12/16 23:52	0.21		
3665	12/12/2006 0:25	12/13 06:42	0.83	0.60	0.35
3525	12/12/2006 9:17	12/13 19:03	0.75		
3630	12/12/2006 9:17	12/13 22:39	0.67		
3147	12/12/2006 15:15	12/13 19:34	0.89		
3644	12/12/2006 15:15	12/13 23:17	0.79	0.77	0.09
			Overall for December Fish Release:	**0.67**	**0.28**
3734	1/22/2007 16:03	1/24 23:40	0.45	0.45	------
3216	1/22/2007 19:08	1/25 2:55	0.45		
3468	1/22/2007 19:08	1/25 3:31	0.45		
5288	1/22/2007 19:08	1/24 18:25	0.53	0.48	0.05
3020	1/22/2007 21:54	1/25 2:35	0.48		
3636	1/22/2007 21:54	1/25 2:53	0.48		
5330	1/22/2007 21:54	1/24 23:47	0.51	0.49	0.02
4518	1/23/2007 1:55	1/26 2:04	0.35		
5344	1/23/2007 1:55	1/25 2:17	0.52	0.44	0.12
5022	1/23/2007 4:48	1/25 5:13	0.52	0.52	------
3230	1/23/2007 8:06	1/29 4:43	0.18		
4896	1/23/2007 8:06	1/25 1:28	0.61	0.39	0.30
4210	1/23/2007 11:05	1/25 3:34	0.62		
5848	1/23/2007 11:05	1/26 5:30	0.38	0.50	0.17
3370	1/23/2007 15:00	1/25 4:23	0.67		
3692	1/23/2007 15:00	1/27 2:28	0.30	0.49	0.26

[5] Provisional data from USGS gauge no. 11447650.
[6] Computed from the day of first fish release to the last day of detection at the downstream receiver.

Table 4. Migration rates (mph) for acoustic-tagged juvenile salmon released during December and January in the Sacramento River at West Sacramento to upper Sutter Slough (a distance of 25.2 river miles).					
Fish ID	**Release Date/Time**	**Detection Date/Time**	**Migration Rate (mph)**	**Average (mph)**	**S.D.**
			Overall for January Fish Release:	**0.47**	**0.12**

Similar migration rate comparisons were made for fish detected at the receiver positioned in the Sacramento River just downstream of Steamboat Slough, a distance of 26.6 river miles. There were no apparent differences between groups of fish released at different times and tidal cycles among releases in December (Table 5) or January (Table 6). However, in comparing the two periods of study, differences in migration rates did occur for those fish released in December (0.71 mph) (Table 5) and January (0.46 mph) (Table 6). The average river flow (as measured at Freeport[7], CA) during the period when these salmon were migrating during December and January was 20,050 cfs and 11,840 cfs, respectively. The faster fish migration rates were associated with the higher flows.

Table 5. Migration rates (mph) for acoustic-tagged juvenile salmon released during December in the Sacramento River at West Sacramento to the Sacramento River just downstream of Steamboat Slough (a distance of 26.6 river miles).

Fish ID	Release Date/Time	Peak Detection Date/Time	Migration Rate (mph)	Average (mph)	S.D.
3042	12/11/2006 19:55	12/13 02:21	0.88		
3049	12/11/2006 19:55	12/13 05:25	0.79		
3154	12/11/2006 19:55	12/13 15:44	0.61		
3196	12/11/2006 19:55	12/14 03:38	0.48		
3224	12/11/2006 19:55	12/13 04:21	0.82		
3420	12/11/2006 19:55	12/14 04:55	0.47		
3434	12/11/2006 19:55	12/14 00:48	0.50		
3462	12/11/2006 19:55	12/13 18:05	0.58		
3469	12/11/2006 19:55	12/13 03:01	0.86		
3483	12/11/2006 19:55	12/14 01:25	0.50		
3518	12/11/2006 19:55	12/13 04:17	0.82		
3532	12/11/2006 19:55	12/13 01:11	0.91		
3553	12/11/2006 19:55	12/14 00:20	0.51		
3588	12/11/2006 19:55	12/14 16:45	0.39		
3623	12/11/2006 19:55	12/17 23:04	0.18		
3672	12/11/2006 19:55	12/14 19:15	0.37		
3693	12/11/2006 19:55	12/13 06:06	0.78	0.61	0.21
3105	12/12/2006 0:25	12/13 17:33	0.65		
3161	12/12/2006 0:25	12/13 02:15	1.03		
3203	12/12/2006 0:25	12/13 05:14	0.92		
3210	12/12/2006 0:25	12/13 03:39	0.98		
3245	12/12/2006 0:25	12/13 07:50	0.85		
3266	12/12/2006 0:25	12/13 17:29	0.65		
3413	12/12/2006 0:25	12/13 01:34	1.06		
3546	12/12/2006 0:25	12/15 21:22	0.29		

[7] Provisional data from USGS gauge no. 11447650.

Table 5. Migration rates (mph) for acoustic-tagged juvenile salmon released during December in the Sacramento River at West Sacramento to the Sacramento River just downstream of Steamboat Slough (a distance of 26.6 river miles).					
Fish ID	**Release Date/Time**	**Peak Detection Date/Time**	**Migration Rate (mph)**	**Average (mph)**	**S.D.**
3658	12/12/2006 0:25	12/14 00:52	0.55	0.77	0.26
3000	12/12/2006 9:17	12/13 17:20	0.83		
3070	12/12/2006 9:17	12/13 15:37	0.88		
3189	12/12/2006 9:17	12/13 19:02	0.79		
3238	12/12/2006 9:17	12/13 10:12	1.07		
3280	12/12/2006 9:17	12/13 23:42	0.69		
3336	12/12/2006 9:17	12/16 07:46	0.28		
3357	12/12/2006 9:17	12/13 17:52	0.82		
3385	12/12/2006 9:17	12/13 16:46	0.85		
3455	12/12/2006 9:17	12/13 21:03	0.74		
3476	12/12/2006 9:17	12/13 18:33	0.80		
3504	12/12/2006 9:17	12/13 17:56	0.82		
3574	12/12/2006 9:17	12/18 19:43	0.17		
3616	12/12/2006 9:17	12/13 15:54	0.87	0.74	0.24
3021	12/12/2006 15:15	12/16 8:05	0.30		
3091	12/12/2006 15:15	12/14 02:14	0.76		
3133	12/12/2006 15:15	12/14 01:42	0.77		
3168	12/12/2006 15:15	12/13 22:01	0.87		
3231	12/12/2006 15:15	12/13 18:06	0.99		
3252	12/12/2006 15:15	12/15 21:07	0.34		
3259	12/12/2006 15:15	12/14 00:50	0.79		
3322	12/12/2006 15:15	12/13 20:34	0.91		
3350	12/12/2006 15:15	12/13 18:11	0.99		
3364	12/12/2006 15:15	12/14 03:50	0.73		
3371	12/12/2006 15:15	12/14 02:57	0.75		
3539	12/12/2006 15:15	12/14 00:00	0.81		
3560	12/12/2006 15:15	12/13 19:14	0.95		
3567	12/12/2006 15:15	12/15 04:23	0.44		
3595	12/12/2006 15:15	12/14 00:19	0.81		
3602	12/12/2006 15:15	12/14 03:19	0.74	0.75	0.21
Overall for December Fish Release:				**0.71**	**0.23**

Table 6. Migration rates (mph) for acoustic-tagged juvenile salmon released during January in the Sacramento River at West Sacramento to the Sacramento River just downstream of Steamboat Slough (a distance of 26.6 river miles).					
Fish ID	**Release Date/Time**	**Peak Detection Date/Time**	**Migration Rate (mph)**	**Average (mph)**	**S.D.**
3244	1/22/2007 16:03	1/24 23:43	0.48		
3580	1/22/2007 16:03	1/24 23:04	0.48		
3678	1/22/2007 16:03	1/24 2:56	0.76		
4350	1/22/2007 16:03	1/24 21:35	0.50	0.56	0.14
3048	1/22/2007 19:08	1/25 3:13	0.47		
3790	1/22/2007 19:08	1/24 22:37	0.52		
4252	1/22/2007 19:08	1/25 3:56	0.47		
4406	1/22/2007 19:08	1/25 4:12	0.47		

Table 6. Migration rates (mph) for acoustic-tagged juvenile salmon released during January in the Sacramento River at West Sacramento to the Sacramento River just downstream of Steamboat Slough (a distance of 26.6 river miles).					
Fish ID	**Release Date/Time**	**Peak Detection Date/Time**	**Migration Rate (mph)**	**Average (mph)**	**S.D.**
5694	1/22/2007 19:08	1/25 3:24	0.47	0.48	0.02
3188	1/22/2007 21:54	1/24 20:40	0.57		
3258	1/22/2007 21:54	1/24 23:22	0.54		
3888	1/22/2007 21:54	1/30 20:51	0.14		
4546	1/22/2007 21:54	1/24 15:10	0.65		
4812	1/22/2007 21:54	1/25 19:34	0.38		
5890	1/22/2007 21:54	1/26 22:01	0.28	0.43	0.19
3328	1/23/2007 1:55	1/26 20:21	0.29		
3342	1/23/2007 1:55	1/25 23:23	0.38		
3510	1/23/2007 1:55	1/25 2:17	0.55		
3832	1/23/2007 1:55	1/25 23:04	0.39		
4028	1/23/2007 1:55	1/27 0:54	0.28		
4238	1/23/2007 1:55	1/25 4:39	0.52		
4952	1/23/2007 1:55	1/25 1:11	0.56		
5316	1/23/2007 1:55	1/24 21:27	0.61	0.45	0.13
3412	1/23/2007 4:48	1/27 21:00	0.24		
3818	1/23/2007 4:48	1/29 20:43	0.17		
4112	1/23/2007 4:48	1/25 3:18	0.57		
4224	1/23/2007 4:48	1/25 4:20	0.56		
4364	1/23/2007 4:48	1/26 3:57	0.37		
5484	1/23/2007 4:48	1/25 2:48	0.58		
5750	1/23/2007 4:48	1/25 1:00	0.60	0.44	0.18
3594	1/23/2007 8:06	1/25 4:12	0.60		
3622	1/23/2007 8:06	1/26 4:02	0.39		
3930	1/23/2007 8:06	1/24 19:27	0.75		
5078	1/23/2007 8:06	1/28 13:46	0.21		
5386	1/23/2007 8:06	1/25 4:41	0.60	0.51	0.21
3286	1/23/2007 11:05	1/25 18:34	0.48		
4266	1/23/2007 11:05	1/26 20:28	0.33		
4840	1/23/2007 11:05	1/25 23:06	0.44		
5176	1/23/2007 11:05	1/25 19:03	0.48		
5372	1/23/2007 11:05	1/25 2:34	0.67		
5470	1/23/2007 11:05	1/27 3:40	0.30		
5568	1/23/2007 11:05	1/27 23:50	0.24	0.42	0.14
3272	1/23/2007 15:00	1/25 17:13	0.53		
3384	1/23/2007 15:00	1/25 22:59	0.48		
3608	1/23/2007 15:00	1/26 2:44	0.45		
4322	1/23/2007 15:00	1/31 6:11	0.15		
4448	1/23/2007 15:00	1/26 19:25	0.35		
4658	1/23/2007 15:00	1/31 1:23	0.15		
4798	1/23/2007 15:00	1/25 4:32	0.71		
4910	1/23/2007 15:00	1/25 3:39	0.73		
5064	1/23/2007 15:00	1/25 19:10	0.51		
5246	1/23/2007 15:00	1/25 5:21	0.69	0.47	0.21

Table 6. Migration rates (mph) for acoustic-tagged juvenile salmon released during January in the Sacramento River at West Sacramento to the Sacramento River just downstream of Steamboat Slough (a distance of 26.6 river miles).					
Fish ID	**Release Date/Time**	**Peak Detection Date/Time**	**Migration Rate (mph)**	**Average (mph)**	**S.D.**
			Overall for January Fish Release:	**0.46**	**0.16**

Similar migration rate comparisons were made for fish detected at the receiver positioned in upper Steamboat Slough, a distance of 26.7 river miles. Although sample sizes were small, there were no apparent differences between groups of fish released at different times and tidal cycles among releases in December or among releases in January (Table 7) but there were differences in migration rates for those fish released in December (0.75 mph) as compared to those fish released in January (0.53 mph) (Table 7). The average river flow as measured at Freeport[8], CA during the period when these salmon were migrating during December and January was 19,167 cfs and 11,850 cfs, respectively. Again, the faster fish migration rates were associated with the higher flows. Sample sizes were small for fish reaching Georgiana Slough, but a similar pattern in migration rates was observed (Table 8).

Table 7. Migration rates (mph) for acoustic-tagged juvenile salmon released during December and January in the Sacramento River at West Sacramento to upper Steamboat Slough (a distance of 26.7 river miles).					
Fish ID	**Release Date/Time**	**Peak Detection Date/Time**	**Migration Rate (mph)**	**Average (mph)**	**S.D.**
3063	12/11/2006 19:55	12/13 01:26	0.90		
3441	12/12/2006 0:25	12/13 00:44	1.10		
3301	12/12/2006 9:17	12/16 19:29	0.25		
Overall for December Fish Release:				**0.75**	**0.44**
5358	1/22/2007 21:54	1/25 17:58	0.39		
3566	1/23/2007 1:55	1/25 1:32	0.56		
3524	1/23/2007 4:48	1/25 2:04	0.59		
4336	1/23/2007 4:48	1/25 2:06	0.59		
5526	1/23/2007 15:00	1/25 19:53	0.50		
			Overall for January Fish Release:	**0.53**	**0.08**

Table 8. Migration rates (mph) for acoustic-tagged juvenile salmon released during December and January through Georgiana Slough (northern to southern Georgiana Slough - a distance of 11.4 river miles in December and 11.2 miles in January*).					
Fish ID	**Upper GS Date/Time**	**Lower GS Date/Time**	**Migration Rate (mph)**	**Average (mph)**	**S.D.**
3154	12/11/2006 19:55	12/15 16:10	0.12		
3189	12/12/2006 9:17	12/15 03:43	0.17		
3455	12/12/2006 9:17	12/15 17:19	0.14		
3231	12/12/2006 15:15	12/14 22:50	0.20		
Overall for December Fish Release:				**0.16**	**0.04**
3790	1/25 7:57	1/26 18:35	0.33		
5316	1/25 9:18	1/26 2:27	0.66		

[8] Provisional data from USGS gauge no. 11447650.

4350	1/25 18:11	1/26 22:01	0.41		
5750	1/25 23:47	1/27 0:46	0.46		
Overall for January Fish Release:				**0.46**	**0.14**
*** The difference in distances is attributable to placement of receivers at different locations in December and January.**					

Figures 15 and 16 show a comparison in migration rates among fish released and detected during the December and January fish releases within the various reaches. Most fish reached the Sutter/Steamboat region within a day and a half in December and two and a half days in January. Most fish migrated from the West Sacramento release site to the confluence of Cache Slough within about three and a half days in December and about five days in January. A great majority of acoustic-tagged salmon reached the downstream receiver locations well within the anticipated battery life of the transmitters. The relative temporal distribution among detections indicates that very few, if any, fish would have passed the downstream receiver sites after transmitter batteries may have died, although this could not be empirically confirmed.

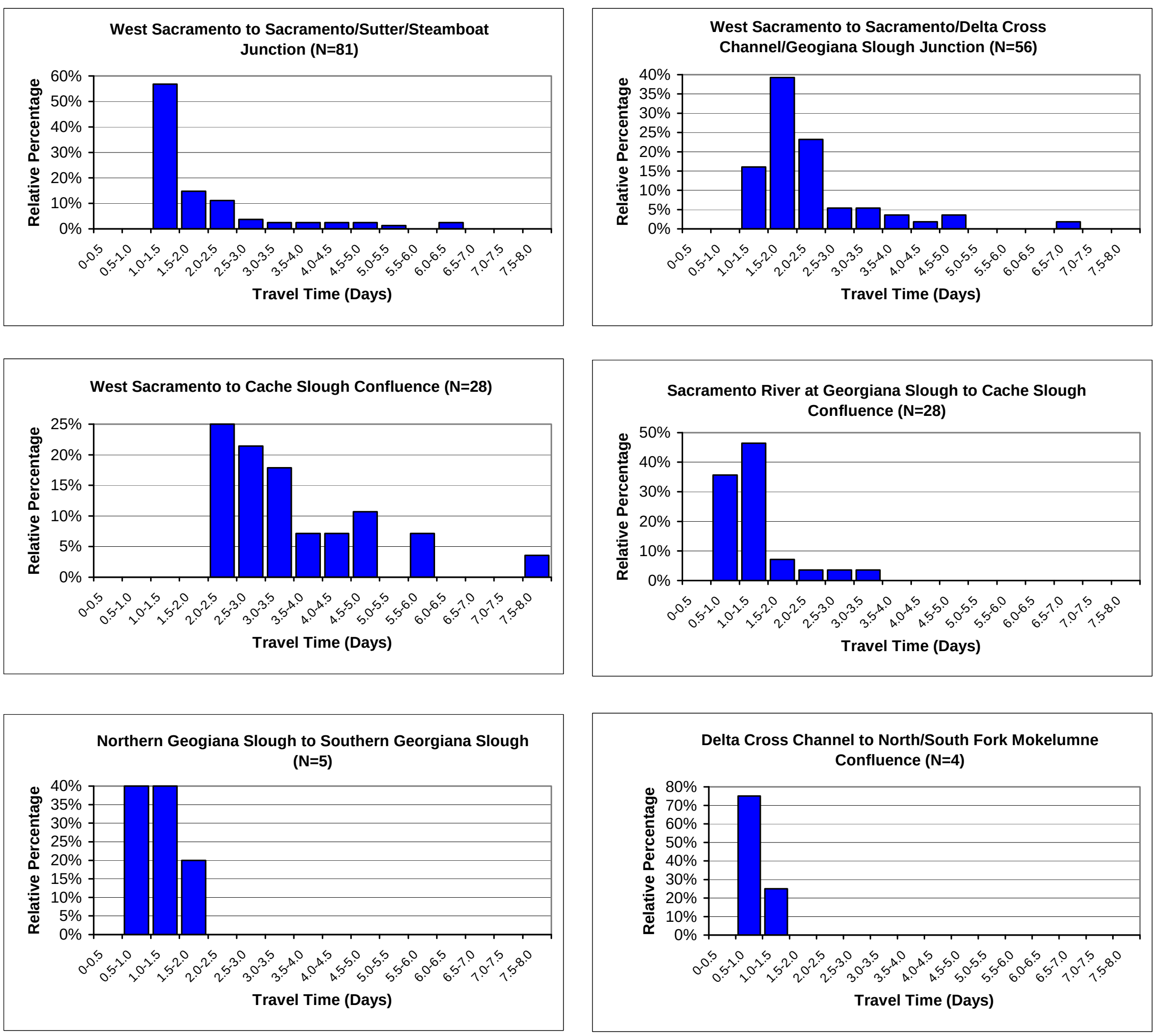

Figure 15. Travel time in days for acoustic-tagged juvenile late-fall-run Chinook salmon to migrate within various river reaches of the northern Sacramento-San Joaquin Delta during December 2006.

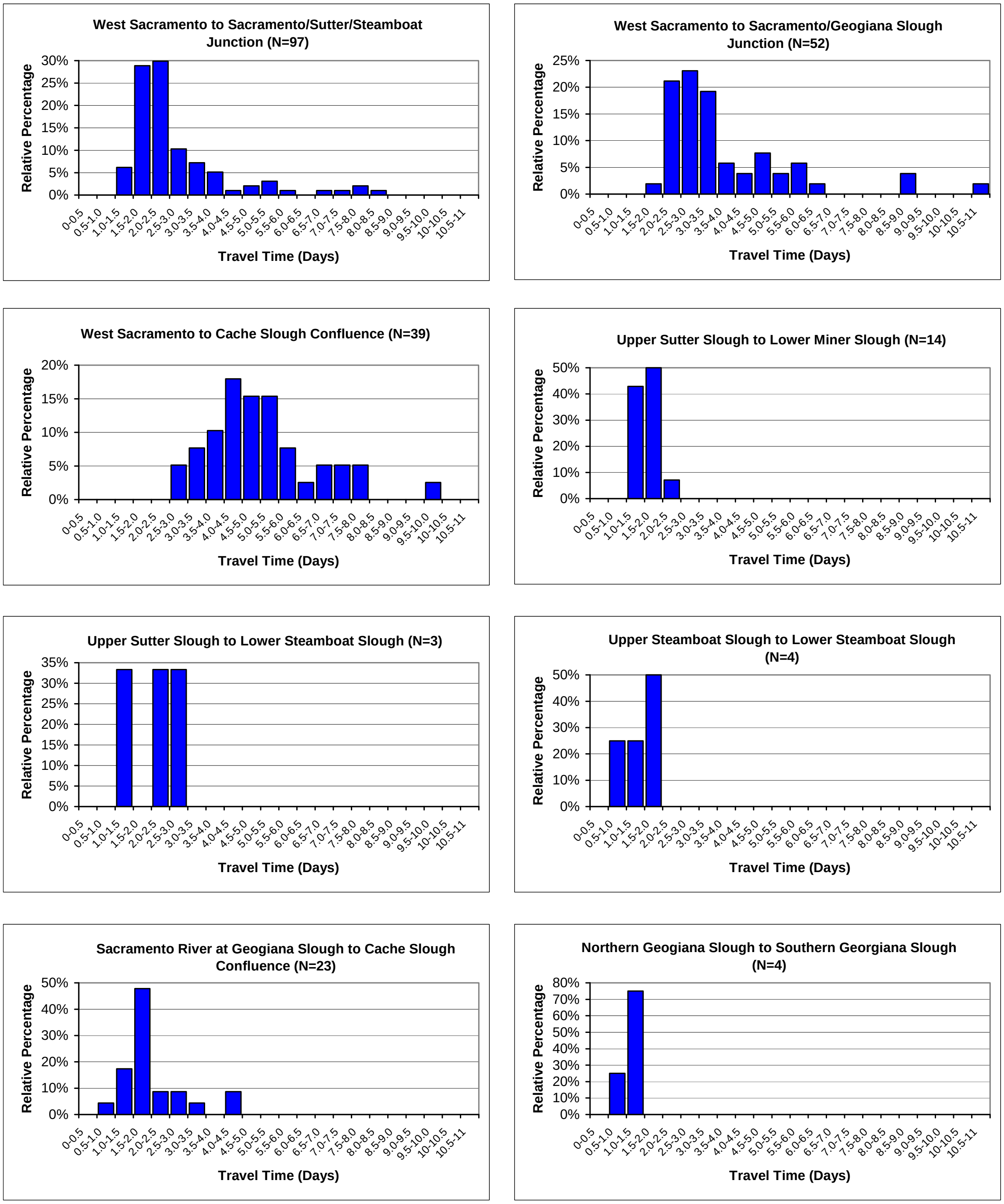

Figure 16. Travel time in days for acoustic-tagged juvenile late-fall-run Chinook salmon to migrate within various river reaches of the northern Sacramento-San Joaquin Delta during January 2007.

Potential Predation on Acoustic-Tagged Salmon

One of the greatest challenges in interpreting acoustic tag detection data in the Delta is determining if tags were transmitting from live salmon or, alternatively, dead salmon inside predatory fish. This issue is important, because if a tag detection is assumed to be a live salmon, but is actually a dead salmon inside a predator, the analysis of data would be biased toward an assumed higher survival rate among fish released than actually occurred. Additionally, if salmon mortality due to predation is high, it could mask the ability to discriminate and measure other potential sources of mortality (e.g., toxics, water diversions). This phenomenon is likely particularly evident with the non-native, predacious striped bass (*Morone saxatilis*), which is abundant and highly migratory throughout the Delta, but could also occur with the native predatory Sacramento pikeminnow (*Ptychocheilus grandis*), a species which is also migratory within the Central Valley rivers and the Delta. Other predators such as black bass (*Micropertus* sp.) and catfish (*Ictalurus* sp.) are also abundant throughout the region but generally exhibit more residency behavior within localized habitats. Surprisingly, little information on the specific interaction between these predators and juvenile salmon in the Delta is available.

During prior juvenile salmon radio-telemetry studies using juvenile salmon in the Delta, Vogel (2004) observed aberrant characteristics of radio tag transmissions that indicated some radio-tagged salmon were likely consumed by predators. These characteristics were derived from more than a thousand individual observations of radio-tagged salmon. Some indicators of probable predation on radio-tagged salmon 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 same location where a juvenile salmon would not be expected to maintain position for such a long duration (e.g., mid channel) (Vogel 2004).

The first empirically documented evidence of multiple predation events on acoustic-tagged salmon occurred in a study on the middle Sacramento River when five acoustic-tagged salmon were consumed by a single predatory fish (Vogel 2006c). In this latter research project, an acoustic receiver logged five acoustic tags moving in a downstream direction on the Sacramento River. A thorough data processing technique revealed that five of the acoustic transmitters exhibited identical, detailed movements that would not have otherwise been evident through typical data processing to determine transmitter presence/absence. The significance of this breakthrough is that predation on tagged fish was confirmed and, most importantly, absent that information, the tags would have inadvertently been assumed (incorrectly) to be inside live salmon, instead of dead salmon inside a predator. Without this discovery, the estimated juvenile salmon survival would have been 100% whereas, in reality, survival was 0%. Further examination of other data files in the middle Sacramento River study demonstrated that all salmon released were eventually eaten by predatory fish (Vogel 2006c).

There were indications of predation on some of the acoustic-tagged salmon during this study in the Delta. Uncharacteristic behavior of an acoustic-tagged salmon compared to the majority of observed behavior patterns suggested some tagged fish were consumed by a predator and the transmitter inside the predator was subsequently detected passing a receiver. For example, there were instances where a transmitter was detected in a sequential downstream direction then eventually moved back upstream. Although predation could not be empirically confirmed in these cases, this behavior was considered unlikely for a salmon smolt. Also, the acoustic receivers can determine if a transmitter remains motionless. For example, Figure 17 shows a data file displaying one transmitter on January 27, 2007 in close proximity to the fixed-station receiver positioned in northern Georgiana Slough. The left side of the graphic clearly shows movement of the transmitter because of changes in amplitude and voltage of received tag transmission indicating the tag was moving. The right side of the graphic shows that the tag ceased movement as shown by no change in amplitude or voltage indicating the juvenile salmon died or the tag was defecated from a predator that had consumed the acoustic-tagged salmon. Examination of the hourly files prior to this period showed that the tag was moving in this area for an extended period (many hours). It was therefore assumed that the tag had been defecated by a predator although this could not be conclusively determined. In these instances, fish mortality was certain, but the reason for the mortality could not be ascertained.

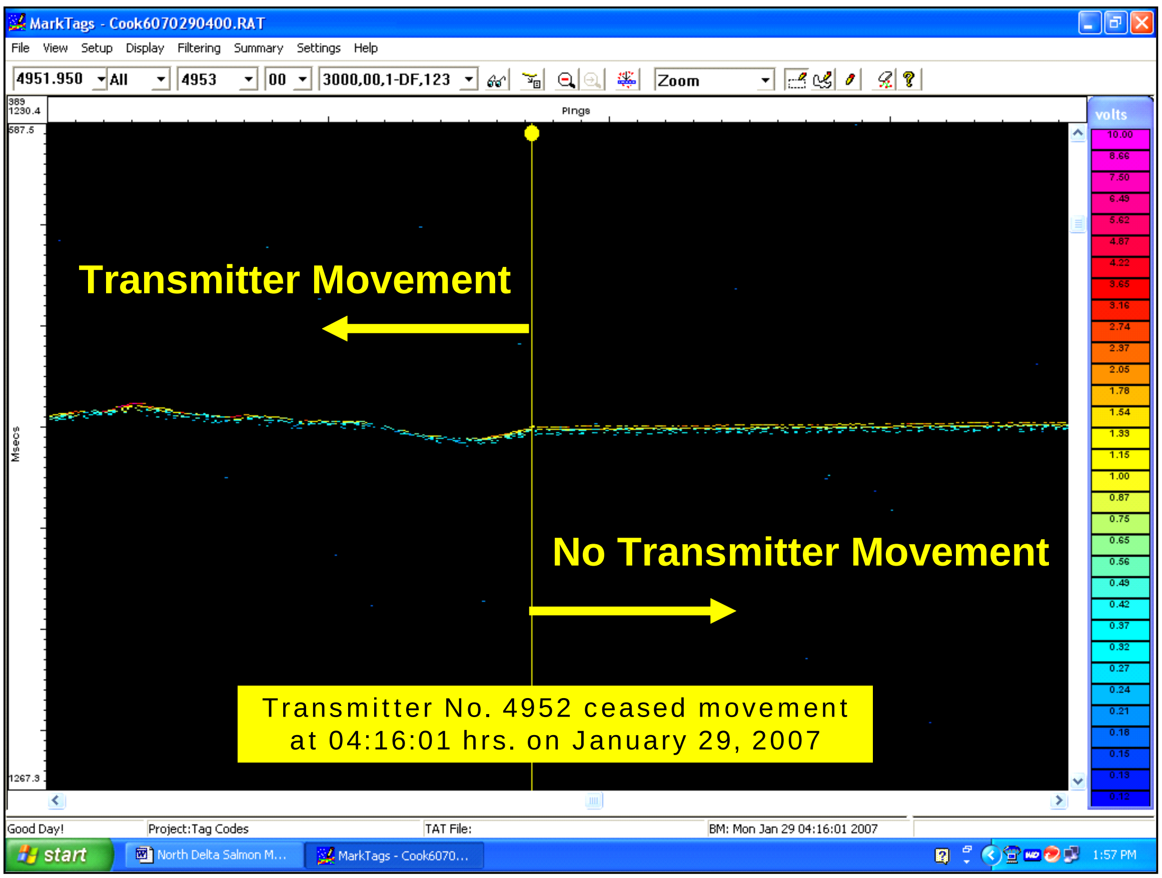

Figure 17. Post-processing display of transmitter no. 4952 in the vicinity of the fixed-station acoustic receiver positioned in northern Georgiana Slough on January 29, 2007.

The use of mobile telemetry is a useful technique to complement fixed-station telemetry for interpreting fish behavior and confirming fish mortality between fixed stations. On January 30 and February 1, 2007, some limited mobile telemetry was conducted in several Delta channels to locate acoustic transmitters. Figure 18 shows areas in the north Delta where mobile reconnaissance by boat was performed. Seven acoustic transmitters were located at stationary positions which were assumed to be where predatory fish may have defecated acoustic tags after consuming the juvenile salmon. Sites where tagged fish may have been eaten by a predator could not be determined; the data only show where a dead acoustic-tagged salmon or a defecated tag was detected.

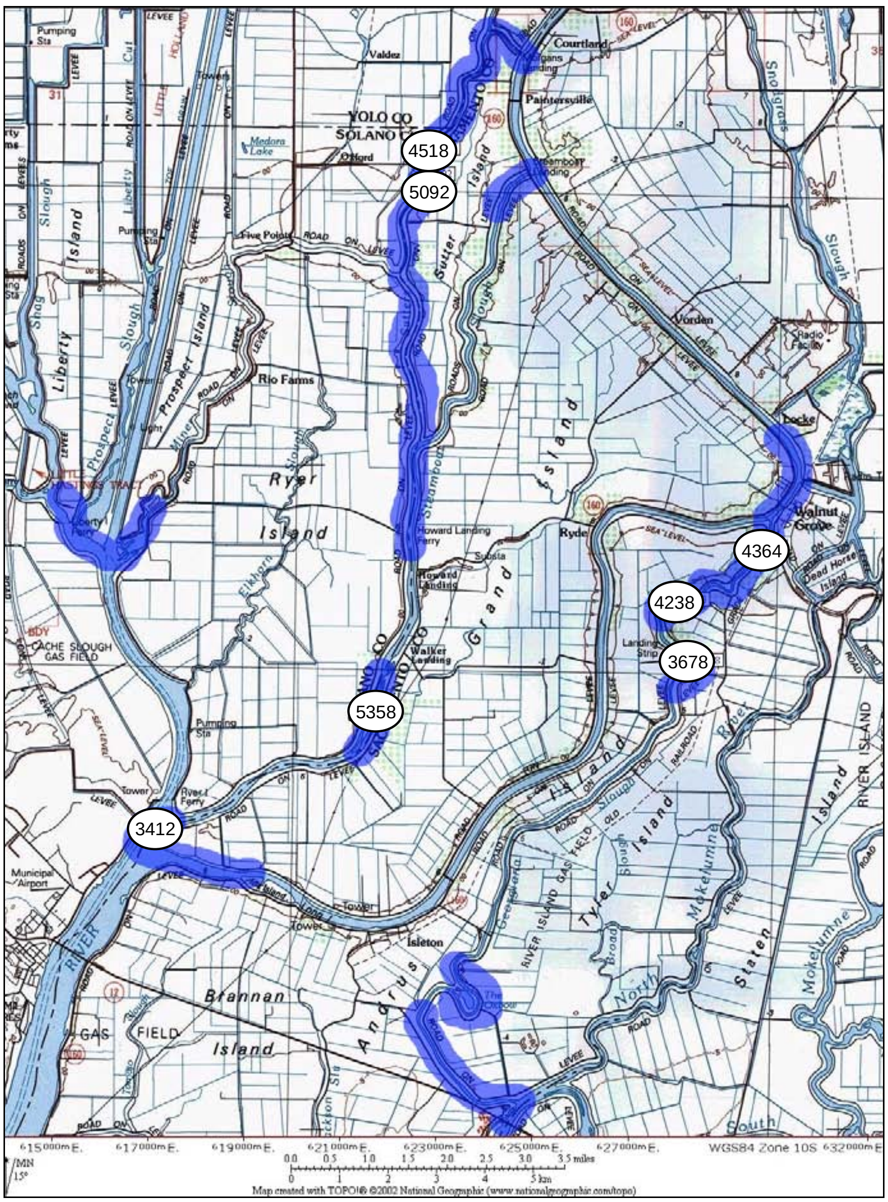

Figure 18. Areas in the north Delta surveyed for acoustic tags by boat mobile reconnaissance (shaded in blue) and locations of acoustic tags and tag codes found during the survey.

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Appendix A. Locations of acoustic receivers and fish release site during the 2006-2007 North Delta Juvenile Salmon Telemetry Study (WGS 84 datum). Refer to Figures 2 and 3 in the report.			
December Fish Release			
Receiver No.	**Location**	**Latitude**	**Longitude**
---	Fish Release Site	38º 34' 56"	121º 30' 27"
003	Sutter Slough (upstream)	38º 19' 46.37"	121º 34' 45.05"
004	Sutter Slough (downstream)	38º 19' 54.74"	121º 34' 58.35"
006	Steamboat Slough (upstream)	38º 18' 15.35"	121º 34' 35.24"
007	Steamboat Slough (downstream)	38º 18' 02"	121º 34' 50"
005-X	Sacramento River (just downstream of Steamboat Slough)	38º 18' 15.61"	121º 34' 21.73"
026-X	Delta Cross Channel	38º 14' 39.03"	121º 30' 4.91"
008	Sacramento River (just downstream of Georgiana Slough)	38º 14' 21.69"	121º 31' 14.54"
615	Upper Georgiana Slough	38º 14' 3.64"	121º 31' 9.5"
610	Lower Sacramento River	38º 10' 29.42"	121º 39' 26.38"
C-611	Lower Sacramento River	38º 10' 23.45"	121º 39' 0.13"
025	Lower Georgiana Slough	38º 7' 49.56"	121º 35' 18.82"
C-619	Mokelumne River (just downstream of Staten Island)	38º 7' 54.18"	121º 34' 17.27"
C-607	Mokelumne River (upstream of Willow Berm)	38º 6' 38.83"	121º 34' 55.33"
C-620	South Fork Mokelumne River	38º 7' 43.98"	121º 29' 56.17"
601	Little Potato Slough	38º 6' 0.26"	121º 29' 31.4"
January Fish Release			
Receiver No.	**Location**	**Latitude**	**Longitude**
---	Fish Release Site	38º 34' 56"	121º 30' 27"
003	Sutter Slough (upstream)	38º 19' 46.37"	121º 34' 45.05"
C-010	Sutter Slough (downstream)	38º 19' 54.74"	121º 34' 58.35"
006	Steamboat Slough (upstream)	38º 18' 15.35"	121º 34' 35.24"
025	Steamboat Slough (downstream)	38º 18' 02"	121º 34' 50"
005-X	Sacramento River (just downstream of Steamboat Slough)	38º 18' 15.61"	121º 34' 21.73"
008	Sacramento River (just downstream of Georgiana Slough)	38º 14' 21.69"	121º 31' 14.54"
004	Lower Miner Slough	38º 34' 18.04"	121º 39' 58.46"
007	Steamboat Slough	38º 11' 6.62"	121º 38' 58.37"
026-X	Sacramento Rive4r (downstream of Cache Slough - Right Channel)	38º 10' 39"	121º 40' 06"
C-620	Sacramento Rive4r (downstream of Cache Slough - Left Channel)	38º 10' 36.73"	121º 59' 57.92"
C-611	Sacramento River (just upstream of Cache Slough)	38º 10' 29.42"	121º 39' 26.38"
601	Sacramento River (downstream of Georgiana Slough and 008)	38º 14' 20.35"	121º 31' 24.37"
615	Upper Georgiana Slough	38º 14' 3.64"	121º 31' 9.5"
C-607	Upper Georgiana Slough (just downstream of 615)	38º 13' 57.95"	121º 31' 14.9"
610	Lower Georgiana Slough	38º 7' 49.56"	121º 35' 18.82"
C-619	Lower Georgiana Slough (just downstream of 610)	38º 7' 48.07"	121º 35' 0.35"

Appendix B. Data for releases of acoustic-tagged juvenile late-fall run Chinook salmon in the Sacramento River at Sacramento, CA during December 2006.			
Group 1: Released December 11, 2006 at 1955 hours. Approximate mean tide during transition from high to low tide.			
Acoustic Tag Code	**PIT Tag Number**	**FL (mm)**	**TL (mm)**
3042	4253636F19	141	151
3049	4254753710	140	153
3056	4251421A50	130	140
3063	425501682E	132	144
3126	4253641433	111	120
3140	4255141018	146	155
3154	4255043831	154	165
3175	4252495A1E	151	161
3196	42551A2A2B	175	190
3224	4253376267	153	164
3315	42550C717A	138	149
3420	42555B356B	133	144
3434	4253465020	144	155
3448	425336003D	122	133
3462	4253460027	141	151
3469	42514D6B5F	158	170
3483	4254390757	128	138
3518	42536C4E11	148	158
3532	42547C3753	153	161
3553	4253190B53	143	153
3588	42546F3133	142	153
3623	4253693768	149	159
3672	42551A1862	127	137
3693	4253580360	136	147
Group 2: Released December 12, 2006 at 0025 hours. Approximate mean tide during transition from low to high tide.			
Acoustic Tag Code	**PIT Tag Number**	**FL (mm)**	**TL (mm)**
3028	42551D7867	146	159
3084	4251694222	145	155
3098	425518087B	115	123
3105	42536D382F	127	137
3161	42545F2749	135	145
3182	42551F2924	142	151
3203	42530B084F	142	152
3210	4252262036	130	141
3245	42543E551B	147	157
3266	42530E3E04	180	192
3287	42533B0917	138	147
3294	4255271133	168	177
3329	42552A2B73	144	156
3343	425475276E	146	156
3378	4253383D03	143	154
3413	42553B7B0C	161	173
3441	42532B1559	172	185

3511	425523247B	129	139
3546	4254546B48	124	133
3581	4255233D60	142	152
3651	4253212D52	130	140
3658	4255620639	147	156
3665	4255254A02	137	147
3679	4252294D1B	140	150
Group 3: Released December 12, 2006 at 0917 hours. Approximate mean tide during transition from high to low tide.			
Acoustic Tag Code	**PIT Tag Number**	**FL (mm)**	**TL (mm)**
3000	425369347F	137	146
3014	4255087E3D	141	149
3070	42551A7F15	134	144
3077	4255006248	132	140
3112	42550B7A54	138	149
3189	4253644D51	123	132
3217	42552B616C	129	140
3238	42531D1836	167	179
3280	4253385D79	135	146
3301	42536F554D	144	155
3336	4255024402	130	140
3357	42534A4231	136	146
3385	42547F5D28	147	158
3427	425D08351F	149	159
3455	425C7A0042	150	162
3476	4253575755	124	135
3504	42551D1756	140	149
3525	425435270F	122	131
3574	425315505E	139	150
3609	42543E4446	113	123
3616	4255207970	142	151
3630	42527C1E1E	137	146
3637	42551C5E5E	131	140
3686	42546A5334	130	140
Group 4: Released December 12, 2006 at 1515 hours. Approximate mean tide during transition from low to high tide.			
Acoustic Tag Code	**PIT Tag Number**	**FL (mm)**	**TL (mm)**
3021	425340716B	137	147
3035	4253096719	173	183
3091	4254603069	168	179
3133	425523622C	180	192
3147	42534C7976	150	161
3168	42534F1E72	161	175
3231	425C620079	137	149
3252	42550E4B12	128	139
3259	42544B0A55	146	156
3273	4255210C59	107	117
3322	42511F6147	140	151
3350	4253685A79	144	156

3364	4255210960	181	195
3371	4255133373	129	140
3392	42533F4F4C	121	132
3399	42536B4B57	137	148
3406	4255282E2D	139	149
3490	425476071E	140	151
3539	42533E4409	133	140
3560	4253611A43	127	137
3567	4254710476	144	156
3595	4253001F18	124	135
3602	4254444D09	118	125
3644	42545F774E	124	134

Appendix C. Data for releases of acoustic-tagged juvenile late-fall run Chinook salmon in the Sacramento River at Sacramento, CA during January 2007. Note: Acoustic tag codes with an asterisk are old tags with short-lived batteries and were not used in this study; however, these fish are reported here because the tag codes were used in the 3D study at Clarksburg Bend (separate report by USGS).

Group 1: Released January 22, 2007 at 1603 hours. Approximate mean tide during transition from high to low tide.			
Acoustic Tag Code	**PIT Tag Number**	**FL (mm)**	**TL (mm)**
3006	490B030B61	165	177
3244	4255067F22	162	173
3580	4252795223	157	170
3678	487A536358	165	174
3734	490A5D6712	162	175
3804*	424D663E22	161	174
4000	4254782D53	169	183
4140	4255204068	162	175
4350	4878403214	145	158
4420	425470653B	166	179
4504	42530B177A	150	161
4742	42515D7C40	150	163
4882	4255132C46	152	165
4938*	42543D7C0E	160	170
4966*	5031592520	157	169
4994	42547B3518	168	179
5120	487A1C5C27	152	164
5134	490A4D1D08	162	175
5162*	424E614E4A	148	160
5190	4253653507	136	147
5302	487A4E0016	165	179
Group 2: Released January 22, 2007 at 1908 hours. Approximate low tide.			
Acoustic Tag Code	**PIT Tag Number**	**FL (mm)**	**TL (mm)**
3048	487A632279	163	177
3216	487A4D4228	175	189
3300*	424E7C662C	155	166
3356	487B071C72	155	167

3468	4255037A03	163	178
3650	42543D2C09	120	131
3790	42533C6659	169	182
3860	490A694C37	166	179
4252	490A624B1E	155	167
4308*	424B2C650E	143	159
4406	4254335259	144	157
4490	4253336671	138	149
4672*	424D091D68	181	194
4924	490B00495F	160	172
5036	4253491914	162	174
5288	487A742349	165	180
5456	4255251C2B	140	150
5540	42547A7B1D	150	161
5582	487B051744	152	164
5694	4253525040	164	177
5722	487A665051	174	186
Group 3: Released January 22, 2007 at 2154 hours. Approximate mean tide during transition from low to high tide.			
Acoustic Tag Code	**PIT Tag Number**	**FL (mm)**	**TL (mm)**
3020	4255131B36	144	155
3132	490B053212	142	153
3188	487A3D2E14	135	146
3258	42550C0A2F	166	178
3314	4253340F11	127	140
3440*	48797E1D7F	171	183
3482	4253415D20	139	149
3636	487A6E5C5A	161	175
3664	42552B4456	126	137
3846	42533F3237	161	175
3888	4253500945	155	166
4546	42546F6923	182	196
4644	48793E176C	152	164
4756	4255055019	180	195
4770	48754F0C1B	170	182
4812	4255312470	150	162
5330	487837087E	185	197
5358	4254701311	150	162
5680	490A7F337F	158	170
5736	487A516725	154	166
5890	487A6B085F	135	146
Group 4: Released January 23, 2007 at 0155 hours. Approximate high tide.			
Acoustic Tag Code	**PIT Tag Number**	**FL (mm)**	**TL (mm)**
3328	490A7B6D1C	153	166
3342	490A5F107C	155	166
3510	4253674D22	170	181
3566	487A386633	161	175
3832	487A57157E	175	187

4014	490A582773	146	159
4028	487833480B	135	146
4238	4875574312	175	186
4462	42551D4E34	148	160
4518	4253044561	161	173
4574	487B042103	169	182
4784	4254770629	160	172
4952	487A301E26	180	193
5106	490A5B284B	152	164
5148	4254740074	176	189
5218*	487A441F13	165	176
5316	42546F3924	186	197
5344	42550A404F	172	183
5512	NO PIT TAG	142	153
5638	42527F662F	182	196
5764	487A457202	149	160
Group 5: Released January 23, 2007 at 0448 hours. Approximate mean tide during transition from high to low tide.			
Acoustic Tag Code	**PIT Tag Number**	**FL (mm)**	**TL (mm)**
3174	4254611D01	156	170
3412	42552A760B	150	162
3454	42551E6721	145	158
3524	42535B570E	175	187
3818	4254443072	153	160
3874	42552C1D4B	157	169
3986	487A7D5F52	164	177
4084	4252270E49	155	169
4112	4255321373	185	197
4224	487A0C637D	166	179
4280	4255144526	154	169
4336	487A4E540B	142	153
4364	4254550D08	161	173
4532	42552C4D4C	197	210
4602	4253505213	151	162
4826*	424D04405F	166	179
5022	490A5E5225	172	186
5232	42551E1A5A	120	129
5484	425342086D	159	172
5750	487B035F10	169	182
5778	42551D6D20	129	139
Group 6: Released January 23, 2007 at 0806 hours. Approximate low tide.			
Acoustic Tag Code	**PIT Tag Number**	**FL (mm)**	**TL (mm)**
3202	42547F333A	119	129
3230	48783C530C	173	185
3538	487A52317F	167	182
3594	487A291827	155	167
3622	490A742032	161	173
3930	42536F4B5B	190	200

4042	42543C2D3E	158	171
4056	42543C2162	173	186
4070	48791C7766	163	178
4154*	487A1F231B	166	179
4378	487A1C3E69	142	155
4630	4255254D0F	191	206
4714*	490A676B05	170	184
4896	4254606763	168	182
4980	42552C7454	160	172
5008	42552C342D	146	158
5078	4878417574	172	183
5386	425274372F	155	168
5414	487A414C1B	180	192
5666	487A250044	188	201
5876	42546A5151	150	161
Group 7: Released January 23, 2007 at 1105 hours. Approximate mean tide during transition from low to high.			
Acoustic Tag Code	**PIT Tag Number**	**FL (mm)**	**TL (mm)**
3146	4253491F3A	175	187
3286	487A3A5124	145	156
3398	4255222156	153	165
3426*	424D495C53	155	168
3720	487A732944	168	180
3748	4253176353	182	195
4210	490A570055	185	199
4266	487A254958	173	186
4294	487A5E6D7F	168	179
4560	487A533A3A	183	196
4728	487A696961	160	173
4840	487A463C60	145	156
4854*	424D187853	143	154
5176	4879641B0D	145	156
5372	425352B53	150	163
5400	42551E3C77	166	178
5470	42547B5B0A	156	166
5568	487A625938	145	158
5610	487B091F59	168	180
5848	487A1A3F21	176	188
Group 8: Released January 23, 2007 at 1500 hours. Approximate high tide.			
Acoustic Tag Code	**PIT Tag Number**	**FL (mm)**	**TL (mm)**
3034	4254754520	166	179
3272	425D15083E	143	155
3370	487A6A4911	152	164
3384	42546F587D	158	170
3552	4875600541	159	171
3608	48752C074F	155	167
3692	42551A1A56	150	160
3944	4255357376	166	179

4322	4255197E45	156	169
4448	487A594652	158	170
4658	42532E0B57	166	179
4798	487A591F30	178	192
4910	487B085651	170	183
5064	487A5A6416	180	193
5092	425503554B	164	175
5246	487A565F61	170	182
5498*	424B24513E	155	167
5526	4255561713	126	136
5652*	424E5D0A09	154	165
5862	487A7B7D0E	150	161