doi:10.7289/V5/TM-SWFSC-573

NOAA Technical Memorandum NMFS

APRIL 2017

CENTRAL VALLEY PASSIVE INTEGRATED TRANSPONDER (PIT) TAG ARRAY FEASIBILITY STUDY

David E. Rundio
Alina N. Montgomery
Matthew G. Nesbit
Matthew S. Morris
Gabriel T. Brooks
Gordon A. Axel
Jesse J. Lamb
Richard W. Zabel
John Ferguson
Steven T. Lindley

NOAA-TM-NMFS-SWFSC-573

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Southwest Fisheries Science Center

NOAA Technical Memorandum NMFS

The National Oceanic and Atmospheric Administration (NOAA), organized in 1970, has evolved into an agency which establishes national policies and manages and conserves our oceanic, coastal, and atmospheric resources. An organizational element within NOAA, the Office of Fisheries is responsible for fisheries policy and the direction of the National Marine Fisheries Service (NMFS).

In addition to its formal publications, the NMFS uses the NOAA Technical Memorandum series to issue informal scientific and technical publications when complete formal review and editorial processing are not appropriate or feasible. Documents within this series, however, reflect sound professional work and may be referenced in the formal scientific and technical literature.

SWFSC Technical Memorandums are accessible online at the SWFSC web site.
(http://swfsc.noaa.gov)

Print copies are available from the National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161.
(http://www.ntis.gov)

doi:10.7289/V5/TM-SWFSC-573

NOAA Technical Memorandum NMFS

APRIL 2017

CENTRAL VALLEY PASSIVE INTEGRATED TRANSPONDER (PIT) TAG ARRAY FEASIBILITY STUDY

David E. Rundio[1], Alina N. Montgomery[1], Matthew G. Nesbit[2], Matthew S. Morris[2],
Gabriel T. Brooks[2], Gordon A. Axel[2], Jesse J. Lamb[2], Richard W. Zabel[2],
John Ferguson[3], and Steven T. Lindley[1]

[1] Fisheries Ecology Division
Southwest Fisheries Science Center
NOAA National Marine Fisheries Service
110 McAllister Way, Santa Cruz, CA 95060

[2] Fish Ecology Division
Northwest Fisheries Science Center
NOAA National Marine Fisheries Service
2725 Montlake Boulevard East, Seattle, WA 98112

[3] Anchor QEA, LLC
720 Olive Way, Suite 1900, Seattle, WA 98101

NOAA-TM-NMFS-SWFSC-573

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Southwest Fisheries Science Center

(This page intentionally left blank)

Preface

This document is a reproduction of the final report submitted to California Department of Fish and Wildlife on December 31, 2016, under agreement D1481034 “Central Valley Passive Integrated Transponder (PIT) Tag Array Feasibility Study”; minor edits were made as a result of internal review, but otherwise this document is unchanged from the final report. The report summarized the results and conclusions from a study in 2015-16 to develop and test two new prototype passive integrated transponder (PIT) tag detection systems for detecting juvenile fish in large open channels and to assess the potential for using PIT tags to monitor the movement and survival of listed salmonids in the Central Valley and Sacramento-San Joaquin Delta.

Summary

Chinook salmon and steelhead in the Sacramento and San Joaquin rivers have been in decline for over 100 years. Causes of the decline are numerous and complex, but one of several factors responsible for salmonid decline and limiting recovery is high mortality of juvenile salmonids as they pass through the labyrinth of canals, channels, and sloughs comprising the Delta. Water quality and physical habitat in the Delta have been severely degraded over time, and populations of non-native predators have become well established.

Understanding how survival is affected by route selection through the Delta over a range of environmental circumstances could inform how management actions may improve the long-term viability of listed salmon and steelhead, but this requires additional and more precise information on movement and mortality. Generating the additional information needed for management will require expanding the use of existing methods based on coded wire and acoustic tags, but could also benefit substantially by the additional use of PIT tags, which would enable monitoring of the entire life cycle and increase sample sizes due to the small size, low cost, and ease of application of the tags. However, use of PIT tags in the Central Valley and Delta requires the development of new detection systems for large open channels.

The major goal of this project was to determine the feasibility of applying PIT-tag detection systems in key locations in the Delta representing the range of channel types and structures present. This involved designing and testing new PIT tag arrays for detecting juvenile salmonids in the upper water column in large open channels, and using these results along with existing antenna designs to assess the overall feasibility of employing PIT tags for research and monitoring of salmonids in the Central Valley and Delta.

Two array approaches for open channels were successfully developed: (1) a raft-mounted hydrofoil array that can be deployed similarly to a rotary-screw trap, and (2) a modular flexible antenna array that can be towed by two small vessels or deployed at stationary structures such as pile dikes. These two designs represent major advances in array designs and performance in challenging habitats and allow for versatile approaches to detecting tagged fish across a range of situations.

Prototype hydrofoil arrays were installed in the upper Mokelumne River near Lockeford and in the lower San Joaquin River near Lathrop in spring 2016 and releases of PIT-tagged fish were used to estimate detection efficiency. At each site, two arrays were installed in an upstream-downstream pair, where each array consisted of a raft-mounted vertical hydrofoil array and a standard swim-over antenna installed flat on the stream bed at the same location to determine fish use of the surface versus bottom. The paired upstream-downstream arrays were intended to allow for mark-recapture models to be used to estimate survival and detection probability of the released PIT-tagged test fish. The Mokelumne River arrays were located immediately downstream of East Bay Municipal Utility District’s rotary screw trap to allow comparison of detection of tagged test fish between the arrays and RST. A total of 20,000 juvenile Chinook salmon were PIT-tagged and released (4,000 in the Mokelumne River and 16,000 in the San Joaquin River) to estimate detection efficiency. In addition, 1,440 steelhead smolts were double-tagged with acoustic and PIT tags and released in the San Joaquin River as part of the USBR Six Year Study.

Raw detection rates were about 4 – 8% among release groups of Chinook in the Mokelumne River and about 1.5 – 7% for Chinook and 5% for steelhead in the San Joaquin River. At both sites, the majority of detections were on the hydrofoil antennas rather than the bottom-mounted swim-over antennas. On the Mokelumne River, the RST captured 244 PIT-tagged fish compared to 178 detected on the hydrofoil antennas; however, the RST appeared to have a better position with respect to a defined thalweg than the locations where the arrays deployed, which may have contributed to higher efficiency by the RST. While this information on approximate raw detection rates will be useful for considering future study designs and methods, results of the mark-recapture analysis suggested that detection data from the dual-array installations violated assumptions of standard Cormack-Jolly-Seber models and appeared to produce biased estimates of survival and detection. This issue was particularly evident from comparison of the survival estimates based on acoustic versus PIT tags for the double-tagged steelhead smolts in the San Joaquin River, where survival for the third release group (when both PIT arrays were fully functioning) was estimated as 84% from acoustic detections but only 9% from PIT tag detections. These results suggest that alternative study approaches (such as Bayesian mark-recapture models that incorporate auxiliary information on detection probability based on double-tagging studies) will be needed to accurately estimate detection probability, survival, and abundance.

For the modular flexible antenna array, production models of the armored antenna cable and submersible reader enclosure were developed after extensive engineering and testing. The array can be configured with one to twelve 6.1 x 2.4 m antennas; the array tested in this project consisted of six antennas and had a total sampling width of about 30 m under tow. Salinity testing revealed that read range of the flexible antenna dropped in salinities above 0.5 ppt. Based on salinities observed in the lower Delta, it is expected that conditions upstream of Rio Vista on the Sacramento River and upstream of False River on the San Joaquin River would be frequently suitable for use of the flexible towed antenna during the smolt outmigration season. It is believed that a pair-trawl array, similar to that used in the upper Columbia River estuary, could be used downstream of these locations to Chipps Island for detecting PIT-tagged fish in the lower Delta and upper San Francisco Bay estuary; by using trawl wings to concentrate fish down to a smaller antenna matrix and housing antennas in PVC with more air space, the pair-trawl array is able to effectively sample in higher salinities than the flexible antenna array.

These new designs, along with existing PIT tag antennas that can be used in smaller and shallower channels or on special structures, now make it technically possible to detect tags in all of the channel types present in the Central Valley and Delta. Further research and development is needed to refine several aspects of the new array designs, particularly to achieve full electrical performance of the hydrofoil antennas in water, and to identify study designs and analytical approaches to accurately estimate detection probability, survival, and abundance from PIT tag detection data produced by arrays in open channels. Thus, application of PIT tags is currently feasible for certain research and monitoring questions, such as route use and passage timing, that do not necessarily require robust estimation of detection probability, but determining the feasibility of full-scale monitoring to estimate survival and abundance throughout the system will require further research to develop a study design and analytical framework before the effort and cost of such a monitoring program can be estimated.

Acknowledgements

This project was funded by the California Department of Fish and Wildlife (CDFW) as contract D1481034 under the Drought Executive Order of 2014, and was based on a proposal developed by John Ferguson, Anchor QEA. Jonathan Nelson, CDFW, provided substantial support as the contract manager. Bill Smith and Darrick Baker, CDFW, provided support for tagging and holding of fish at Mokelumne River Hatchery, and Javier Miranda, DWR, provided support at the Horseshoe Bend salvage release pipe. Michelle Workman and Robyn Bilski, EBMUD, provided access, equipment, data, and support for the array site on the Mokelumne River and for transporting test fish. Josh Israel, USBR, and Pat Brandes, USFWS, led the double-tagging of fish for Task 5 as part of their Six-Year Study. Randy Cutter, Suzanne Manugian, and David Demer, NOAA SWFSC, provided bathymetry data for the San Joaquin River that was helpful for evaluating potential study sites and array locations. Steve Anglea, Biomark, and Ken Collis, Real Time Research, led the subcontract team that designed and installed the arrays under Tasks 1-2, PIT-tagged fish for detection efficiency testing under Task 3, and contributed materials that were incorporated into the report. Rachel Johnson, SWFSC, provided internal review of the report prior to its reproduction as a NOAA Technical Memorandum. Reference to trade names or manufacturers is for information purposes only and does not imply U.S. Government endorsement of commercial products.

Table of Contents

Background

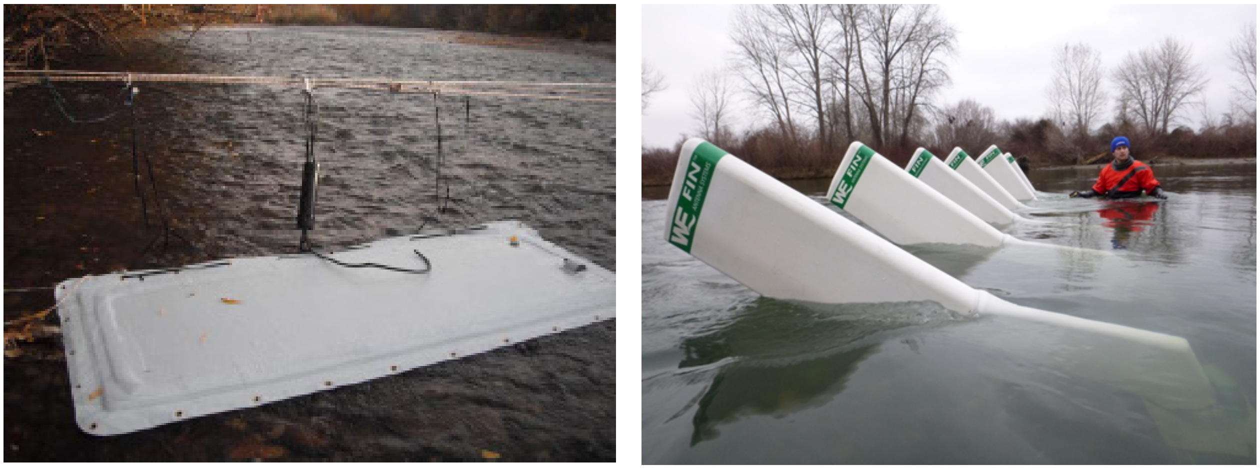
Passive integrated transponder (PIT) tag technology was developed for use in fisheries by the National Marine Fisheries Service during the 1980s (Prentice et al. 1990). The small tag size, indefinite tag life, and low cost of PIT tags allows a variety of performance metrics across the entire life cycle of salmon to be obtained in a cost-effective manner and over a broad range of environmental conditions. For juvenile salmonids, these metrics include survival, travel time, route selection, residualism, and loss to predation. For adults, these metrics include smolt-to-adult return rates, age at maturity, run timing, and stray rates. The technology was quickly incorporated into programs to monitor juvenile salmon and steelhead behavior and survival through hydropower dams on the Columbia River, and has become the primary method used to assess survival across various river reaches and inter-annual variability in survival associated with environmental conditions and system operations. The data collected from PIT tag monitoring are used to inform a multitude of management decisions requiring information ranging from estimates of reach- and life stage-specific survival to egg-to-spawner survival. The data also support development of life cycle models that are used to identify scientific uncertainty, evaluate the effects of environmental conditions and anthropogenic actions on specific life stages, adjust stock management actions, and prioritize species recovery efforts.

The primary limitations of PIT tags are that a tag has to pass close to an antenna (typically ≤ 1 m) in order to be detected and that antennas have been restricted to relatively small sizes (typically ≤ 6 m wide by 1 m tall). Traditional installations were initially deployed at concrete structures in a confined passage route, such as pipes, flumes, and weirs located in fish ladders or juvenile bypass systems at hydroelectric projects; it was presence of these structures that allowed for application of PIT tags in the Columbia Basin. Use was expanded to rigid swim-through pipe or swim-over antennas in natural streams and rivers (Figure 1). Continued innovation in receiver design and applications has resulted in increased flexibility for detection of PIT tags across a wider range of sites, including pair-trawl antenna surveys in the upper Columbia River estuary (Figure 2) and new floating and bottom-mounted vertical fin arrays for use in open channels (Figure 3).

Figure 1. Examples of standard swim-through and swim-over antennas used in open stream and river channels.

Figure 2. Towed pair-trawl antenna array used in the upper Columbia River estuary.

Figure3. Recently developed antenna designs for open channels: floating mat antenna made by Biomark, and bottom-mounted vertical fin antenna made by West Fork Environmental.



However, there are no existing antenna designs (other than the large pair-trawl array) capable of detecting tagged fish in the upper water column of large open channels that are more than a couple meters deep. Juvenile salmonids are thought to migrate in the upper portion of the water column, and lack of a means of detection has prevented the application of PIT tags for monitoring salmonids in large water systems, such as the Sacramento-San Joaquin rivers and Delta in the California Central Valley, that lack infrastructure such as dams.

Chinook salmon and steelhead in the Sacramento and San Joaquin rivers have been in decline for over 100 years. Two evolutionarily significant units (ESUs) of Chinook salmon (Sacramento River winter-run and Central Valley spring-run) and a single Distinct Population Segment of steelhead (California Central Valley) are listed as threatened or endangered under the federal Endangered Species Act. Two additional populations of Central Valley Chinook salmon (fall-run and late fall-run) have been combined in a single ESU by the National Marine Fisheries Service and are currently classified as a Species of Concern.

Causes of the decline are numerous and complex, but one of several factors responsible for salmonid decline and limiting recovery is high mortality of juvenile salmonids as they pass through the labyrinth of canals, channels, and sloughs comprising the Delta. Water quality and physical habitat in the Delta have been severely degraded over time, and populations of non-native predators have become well established.

Understanding how survival is affected by route selection through the Delta over a range of environmental circumstances could inform how management actions may improve the long-term viability of salmon and steelhead, but this requires additional and more precise information on movement and mortality. Coded-wire tags and acoustic telemetry have provided the basis for determining survival and movement of juvenile salmonids in the Central Valley and Delta (e.g., Newman and Brandes 2010, Perry et al. 2010, Michel et al. 2015). Generating the additional information needed for management will require expanding the use of these existing methods but could benefit substantially by the additional use of PIT tags. PIT tags would provide performance metrics across the entire life cycle, and the small size, ease of application, and low cost of PIT tags could allow for much larger sample sizes compared to existing methods. However, use of PIT tags in the Central Valley and Delta requires the development of new detection systems for use in large open channels.

The major goal of this project was to determine the feasibility of applying PIT-tag detection systems in key locations in the Delta representing the range of channel types and structures present. This involved designing and testing new PIT tag arrays for detecting juvenile salmonids in the upper water column in large open channels, and using these results along with existing antenna designs to assess the overall feasibility of employing PIT tags for research and monitoring of salmonids in the Central Valley and Delta. This project was funded by the California Department of Fish and Wildlife (CDFW) as contract D1481034 under the Drought Executive Order of 2014.

Summary of activities

The contract was executed on May 19, 2015. Work during the first several months focused on bringing key NOAA staff from the Southwest Fisheries Science Center (SWFSC) and Northwest Fisheries Science Center (NWFSC) up to speed on the project and on major administrative and logistical tasks required to implement the study.

The specific tasks under the contract were:

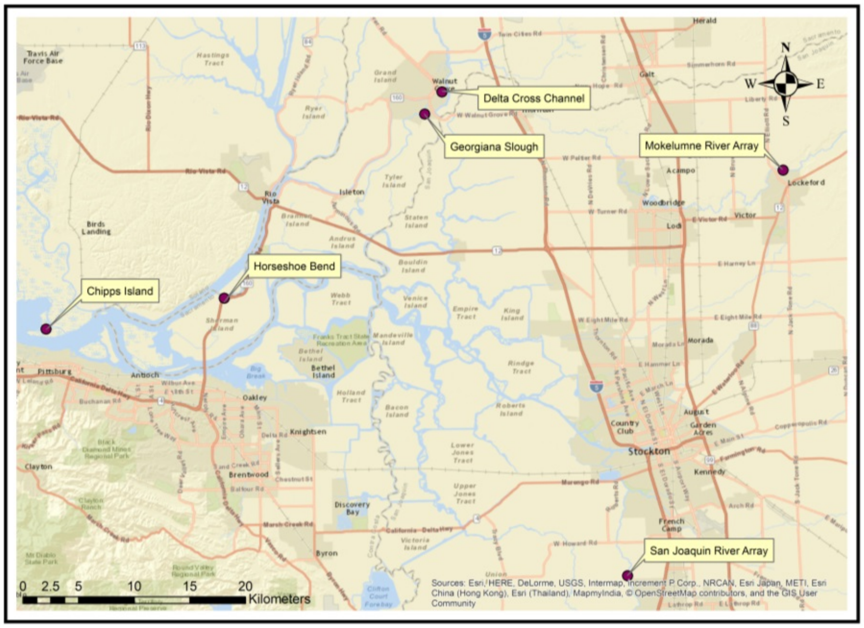
- Task 1 – PIT tag receiver deployment
- Task 2 – PIT tag receiver engineering and deployment
- Task 3 – Conduct initial efficiency tests
- Task 4 – Monitoring PIT tag receiver arrays
- Task 5 – Tag and release test fish in 2016
- Task 6 – Evaluate the feasibility of developing estuary detection sites – towed array
- Task 7 – Evaluate the feasibility of Delta Cross Channel and Georgiana Slough
- Task 8 – Project and system management, data analysis and reporting

The SWFSC managed and supervised the overall project and performed Tasks 1– 5, the NWFSC performed Tasks 6–7, and both centers contributed to Task 8.

Activities associated with initial project planning and implementation in 2015 (Year 1) included: gathering background information about bathymetry, historical flows and water temperatures, smolt behavior and movement through the Delta, predator hot spots, tidal influence, land ownership, and permitting requirements; identifying logistical details for study implementation; networking with personnel at collaborating agencies (CDFW, DWR, USBR, USGS, USFWS, EBMUD); conducting visits to the proposed array locations to evaluate sites, collect additional bathymetry data, inspect other potential alternative locations, and select final study sites; hiring a dedicated SWFSC technician (UCSC Laboratory Assistant III) for the project; and awarding a subcontract to a team composed of Real Time Research, Biomark, and FISHBIO to design and install PIT arrays for Tasks 1-2 and perform tagging for Task 3.

Activities in 2016 (Year 2) focused on fabrication and installation of prototype arrays on the Mokelumne and San Joaquin rivers, and installation of shielded antennas on the DWR salvage release pipe at Horseshoe Bend (Tasks 1-2; Figure 4); tagging and release of fish to estimate detection efficiency of the Mokelumne, San Joaquin, and Horseshoe Bend arrays (Tasks 3 and 5); monitoring of the Mokelumne, San Joaquin, and Horseshoe Bend arrays (Task 4); engineering, fabrication and testing of a flexible towed antenna array, and assessing use of the flexible array and existing pair-trawl array in the upper estuary near Chipps Island (Task 6); preliminary assessment of array designs suitable for Georgiana Slough and Delta Cross Channel (Task 7); and database development, data analysis, and reporting (Task 8).

Figure 4. Map of the Sacramento-San Joaquin Delta with key project locations.



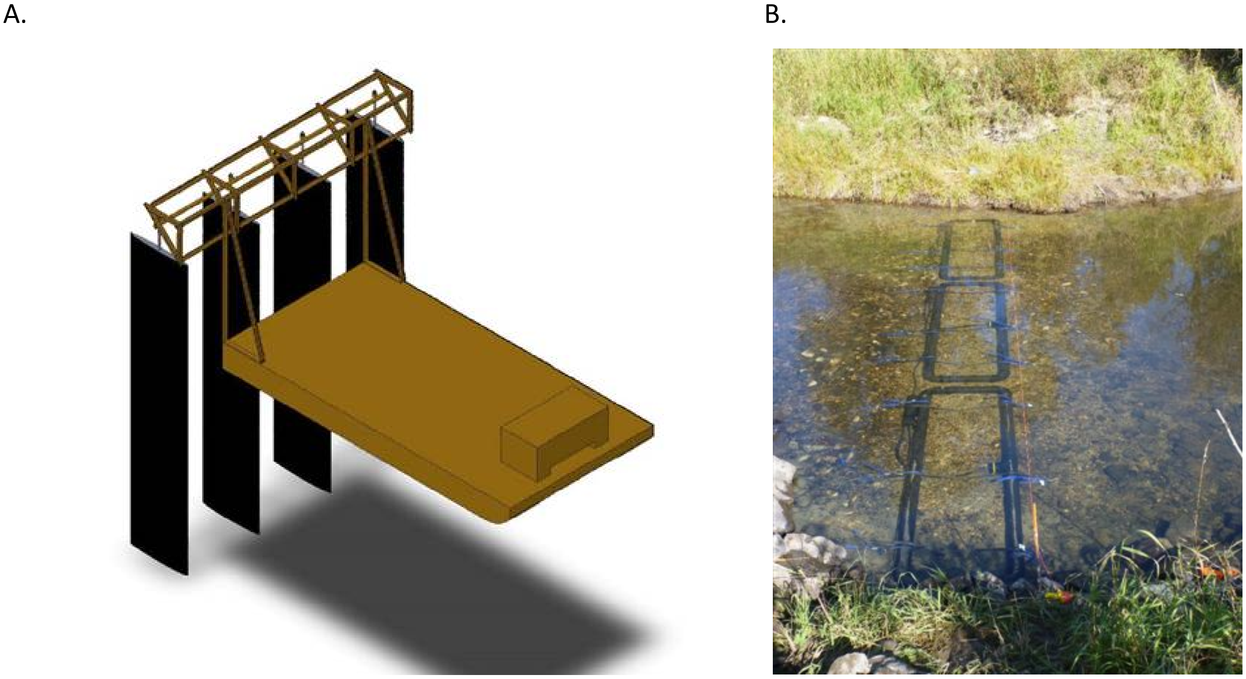
Detailed descriptions of activities and results under each task are presented below.

Task 1 – PIT tag receiver deployment

Task 1a/b (Mokelumne River array)

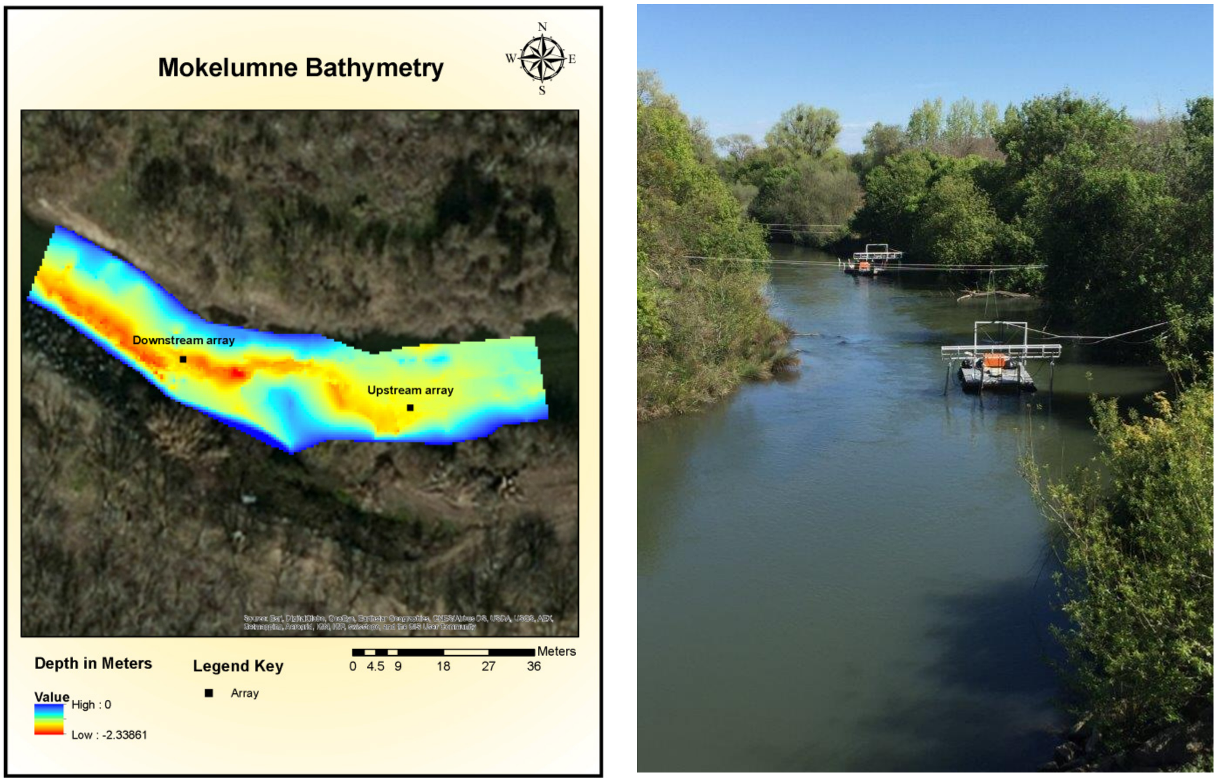
Arrays were originally proposed for the Grant Line Canal temporary barrier (1a) and the VAKI camera on Caswell Weir on the Stanislaus River (1b) employing a combination of existing antenna designs. However, these locations were determined to be unsuitable after details about the planned operations for these structures in 2016 were obtained from DWR (Grant Line Canal barrier) and FISHBIO (Caswell Weir): the Grant Line Canal barrier was not to be completely installed until June 2016, when water quality would have been too poor to release fish for detection efficiency testing, and Caswell Weir was not to be operated past January 2016, which would have been too early to tag and release fish for testing. Therefore, after extensive investigation into alternative locations and with approval by the CDFW contract manager, it was decided to replace the Grant Line Canal and Caswell Weir sites with a combination of a new prototype raft-mounted vertical fin array paired with a standard swim-over streambed antenna (Figure 5) at a single location on the upper Mokelumne River near East Bay Municipal Utility District's (EBMUD) upstream rotary screw trap (RST). The raft array concept is essentially a smolt-trap analog for detecting PIT-tagged fish in the upper water column under fluctuating river heights and has potential for widespread application for research and monitoring. In this respect, the new approach tested on the Mokelumne River (and a larger version tested on the San Joaquin River under Task 2) was considered much more informative and transferable to situations beyond the present study than the sites at Grant Line Canal and Caswell Weir would have been, as they represented application of existing antenna designs at sites where special infrastructure exists.

Figure 5. (A) Schematic diagram of prototype raft-mounted vertical fin array. (B) Example of streambed swim-over array consisting of three 10-ft wide antennas; at the Mokelumne River site, a single 20-ft wide antenna was installed below each raft array.



The final study design on the Mokelumne River was to install two arrays in an upstream-downstream pair, where each array consisted of a raft-mounted vertical fin array (Figure 5a) and a standard swim-over antenna installed flat on the stream bed (Figure 5b) at the same location to determine fish use of the surface versus bottom. The paired upstream-downstream arrays were intended to allow for mark-recapture models to be used to estimate survival and detection probability of the released PIT-tagged test fish (Task 3). The arrays were located approximately 120 m downstream from EBMUD's rotary screw trap near Elliot Road (referred to as their Vino trap site) to allow comparison of detection of tagged test fish between the arrays and RST. The arrays were located in the deeper areas of the channel where water depth under the rafts was about 1.25-1.5 m (Figure 6a) at the time of installation when releases from Camanche Reservoir were about 200 cfs. The arrays were approximately 50 m apart, and width of the river was about 22 m at the upstream array and 20 m at the downstream array (Figure 6b).

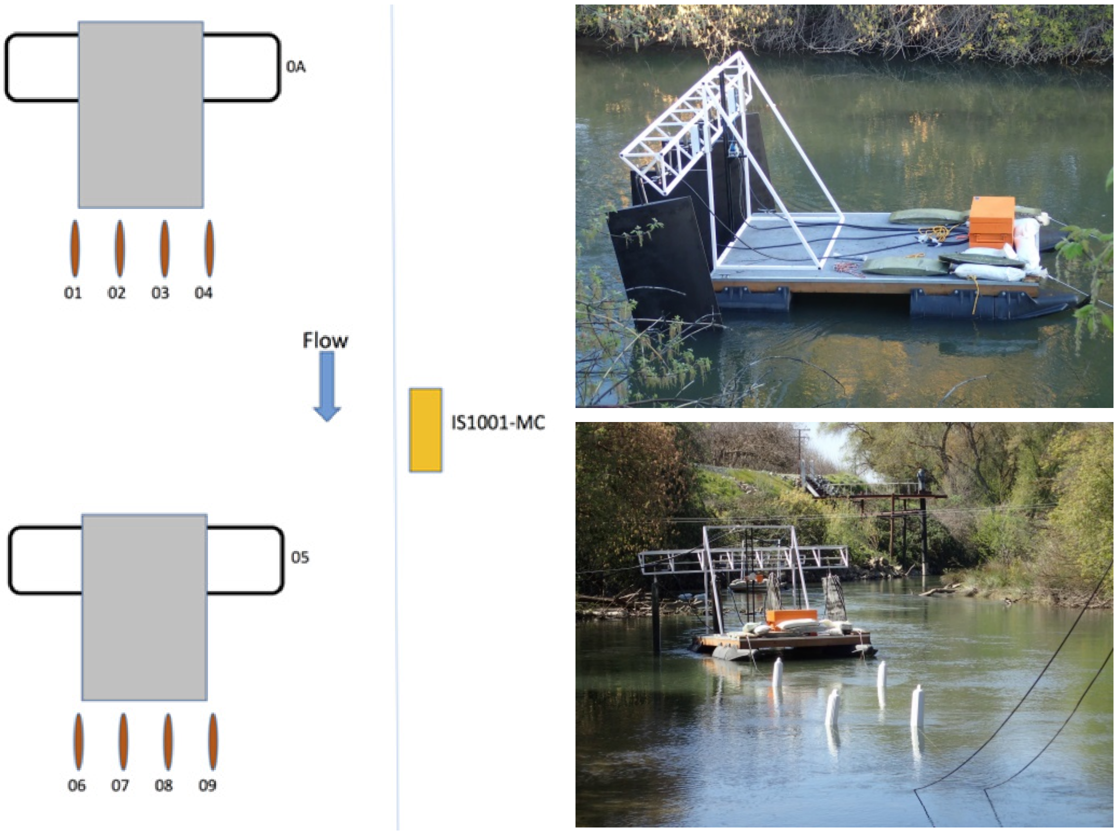
Figure 6. (A) Location of the raft antenna arrays with respect to channel bathymetry at the Mokelumne River site; hot colors (yellow-red) indicate deeper areas. (B) View of the arrays looking from downstream to upstream.


A.

B.

The two raft arrays and bottom-mounted swim-over antennas for the site were fabricated at the Biomark shop in Boise, Idaho, in January-February 2016 and installed March 14-18 (Figure 7). The raft platforms were held in place by an overhead cable and pulley system suspended across the river. The deck of each raft was 2.4 m wide and 3.6 m long. Each raft array consisted of four 2.27 m-long hydrofoils (0.95 m wide and 0.10 m thick) spaced 1.2 m apart for a total physical span of 3.6 m. The antenna within each hydrofoil was 1.5 m long and the bottom of the antenna was 0.25 m from the bottom of the hydrofoil. The hydrofoils were suspended from an adjustable trolley by self-steering linkages that independently maintained the orientation of each fin to the flow and allowed the fins to pivot in the downstream direction to pass debris. Ballast bags containing non-magnetic sand were used to counter the buoyancy of the hydrofoils and orient the hydrofoils vertically once in the lowered position. The hydrofoils were lowered until they were approximately 0.30 m above the riverbed; at the upstream array, this resulted in about 1.0 m of the hydrofoils being submerged, while at the downstream array about 1.2 m of the hydrofoils were submerged. In addition to the hydrofoil antennas, a single 6-m bottom-mounted antenna was positioned beneath the front of each raft. The bottom-mounted antennas were held in place using duckbill anchors and ratchet and cam straps installed by snorkeling. The initial IS1001 reader for the upstream bottom-mounted antenna did not fully tune upon installation. It was replaced with a new reader on March 29, 2016. It was later determined that one of the capacitors in the auto-tuning capacitor bank had broken off the circuit board. The damage likely occurred during transportation to the site as it passed inspection at Biomark during the initial testing phase.

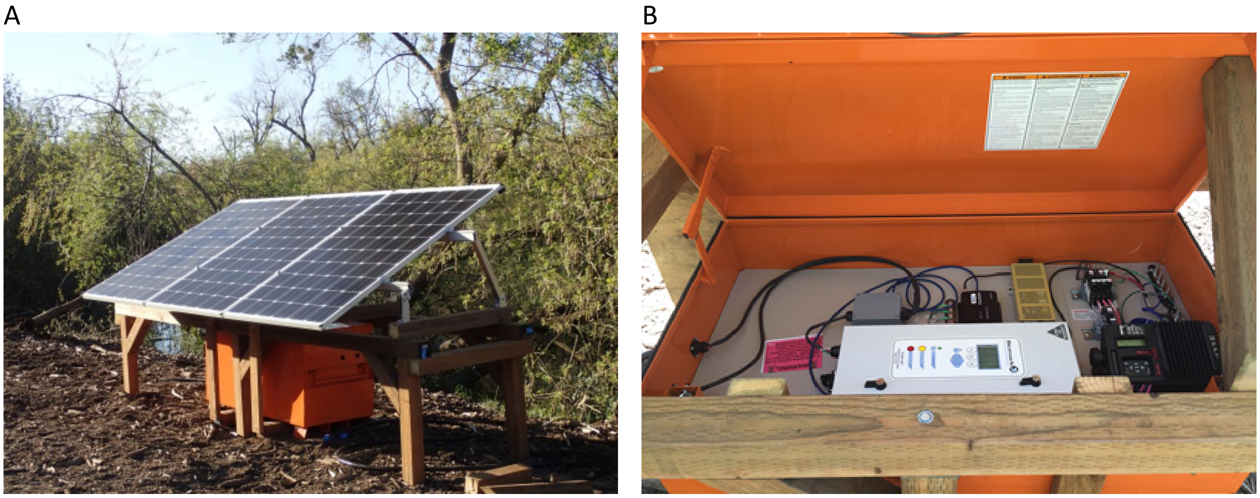
Figure 7: Schematic diagram and pictures of the prototype raft-mounted vertical fin arrays on the Mokelumne River.



Biomark's Data-Over-Power (DOP) configuration was used to enable a single shore-based IS1001-Master Controller (IS1001-MC) to provide power to and communication with the ten IS1001 readers nodes at the site (5 per array). The IS1001 readers associated with the hydrofoil antennas were housed in electronics enclosures located on the raft decks, while the IS1001 readers associated with the bottom-mounted antennas were housed in submersible enclosures secured to the antennas. A DOP cable extended from the electronics enclosure housing the IS1001-MC to a DOP hub on the bank near each array. From each DOP hub, DOP cables extended to the submersible enclosure housing the IS1001 on the bottom-mounted antenna and to the IS1001 enclosure on the raft deck.

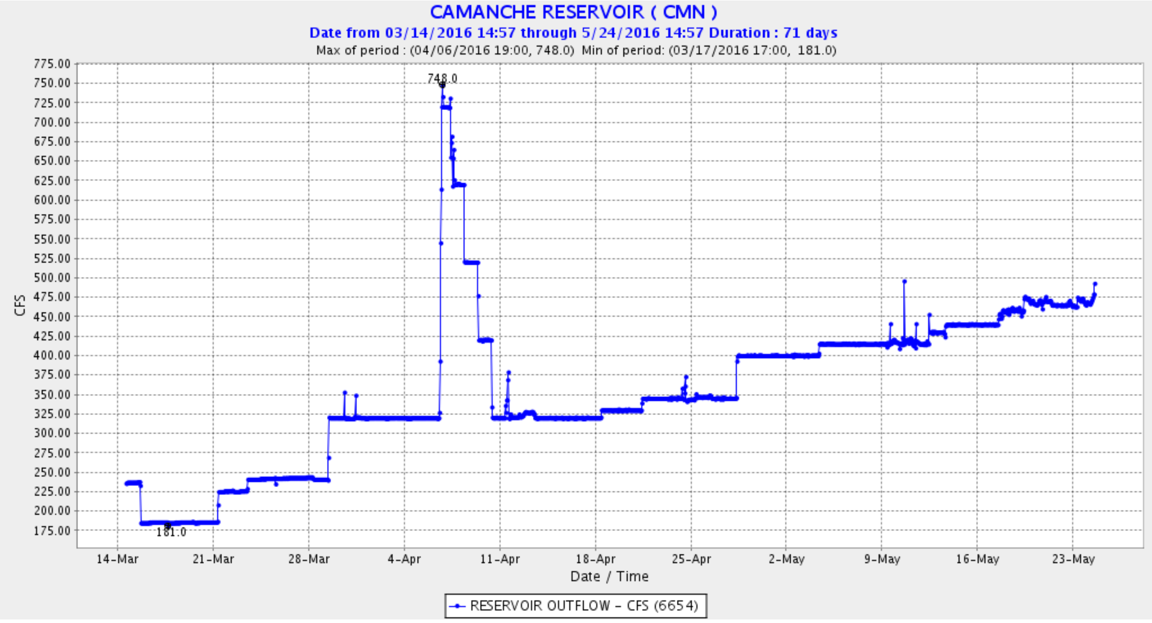
The electronics enclosure housing the IS1001-MC was positioned on the bank between the two arrays and under the solar panels (Figure 8). A Midnite Solar Kid 30A MPPT charge controller connected to three 285 watt panels and four 260AH batteries provided power to the site. The DC input voltage to the IS1001-MC was regulated using an Acopian Model 18-75C28NT620 DC-DC power supply. A Cloudgate modem connected to the IS1001-MC provided remote access to the site for system control and data retrieval. Biomark's Data Collection Application (DCA) polled diagnostic and tag detection data every 4 hours. The readers are capable of detecting both full-duplex (FDX) and half-duplex (HDX) PIT tags, but settings were enabled for FDX-only to match the tag type used for detection efficiency testing, which were the only known PIT-tagged fish at large in the system.

Figure 8. (A) Shore-based solar power and electronics enclosure for the Mokelumne arrays, and (B) electronics enclosure housing IS1001-MC, solar charge controller, power supply regulator, modem, and batteries.



The arrays were operated successfully March–May for detection efficiency testing (see Task 3 below) under flows ranging from 180 to 750 cfs releases from Camanche Reservoir (Figure 9) that resulted in an approximately 1.2-m range in water depth at the arrays.

Figure 9. Releases from Camanche Reservoir (about 15 river km upstream of arrays) during operation of the arrays on the Mokelumne River in March-May 2016. Data from the California Data Exchange Center (CDEC) website (http://cdec.water.ca.gov/cgi-progs/staMeta?station_id=CMN).



The technical performance and detection efficiency of the Mokelumne River arrays are described in detail in later sections of this report under Tasks 3 and 4.

The Mokelumne arrays were removed on May 24, 2016, prior to the summer recreational boating season, and placed in storage at Mokelumne River Hatchery (Figure 10). Operation and maintenance manuals (digital and hard-copy) containing installation information, site and wiring diagrams, and operating manuals for all components were delivered to the CDFW contract manager.

Figure 10. (A) Removal of the Mokelumne raft arrays in May 2016 and (B) storage of the arrays (along with the San Joaquin arrays from Task 2) at Mokelumne River Hatchery after completion of the field testing.

Task 1c (Horseshoe Bend Salvage Release Pipe array)

For installation of an array on one of the salvage release pipes in the upper estuary associated with the Harvey Banks or Tracy pumping facilities, the DWR release pipe at Horseshoe Bend (on the Sacramento River side of Sherman Island) was chosen because DWR had an existing program of using PIT-tagged fish and antennas to evaluate their operations but high electromagnetic interference (EMI) at Horseshoe Bend had caused their existing antennas to fail. The three existing Biomark HPR Plus readers and three 30 cm circular unshielded antennas on the release pipe were replaced with 3 Biomark IS1001 readers, new antenna coils, and external aluminum shields (Figure 11). The existing antennas were cut off the release pipe and replaced with externally shielded antennas. The new antennas were fabricated in the field by wrapping wire directly around the existing pipe to eliminate the need to disassemble the pipe. The external shields were 61 cm long and 56 cm in diameter. The exciter frequencies of the IS1001 readers were synchronized allowing the readers to operate without interfering with each other. Synchronizing the exciter frequencies allows the readers to scan continuously, providing higher detection efficiency for fast moving PIT-tagged fish. All antennas were operated at exciter level 1 until March 14, 2016, at which time the exciter level of antennas 1 and 3 was increased to level 5 and antenna 2 remained at level 1. Operating antennas 1 and 3 at the higher exciter level resulted in a longer field which is desirable where tag speed is a concern. Read range was determined by securing a 12-mm FDX-B tag to a tape measure and placing it inside the release pipe.

Figure 11. Picture of the (A) three shielded antennas and (B) IS1001 readers installed on the DWR salvage release pipe at Horseshoe Bend.

The IS1001 readers were placed in the existing DWR electronics enclosure. Each IS1001 reader was equipped with a Biomark Remote Communication Board and each board was connected to a single Cloudgate wireless modem configured with a multiple port Ethernet expansion card. Power was provided by a Biomark Battery Switcher system, placed in a separate enclosure from the readers, connected to existing AC power at the site. The Biomark Battery Switcher provided isolated power to the readers by charging one pair of batteries while the system is powered by a separate pair of batteries, and switching states every 2 hrs. A single Acopian 24C28FT420 power supply provided regulated DC voltage to the readers. Biomark's DCA polled data from the site every 4 hrs. The array was installed December 15-16, 2015, to meet DWR's schedule for operations.

The Horseshoe Bend array was successfully operated from December 2015 through the end of DWR salvage operations and studies involving PIT-tagged fish in mid-June 2016. There was a short loss of operation March 20-30, 2016, when a power outage and surge damaged the batteries. The system ceased operation in August 2016 when the site lost power due to a downed utility pole. The equipment was left at the site for use by DWR.

Technical performance and detection efficiency of the Horseshoe Bend array are described in detail in later sections of this report under Tasks 3 and 4.

Task 2 – PIT tag receiver engineering and deployment (San Joaquin River array)

This task involved assessing and developing a prototype array design for applications in challenging large channel habitats. The task was structured as two stages: (1) initial engineering studies at two locations (West Howard Road and Turner Cut) to determine if it was feasible to develop and test prototype array designs at both sites, and (2) if the initial assessments proved feasible, fabricate and install arrays at the sites.

Initial site and engineering studies were completed at both proposed locations in September-December 2015. This included gathering environmental data such as bathymetry and flow from existing sources; evaluating logistical factors such as access, vandalism risk, and boat traffic; site visits to gather additional bathymetry data and measure EMI noise; and processing high resolution bathymetry data from NOAA surveys on the San Joaquin River in 2014-15. These assessments covered both proposed locations as well as potential alternative locations on the San Joaquin River from Durham Ferry to Hwy 4 and throughout channels in the south Delta.

The proposed location at Turner Cut near Acker Island was determined to be infeasible for array testing due to logistical constraints affecting both array deployment and release of tagged test fish for detection efficiency testing. Boat traffic and risk of vandalism were the primary concerns for installation and operation of the array. For detection testing, there was concern that dividing the limited number of test fish between two large-channel sites would result in very sparse detection data and poor estimation of detection efficiency, with particular worry that detection rates might be especially low at Turner Cut given its location at a major channel junction at Acker Island and complex tidal flow dynamics. Therefore, with approval of the CDFW contract manager, no further efforts were expended in establishing an array at this location.

For the West Howard Road reach, a site at Haven Acres marina near Lathrop was identified as feasible for array testing based on a suitable combination of habitat characteristics and logistical factors. There is an approximately 400 m long no-wake zone centered on the marina that slows boat traffic and minimized the navigation hazard associated with the arrays, and there were areas within the reach to test the arrays in deep, open-channel conditions. A small boat ramp and docks at the marina facilitated installation and removal of the arrays.

The main design challenges at this site were: (1) daily tidal fluctuations in river height of 1 m; (2) reversal of flow on flood tides; (3) large amounts of aquatic vegetation debris (water hyacinth); and (4) high recreational boat traffic. The array design chosen for the San Joaquin was similar to the Mokelumne River site in Task 1a/b with an upstream-downstream pair of raft-mounted vertical fin arrays and swim-over streambed antennas but with two differences: (1) power and electronics were fully contained on each raft, making the arrays physically independent from one another and from shore; and (2) the hydrofoil fins on these raft arrays were longer (3.8 m) to account for the greater channel depth at this site, and half of the fins contained separate upper and lower antennas to determine position of detected fish in the water column. The arrays were located in deeper areas (5-6 m at low tide) about 300 m apart near either end of the no-wake zone (Figures 12 and 13). The channel was about 55 m wide at the upstream array and 50 m wide at the downstream array.

Figure 12. Bathymetry of the study reach on the San Joaquin River. Hot colors (yellow-red) indicate deeper areas in the channel. Data provided by R. Cutter, S. Manugian, and D. Demer, SWFSC.

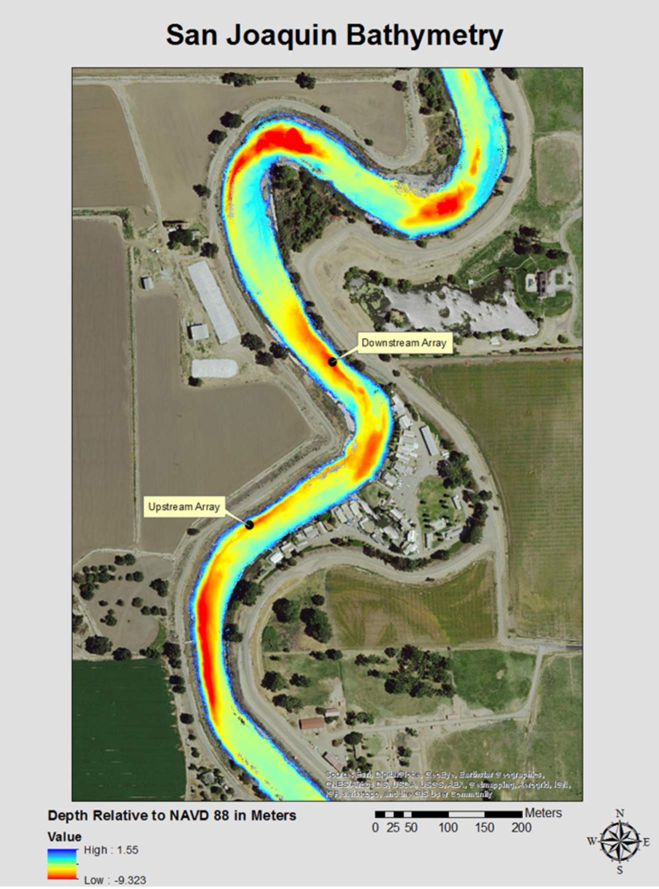


Figure 13. Google Earth image (captured March 14, 2016) of the arrays on the San Joaquin River.

The two raft arrays and bottom-mounted swim-over antennas for the site were fabricated at the Biomark shop in Boise, Idaho, in January-February 2016 and installed February 23-26. The raft platforms were held in place by anchor chains secured to the riverbed with duckbill anchors installed by SCUBA divers. The deck of each raft was 2.4 m wide and 3.6 m long (Figure 14). Each raft array consisted of four 3.8 m-long hydrofoils spaced 1.2 m apart for a total physical span of 3.6 m. The hydrofoils were suspended from an adjustable trolley by self-steering linkages that maintained the orientation of each fin to the flow independently and allowed the fins to pivot in the downstream direction to pass debris. Two hydrofoils of each raft array consisted of full length antennas 3.0 m in length (single) and two hydrofoils contained two antennas (top and bottom), each 1.5 m in length and separated by 0.08 m (Figure 15a). The bottom antenna of each hydrofoil type (single or double antenna) was 0.25 m from the bottom of the hydrofoil. A ballast section, made of fiberglass-encased cement 0.30 m tall, was secured to the bottom of each hydrofoil (Figure 15b) resulting in the bottom of the antenna positioned 0.55 m from the bottom of the overall hydrofoil assembly. However, during installation it was discovered that ballast sections did not provide sufficient weight for the hydrofoils to maintain vertical position when lowered all the way, so the hydrofoils could not be submerged fully until additional ballast sleeves were added later. In addition to the hydrofoil antennas, a single 6-m bottom-mounted antenna was positioned beneath each raft. The bottom-mounted antennas were held in place using duckbill anchors and ratchet and cam straps and were installed by SCUBA. Navigation lights and warning signs were placed on each raft and lighted warning buoys were placed in front of each raft in the direction of boat traffic entering the no-wake zone.

Figure 14. Schematic diagram and pictures of the prototype raft-mounted vertical fin arrays on the San Joaquin River during and after initial installation.

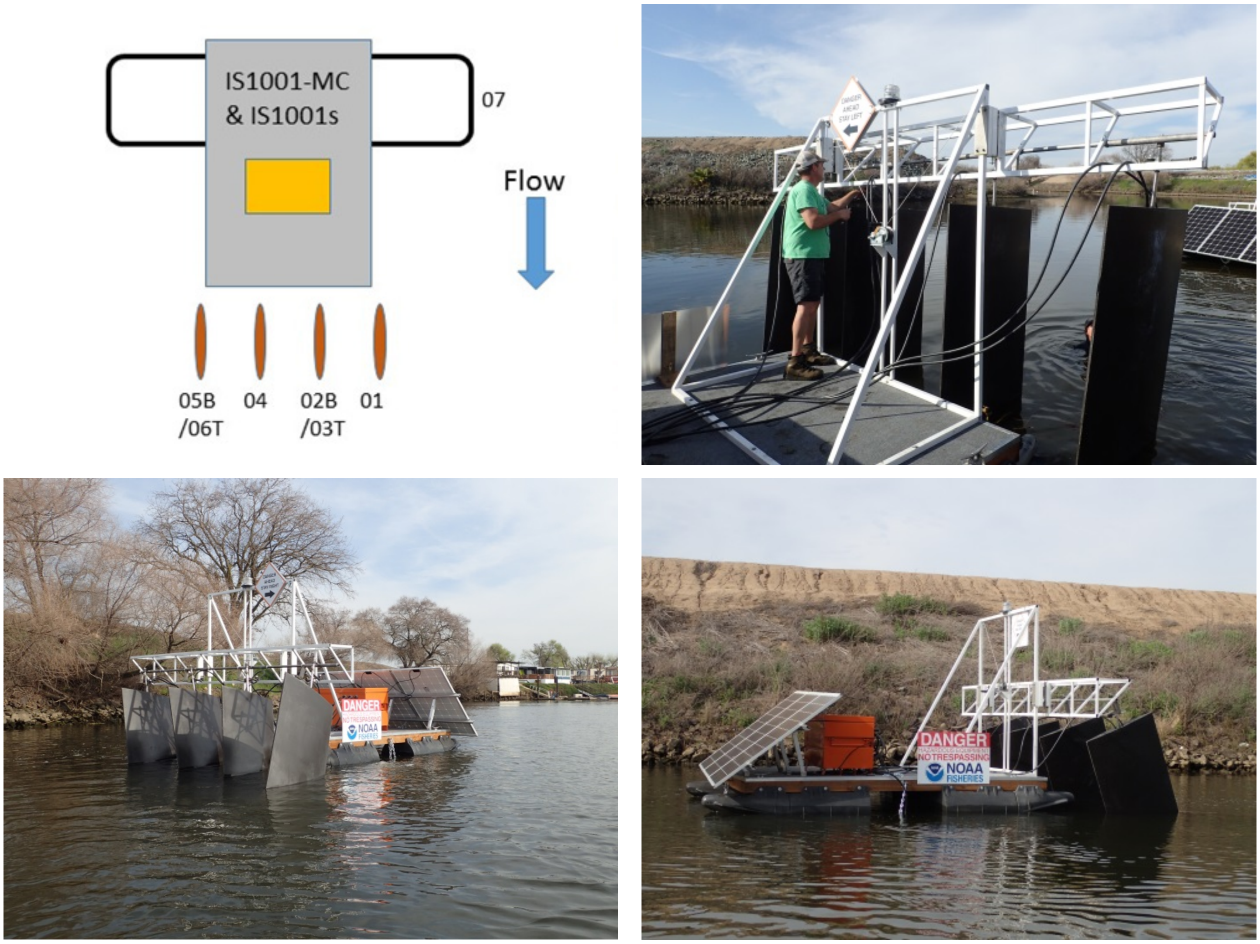
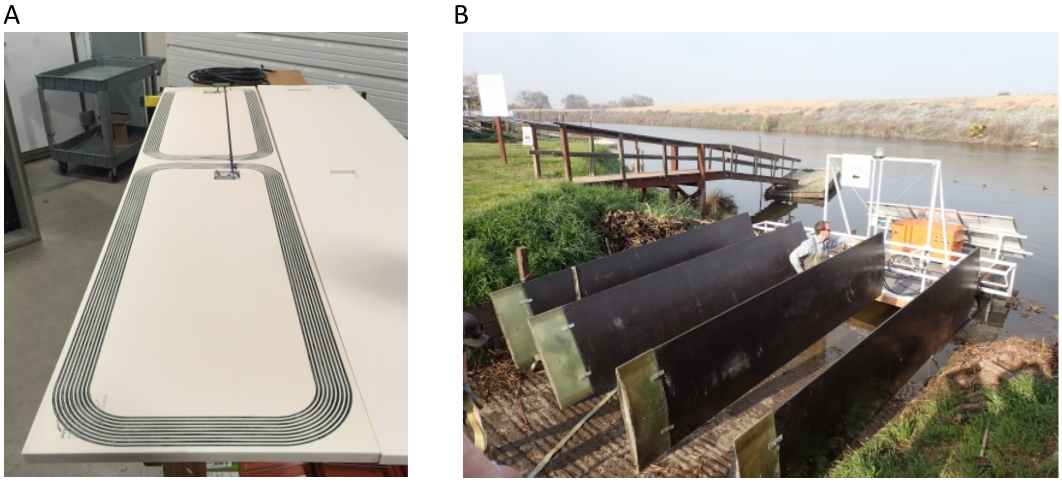


Figure 15. (A) Independent dual antenna coils used in half of the hydrofoils (2 per raft) on the San Joaquin arrays. (B) Hydrofoils showing cement-filled ballast sections attached to the bottom of each fin.



Each raft array consisted of a Biomark IS1001-MC and seven IS1001 readers and antennas (six for the single- and dual-coil hydrofoils and one for the bottom-mounted antenna). The IS1001 readers associated with the hydrofoil antennas were co-located with the IS1001-MC in an electronics enclosure on the raft deck (Figure 16). The IS1001 reader associated with the bottom-mounted antenna was housed in a submersible enclosure secured to the antenna and connected to the IS1001-MC on the raft by a DOP cable. Each raft was equipped with a Midnite Solar Kid 30A MPPT charge controller, three 285 watt panels, and four 260AH batteries that provided power. The DC input voltage to the IS1001-MC was regulated using an Acopian Model 18-75C28NT620 DC-DC power supply. A Cloudgate modem connected to the IS1001-MC provided remote access to the site for system control and data retrieval. The IS1001-MC, IS1001s, DC-DC power supply, solar charge controller, batteries, and modem were housed in a metal enclosure positioned on the raft deck. Biomark's DCA polled data from the site every 4-hrs.

Figure 16. Electronics enclosure housing the IS1001-MC, IS1001 reader nodes, DC-DC power supply, solar charge controller, batteries, and modem positioned behind the solar panel on each raft array.

The raft arrays were installed with 3 anchor chains, one from the bow and one on each side, which initially appeared to be adequate as the arrays maintained proper position during the couple days of installation. However, starting a couple of days after installation, the rafts began rotating during the tidal changes in river height and flow, causing the fins to be pinned out of orientation against the raft (Figure 17) and the rafts to list toward the tightest anchor chain. On March 3, the anchor chains were shortened to reduce slack at low tide and the fins were raised about half way out of the water; these steps reduced (but did not eliminate) the degree of rotation by the rafts and hydrofoils but significantly reduced the detection area of the arrays. Final modifications were made on March 15 to solve this problem. A 4th anchor line was added to the stern of each raft, and fore and aft spring lines were run to shore (Figure 18), which together maintained the position of the rafts throughout the tidal cycle. In addition, ballast sleeves containing non-magnetic sand were added to the bottom of each fin, which allowed the hydrofoils to be lowered to their full depth in the water (submerged 3.5 m) while remaining vertical and also eliminated rotation of the fins when flow direction changed. After these modifications, the arrays then operated well through the rest of the spring, other than a brief outage on the upstream array due to a solar charger that failed after a month of operation and caused loss of power March 22-29 until it was replaced.

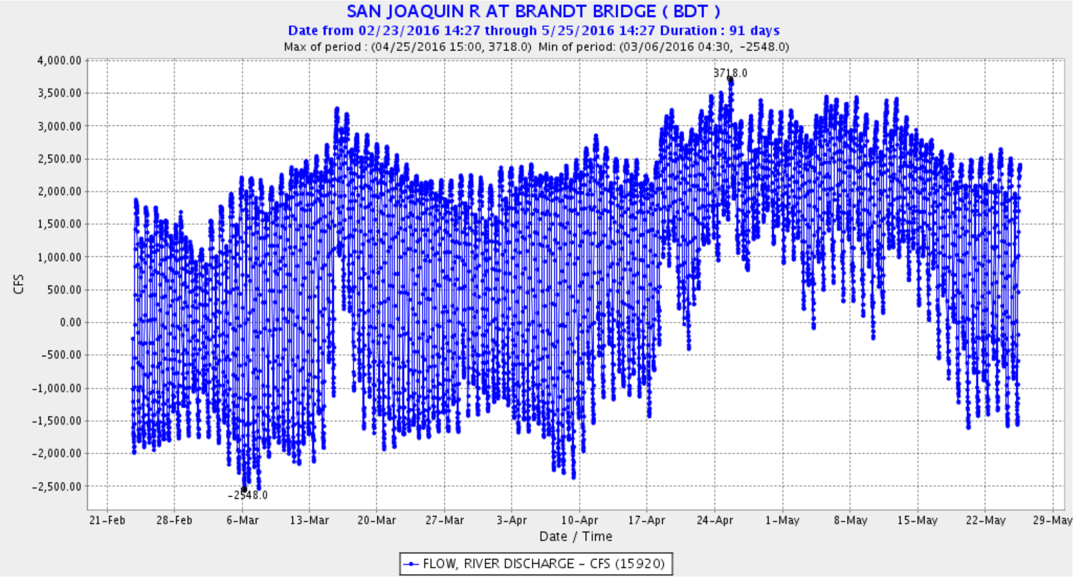
Figure 17. Rotation of the San Joaquin after several days of tidal cycles before modifications were made to stabilize orientation of the hydrofoils and position of the rafts.

Figure 18. Downstream raft after final modifications, including spring lines marked with high-visibility flagging, to stabilize position throughout tidal cycle. Note that trolley is in the fully raised position in this picture but was fully lowered for maximum hydrofoil depth for operation.

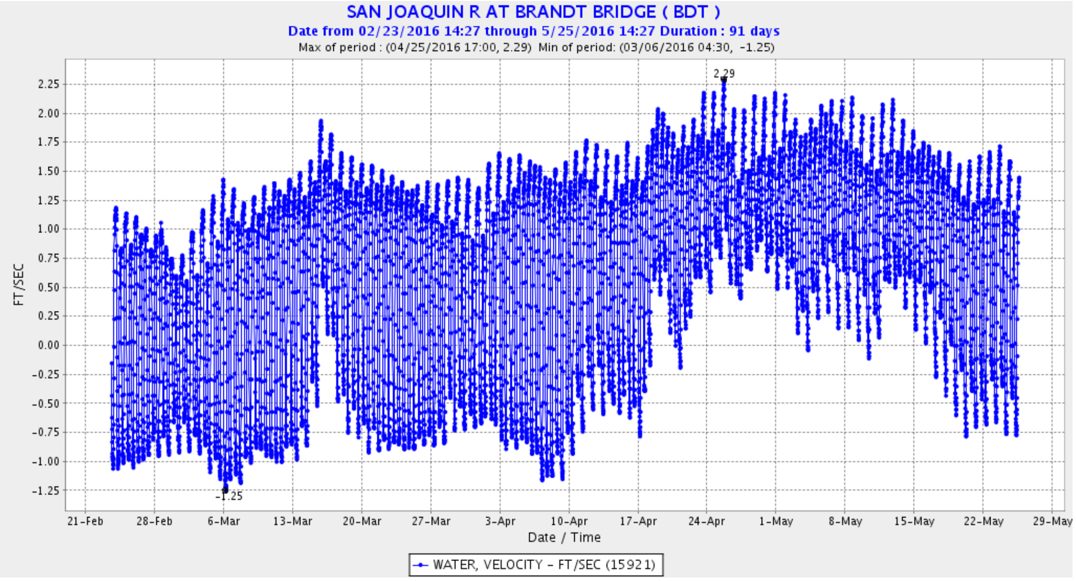
The arrays on the San Joaquin River were operated successfully March–May for detection efficiency testing (see Tasks 3 and 5 below). The arrays withstood flows of -2500 to 3700 cfs, water velocities of -1.25 to 2.3 ft/sec, total range of river stage (height) of 1.5 m, and conductivity of 200 to 1100 µS/cm, (Figures 19 a-d). Negative flows and velocities were the result of flow reversal on the flood tide. It should be noted that flow in 2016 was low relative to historical conditions: based on mean annual discharge at the USGS gage near Vernalis, flow for water year 2016 (1006 cfs) was less than half of the median annual flow from 1950 to 2016 of about 2500 cfs (https://waterdata.usgs.gov/ca/nwis/uv/?site_no=11303500&PARAmeter_cd=00065,00060). Therefore, while the flows in 2016 enabled proof-of-concept testing across a range of conditions, higher flows in other years may alter the challenges encountered (e.g., higher flows may produce higher water velocities, although they may also eliminate the tidal reversal of flow direction).

Figure 19. Environmental conditions during the operation of the San Joaquin array from February-May 2016: (A) discharge, (B) water velocity, (C) river height, and (D) conductivity. Data from the California Data Exchange Center Brandt Bridge sensor, located about 2 km downstream of the arrays (CDEC) website (http://cdec.water.ca.gov/cgi-progs/staMeta?station_id=BDT).

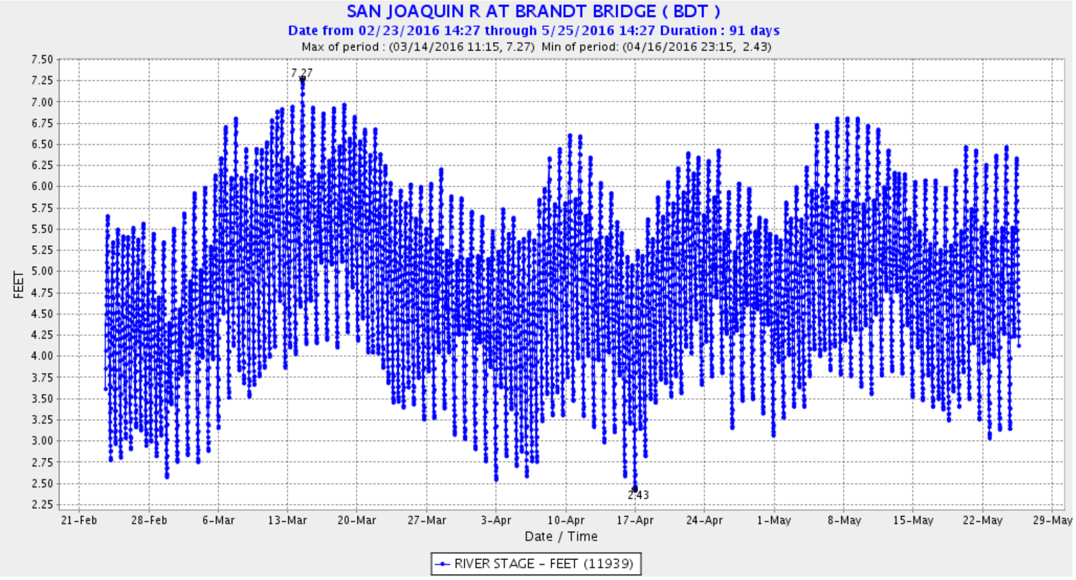
A.



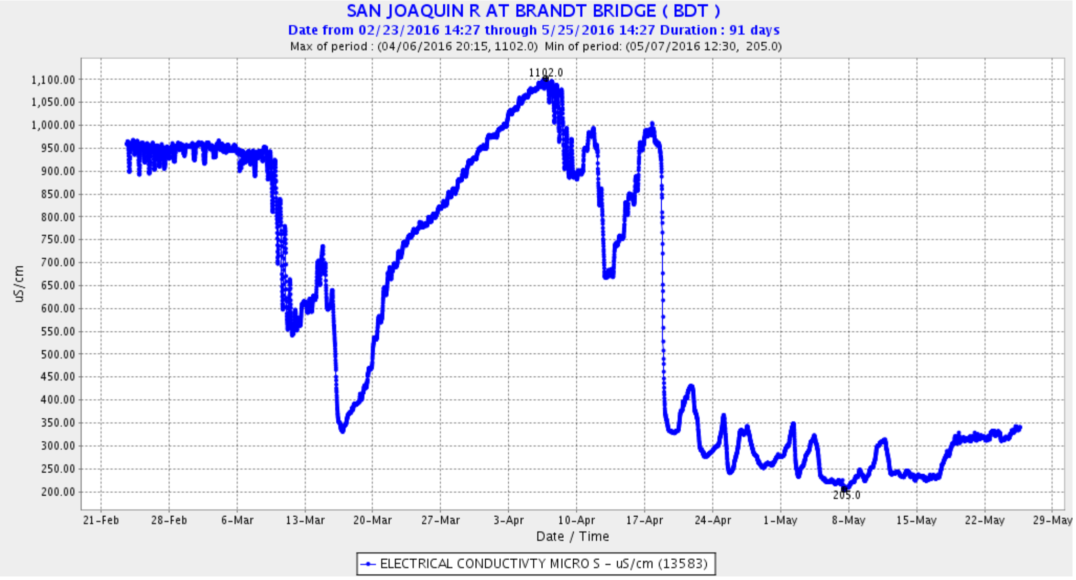
B.



C.



D.



The technical performance and detection efficiency of the arrays are described in detail in later sections of this report under Tasks 3, 4, and 5.

The San Joaquin arrays were removed on May 25, 2016, prior to the summer boating season. All equipment from the San Joaquin site was moved to storage at the Mokelumne River Hatchery. The solar power systems for each array were set up to charge the batteries to maintain them in good condition during storage. O&M binders (digital and hard-copy) were delivered to the CDFW contract manager.

Task 3 – Conduct initial efficiency tests

Pre-installation diagnostics and performance

The hydrofoil and bottom-mounted antennas fabricated for the Mokelumne and San Joaquin arrays were tested in Biomark's RF room during production and exciter level, antenna current, FDX-B noise level, and read range using a 12-mm FDX-B PIT tag (Biomark model HPT12) were recorded for each antenna (Tables 1 and 2). The IS1001 reader has the ability to operate an antenna at five exciter levels (1-5). Higher exciter levels result in higher antenna current, which can result in increased read range. Higher antenna current can also amplify environmental electromagnetic interference (EMI) resulting in a decrease in read range. The IS1001 has an upper antenna current threshold of 11 amps. The reader will automatically go into standby mode to protect the reader circuitry or reduce the exciter level to decrease the antenna current. The bottom-mounted antennas were designed to achieve the maximum current at exciter level 3 in air. This allows the exciter level to be increased if there is a decrease in current once submerged in water. The FDX-B signal level is an indicator of conducted or emitted EMI ("noise") at 134.2 kHz. In general, noise levels in excess of 25% can significantly reduce read range. Read range was determined using a 12-mm FDX-B tag in "pass-by" orientation to the antenna coil to mimic what would be expected if a PIT-tagged fish were to swim by the antennas once installed.

Table 1. Summary of diagnostic and performance data for the antennas produced for the Mokelumne River array. Measurements recorded in Biomark's RF room, in air, prior to delivery.

Serial No.	Antenna Type	Exciter Level (1-5)	Current (Amps)	FDX-B Signal (%)	Read Range (cm)
16-068	Hydrofoil	5	10.1	4	89
16-069	Hydrofoil	5	9.8	5	89
16-070	Hydrofoil	5	9.7	5	89
16-071	Hydrofoil	5	9.7	3	89
16-099	Hydrofoil	5	9.7	3	89
16-100	Hydrofoil	5	9.9	2	89
16-101	Hydrofoil	5	10.0	3	89
16-102	Hydrofoil	5	10.1	4	89
16-047	Bottom-mounted	3	10.2	3	86
16-049	Bottom-mounted	3	10.2	3	86

Table 2. Summary of diagnostic and performance data for the antennas produced for the San Joaquin River array. Measurements recorded in Biomark's RF room, in air, prior to delivery.

Serial No.	Antenna Type	Exciter Level (1-5)	Current (Amps)	FDX-B Signal (%)	Read Range (cm)
16-078	Hydrofoil: full length	5	9.8	3	81
16-079	Hydrofoil: dual - top	5	9.5	3	79
16-079	Hydrofoil: dual - bottom	5	8.6	2	81
16-080	Hydrofoil: dual - top	5	9.7	3	89
16-080	Hydrofoil: dual - bottom	5	8.7	5	89
16-081	Hydrofoil: full length	5	9.5	3	86
16-089	Hydrofoil: full length	5	9.7	5	85
16-090	Hydrofoil: dual - top	5	11.8	2	89
16-090	Hydrofoil: dual - bottom	5	11.8	3	89
16-092	Hydrofoil: dual - top	5	9.7	5	86
16-092	Hydrofoil: dual - bottom	5	8.6	3	86
[a]	Hydrofoil: full length	-	-	-	-
16-051	Bottom-mounted	2	10.6	4	86
16-075	Bottom-mounted	3	10.7	5	79

[a] One of the full length hydrofoils was not serialized and an electronic record was not generated during production.

The antennas for the Horseshoe Bend salvage release pipe antenna were constructed on-site by wrapping antenna wire directly around the pipe, so there were no pre-installation data for this site.

Post-installation diagnostics and performance

Initial performance was assessed from reader diagnostics (the readers generated status reports with hourly data on current, voltage, noise, etc. for each antenna) and by measuring the read range of a 12-mm FDX-B tag.

It was originally intended to use the virtual test tag (VTT) feature of the IS1001 readers to serve as a "dummy" tag to monitor read range hourly during array deployment. The purpose of the VTT is to provide a front-to-back test of reader functionality. The VTT introduces a tag signal directly into the reader circuitry. The VTT introduces its signal by modulating the antenna field, just like a real tag, only its position is fixed close to antenna trace and so it is always strongly coupled to antenna field; different levels of coupling between a tag and an antenna are simulated by adjusting the depth of VTT modulation. The setting of the VTT ranges from 0 to 255; the higher the value the higher the amplitude of the test signal. The amplitude of the VTT at a given value is a function of the antenna and exciter level. The IS1001 reader has a “detection efficiency” test that can determine the detection efficiency of a particular VTT setting or a real tag placed in the antenna field. The most important aspect of detecting a PIT tag is the signal-to-noise ratio. With an IS1001 reader, the amplitude of the tag signal needs to be approximately 20 mV greater than the noise floor to be detected; this does not account for noise spikes. The amplitude of the tag signal is an indication of how strongly the tag couples with the antenna field and is a function of the distance and orientation of the tag to the field. Therefore, a given amplitude (e.g., 200 mV) can be generated by a tag at multiple locations or orientations from the antenna. Determining the VTT level that corresponds to 100% detection efficiency requires generating a rating curve to relate VTT value and signal level to measured read ranges of an HPT12 PIT tag. However, it proved impractical to generate the VTT rating curve for the installed arrays due to the inability to place a tag at a known location and orientation in the field of each of the individual antennas within the arrays. Therefore, antenna current and noise were the best available indicators of antenna performance over the period of deployment.

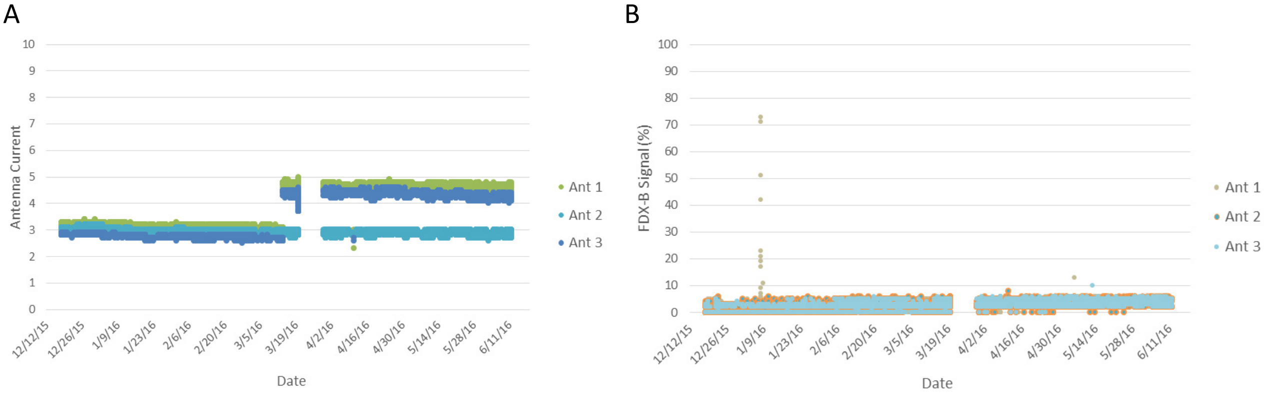
Horseshoe Bend

The shielded antennas on the DWR salvage release pipe at Horseshoe Bend (Task 1c) had a read range of 46 cm when installed, which met performance targets, and operated with stable current and low noise levels for the entire period of operation from December 2015 to June 2016 (Table 3 and Figure 20) despite the high EMI at the site. The increase in exciter level setting on the top and bottom antennas on March 14, 2016, increased antenna current (Figure 20a) and presumably increased read ranges for these antennas, although read range was not measured at this setting.

Table 3. Summary of diagnostic and performance data for the Horseshoe Bend release pipe antennas. Exciter level, current, and signal are average hourly values for the period 1 April to 12 June, 2016, after the exciter level for the top and bottom antennas was increased. Read range values were at the time of installation with all antennas at Exciter Level 1.

Antenna	Position	Exciter Level (1-5)	Current (Amps)	FDX-B Signal (%)	Read Range (cm)
01	Top	5	4.6	3.9	46
02	Middle	1	2.9	1.8	46
03	Bottom	5	4.4	3.7	46

Figure 20. (A) Hourly current and (B) FDX-B signal (noise) for the Horseshoe Bend antennas. The increase in current in March was from increasing the exciter level for antennas 1 and 3.



Mokelumne and San Joaquin arrays

All of the antennas at the Mokelumne and San Joaquin arrays experienced significant reductions in performance after installation compared to their in-air performance in the Biomark RF room, and reductions were variable among antennas. At the Mokelumne site, the current of each individual antenna was stable over the monitoring period (Figure 21a); the spikes on 5-7 April were due to a firmware update and testing of different settings. After screening the hourly diagnostic status reports to remove records affected by the firing of the VTT (which produce a noise signal > 40% in the version of firmware deployed), the average FDX-B signal level was about 10-15% for the hydrofoil antennas and 30-35% for the bottom-mounted antennas (Figure 21b and Table 4; Appendix A contains individual scatter plots for each antenna). Although current of individual antennas was stable, current and read range varied considerably among individual antennas and all were significantly lower than values during pre-installation testing, with read ranges of the hydrofoil antennas dropping from 89 cm in-air to 30-56 cm in-water (Table 4). Read range of the bottom-mounted antennas was not measured after installation due to water depth and poor visibility, but high noise levels (30-35%) suggest that read range probably was considerably reduced from pre-installation measurements. Elevated noise level was likely a result of an irrigation pump operated downstream of the arrays and general emitted EMI at the site.

Figure 21. (A) Hourly current and (B) FDX-B signal (noise) for the Mokelumne River antennas. The deviation in current on April 5-7 was due to a firmware update and testing of different settings.

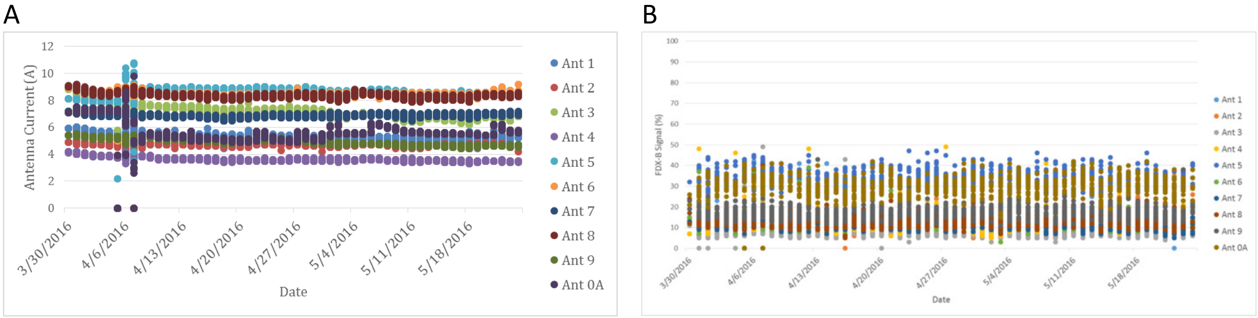


Table 4. Summary of diagnostic and performance data for the upstream (U) and downstream (D) arrays following installation in the Mokelumne River. Current and signal values are the averages for the period 30 March to 24 May 2016. Read range of bottom-mounted antennas was not measured in the field due to poor visibility.

Array	Antenna	Antenna Type	Exciter Level (1-5)	Current (Amps)	FDX-B Signal (%)	Read Range (cm)
U	01	Hydrofoil	5	5.2	11.7	36
U	02	Hydrofoil	5	4.7	10.5	30
U	03	Hydrofoil	5	7.2	8.1	36
U	04	Hydrofoil	5	3.6	12.7	45
U	0A	Bottom-mounted	3	5.7	30.0	NA
D	06	Hydrofoil	5	8.5	12.8	45
D	07	Hydrofoil	5	6.9	12.2	41
D	08	Hydrofoil	5	8.4	13.6	56
D	09	Hydrofoil	5	4.9	17.8	30
D	05	Bottom-mounted	4	8.6	34.3	NA

At the San Joaquin site, antenna current was stable during the period of operation for the individual hydrofoil antennas but increased by 2-3 A in mid-April for the bottom mounted antennas (Fig. 22). This increase in current by the bottom-mounted antennas coincided with a drop in water conductivity (Figure 19d) apparently associated with increased river discharge for seasonal environmental flow releases (Figure 19b). Current varied among individual antennas and most were significantly lower than values during pre-installation testing, especially the antennas in the hydrofoils with dual coils (Table 5). Noise was low and stable for all antennas: after screening the status reports to remove records affected by the firing of the VTT, average hourly FDX-B signal level was less than 6.5% for all antennas at both array locations during the monitoring period (Table 5; Appendix A contains individual scatter plots of noise for each antenna). Measuring read range was difficult due to the length and depth of the submerged hydrofoils, and could not be measured at all for the lower antennas in the dual-coil fins or for the bottom mounted antennas due to depth and poor visibility. Read range of the full length coils was approximately 30 cm after installation, and read range for the upper coil in a dual coil hydrofoil was approximately 25 cm.

Figure 22. Hourly current for the San Joaquin antennas for the (A) upstream and (B) downstream arrays. The deviation in current on April 5 was due to a firmware update. Bottom mounted antennas = Ant 7.

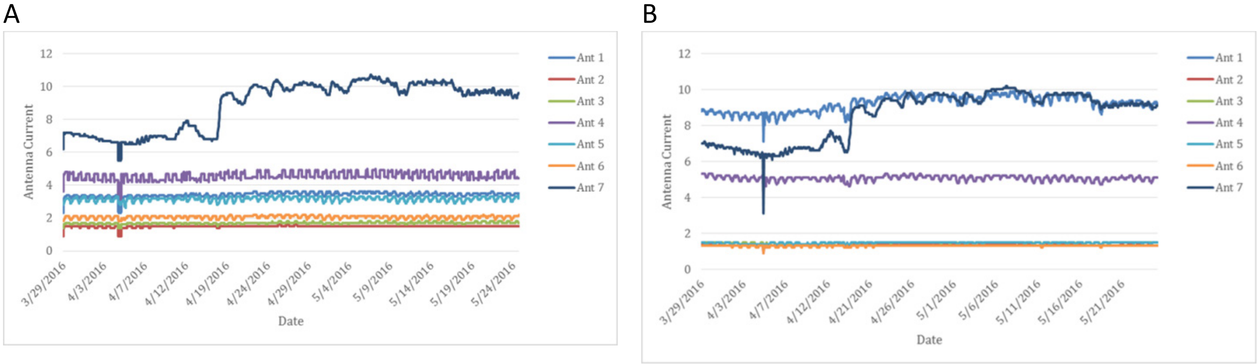


Table 5. Summary of diagnostic data for the San Joaquin arrays following installation for the upstream (U) and downstream (D) arrays. Current and signal values are the averages for the period 29 March to 25 May 2016.

Array	Antenna	Antenna Type	Exciter Level (1-5)	Current (Amps)	FDX-B Signal (%)
U	01	Hydrofoil - full	5	3.4	4.7
U	02	Hydrofoil - dual	5	1.5	4.7
U	03	Hydrofoil - dual	5	1.7	4.2
U	04	Hydrofoil - full	5	4.6	5.5
U	05	Hydrofoil - dual	5	3.2	3.8
U	06	Hydrofoil - dual	5	2.1	5.0
U	07	Bottom-mounted	5	8.9	6.3
D	01	Hydrofoil - full	5	9.2	5.3
D	02	Hydrofoil - dual	5	1.3	4.8
D	03	Hydrofoil - dual	5	1.5	4.6
D	04	Hydrofoil - full	5	5.1	5.5
D	05	Hydrofoil - dual	5	1.5	3.3
D	06	Hydrofoil - dual	5	1.3	4.4
D	07	Bottom-mounted	5	8.6	4.8

The significantly reduced in-water performance of the prototype hydrofoil antennas is believed to be the result of insufficient separation (air space) between the antenna coils and the surrounding water (see additional discussion of air space effects under Task 6 below) or interactions between adjacent hydrofoils that affected dynamic tuning because the fin positions were not rigid or fixed with respect to one another. The hydrofoils were designed with about 2.5 cm separation between the coils and the exterior of the fins in order to minimize drag. Unlike the existing bottom-mounted antennas that are designed to achieve the maximum current in air at exciter level 3 so that the exciter level can be increased if there is a decrease in current once submerged in water, the prototype hydrofoil antennas achieved maximum current in air at exciter level 5 and could not be adjusted to compensate for the decreased current once deployed. The lowered read range of the installed hydrofoils resulted in areas of no detection between adjacent fins and reduced overall detection area by the arrays. However, given the time constraints of the project, it was not possible to redesign and fabricate different hydrofoils.

Detection efficiency testing with live fish

Tagging

Twenty thousand juvenile fall-run Chinook salmon were PIT tagged at Mokelumne Hatchery March 14-19, 2016, by a crew of 5-6 people (Table 6). Fish were obtained under a request for hatchery fish for research use approved by the CDFW Statewide Hatchery Coordinator. Fish were injected with 12-mm FDX-B tags (Biomark model HPT12) using single-use 12-gauge hypodermic needles. A portable tagging station was used to record scanned tag codes and measurements directly into an electronic database. The adipose fins of all fish were clipped, and fork length (FL) was measured for approximately 70% of the fish. The original goal was to PIT-tag fish > 65 mm FL. However, after tagging the first few batches of fish, it was apparent that many fish < 65 mm FL were being rejected. Hatchery personnel indicated that there were no other groups of fish available to replace allotted fish rejected due to size, so the minimum FL target was lowered to 60 mm to meet the tagging goal. Even this lowered target was not adequate to reach the tagging goal, so it was further relaxed and 16% of fish tagged were < 60 mm to reach the goal of 20,000 fish. The average FL of measured fish was 63.5 mm and ranged from 49 to 80 mm.

Tagged fish were placed in hatchery troughs in groups to facilitate release. Fish were maintained under standard hatchery protocols until release, and troughs were checked daily to remove dead fish and retrieve shed PIT tags using a magnet.

Table 6. Number of fish tagged by date and mortalities after tagging but prior to release.

Tag Date	Trough	Number Tagged	Mortalities
14-Mar	37	2,011	8
15-Mar	38	1,992	18
15-Mar	39	1,997	10
16-Mar	40	1,997	22
16-Mar	41	2,000	24
17-Mar	42A	2,001	17
16-Mar	42B	1,000	20
17-Mar	43A	1,001	16
17-Mar	43B	1,000	1
18-Mar	44A	999	8
17-Mar	44B	1,001	9
18-Mar	45A	1,001	11
18-Mar	45B	1,000	15
19-Mar	46A	127	0
19-Mar	46B	873	3
	Total	20,000	182

Releases

Fish were transferred from the hatchery troughs into insulated and aerated tanks for transport to the release sites. Tanks were provided by EBMUD. A 300 gallon trailer tank was used for releases at Horseshoe Bend and the San Joaquin River, while a pair of 75 gallon truck-bed tanks was used for the Mokelumne releases. A random sample of 40-80 fish per release group was measured to estimate size (FL) at release. At the San Joaquin and Mokelumne, fish were acclimated to river water by slowly draining tank water and replacing with river water until the tank was within 1 °C of the river temperature.

Horseshoe Bend

To test efficiency of the Horseshoe Bend salvage release pipe array, 127 tagged Chinook salmon were released on April 28 in a series of group sizes (Table 7). Each fish was scanned and tag code recorded prior to release. Fish were released as individuals and in groups to gauge the impact of tag collision on the number of detections per tag and detection probability as the group size of PIT-tagged fish increased: 50 individual fish, 10 pairs of fish, two groups of five fish, two groups of 10 fish, one group of 12 fish, and one group of 15 fish (Table 7). In addition to releases of live fish, two other tag types (HDX and Biomark Fastag™) were embedded in wooden dowels and released and retrieved through the pipe on fishing line to compare the number of detections generated from 12-mm HDX tags and 12-mm Biomark FDX-B Fastag™ with the detections of the fish implanted with standard 12-mm FDX-B tags. Detection settings for HDX and Fastag tags were enabled on the IS1001 readers for these tests. The existing make-up water pump at the site was used to provide water in the release pipe during the tests.

Table 7. Number of PIT-tagged juvenile Chinook salmon released by release group size at Horseshoe Bend.

Release Group Size	1	2	5	10	12	15
Total Number Released	50	20	10	20	12	15

Mokelumne River

To test the efficiency of the Mokelumne River arrays, four groups of approximately 1,000 tagged Chinook salmon were released at weekly intervals in April 2016 at Stillman Magee County Park, about 7 km upstream of the arrays (Table 8). All releases occurred during mid-day, and releases were timed to include a release on a pulsed flow to capture the widest range of flow conditions (325–750 cfs). The first release was timed for the pulsed flow, while the remaining releases were scheduled for Mondays to maximize overlap with the EBMUD rotary screw trap (8-ft diameter) which was operated Monday to Friday. All adipose-clipped Chinook captured at the RST were scanned for PIT tags, and tagged fish were released off the back of the RST.

Table 8. Summary of releases at Mokelumne River.

Date	Group	Release Time	# Released	Mean Fork Length (mm)
4/6/16	1	Day	980	70.0
4/11/16	2	Day	999	71.4
4/18/16	3	Day	985	76.6
4/25/16	4	Day	992	80.1
	Total	Day	3,956	74.5

San Joaquin River

For testing the San Joaquin arrays, tagged juvenile Chinook salmon were released at the boat ramp at Dos Reis County Park (approx. 2.5 km upstream of the arrays) on the outgoing tide on 3 dates, with paired mid-day and mid-night releases on each date to account for possible diel variation in behavior or survival. It was originally planned to release fish on 4 dates, with approx. 2,000 fish per day and night release groups; however, after raw detection rates declined from the first to second release groups, it was decided to combine the remaining test fish into a single larger third release group to maximize detection (Table 9). Release dates were about 2 weeks apart to span a range of river conditions and were chosen to avoid the full moon to minimize predation and for suitable and consistent timing of the ebb tide (Day: 11:30-13:00; Night: 1:30-2:45); each release was timed for 1 hour before the peak ebb tide.

Table 9. Summary of releases at San Joaquin River.

Date	Group	Release Time	# Released	Mean Fork Length (mm)
3/30/16	1	Day	1,974	66.2
3/30/16	1	Night	2,003	65.8
	1	Total	3,977	
4/12/16	2	Day	1,975	72.5
4/12/16	2	Night	1,987	73.8
	2	Total	3,962	
4/27/16	3	Day	3,836	81.3
4/27/16	3	Night	3,960	79.7
	3	Total	7,796	
	Total	Day	7,785	75.3
	Total	Night	7,950	73.1
	Total	All	15,735	74.4

Efficiency estimation – methods

Horseshoe Bend

Detection efficiency for the Horseshoe Bend 3-antenna array was estimated using the 3-weir model in the program USER Version 4.7 (Lady and Skalski 2009).

Mokelumne and San Joaquin arrays

Cormack-Jolly-Seber (CJS) mark-recapture models implemented in program MARK (White and Burnham 1999) were used to estimate apparent survival and detection probability of the released PIT-tagged juvenile Chinook at the Mokelumne and San Joaquin arrays. Because the focus of this project was to evaluate new array designs for detecting juvenile fish in open channels, and because the majority of detections occurred on the hydrofoil antennas (see below), CJS models were fit to the data using only the detections on the hydrofoils (i.e., excluding detections on the bottom-mounted antennas). A series of models was constructed representing constant vs. release group specific survival and detection probability as well as constant vs. array-specific (upstream vs. downstream) detection probability, and Akaike's information criterion corrected for small sample size (AIC_c) was used to select the model(s) with most support from the data (Burnham and Anderson 1998). Survival between the upstream and downstream arrays at a site was assumed to be 100% and this parameter was fixed to 1 in the CJS models in order to estimate array-specific detection probabilities; this was a necessary assumption in order to estimate array-specific detection probabilities for the upstream and downstream arrays but seemed reasonable given the short distances between arrays (50 m on the Mokelumne and 300 m on the San Joaquin). Formal goodness-of-fit tests could not be applied due to the structure (only 2 detection occasions) and sparseness of the data, so the parameter estimates were judged for reasonableness as an indicator of model adequacy and whether CJS model assumptions were met.

Efficiency estimation – results

Horseshoe Bend array

Table 10 presents detection histories for each of the release groups. The detection probability represents the probability of detecting an individual PIT-tagged fish when released as an individual or in a group. There were not enough different detection histories for the 5 fish release group to estimate detection probability. However, all fish in these releases were detected. Overall detection probability ranged from 1.0 for releases of individual fish to 0.83 for releases of groups of 12 fish (Table 11). The number of detections per coil was variable among antennas and release group size. Fish released as individuals had the highest number of detections on each respective coil (Table 12). In general, the number of detections per coil, within a release group, decreased from antenna 1 to antenna 3. The Fastag™ was detected over twice as many times as the standard length telegram and HDX tags were detected less than half as many times as a standard length telegram FDX-B tag (Table 12). The dowels were likely traveling slower than fish released into the pipe, but one would expect a doubling in the number of detections with the Fastag™ at a minimum due to the short telegram (half as long).

Table 10. Frequencies of detection histories for each release group size.

	Group size					
Detection Histories	1	2	5	10	12	15
000	0	1	0	8	3	4
010	0	0	0	1	1	1
111	50	16	6	7	2	4
101	0	0	0	0	0	3
100	0	1	0	0	1	1
001	0	1	1	2	2	0
110	0	0	3	1	2	0
011	0	1	0	1	1	2
n	50	20	10	20	12	15

Table 11. Detection probability estimates and standard errors for each coil and overall detection probability for the array. Estimates were not calculable for the release groups of five due to limited observations of different detection histories.

	Group size					
Parameter	1	2	5	10	12	15
Coil 1(p1)	1.0	0.85	NA	0.40	0.42	0.53
	(NA)	(0.08)		(0.11)	(0.14)	(0.13)
Coil 2 (p2)	1.0	0.85	NA	0.50	0.50	0.47
	(NA)	(0.08)		(0.11)	(0.14)	(0.13)
Coil 3 (p3)	1.0	0.90	NA	0.50	0.42	0.60
	(NA)	(0.07)		(0.11)	(0.14)	(0.13)
Overall (p)	1.00	0.9978	NA	0.85	0.83	0.90
	(NA)	(0.002)		(0.05)	(0.08)	(0.05)

Table 12. Average number of detections per antenna by release group size for live Chinook with FDX-B tags and for Fastag™ and HDX tags embedded in dowels.

	Group size (live fish)						Dowel tests	
Antenna	1	2	5	10	12	15	Fastag™	HDX
1	8.6	6.1	4.7	5.3	3.2	3.9	28.4	1.9
2	6.3	4.7	1.8	3.6	2.3	3.4	28.4	1.4
3	5.1	3.8	2.9	2.6	2.4	3.4	18.4	2.4

DWR conducted independent releases of PIT-tagged fish as part of their salvage operation evaluations in 2016, where mixtures of tagged and untagged fish were released from tank trucks down the pipe. However, results of their detection efficiency estimates were not yet available at the time of this report. In past DWR tests at Horseshoe Bend (when the old antennas were working properly) and Curtis Landing (2 unshielded circular antennas) release pipes in 2007, total detection efficiency was 98.75% for releases containing 10-PIT tagged Chinook mixed with a large number of un-tagged salvage fish in 2500-2800 gallon tank trucks (Clark et al . 2009). Although detection for releases of 10-15 fish in this study was lower (83-90%), the release methods are not directly comparable: in this study, groups were released from a single net, which may have increased the number of tag collisions and reduced detection rate, while in the DWR releases the PIT tagged fish were mixed in a large volume of water and with non-tagged fish. On the other hand, fish may have been traveling at a higher speed through the pipe during the DWR releases due to the greater volume of water released from the tank trucks. On the whole, it appeared that the new shielded antennas resolved the high-EMI caused antenna failure at Horseshoe Bend while likely achieving comparable detection rates to the older DWR antennas and meeting the needs for detection efficiency for salvage operations.

Mokelumne River

Summary of detections on arrays

Of the 3,956 juvenile Chinook released in the Mokelumne River, a total of 262 individuals (6.6%) were detected by the PIT tag arrays (Table 13). Raw detection rates were highest for the first release group (8.3%), which occurred just before the pulse flow of 750 cfs (Figure 9), and declined slightly over the rest of the releases, which occurred at flows of 325-350 cfs, to 4.4% for the fourth group (Table 13). The number of detections differed between the arrays, with twice as many on the downstream array as on the upstream array, and this pattern was consistent across all 4 release groups (Table 13). Ten tags (4%)

were detected on both arrays. Median time from release to detection was 1.2 days, and 76% of fish were detected within 3 days of release.

Table 13. Detections of juvenile Chinook on the Mokelumne River arrays.

	Release Group				
Array	1	2	3	4	Total
Upstream	28	27	21	14	90
Downstream	56	50	45	31	182
Both	3	4	2	1	10
Total	81	73	64	44	262
Raw detection rate	8.3%	7.3%	6.5%	4.4%	6.6%

The majority of detections (87% total, 71-93% by array) occurred on the hydrofoil antennas rather than the bottom-mounted antennas (Table 14). Very few tags were detected by both antenna types either within the same array (0 for upstream array and 4 for downstream array) or between arrays (1 out of 10).

Table 14. Number of Chinook detected on the hydrofoils and bottom-mounted antennas at the upstream and downstream Mokelumne arrays. Numbers across categories sum to more than the totals because some individual fish were detected on both arrays and antenna types. Percent of tags detected on hydrofoils out of all tags detected shown in parentheses.

Array	Detections by Antenna Type		
	All	Hydrofoil	Bottom
Total	262	228 (87%)	38
Upstream	90	64 (71%)	26
Downstream	182	169 (93%)	17
Both	10	5 (50%)	5

CJS results for survival and detection probability

Of the CJS models fit to the hydrofoil detections, the top model allowed for release-group specific survival and array-specific detection probability (upstream vs. downstream) and the other candidate models received much less support from the data (Δ $AIC_c > 2$; Table 15).

Table 15. Model selection results for CJS models fit to the hydrofoil detections of released Chinook on the Mokelumne arrays. Phi = apparent survival, p = detection probability, Grp = release group; Array = PIT tag array (upstream vs. downstream), and (.) = constant.

Model	AICc	Δ AICc	AICc Weight	Model Likelihood	Number of parameters
phi(Grp) + p(Array)	2053.374	0	0.698	1	6
phi(.) + p(Array)	2055.648	2.274	0.224	0.321	3
phi(.) + p(Grp*Array)	2058.214	4.839	0.062	0.089	9
phi(Grp) + p(Grp*Array)	2060.988	7.614	0.016	0.022	12
phi(Grp) + p(.)	2102.819	49.445	0	0	5
phi(.) + p(.)	2105.096	51.722	0	0	2

Parameter estimates from the top model indicated that survival declined across the release groups, from 64% to 39%, and that detection probability was about 3% on the upstream array and 8% on the downstream array (Table 16). The array-specific detection estimates yielded an overall probability of detecting (on the hydrofoils antennas) a PIT-tagged fish passing through the site of 10.5%, assuming that detection on the two arrays was independent (overall detection $P = 1 – (1-P_1)(1-P_2)$).

Table 16. Survival and detection probability estimates (with 95% confidence intervals) for the juvenile Chinook released in the Mokelumne River from the top model based on hydrofoil detections.

Parameter	Estimate	95% CI
Survival_group 1	0.639	0.143 - 0.949
Survival_group 2	0.627	0.146 - 0.943
Survival_group 3	0.530	0.153 - 0.875
Survival_group 4	0.392	0.133 - 0.731
Detection probability_upstream array	0.030	0.012 - 0.069
Detection probability_downstream array	0.078	0.033 - 0.174

Survival estimates appeared somewhat low considering the short distance (7 km) and time at large (median 1.2 d) between release and detection; in comparison, average 10-km survival rates for juvenile Chinook in the Sacramento River and Delta were > 90% for releases of acoustic-tagged fish in 2007-2010 (Michel et al. 2015). This suggests that detection probability may have been overestimated and that assumptions of the CJS model may have been violated (most likely the assumption that probability of detection was independent between arrays). Confidence intervals for estimates were very wide, especially for survival, indicating low precision. Therefore, the survival and detection probability estimates from the CJS model should be viewed with some caution.

Comparison of detections between PIT tag arrays and RST

To compare detections between the PIT tag arrays and the EBMUD rotary screw trap, the array detection data were filtered to the match the times the RST was operating Monday-Friday. Overall the RST captured 17% more tagged fish than were detected by the full arrays and 37% more than were detected by the hydrofoil antennas only (Table 17); the RST appeared to have a better position with respect to a defined thalweg than the locations where the arrays deployed, which may have contributed in part to the higher detection by the RST. However, for the first group that was released just prior to the highest pulsed flow of the season, more than twice as many fish were detected by the arrays than by the RST, suggesting that the relative performance of the arrays and RST may vary depending on flow conditions (the RST stopped overnight on the two days following the pulse flow, but the array detections were filtered to match the RST outage periods based on the RST rotation counter). Fewer than 4% of fish were detected in common between the arrays and RST (Table 17).

Table 17. Comparison of detections of PIT-tagged Chinook between the PIT arrays (all detection on full arrays and detections on hydrofoil antennas only) and rotary screw trap (RST) on the Mokelumne River.

Release Group	RST Detections	PIT Array Detections		Detected on Both	
		Full array	Hydrofoil only	Full array	Hydrofoil only
1	20	42	29	1	1
2	79	64	57	2	1
3	71	58	51	4	3
4	70	44	41	1	0
Total	244*	208	178	8	5

*Total includes 4 ad-clipped fish whose PIT codes were recorded incorrectly or did not scan and could not be assigned to a release group.

EBMUD conducted independent estimates of RST efficiency in 2016 but the results were not yet available at the time of this report. In 2012-2013, under similar flow conditions as 2016, RST efficiency estimates for juvenile Chinook varied from 0.1– 14% within a season depending primarily on fish size (higher for fry and lower for parr/smolts, which may be able to escape or avoid the RST; Bilski et al. 2013a, 2013b). The PIT tag arrays appeared to have detection rates generally on par with the RST, although further data are needed to determine how the relative performance of the two methods compares under different flow conditions and for different sizes of fish.

San Joaquin arrays

Summary of detections on arrays

Of the 15,735 juvenile Chinook released in the San Joaquin River, a total of 465 individuals (3.0%) were detected by the PIT tag arrays (Table 18). Raw detection rate was highest for the first release group (7.1%) but declined substantially for the second (1.8%) and third (1.4%) groups; flow conditions were similar for the first and second groups but the third group was released during environmental flows when flow and velocity were higher and there were no flow reversals on the flood tide (Figure 19). The difference in total detections between the upstream and downstream arrays changed over time: for the first release twice as many fish were detected on the downstream array than on the upstream array, for the second release the difference was less than 50%, and by the third release detections were basically equal between arrays (Table 18). However, this overall pattern was driven by large increases in detections on the upstream bottom-mounted antenna relative to the downstream bottom-mounted antenna for groups 2 and 3; differences in hydrofoil-only detections between upstream and downstream arrays were consistent across releases groups with more detections on the downstream than upstream array. Eighteen tags (4%) were detected on both arrays. Median time from release to detection was 7.2 hours, and 78% of fish were detected within 24 hours of release.

Table 18. Detections of juvenile Chinook on the San Joaquin River arrays.

	Release Group			
Array	1	2	3	Total
Upstream	94	34	58	186
Downstream	199	41	57	297
Both	11	2	5	18
Total	282	73	110	465
Raw detection rate	7.1%	1.8%	1.4%	3.0%

The majority of detections (80% total, 66-87% by array) occurred on the hydrofoil antennas rather than the bottom-mounted antennas (Table 19). Very few tags were detected by both antenna types within the same array (2 for upstream array and 3 for downstream array). However, nearly half of the tags that were detected on both arrays (8 out of 18) were detected by a hydrofoil antenna on one array but bottom-mounted antenna on the other array, indicating some mixing with respect to vertical position in the water column between arrays.

Table 19. Number of Chinook detected on the hydrofoils and bottom-mounted antennas at the upstream and downstream San Joaquin arrays. Numbers across categories sum to more than the totals because some individual fish were detected on both arrays and antenna types. Percent of tags detected on hydrofoils out of all tags detected shown in parentheses.

Array	Detections by Antenna Type		
	All	Hydrofoil	Bottom-mounted
Total	465	371 (80%)	106
Upstream	186	122 (66%)	66
Downstream	297	259 (87%)	41
Both	18	9 (50%)	1

There were considerably more detections on the single-antenna hydrofoils than on the dual-antenna hydrofoils (Table 20). This likely reflects the greater reduction in current and read range after installation for the antennas in the dual-coil hydrofoils than for the single-coil hydrofoils (Table 5). For the dual-antenna hydrofoils, there were twice as many detections on the bottom (deeper) coil than on the top coil (Table 20), although a substantial amount of debris collected under the rafts (water hyacinth, branches and pieces of wood, etc.) so it is unclear whether this reflects natural fish position in the water column or whether the debris altered behavior and reduced fish movement past the upper coils (both coils were completely submerged when the hydrofoils were fully lowered). However, fish did not appear to use the rafts for cover or hold positions under them: the median number of detections per tag was 4 and the median time between first and last detection was 1.2 seconds.

Table 20. Comparison of detections between single- and dual-antenna hydrofoils on the San Joaquin arrays.

Hydrofoil type	Upstream Array	Downstream Array
Single (full length)	81	231
Dual-antenna	50	44
Top coil	15	15
Bottom coil	36	31

Time of release did not appear to affect detection, as similar numbers of fish were detected between day and night releases (Table 21), suggesting that any differences in diel behavior or survival were small at least over the relatively short time and distance between release and detection.

Table 21. Detections of PIT tagged Chinook salmon at the San Joaquin arrays by release timing (day versus night).

	Release time	
Array	Day	Night
Total	218	247
Upstream	77	109
Downstream	148	149
Both	7	11
Raw detection rate	2.8%	3.1%

CJS results for survival and detection probability

Of the CJS models fit to the hydrofoil detections, the top model allowed for release-group specific survival and array-specific detection probability (upstream vs. downstream) and the other candidate models received very little support from the data (Δ AIC$_c$ > 4; Table 22). Note that in this analysis release groups were all fish released on each of the three different dates; due to the lack of difference in raw detection between day vs. night release groups (Table 21) and the sparseness of the detection data, the day and night releases on each date were combined.

Table 22. Model selection results for CJS models fit to the hydrofoil detections of released Chinook on the San Joaquin arrays. Phi = apparent survival, p = detection probability, Grp = release group; Array = PIT tag array, and (.) = constant.

Model	AICc	Δ AICc	AICc Weight	Model Likelihood	Number of parameters
phi(Grp) + p(Array)	3724.906	0	0.873	1	5
phi(Grp) + p(Grp*Array)	3729.287	4.381	0.098	0.112	9
phi(.) + p(Grp*Array)	3731.704	6.799	0.029	0.033	7
phi(Grp) + p(.)	3776.222	51.316	0	0	4
phi(.) + p(Array)	4058.921	334.015	0	0	3
phi(.) + p(.)	4110.237	385.332	0	0	2

Parameter estimates from the top model indicated that survival declined sharply across the release groups, from 55% to 6%, and that detection probability was about 4% on the upstream array and 8% on the downstream array (Table 23). The array-specific detection estimates yielded an overall probability of detecting (on the hydrofoils antennas) a PIT-tagged fish passing through the site of 11.7%, assuming that detection on the two arrays was independent (overall detection $P = 1 - (1-P_1)(1-P_2)$).

Table 23. Survival and detection probability estimates (with 95% confidence intervals) for the juvenile Chinook released in the San Joaquin River from the top model based on hydrofoil detections.

Parameter	Estimate	95% CI
Survival_group 1	0.546	0.248 - 0.814
Survival_group 2	0.135	0.071 - 0.244
Survival_group 3	0.058	0.030 - 0.108
Detection probability_upstream array	0.039	0.021 - 0.070
Detection probability_downstream array	0.082	0.045 - 0.146

Estimated survival was very low considering the short distance (2.5 km) and time at large (median 7 hr) between release and detection; in comparison, average 10-km survival rates for juvenile Chinook in the Sacramento River and Delta were > 90% for releases of acoustic-tagged fish in 2007-2010 (Michel et al. 2015). This suggests that detection probability was substantially overestimated and that assumptions of the CJS model were violated (most likely the assumption that probability of detection was independent between arrays). Therefore, the survival and detection probability estimates from the CJS model are considered suspect and probably inaccurate.

Summary

In summary, the releases of tagged fish in the Mokelumne and San Joaquin provided information on approximate raw detection rates by the raft-mounted hydrofoil arrays that will be useful for considering future study designs and methods. The results of the mark-recapture analysis suggest that detection data from the dual-array installations violated assumptions of the CJS model and that alternative study approaches may be needed to accurately estimate detection probability, survival, and abundance (see final Summary and Conclusions below).

Task 4 – Monitoring PIT tag receiver arrays

Summary of operation and monitoring

The arrays in Tasks 1-2 were monitored remotely via cellular modem for diagnostic and detection data. The two equipment failures that occurred during operation (the AC power outage and surge that damaged the power system at Horseshoe Bend and the solar power charger failure on the upstream San

Joaquin array) were identified and repaired quickly (considering travel of Biomark personnel from Idaho) and minimized array outages (Table 24). As summarized above under Task 3, performance of all of the arrays (as indicated by current and noise) was stable over the course of operation other than the slight increase in current on the San Joaquin bottom-mounted antennas.

Table 24. Summary of operation of PIT tag detection arrays.

Site	Array	Installed	Removed	Outages and reduced performance	
Horseshoe Bend		12/16/15	NA	3/20/16 - 3/30/16	Total outage: power outage and surge damaged power system
San Joaquin	Upstream	2/26/16	5/25/16	2/26/16 - 3/15/16	Partial performance: hydrofoils raised and rafts rotating before additional weights and anchors installed
	Upstream			3/22/16 - 3/29/16	Total outage: solar power charger failed
	Downstream	2/26/16	5/25/16	2/26/16 - 3/15/16	Partial performance: hydrofoils raised and rafts rotating before additional weights and anchors installed
Mokelumne	Upstream	3/18/16	5/24/16	3/18/16 - 3/29/16	Total outage of bottom-mounted antenna: IS1001 node damaged during transport
	Downstream	3/18/16	5/24/16	None	

Database

A relational database was created on the SQL server at the SWFSC to store the diagnostic and detection data generated by the arrays and the tagging data for the fish released to estimate detection efficiency. Additional supporting tables were created to relate various data codes (e.g., antenna ID#) to meaningful descriptors (e.g., antenna type [hydrofoil or bottom mounted] and location [upstream or downstream array]). For Task 5 (double-tagging USBR steelhead from the Six-Year Study with acoustic and PIT tags – see below), tables were created for acoustic receiver and detection data at the San Joaquin array site. All PIT (and acoustic) tags detected that were not directly associated with this project were able to be identified and source information included in the database. All data tables and fields, and relationships between tables, were explained and defined in a supporting document that accompanied the database.

Summary of all detections

A total of 1,032 unique PIT tags were detected across all sites and arrays during this study (Table 25). The majority of detections (87%) were of fish tagged and released for this study. Detections on the San Joaquin arrays also included a variety of predator fishes that were PIT-tagged in 2014-15 as part of a NMFS SWFSC predation study and two striped bass tagged by DWR as part of predation studies at Clifton Court Forebay. Detections at Horseshoe Bend salvage release pipe included striped bass and juvenile Chinook salmon tagged by DWR as part of predation and salvage operation studies. Note that all detections were FDX tags due to reader settings; FDX was the only type known to be at-large in the system and the setting for detecting HDX tags was disabled.

Table 25. Summary of all PIT tags detected during this study.

Site	Species	Project	Total # detected
San Joaquin	Chinook	This study	465
Mokelumne	Chinook	This study	262
Horseshoe Bend	Chinook	This study	112
San Joaquin	Steelhead	This study (with USBR Six-Year Study)	38*
Horseshoe Bend	Steelhead	This study (with USBR Six-Year Study)	21*
San Joaquin	Largemouth bass	NMFS predation study	9
San Joaquin	Redear sunfish	NMFS predation study	1
San Joaquin	White catfish	NMFS predation study	6
San Joaquin	Striped bass	DWR predation study	2
Horseshoe Bend	Striped bass	DWR predation study	9
Horseshoe Bend	Chinook	DWR salvage study	108
		total	1,032

*Includes one fish that was detected on both San Joaquin and Horseshoe Bend arrays

None of the Chinook released for this project were detected at more than one site, but one steelhead was detected on the San Joaquin array and then detected 11 days later on the Horseshoe Bend array.

Task 5 – Tag and release test fish in 2016

Double-tagging USBR steelhead smolts

As an additional test of detection efficiency of the San Joaquin PIT arrays, steelhead smolts were double-tagged with PIT and acoustic tags to provide an accurate count of fish alive and passing through the study reach (based on essentially 100% detection of acoustic tags) and to allow for direct comparison of survival and detection estimates between the two detection methods. This task involved providing USBR with PIT tags and hand readers for double-tagging 1,500 Mokelumne Hatchery steelhead smolts that were implanted with both acoustic and PIT tags and released at Durham Ferry in spring 2016 during the final year of the USBR Six-Year Study on steelhead survival in the lower San Joaquin River and Delta. Tagging and release data were obtained from USBR and included in the project database.

Acoustic receivers were borrowed from UC Davis and USGS and deployed immediately around the PIT arrays on the San Joaquin River in order to detect tagged steelhead that were alive and passing through the channel at the array location. Four Vemco 180 receivers were deployed, one pair on each side of the channel upstream and downstream of the array study reach. The receivers were deployed on February 18 and retrieved on June 23, 2016. All acoustic detections were included in the project database.

The double-tagged steelhead smolts were released at Durham Ferry in three groups of 480 fish on February 24-27, Mar 16-19, and April 27-29, for a total of 1,440 fish released (Table 26). The first two groups of fish were released before the seasonal Head of Old River barrier was closed while the third group was released after the barrier was in place.

Table 26. Releases of double-tagged steelhead smolts in the San Joaquin River at Durham Ferry.

Release Group	Release Dates	# Released	Mean Fork Length (mm)
1	2/24 - 2/27	480	242
2	3/16 - 3/19	480	246
3	4/27 - 4/30	480	256

CJS mark-recapture models were used to estimate survival and detection probability, applied separately to the acoustic receiver and PIT tag array detections. All three release groups were included in the analysis of the acoustic detections, as the receivers were fully operational for all groups. For analysis of the PIT tag detections, only the third group was analyzed because the arrays were not fully functioning for the first two release groups due to mechanical or electrical problems (Table 24).

Detections and efficiency estimates

Acoustic tags

Of the 1,440 steelhead released at Durham Ferry, 525 were detected by the acoustic receivers around the San Joaquin arrays (Table 27); detection efficiency of the acoustic receivers was high, as only 3 fish were not detected by both the upstream and downstream receivers (in all cases by the upstream receivers but not the downstream). In addition to the steelhead from this study, the receivers also detected a variety of predator fishes that were acoustic-tagged in 2014-15 as part of a NMFS SWFSC predation study (Table 27).

Table 27. Summary of acoustic tags detected on the acoustic receivers at the San Joaquin array site.

Species	Project	Total # detected
Steelhead	This study (with USBR Six-Year Study)	525
Largemouth bass	NMFS predation study	21
Channel catfish	NMFS predation study	1
White catfish	NMFS predation study	2
Striped bass	NMFS predation study	3
	total	552

The majority (77%) of steelhead detected on the acoustic receivers were from the third release group (Table 28), which was released after the Head of Old River Barrier was closed. Median time from release to detection was 14.8 days for the first release group but decreased to 2.0 and 3.4 days for the second and third groups, respectively.

Table 28. Detections of double-tagged steelhead on acoustic receivers.

Release group	# detected
1	31
2	89
3	405
Total	525

CJS results for survival and detection probability

Of the CJS models fit to the acoustic receiver detections, the top model allowed for group-specific survival and array-specific detection probability (Table 29), and the other candidate models received considerable less support from the data ($\Delta AIC_c > 2$).

Table 29. Model selection results for CJS models fit to the acoustic receiver detections of double-tagged steelhead smolts released in the San Joaquin River. Phi = apparent survival, p = detection probability, Array = acoustic receiver array (upstream vs. downstream), and (.) = constant.

Model	AICc	Δ AICc	AICc Weight	Model Likelihood	Number of parameters
phi(Grp) + p(Array)	1153.214	0	0.684	1	5
phi(Grp) + p(.)	1155.363	2.149	0.234	0.342	4
phi(Grp) + p(Grp* Array)	1157.446	4.232	0.082	0.121	9
phi(.) + p(Grp* Array)	1759.061	605.847	0	0	7
phi(.) + p(Array)	1932.292	779.078	0	0	3
phi(.) + p(.)	1934.445	781.231	0	0	2

Parameter estimates from the top model indicated that apparent survival increased across the release groups, from 7 to 19% for the first two groups to 84% for the third group (Table 30); the low apparent survival of the first two groups corresponded to when the Head of Old River was open and fish could migrate down that route rather than down the San Joaquin past the study site. Detection probability on the acoustic receivers was about 100% on the upstream array and 99% on the downstream array (Table 30).

Table 30. Survival and detection probability estimates (with 95% confidence intervals) for the double-tagged steelhead smolts released in the San Joaquin River from the top model based on acoustic receiver detections.

Parameter	Estimate	95% CI
Survival_group 1	0.065	0.046 - 0.090
Survival_group 2	0.185	0.153 - 0.223
Survival_group 3	0.844	0.808 - 0.874
Detection probability_upstream array	1.000	1.000 – 1.000
Detection probability_downstream array	0.994	0.982 - 0.998

PIT tags

Of the released double-tagged steelhead, 38 were detected on the San Joaquin PIT tag arrays; all of these fish were also detected on the acoustic receivers. The majority of detections occurred for the third release group when the PIT tag arrays were fully functioning (Table 31); during the first group, the hydrofoil fins were partially raised and the rafts were having problems rotating during the tidal cycle before additional weights and anchors were added, and during the second release the upstream array suffered an outage due to a failed solar charger (Table 24). There were more detections on the downstream array than on the upstream across all release groups (Table 31), and the majority of detections (74%) occurred on the hydrofoils rather than the bottom-mounted antennas (Table 32). Median time from release to detection was 4.8 days for the third release group (the only group for which the arrays were fully functioning).

Table 31. Detections of double-tagged steelhead on the San Joaquin PIT tag arrays.

Array	Release Group			Total
	1*	2*	3	
Upstream	2	3	7	12
Downstream	4	7	16	27
Both	0	0	1	1
Total	6	10	22	38

* The PIT tag arrays were not fully functioning for the first two release groups.

Table 32. Number of steelhead detected on the hydrofoils and bottom-mounted antennas at the upstream and downstream San Joaquin arrays. Numbers across categories sum to more than the totals because some individual fish were detected on both arrays and antenna types.

Array	Detections by Antenna Type		
	All	Hydrofoil	Bottom-mounted
Total	38	29 (76%)	10
Upstream	12	7 (58%)	5
Downstream	27	23 (85%)	5
Both	1	1 (100%)	0

CJS results for survival and detection probability

With the analysis limited to the single release group for which the PIT arrays were fully functioning, only 2 CJS models were compared, one with array-specific detection probability and the other with constant detection probability. The model with array-specific detection probability received the most support from the data (Table 33).

Table 33. Model selection results for CJS models fit to the hydrofoil detections of double-tagged steelhead smolts on the San Joaquin PIT arrays; data were limited to the third release group. Phi = apparent survival, p = detection probability, Array = PIT tag array, and (.) = constant.

Model	AICc	Δ AICc	AICc Weight	Model Likelihood	Number of parameters
phi(.) + p(Array)	172.683	0	0.983	1	3
phi(.) + p(.)	180.782	8.099	0.017	0.017	2

The top model estimated survival of 9% and detection probabilities of about 7% on the upstream array and 33% on the downstream array (Table 34), yielding an overall probability of detection (on the hydrofoils antennas) of 37.8%.

Table 34. Survival and detection probability estimates (with 95% CI) for the third group of double-tagged steelhead smolts released in the San Joaquin River from the top model based on hydrofoil detections.

Parameter	Estimate	95% CI
Survival	0.094	0.078 - 0.369
Detection probability_upstream array	0.067	0.009 - 0.352
Detection probability_downstream array	0.333	0.043 - 0.846

These estimates appear to be highly suspect compared to the survival estimate of 84% based on the acoustic tag detections (Table 30) and the low raw detection rate on the hydrofoil antennas of fish known to be present based on acoustic detections (22 out of 405 [Table 28] = 5%). This indicates that the PIT-tag based estimates were extremely biased and that the PIT tag data violated assumptions of the CJS model, most likely the assumption that probability of detection was independent between arrays.

Task 6 – Evaluate the feasibility of developing estuary detection sites – towed array

There were two components under this task: (1) develop and field test a production model of a prototype towed flexible antenna array, and (2) assess the feasibility of detecting PIT tagged fish in the lower Delta and upper Estuary using either this new flexible towed array or the existing larger pair-trawl array used in the lower Columbia River.

The towed flexible antenna array has been developed with the goal of being a lower-cost and simpler-to-operate alternative to the existing pair-trawl array that has been used in the upper Columbia River estuary since 1995. The flexible array is designed to be modular and towed by two small vessels, compared to the pair-trawl array that requires three larger vessels; the flexible array is therefore designed to be operated at less expense and across a greater range of habitats (i.e., from large open channels and bays down to channels too small to employ the pair trawl). Both arrays were evaluated for use in the Delta; below, a description of the existing pair-trawl design and performance in the Columbia River estuary is provided first for background, followed by a description of the development of towed array and conclusions about their application to the Delta.

Background on existing Columbia pair-trawl antenna

Since 1995 the Northwest Fisheries Science Center has conducted research aimed at collecting data on migrating juvenile Pacific salmon *Oncorhynchus* spp. implanted with passive integrated transponder (PIT) tags in the upper reaches of the Columbia River estuary (Ledgerwood et al. 2004; Morris et al. 2015). Data from estuary detections are used to estimate the survival to Bonneville Dam and downstream migration timing of fish tagged at upstream locations throughout the basin.

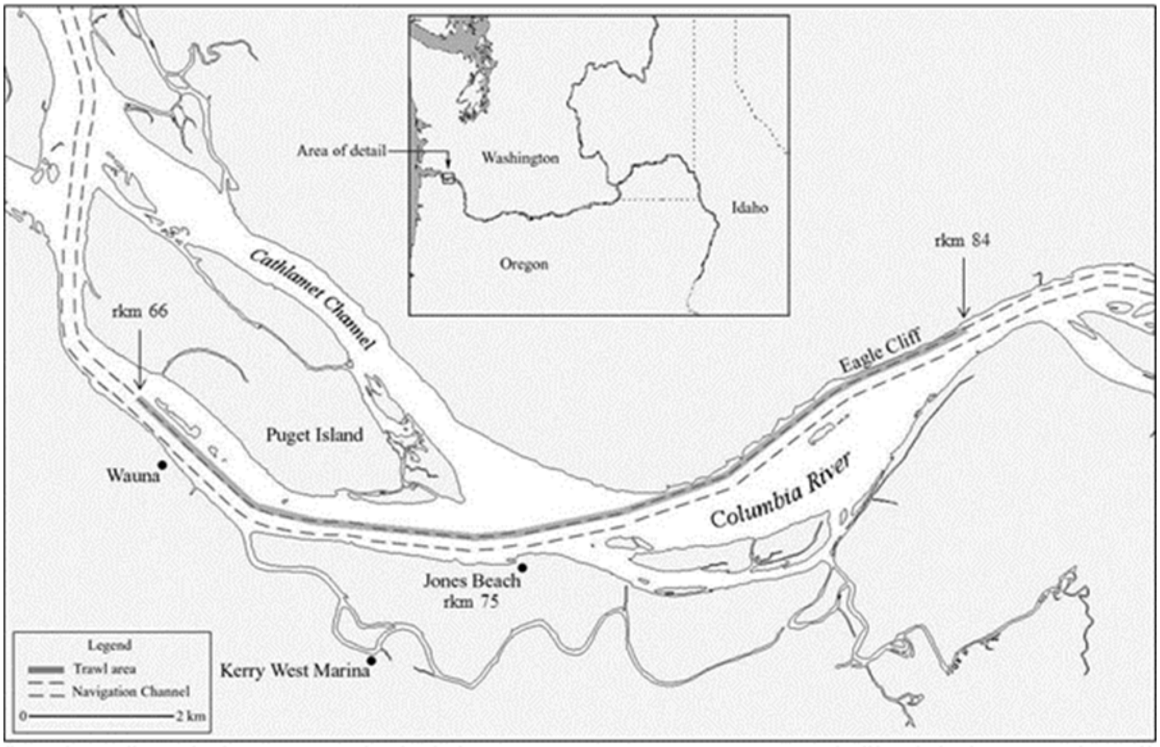
The study is conducted in the estuary near Jones Beach, Oregon, approximately 75 river kilometers (rkm) upstream from the mouth of the Columbia River (Figure 23). A large surface pair-trawl is used to guide fish through an array of detection antennas mounted in place of the cod-end of the trawl net. Target fish are those PIT-tagged by other researchers for various research projects at natal streams, hatcheries, collection facilities at dams, and other upstream locations (PSMFC 2016). When PIT-tagged fish pass through the trawl and antennas, the tag code, GPS position, and date and time of detection are recorded.

The main objective for this study is to estimate hydrosystem survival to Bonneville Dam. To complete these estimates, a detection site below the dam is necessary to establish detection efficiency at the dam (to differentiate between fish that did not survive to a given point vs. those that passed without being detected). Target fish are those tagged and released above Bonneville that are left to migrate in-river through the system, rather than being removed for transportation and released at a site below the Dam. This study therefore estimates survival to the Dam and not from the Dam to the estuary (Faulkner et al. 2016; Morris et al. 2015)

Study area

Trawl sampling is conducted in the upper Columbia River estuary between Eagle Cliff (rkm 84) and the west end of Puget Island (rkm 66; Figure 23). This is a freshwater reach with river currents often exceeding 1.1 m s^{-1} and semi-diurnal tides. During the spring freshet (April-June), little or no flow reversal occurs in this reach during flood tide, especially in years of medium-to-high river flow. The trawl is deployed adjacent to a 200-m-wide navigation channel, which is maintained at a depth of 14 m.

Figure 23. Pair-trawl sample area adjacent to the navigation channel in the upper Columbia River estuary between rkm 66 and 84.



Target fish

The trawl focuses detection efforts on large release groups of PIT-tagged fish detected at Bonneville Dam rkm 234 (lowest dam on the Columbia River) or transported and released just downstream of the dam. The vast majority of these fish migrate through the tidal freshwater reach of the estuary from late April through late June. Release dates and locations of fish detected with the trawl are retrieved from the PTAGIS database (PSFMC 2016). Specific groups of tagged fish targeted for detection typically include over 200,000 fish released for a comparative survival study of hatchery fish and about 150,000 fish diverted to barges for NMFS transportation studies, as well as smaller groups released for other studies. In total, annual releases of PIT-tagged fish into the basin have averaged about two million since 2000.

Detection rates in the pair-trawl have been sufficient for analyses of timing and survival for yearling Chinook salmon and steelhead (the majority of detections in Tables 36 and 37). Trawl detections of sockeye and subyearling Chinook salmon are fewer, and analyses are limited due to smaller sample sizes for these fish.

Sample period

Spring sampling begins in late March and continues through the summer migration period to mid-July. Sample effort varies commensurate with fish availability in the estuary. Early and late in the migration season, the trawl samples 2-5 d week with a single shift, for an average daily effort of 6 h/d (sample effort is defined as full deployment of the trawl). During the peak of the spring migration from late April through mid-June, the trawl samples with two daily shifts, both day and night, for an average effort of 15 h/d.

Trawl system design

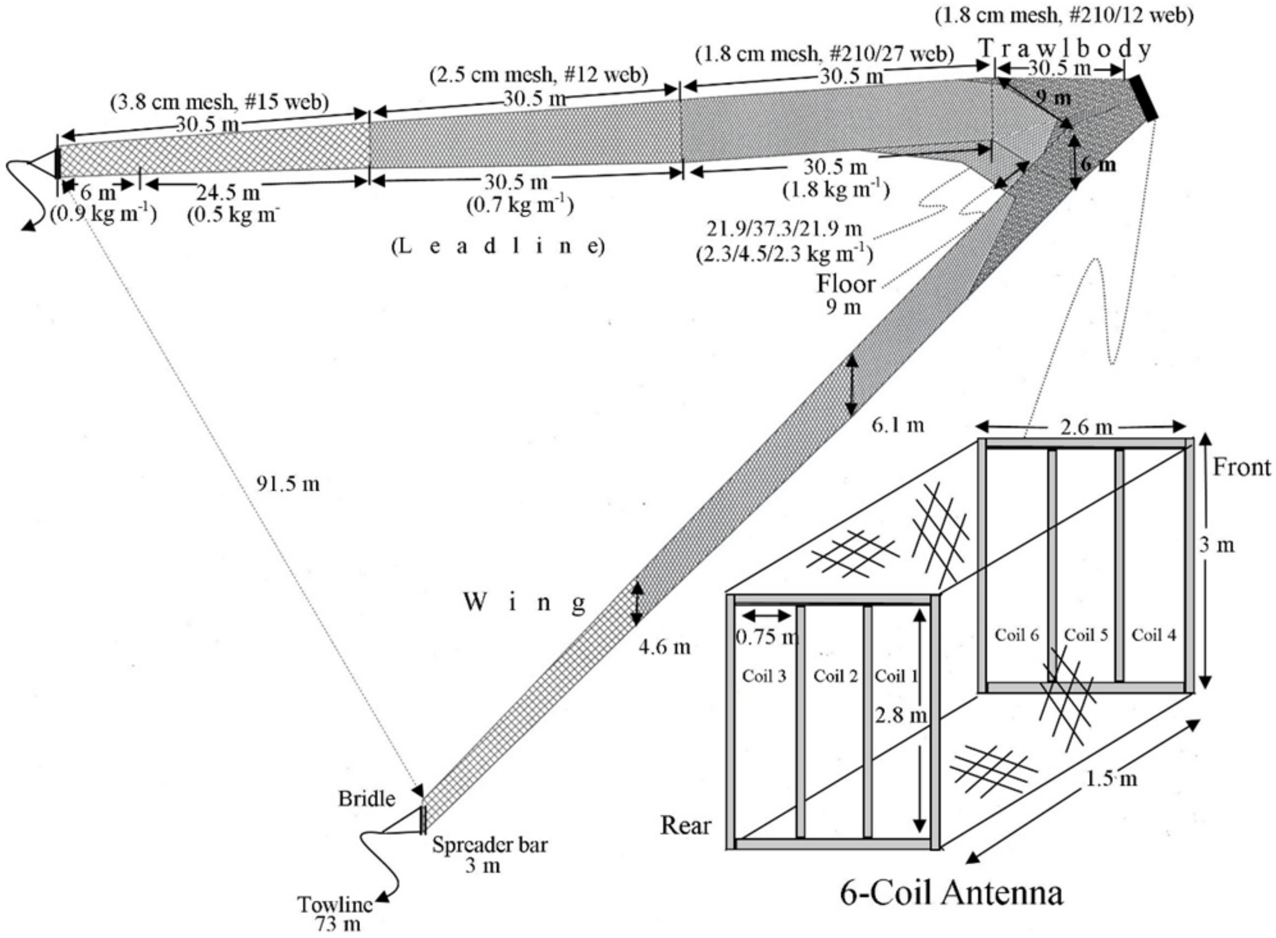
Since 2008, PIT trawl sampling has been conducted with a matrix-style antenna (Figure 24). The fish-passage corridor is configured with three parallel antennas (coils) in front and three in the rear, for a total of six detection coils. Inside dimensions of individual coils measure 0.75 by 2.8 m. Front and rear components are connected by a 1.5-m length of net mesh, and the overall fish-passage opening is 2.6 by 3.0 m. The matrix antenna is attached at the rear of the trawl and suspended by buoys 0.6 m beneath the surface.

This configuration allows fish collected in the trawl to exit through the antenna while remaining in the river. Each 3-coil component weighs approximately 114 kg in air and requires an additional 114 kg of lead weight to suspend in the water column (total weight of front and rear components is 456 kg in air).

The basic configuration of the pair-trawl net has changed little through the years, despite changes to the PIT-tag detection apparatus (Ledgerwood et al. 2004). The upstream end of each trawl wing is shackled to a 3-m-long spreader bar. The downstream end of each wing is attached to the 30.5-m-long trawl body, which has been modified for antenna attachment at the cod end. The mouth of the trawl body has an opening 9 m wide by 6 m tall with a 6.3-m floor extending forward from the mouth. Sample depth is approximately 5.0 m due to curvature in the side-walls while under tow.

The net and matrix antenna are transported and deployed from one vessel. After the trawl and antenna are deployed, one tow line is passed to an adjacent tow vessel. The tow lines are 73-m-long to prevent turbulence on the net from the tow vessels. Both vessels tow the net facing upstream into the current, maintaining a distance of about 91.5 m between the distal ends of the trawl wings. Even though volitional passage through the trawl and antenna occurs while towing with the wings extended, the wings of the trawl are brought together every 17 minutes to flush debris out of the system. The majority of fish are detected during these 7-minute net-flushing periods.

Figure 24. Basic design of the surface pair-trawl used with the matrix antenna system to sample juvenile salmonids in the Columbia River estuary.



Electronic equipment and operation

The matrix antenna system uses a single FS1001M multiplexing transceiver, which is capable of simultaneously powering, recording, and transmitting data for up to six antennas. Electronic components for the trawl system are contained in a water-tight box mounted on a 2.4 by 1.5 m floating pontoon raft tethered behind the antenna.

Data are transmitted from each antenna coil to specific transceiver ports via armored cable. A battery power source is used for the transceiver and antenna. Data are stored in the transceiver buffer and transmitted wirelessly in real-time to a computer on board a tow vessel.

Detection efficiency tests are conducted prior to the sample season to verify system performance. During the season, status reports generated by the transceiver are monitored in real-time to confirm performance, and each antenna is tested periodically using a PIT tag attached to a telescoping pole.

For each fish detected, the date and time of detection, tag code, coil identification number, and GPS location are received and recorded automatically using the computer software program MiniMon (PSMFC 2016). Written logs are maintained for each sampling cruise noting the time and duration of net deployment, net retrieval, location, and any incidence of impinged fish.

Detection data files are uploaded to PTAGIS using standard methods described in the *PIT Tag Specification Document* (Marvin and Nighbor 2009). Pair-trawl detections are designated in the PTAGIS database with site code TWX (towed array-experimental).

Operating requirements and cost

The PIT trawl is a large, logistically-intensive operation. The trawl has sampled for an average of over 800 hours per season since 1998. To accomplish this, a suite of biologists, boat operators, deckhands, and mechanics are used. During an average sample season, 22 project-specific personnel are required. This does not include administrative support staff. The project staffs five biologists, four supervisory-level licensed boat operators in charge of the fleet of boats during sampling operations, four additional licensed boat operators, three unlicensed skiff operators, four deckhands, one net mender, and one marine mechanic. Eight of these positions are full-year project staff while the others are seasonal staff with varying durations.

The project utilizes three 12.5 m tow vessels (twin 350 hp inboard engines) and three 6.4 m tender skiffs (135 hp outboard engine). During sampling operations, two tow vessels and one tender skiff are used. The others act as backups to accommodate maintenance, breakdowns, net swaps, and crew transfers. The vessels all require off-season maintenance, repair, and upgrades.

The trawl net design has changed little throughout the project's duration, but a new net is required about every three years. During sampling operations, one net is used on the water, while two others are constantly being repaired and maintained on the shore. Age and debris are the two most common reasons for net repair. Rib lines frequently need to be replaced, holes in the mesh need to be patched and high debris loads can tear a net in half. Net mending and replacement represent a significant cost for the project.

The operating budget for the pair trawl in 2016 was $2.1 million for 900 hours of sampling (Table 35).

Table 35. Total operating cost for the Columbia River pair-trawl in 2016.

2016 Pair-trawl operating budget	
Personnel*	$1,500,000
Supplies and Equipment	$150,000
Facilities support	$170,000
NOAA support	$280,000
Total	$2,100,000

*Personnel include Biologists (6), Biometricians (2), an Electronics Technician (1), Boat Operators (13), Deckhands (5), a Vessel Operations Coordinator (1), and Research Mechanics (2).

Detection efficiency

Detection probabilities for the pair-trawl with respect to the total number of PIT tags released in a given season vary with effort, number of PIT-tagged fish released and a myriad of environmental factors such as flow, temperature and environmental conditions that may affect survival. Summarized in Table 36 are detection efficiencies of the pair-trawl with respect to the total number of PIT-tagged fish released in the Columbia River Basin. Note there are no adjustments made to these tag numbers to account for upstream loss within the hydropower system.

Table 36. Detection efficiency of the pair-trawl in relation to all PIT-tagged fish released in the Columbia Basin. No adjustments have been made to account for upstream loss within the hydrosystem.

Year	Total Released	Detected at pair-trawl	%
2016	1,469,776	12,165	0.83
2015	2,128,548	19,889	0.93
2014	2,335,628	15,904	0.68
2013	2,356,818	22,879	0.97
2012	2,931,538	16,732	0.57
2011	2,828,076	14,123	0.50
Mean:	2,341,731	16,948	0.75

The pair-trawl focuses detection efforts on large release groups of PIT-tagged fish detected at, or transported and released below, Bonneville Dam and sampling effort varies with fish availability in the estuary. During the peak of the spring migration, early May to mid-June, the pair-trawl is operated under intensive sampling period protocols. The intensive sampling period is a two-shift period, day shifts begin before dawn and continue for 6-11 h, while night shifts begin in early evening and continue through most of the night or until relieved by the day crew. Trawl sampling is intended to be continuous throughout the two-shift period except between 1400 and 1900, when sampling is interrupted for refueling and maintenance. Effort over a given season varies but the pair-trawl has an average daily effort of 15h/d during the intensive sampling period. Table 37 shows the detection efficiency of the pair-trawl with respect to known populations of salmonids detected at Bonneville Dam.

Table 37. Detection efficiency of the pair-trawl for known populations of salmonids detected at Bonneville Dam, since 2007.

Year	Detected at Bonneville	Detected at pair-trawl	%
2016	33,114	669	2.02
2015	32,363	1,065	3.29
2014	23,554	431	1.83
2013	24,045	649	2.70
2012	28,252	486	1.72
2011	15,701	281	1.79
2010	91,027	3,464	3.81
2009	43,033	1,436	3.34
2008	31,276	760	2.40
2007	44,078	1,575	3.60
Mean:	36,644	1,082	2.65

Flexible antenna development

The NWFSC began developing a flexible antenna in 2011, and the goal under this contract was to engineer, fabricate, and test production models of the armored antenna cable and submersible IS1001 reader enclosure to improve the durability and robustness of the components, reduce the intensive time and labor involved in building components in-house, and make the new antenna design widely available. Engineering the armored cable required extensive testing of cable properties (wire type, insulation type, wire layout, etc.) to determine specifications of the production-version cable. This testing was done at the NWFSC Pasco Field Station in Washington, and full details of these engineering tests and results are provided in Appendices B and C. Final wire specifications were provided to Falmat, Inc., which fabricated a production model of the cable that was field tested in 2016. In addition to the armored cable, a custom submersible reader enclosure was designed and tested, with prototype and final versions fabricated by West Fork Environmental; development of the enclosure is provided in Appendix D.

Development of the flexible antenna began in 2011 as part of a study focusing on collecting data on PIT-tagged adult Pacific salmon returning from the ocean and migrating to upstream spawning grounds to complement the Columbia River estuary PIT trawl. A sediment control structure (pile dike) is used to passively detect migrating fish near rkm 70 in the freshwater reach of the Columbia River estuary. Migrating fish are detected by a series of PIT antennas installed along a pile dike as they navigate past the structure. This study has undergone numerous site and antenna modifications to test and utilize new technology since its inception. It is from these modifications that the flexible antenna was developed and subsequently the flexible towed antennas. These prototype antennas were first used in August of 2013 on the pile dike system, and the design was tested and refined in 2014 and 2015.

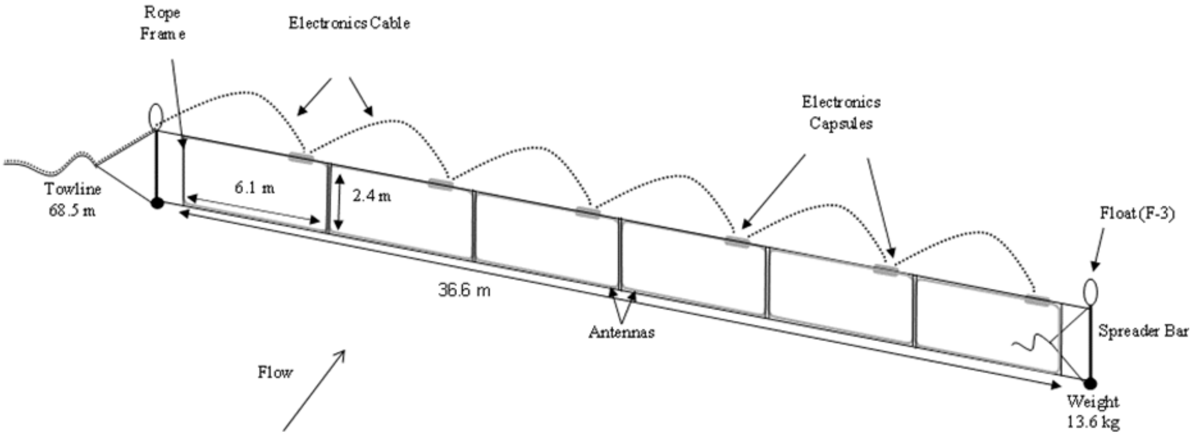
The large flexible antenna is 6.1 m wide by 2.4 m tall. Typical read range (in air) from the center plane is 1.0 m for a 12-mm FDX tag in pass-through orientation. The antennas operate the same as the smaller traditional antennas described in the Biomark IS1001MTS user manual. The main difference between the two is in their construction, therefore users with transceiver and electronic set up questions can refer back to the user manual for assistance. Flexible antennas are versatile and can be used in a variety of settings and deployment strategies. In addition to the towed and fixed applications, the antennas can also be used in smaller streams and rivers where conventional rigid pipe antennas are currently used. They are much easier to transport, handle, and deploy than those constructed out of rigid PVC or HDPE and have numerous applications.

Towed flexible antenna array development

Development of a towed flexible antenna array began in 2014 with a goal to duplicate the function of the estuary pair-trawl array while eliminating the trawl net and reducing the tow vessel and crew size. During early developmental phases, flexible antenna design was altered (in conjunction with its use on the pile dike) to eliminate water intrusion issues, reduce weight for deployment ease, and to reduce drag while under tow. By 2015, a series of towed antennas were being tested and by 2016 a working prototype array and method were achieved. Appendices E-G provide information on materials and equipment required to build a towed array (Appendix E), cost (excluding labor) to build an array (Appendix F), and standard operating procedures for deploying the towed array (Appendix G).

The modular detection system, or array, is made up of one or more 6.1 m x 2.4 m flexible antennas attached to non-stretch rope frames (Figure 25); the rope frames provide structure for and prevent strain on the antennas while under tow. The cost of materials and equipment to construct the six-antenna array used for testing in this project was $39,000 (Appendix F).

Figure 25. Basic configuration of the six-antenna array and modular rope frame system used in 2016. The array consisted of six 6.1 x 2.4-m flexible antennas and had a total width of 36.6 m.



The towed flexible antenna array utilizes each antennas non-stretch rope frame and two 3.0 m aluminum spreader bars to maintain shape while under tow (Figure 25). Individual antennas are easily attached or detached at the rope frames to modify the horizontal reach of the array. Testing configurations have ranged from one to six antennas. Two 68.6 m lengths of 1.6-cm-diameter tenex rope are used for tow lines. Each tow line is attached to a 6.1-m-long bridle, which is attached at the top and bottom of the spreader bar. The antenna frames are extended by another 4.6 m of non-stretch rope to keep the aluminum spreader bar bars out of the detection field. A large buoy and 13.6 kg counter weight on the spreader bars is used to orient the antennas vertically in the water column, suspending them approximately 0.3 m beneath the surface, the spreader bars are then bridled to tow lines. Equipment and deployment are the same regardless of the array size. Optimal sampling speed through the water is 1.5 knots.

Electronics for the towed array are housed on the deployment vessel. The master controller (MC), controller area network (CAN-Bus), and batteries (two 12V batteries connected in series) are used to power and run the system once deployed. The CAN-Bus provides power and communications between the Master Controller and each IS1001 reader housing located adjacent to each antenna. Each 2.4 x 6.1 m antenna requires a 7.6 m section of CAN-Bus cable to connect adjacent antennas and provide enough slack for the cable to drift behind the antenna while under tow, avoiding electrical interference. The system is connected to the MC by running CAN-Bus from the leading antenna, up the bridle and towline to the deployment vessel. It is secured to the towline using 45 kg strength cable ties and is 7 m longer than the towline and bridle to allow for stretch while under tow. If a deeper but narrower sample depth is desired, the antennas can be rotated 90 degrees and connected on their long side. This deployment configuration would require longer spreader bars and bridles.

During the towed operation, four crew members are required. One biologist, two skiff operators, and one deckhand are sufficient for deployment and retrieval. Sampling in 2016 was conducted using two tender skiffs as tow vessels (Figure 26). Without a third tender skiff there is a significant reduction in the personnel and vessel requirements needed to complete sampling operations.

Figure 26. Operating the towed flexible antenna array with 2 skiffs in the Columbia River.

Flexible towed antenna vs. pair-trawl comparison testing

In 2016, the NWFSC conducted a study concurrently testing the flexible antenna system with the pair-trawl. The pair trawl has an opening of 90 m across and 6 m deep and the fish are funneled by the trawl wings down to a detection area of 2.6 x 3.0 m. By contrast, the towed flexible system used in 2016 had a total detection area of about 30 m across by 2.4 deep (width under tow was slightly less than full width due to bowing of the array). Video footage has shown that the trawl net can alter fish behavior, leading to pacing along the wings. To mitigate for this, the boats “flush” the net every half hour. The majority of fish are detected during this “flushing” period. One other major difference between the two detection systems is the discrepancy in sampling depth.

Comparison testing occurred over a 10-day period with 7 deployments during the day and 3 at night. Tests were conducted with the flexible system 0.5 km directly upstream of the trawl. Each system used the edge of the shipping channel (shown on vessel navigation chart) to ensure that the same swath of water was sampled. The flexible system matched the tow speed of the trawl. This strategy was chosen because the flexible system shows little evidence of altering fish behavior as they pass through the antennas and therefore would not bias fish availability to the trawl downstream. In contrast, the trawl focuses fish to an end point and video footage shows fish dive after exiting the system.

Detection efficiency of the flexible system relative to the trawl was calculated by taking the average of the daily sample ratios for the ten concurrent sampling events. Comparisons were only made when both systems were deployed. When comparing all species combined, the average of daily ratios showed the flexible antenna system sampled at a rate of about 60% of the trawl. The ratio based on total detections from all 10 sample events was 46% (Table 38), but this was influenced by a few outlying days with unusually high detections in the trawl. Therefore, the average daily ratio of 60% was considered a more accurate reflection of the general difference between the systems.

Table 38. Total number of fish detected over 10 sampling periods in flexible antenna vs pair-trawl comparison tests in 2016.

	Total # Detected	
	Pair-trawl	Flexible antenna
Chinook	475	62
Steelhead	332	343
Coho	92	19
Sockeye	22	3
Unknown	29	13
Total	950	440

The flexible antenna system had a sample width of 36.6 m and depth of 2.4 m compared to the trawls 91.5 m width and 5 m depth (observed depth; dry net dimension is 6 m). Given that the flexible system only used six of a possible twelve antennas in the array, we can expect improved performance by incorporating additional antennas in the future. Simple extrapolation suggests comparable totals to the trawl with a larger array. Even though total detections would be similar between systems with a larger flexible array, the flexible system detected steelhead at a higher rate and Chinook at a lower rate than the trawl during concurrent sampling (Table 39). This was likely a combination of steelhead avoiding the trawl net and a difference in sample depth between the two systems. Steelhead have been observed pacing the trawl net and have the ability to swim out of the net once they are entrained. This avoidance is thought to be eliminated in the flexible system. Additionally, Steelhead appear to be more surface-oriented during their outmigration than Chinook. The differing sample depths of the two systems likely contributed to these differences in species composition. Off-season testing showed the flexible antennas can be rotated 90 degrees and attached on their long side to achieve a greater sample depth. With a 12-flexible-antenna array, this would produce a total detection area of approximately 30 m wide by 6.1 m deep and allow for improved detection of species that migrate deeper in the water column like Chinook.

Table 39. Species composition comparison. Flexible antenna vs Pair-trawl.

	Species Composition (%)	
	Pair-trawl	Flexible antenna
Chinook	50	14
Steelhead	35	78
Coho	10	4
Sockeye	2	<1
Unknown	3	3

While the flexible antenna detected fewer total fish in these side-by-side trials, as mentioned above the area- or volume-adjusted detection rate was actually higher than the pair trawl, and in actual practice the flexible antenna array can be towed faster and sample a larger area.

In terms of cost, sampling using the flexible antenna array at a similar effort to the current pair-trawl surveys is conservatively estimated to be about 25% ($500,000) less than the pair-trawl (compare Table 40 with Table 35) and actual savings could be higher.

Table 40. Estimated total operating cost for flexible antenna array for 900 sampling hours.

Flexible antenna estimated budget	
Personnel*	$1,125,000
Supplies and Equipment	$150,000
Facilities support	$105,000
NOAA support	$220,000
Total	$1,600,000

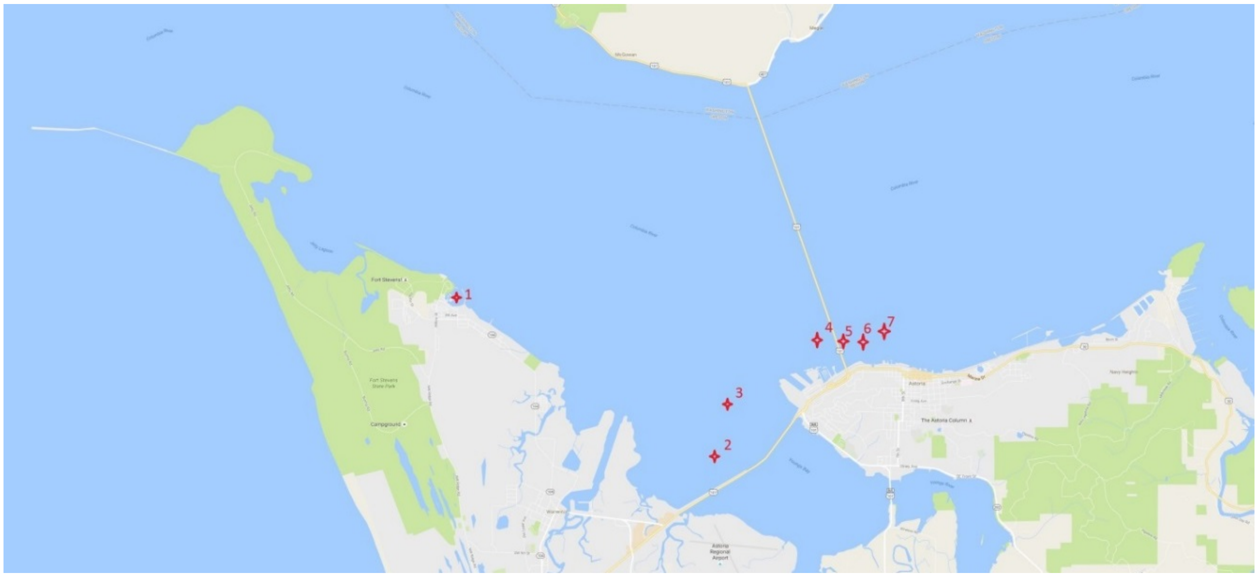
*Personnel include Biologists (4), Biometricians (2), an Electronics Technician (1), Boat Operators (5), a Vessel Operations Coordinator (1), and Research Mechanics (2). This is likely a high estimate for all categories.

Flexible antenna salinity tests

In order to determine maximum salinity threshold for the flexible antenna array in the lower Sacramento and San Joaquin Rivers the NWFSC conducted a series of tests on the lower Columbia River in varying salinities. To collect these data while simultaneously testing the Falmat cable against the hand built hose antenna, an array consisting of four hose antennas (antennas 1, 2, 4, and 5 in Figures 28-29) and two Falmat cable antennas (antennas 3 and 6 in Figures 28-29) were used. The master controller was located on one skiff, which was also used to deploy a Seabird SBE 25 Sealogger CTD (Conductivity, Temperature, Pressure) to measure the salinity at varying depths. During deployment, the antenna activation current, antenna signal level, and the phase deviation were recorded. These levels are indicators of the read field produced by the antennas. Additionally, a Biomark SST-1 12 mm PIT tag was used to conduct read range measurements.

In August of 2016, NWFSC launched two work skiffs and one 40’ boat to perform salinity testing of the flexible antenna array. At 8:25 a.m. the SBE 25 was deployed dockside (deployment site [DS] 1, Figure 27) to verify operation. The salinity was recorded at 7 parts per thousand (ppt). Once the equipment was verified, all three vessels transitioned to Youngs Bay (DS2, Figure 27) where a second salinity measurement was taken. The salinity at this point varied from 9 ppt at 6.1 m, 7 ppt at 3.05 m and 4 ppt at the surface.

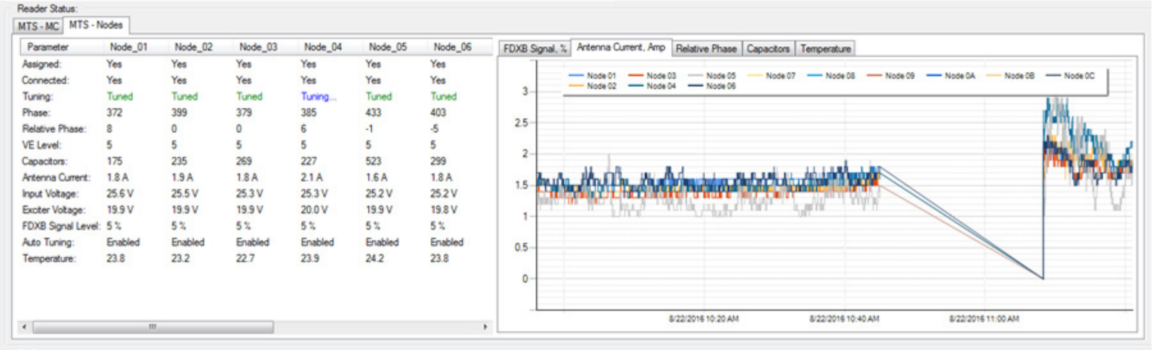
Figure 27. Deployment Sites (DS) 1-7 for salinity testing in the lower Columbia River near Astoria, OR.



At 9:05 a.m. the SBE 25 was deployed (DS3, Figure 27) to 4.57m and the salinity was recorded at 4 ppt uniformly to the surface.

At 9:16 a.m. the SBE was deployed (DS4, Figure 27) and the salinity was recorded at 5 ppt from 6.1 m to the surface. The flexible antenna array was then deployed. At 9:50 a.m. all antennas were deployed and tuned. Current measurements were continually monitored and recorded (Figure 28). With a salinity of 5 ppt all antenna currents averaged around 1.5 A from time of deployment until 10:45 a.m. At this time virtual test tag (VTT) measurements were taken (Table 41). Following the VTT measurements, a read range was taken with the 12 mm SST-1 tag and recorded at 0.15 m from the top antenna lobe of antenna 4. Because the VTT measurement and the read range data did not appear to correlate, an engineer at Biomark was contacted. It was determined that a tuned antenna with low noise will detect a VTT signal regardless of the activation field around that antenna. Therefore, no further VTT measurements were taken.

Figure 28. Tuning antennas at 9:50 a.m. and antenna amps from 9:50 to 11:20 a.m.



Parameter	Node_01	Node_02	Node_03	Node_04	Node_05	Node_06
Assigned:	Yes	Yes	Yes	Yes	Yes	Yes
Connected:	Yes	Yes	Yes	Yes	Yes	Yes
Tuning:	Tuned	Tuned	Tuned	Tuning...	Tuned	Tuned
Phase:	372	399	379	385	433	403
Relative Phase:	8	0	0	6	-1	-5
VE Level:	5	5	5	5	5	5
Capacitors:	175	235	269	227	523	299
Antenna Current:	1.8 A	1.9 A	1.8 A	2.1 A	1.6 A	1.8 A
Input Voltage:	25.6 V	25.5 V	25.3 V	25.3 V	25.2 V	25.2 V
Exciter Voltage:	19.9 V	19.9 V	19.9 V	20.0 V	19.9 V	19.8 V
FDXB Signal Level:	5 %	5 %	5 %	5 %	5 %	5 %
Auto Tuning:	Enabled	Enabled	Enabled	Enabled	Enabled	Enabled
Temperature:	23.8	23.2	22.7	23.9	24.2	23.8

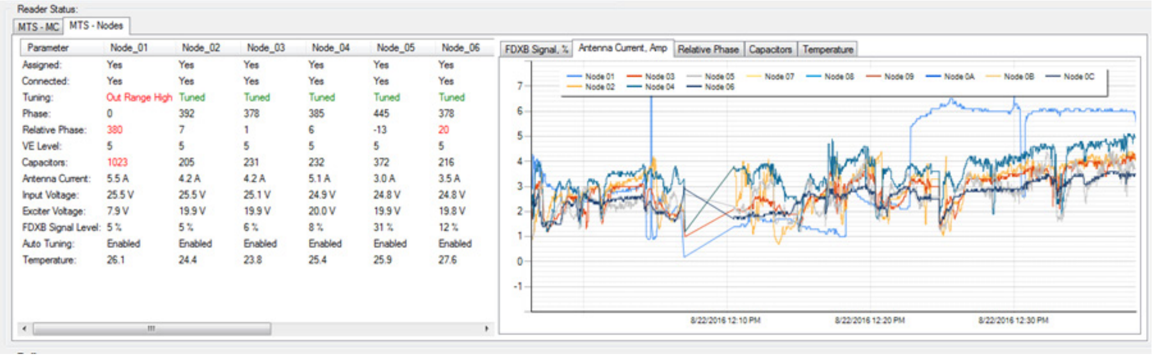
Table 41. Virtual Test Tag levels taken at 10:45 a.m. Due to confounding read range measurements and VTT levels no further measurements were taken.

Antenna Number	Virtual Test Tag Level
1	15
2	14
3	15
4	10
5	11
6	9

The antenna array was then towed upstream while periodic salinity measurements were taken with the SBE 25. At 11:15 a.m. the SBE 25 was deployed (DS5, Figure27) which recorded 3 ppt from 6.1 m to the surface. Current at this point varied from ~2 A to 3 A on all antennas (Figure 28). A read range was taken on antenna 3 with the SST-1 tag and recorded at approximately 0.15 m.

While transitioning the antenna array between DS5 and DS6 (Figure 27) something appeared to have been caught up on antenna 1, which can be seen in the divergent antenna current (Figure 29). The node was taken off antenna 1 and inspected. Upon resumption of testing at 12:40 p.m. the salinity was again measured (DS7) and recorded at 0.5-0.57 ppt. The antenna currents were between 3.0 A and 5.5 A (Figure 29), and were generally increasing towards the shore (Antenna 1). Read range was measured on antenna 3 (Falmat Cable Antenna) at 0.76 m and on antenna 4 (Hose Antenna) at 0.91 m from the top lobe.

Figure 29. Antenna measurements showing problems with antenna 1, beginning at 12:22 p.m., and antenna current at 12:40 p.m. with salinity of 0.5-0.57 ppt.



Parameter	Node_01	Node_02	Node_03	Node_04	Node_05	Node_06
Assigned:	Yes	Yes	Yes	Yes	Yes	Yes
Connected:	Yes	Yes	Yes	Yes	Yes	Yes
Tuning:	Out Range High	Tuned	Tuned	Tuned	Tuned	Tuned
Phase:	0	392	378	385	445	378
Relative Phase:	380	7	1	6	-13	20
VE Level:	5	5	5	5	5	5
Capacitors:	1023	205	231	232	372	216
Antenna Current:	5.5 A	4.2 A	4.2 A	5.1 A	3.0 A	3.5 A
Input Voltage:	25.5 V	25.5 V	25.1 V	24.9 V	24.8 V	24.8 V
Exciter Voltage:	7.9 V	19.9 V	19.9 V	20.0 V	19.9 V	19.8 V
FDXB Signal Level:	5 %	5 %	6 %	8 %	31 %	12 %
Auto Tuning:	Enabled	Enabled	Enabled	Enabled	Enabled	Enabled
Temperature:	26.1	24.4	23.8	25.4	25.9	27.6

The results of the salinity tests indicate the flexible antenna array can only be used in water with very low to no salinity. Salinities as low as 0.5 ppt result in read ranges of only 0.76-0.91 m from the antenna cable, creating a large detection "hole" in the center of the antenna and resulting in missed detections.

It is beyond the scope of this report to detail the electrical phenomenon that occurs when a low frequency antenna emits an electromagnetic wave in a conductive medium such as saltwater. However, a brief summary is necessary. The current in a tuned PIT antenna decreases as the medium's (water, air etc.) conductivity increases. For example, an antenna in a tidal water environment will experience a decrease in current as the water becomes more saline. The decrease in current is due to an increase in AC resistance. The AC resistance is caused by an increase in eddy currents that form in the conductive medium, in this case salt water. These eddy currents form in opposition to electromagnetic field which is created by AC signal in the tuned antenna.

PIT transceivers rely on their ability to develop an electromagnetic field in order to energize and read a PIT tag. Eddy currents are formed in such a way as to be counter to the original current (Lenz Law), resulting in AC resistance. Since the strength of the electromagnetic field is proportional to the antenna current (Biot-Savart Law), an increase in AC resistance will decrease the transceiver's ability to generate a detection field and therefore activate and read PIT tags.

In power electronics, a very common method to inhibit eddy currents and thus reduce core losses in transformers is to use a laminated core. Similarly, the method to reduce eddy currents and their effect on PIT antennas in saltwater is to separate the antenna windings from the conductive medium via an air gap, often implemented with the addition of PVC pipe around the windings of the antenna. Since air is a relative non-conductor, eddy currents can't form in that space and thus AC resistance is reduced. The larger the air gap, the farther away any eddy currents are from the windings and thus have less effect. The addition of PVC pipe around a flexible towed array is impractical, and thus the use of the flexible towed array will be limited to areas with salinity levels of lower than 0.5 ppt (900 µS/cm). However, the design of the pair-trawl antenna system allows for an air gap around the windings of each antenna, and therefore could be operated in much higher salinity.

Evaluation of using towed arrays in the upper estuary and lower Delta

Salinities in the upper estuary/lower Delta and lower Sacramento and San Joaquin rivers were evaluated with respect to the salinity threshold for the flexible towed array (0.5 ppt or 900 µS/cm) to determine where the towed arrays (new flexible antenna array versus existing pair-trawl array) could be used. Data were obtained from the Data from the California Data Exchange Center (CDEC) website (http://cdec.water.ca.gov). On the Sacramento River side of the Delta, salinity was checked from Chipps Island upstream to Rio Vista; on the San Joaquin side, salinity was checked from Chipps Island upstream to Prisoners Point. Salinity was assessed in April-May 2015 and 2016 to compare conditions under lower (2015) vs higher (2016) spring discharge (Sacramento River flow at Verona was 5,000-8,000 cfs in spring 2015 vs. 7,000-22,000 cfs in spring 2016; water year 2016 was near the long-term median for mean annual discharge, while 2015 was in the lowest 10% of years).

The following charts (Figures 30-32) display the intra-season and daily fluctuations of salinity in the lower Sacramento system at three locations in April-May 2016: Mallard Island (directly across from Chipps Island), Sherman Island (15 km upstream from Mallard Island) and the Rio Vista Bridge (13 km upstream from Sherman Island). Salinity levels decline significantly moving upstream of Chipps Island toward Rio Vista.

Figure 30. Salinity levels at Mallard Island in April and May of 2016, directly across from Chipps Island. The 900 µS/cm level is delineated by the solid black line.

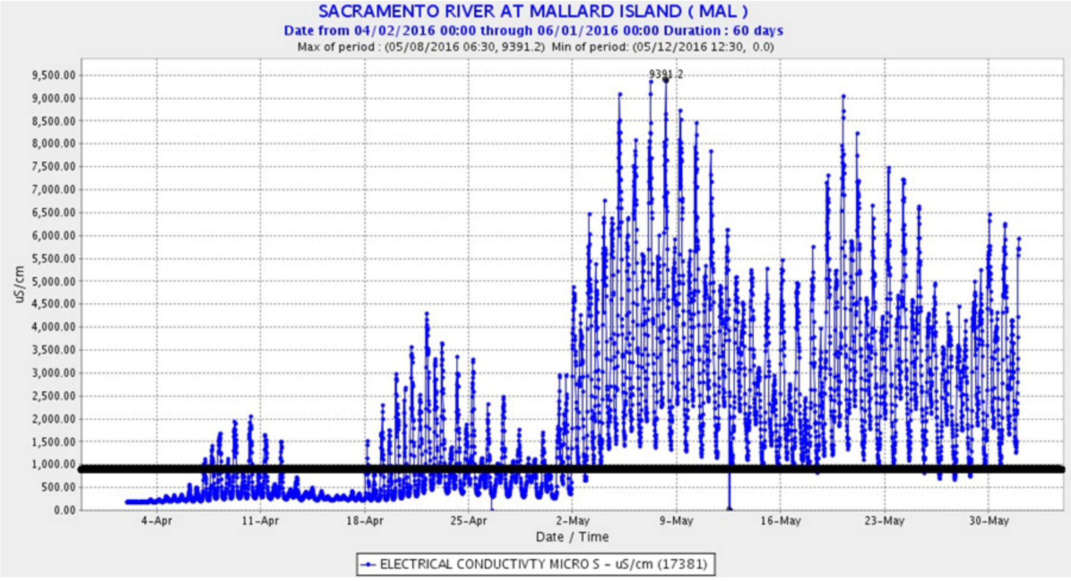


Figure 31. Salinity levels at Sherman Island in April and May of 2016. The 900 µS/cm level is delineated by the solid black line.

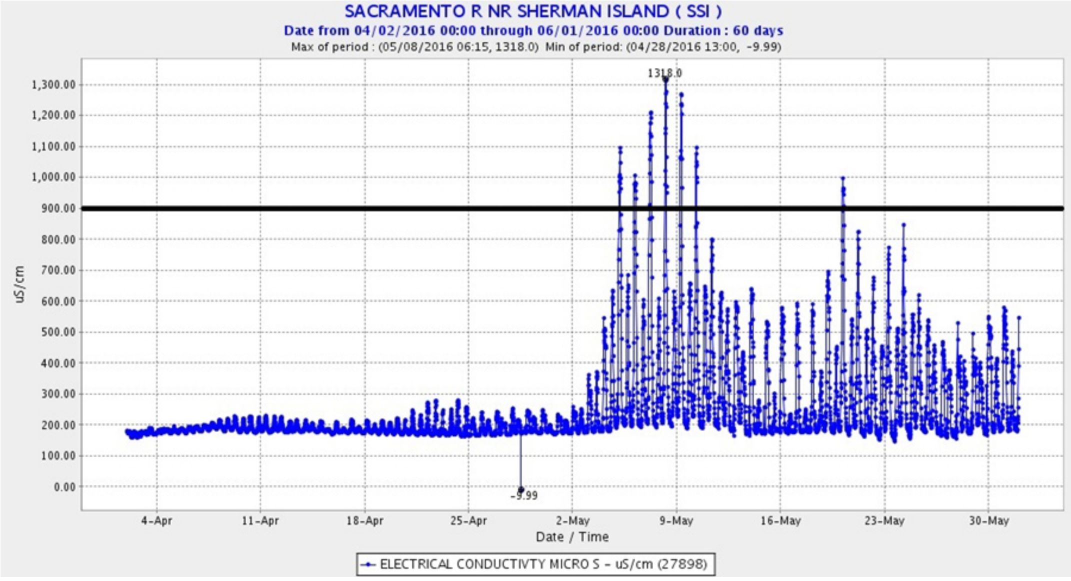


Figure 32. Salinity levels in uS/cm at the Rio Vista bridge in April and May of 2016.

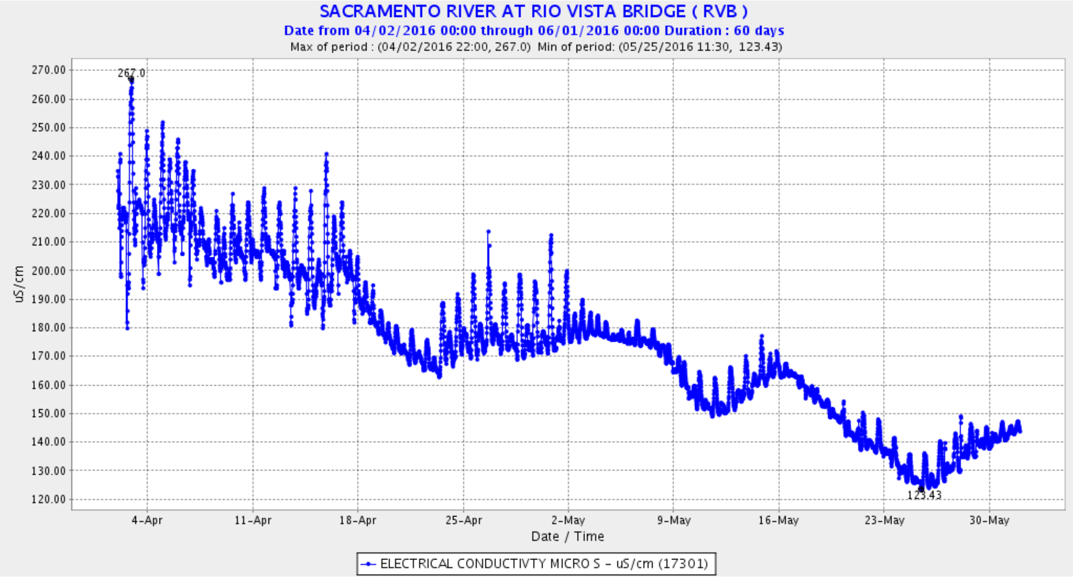
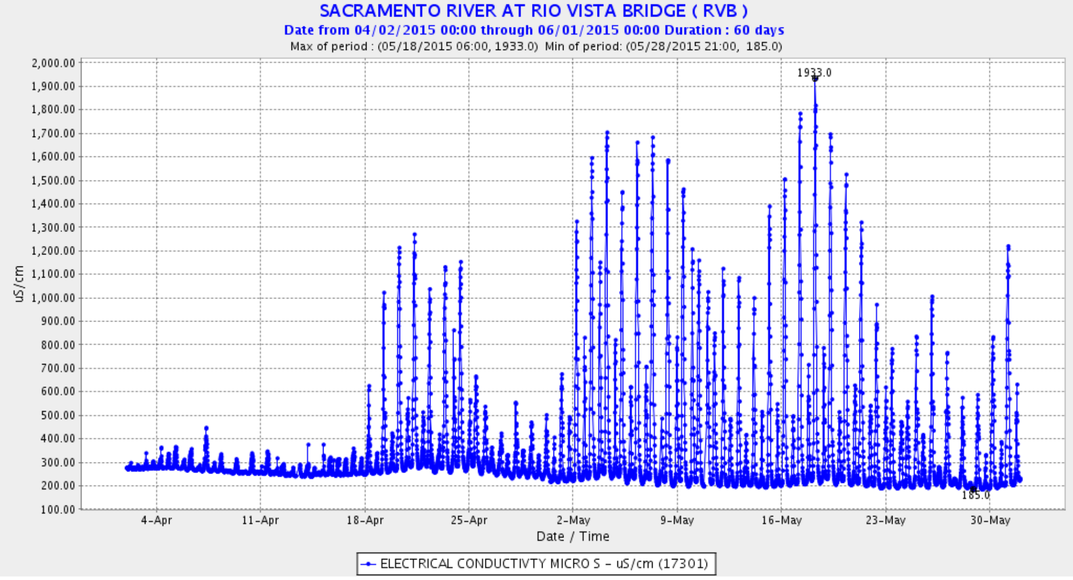


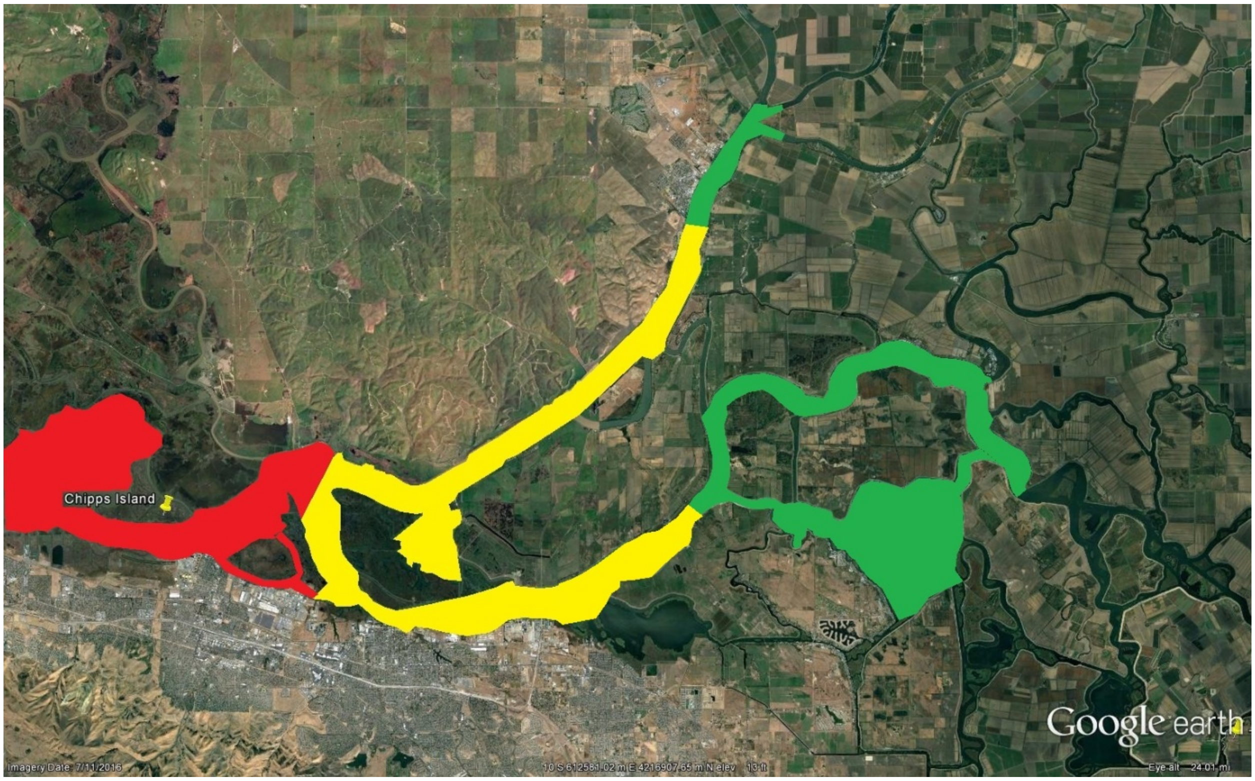
Figure 33. Salinity levels in uS/cm at the Rio Vista bridge in April and May of 2015.



Possible deployment areas for the towed flexible antenna array

Given the observed salinities, the upper estuary and lower Delta were delineated into approximate areas in which sampling with the flexible antenna will likely be possible during a sampling season (Figure 34, green), possible at times depending on discharge and tidal influence (yellow), and likely not possible (red).

Figure 34. A generalization of where the towed flexible PIT antenna array could or could not be consistently operated on a regular basis throughout the season. Green = usually possible during a spring sampling season, Yellow = occasionally possible depending on flow and tide, and Red = not possible.



It is expected that conditions on the Sacramento River upstream of the Rio Vista Bridge would be frequently suitable for use of the flexible towed antenna during the smolt outmigration season; in some years it could be suitable on all days and times within a season (e.g., 2016, Figure 32) and in other years it might be suitable on most days but only on the ebb tide (e.g., 2015, Figure 33). This location is directly below the confluence of the Sacramento Deep Water Channel, Steamboat Slough and the mainstem Sacramento River and would therefore capture tagged fish migrating down all three routes. On the San Joaquin River, areas upstream of False River often may be suitable for use of the flexible antenna, although the downstream limit of suitable conditions may vary between False River and San Andreas Landing depending on year.

Father downstream toward the estuary, based on hourly salinity data taken from multiple points between Rio Vista and Chipps Island, the lowermost point where sampling will be possible on an occasional basis will fluctuate daily and annually between Decker Island and Chipps Island.

From a sampling effort and cost standpoint, the 3 km reach above the Rio Vista Bridge is roughly 500 m wide with a maximum depth is 15 m. In comparison, the sampling reach in the lower Columbia River varies from 750 to 1500 m wide and has a maximum depth of 14 m (Morris et al. 2015). Given the significant difference in width between the two, it is expected that detection rates for comparable sampling efforts could be at least 30% greater in the Sacramento than the Columbia.

Deployment of a pair-trawl antenna at Chipps Island

By using trawl wings to concentrate fish down to small antenna matrix and housing antennas in PVC with more air space, the pair-trawl array is able to effectively sample in higher salinities than the flexible antenna array. There have been tests conducted in 2002-2004 using the pair-trawl system with a specialized antenna in waters with higher salinities, similar to and above levels at Chipps Island (Ledgerwood et al. 2005, Ledgerwood et al. 2006). It is the opinion of the NWFSC that it would be possible to design a matrix-style antenna, for use with a pair-trawl, that would be able to efficiently detect fish in high salinity environments such as the upper estuary near Chipps Island.

For comparison of channel size between the Columbia River estuary and the upper San Francisco Bay estuary near Chipps Island, the survey area for the pair-trawl in the Columbia River is a 12 km reach of river that varies in width from 750 to 1500 m and has a maximum depth of 14 m (Morris et al. 2015). In comparison, the 4 km reach between Chipps Island and the city of Pittsburg, CA, is roughly 900 m wide with a maximum depth of 18 m. Therefore, it seems likely that if the same sampling effort used in the lower Columbia were applied near Chipps Island it could produce similar detection rates to the lower Columbia River (Table 37).

Task 7 – Evaluate the feasibility of Delta Cross Channel and Georgiana Slough

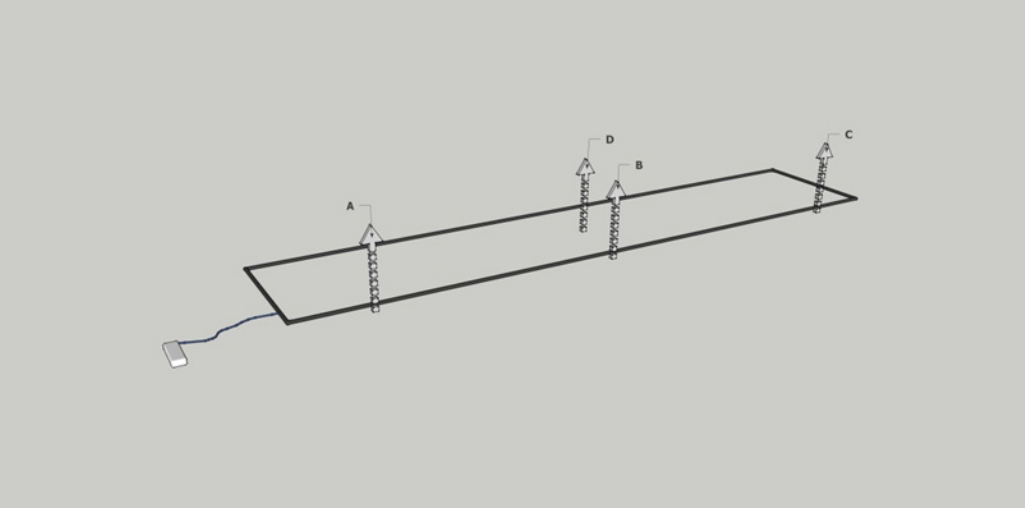
The potential feasibility of deploying PIT tag arrays at the Delta Cross Channel (DCC) and Georgiana Slough was assessed in 2016. The locations were evaluated by (1) conducting noise, read range, and spectrum analyzer measurements to determine whether there were any major sources of EMI that might interfere with antenna operation, (2) considering what kind of array designs could be appropriate for the channel characteristics at the sites, and (3) identifying logistical factors the could be involved in deploying arrays.

Noise testing, read ranges and spectrum analyzer results from Delta Cross Channel

Due to concerns that nearby low frequency antenna transmissions might interfere with PIT tag antenna read range or efficiency, a site evaluation was completed at the west (Sacramento River) end of the Delta Cross Channel (near the radial gates) using a spectrum analyzer (HP8560E Spectrum Analyzer, ARA BBH-1100/A Antenna), Biomark 12V IS1001 and 6.1 m x 1.2 m flexible antenna. Measurements were taken over a 4-hour period on April 14, 2016, to assess variation in noise. This location was chosen for testing due to the proximity of power transmission lines and communications towers (Figure 35) that posed the greatest potential for producing EMI, so it appeared to reflect a worst-case site for noise. This test site was about 1 km from the confluence of Georgianna Slough and the Sacramento River so results are assumed to apply to Georgiana Slough as well. Read ranges with a 12-mm SST-1 FDX-B test tag were taken at four points on the antenna (Figure 36) and were recorded in cm.

Figure 35. Picture of testing location at the west end of the Delta Cross Channel.

Figure 36. Testing points for read ranges on the flexible antenna.



Spectrum analyzer and read range results indicated low noise and good read range, respectively, at the site (Table 42); for a benchmark, readings at the NWFSC Sand Point lab, which is a semi-quiet location, were -99 to -102 dBm and read ranges at location B were 22-25 cm. Based on this testing, it is believed that barring any changes, the sites at the Delta Cross Channel and Georgianna Slough should be acceptable for any type of antenna installation, including but not limited to raft-mounted hydrofoil antennas, temporary pile dike structure, and periodic flexible towed antenna sampling.

Table 42. Spectrum analyzer and read range results for tests conducted at the Delta Cross Channel. Read ranges A, B, C, D refer to locations as seen on Figure 36. dBm is a measure of signal strength (decibels relative to one milliwatt).

Time	Minimum dBm (300°)	Maximum dBm (300°)	Minimum dBm (210°)	Maximum dBm (210°)	A	B	C	D
11:34am	-107	-97	-102	-99	N/A	N/A	N/A	N/A
11:44am	-107	-97	-109	-99	N/A	N/A	N/A	N/A
11:54am	-107	-98	-102	-96	27	28	27	17
12:04pm	-107	-98	-107	-94	27	28	27	18
12:14pm	-105	-92	-105	-95	28	28	28	17
12:45pm	-103	-93	-101	-91	27	27	28	15
1:15pm	-105	-95	-107	-93	26.5	26	26	15
1:45pm	-109	-93	-105	-93	26.5	26.5	26	19
2:15pm	-109	-96	-105	-95	26	27	26	16
2:35pm	-104	-94	-106	-96	27	26.5	27	18
3:05pm	-103	-94	-105	-96	26	26.5	27	18
3:35pm	-103	-93	-107	-93	27	27	28	19

Potential PIT tag antenna designs for Delta Cross Channel and Georgiana Slough

Delta Cross Channel and Georgiana Slough are both large open channels (DCC: 100 m wide, 4.5-6 m deep at center; GS: 40-50 m wide, generally > 6.0 m), so similar PIT tag array designs were judged to be suitable for both sites. As with the above tasks, the focus here was to detect juvenile salmonids in the upper water column of these large channels. Other traditional (swim-through or bottom-mounted swim-over antennas) or recently developed designs (floating mat antenna by Biomark or bottom-mounted vertical fin array by West Fork Environmental) could be used in shallower habitats or to target different species or life stages that might have different habitat use, depending on the research or monitoring questions. The following are examples of PIT tag antenna systems for large open channels and how they could be applied to the Delta Cross Channel and Georgiana Slough areas.

Flexible antenna array

The flexible antenna array developed under Task 6 could be applied to these locations in several manners: towed with two vessels, used in combination with a fixed anchor point and a single vessel, or attached to pile dikes or similar structures. An array could be towed in the Sacramento River above and below the entrance of the DCC (Figure 37) or Georgiana Slough (Figure 38) as well as within the DCC or the Slough itself. The Delta Cross Channel is only 2 km in length (Figure 39) and the entire channel could be sampled multiple times in a sampling session. In contrast, Georgiana Slough is 20 km in length. While it may be possible to sample the majority of the slough in a given day, sampling the upper and lower ends of the Slough separately may be necessary.

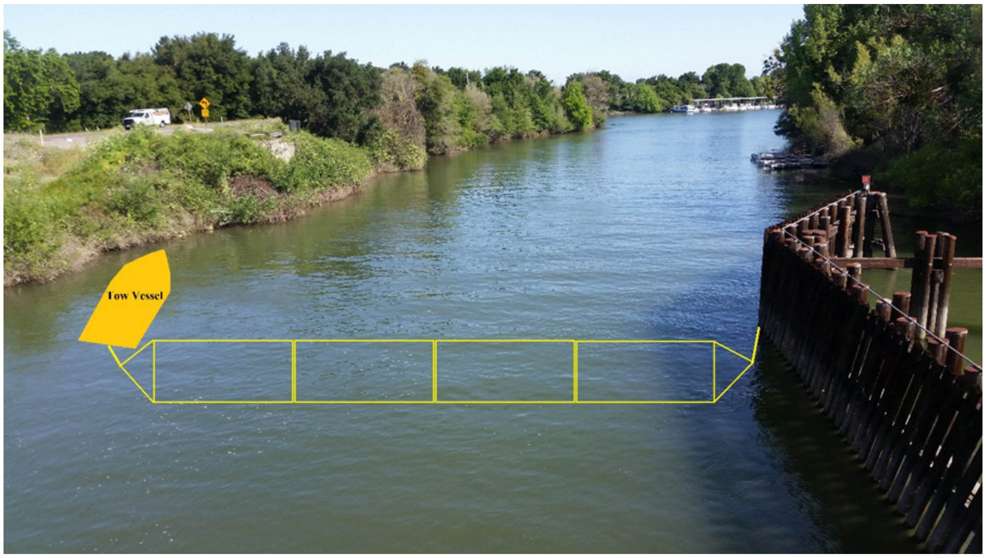
Figure 37. Potential sampling locations above and below the Delta Cross Channel.

Figure 38. Potential sampling locations above and below Georgiana Slough.

Figure 39. An overview of the entire 2 km length of the Delta Cross Channel.

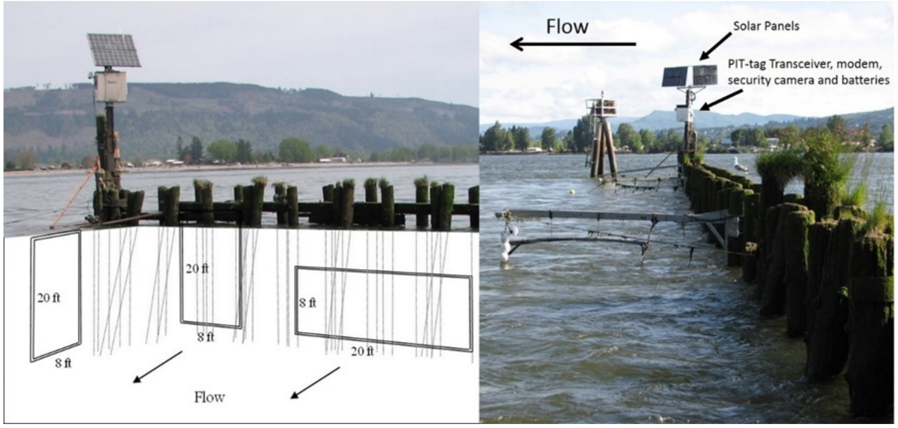
Depending on study design and sampling objectives, the flexible antenna array could also be operated in those locations using a stationary deployment strategy. The benefit of stationary deployment would be the reduction in crew size needed for operation as well as requiring one less vessel for sampling. There are multiple tie off points in both the DCC and Georgiana Slough from which the flexible antenna could be deployed and held stationary. One such location discussed was the upstream pilings of the Isleton Road bridge in Georgiana Slough (Figure 40). It is thought that one boat could operate a stationary antenna at that location, moving out of the way of personal watercraft when necessary.

Figure 40. Potential stationary deployment of a flexible antenna array at the upper end of Georgiana Slough at the Isleton Road bridge.



Finally, flexible antennas could be deployed on pile dikes or similar structures. There was not enough time during the April visit to view and evaluate all piling structures in and around the Delta Cross Channel and Georgiana Slough but it is likely that multiple locations exist where large flexible antennas could be permanently or temporarily installed. One such location would be the pilings of the Isleton Road bridge at the entrance of Georgiana Slough, as seen in Figure 40. In addition, it might be possible (if necessary permits could be obtained) to install pilings specifically for the purpose of installing arrays if certain locations were of special interest. Different piling configurations as used on the lower Columbia River are shown for example in Figure 41.

Figure 41. Pile dike flexible antenna configurations as used on lower Columbia River.



Raft-mounted hydrofoil arrays

The raft-mounted hydrofoil arrays developed under Tasks 1 and 2 (Figure 42) are flexible in terms of how they can be held in place (overhead cable, anchored to bottom, or secured to a fixed object) and could be deployed at numerous locations in and around the Delta Cross Channel and Georgiana Slough.

Figure 42. Raft-mounted hydrofoil arrays on the Mokelumne River.

Logistical considerations for potential array applications

There are a number of logistical factors that would be involved in deploying antenna arrays at Delta Cross Channel and Georgianna Slough including power supply, access required to deploy and maintain arrays, permission from property owners for access or any equipment requiring placement on shore, boat traffic and navigation, permitting, and risk of vandalism. The particular factors involved and the degree of challenge they pose will vary depending on the array design and specific location. It is now possible to power many arrays using self-contained solar systems, such as those used on the raft arrays on the San Joaquin or the pile-dike antennas on the Columbia River, which eliminates the need for an AC power source on location. Thermo-electric generators using propane have a small footprint and have been used extensively for an independent PIT array power source. Access issues will depend on whether the arrays are entirely boat-deployed, such as the San Joaquin hydrofoil rafts, or whether some shore access is needed for installation or to house shore-based equipment. For boat based arrays – either operating the towed flexible antennas or deploying raft or pile-dike arrays – there are several marinas with boat ramps in Walnut Grove on both the Sacramento River and Snodgrass Slough that would provide convenient access. Shore access will require permission from the local reclamation district to access levees and likely permission from private property owners as well. Remote communication with arrays via cellular modem, as used in Tasks 1-2, or satellite modems simplifies monitoring and reduces routine site visits. Towed or raft arrays will need to be operated in a way to minimize navigation hazard posed to boat traffic, and permits or permission from state and/or federal agencies may be required. Likewise, attaching arrays to existing structures or installing new structures to attach or anchor arrays may require state and/or federal permits depending on jurisdiction. The risk of vandalism is unclear; there is a lot of activity and use of the area for boating and fishing, and throughout the Delta there is a general concern about high risk of vandalism among agency, academic, and private staff that deploy scientific equipment. However, the arrays on the Mokelumne and San Joaquin were operated for several months without incident, although their locations were chosen to minimize vandalism risk by either having restricted access (Mokelumne) or being in a highly visible location (San Joaquin, in view of the marina and trailer park).

Overall, it is believed that there will be many options for deploying arrays at Delta Cross Channel and Georgiana Slough that could work within these logistical considerations. The main factor will be allowing sufficient time to fully investigate the logistical issues and secure any necessary permissions and permits; this planning and permitting step might take a minimum of 6-12 months for arrays requiring temporary or permanent installment, but likely less for towed surveys using the flexible antenna array.

Task 8 – Project and system management, data analysis and reporting

All required project reports and other deliverables were completed and submitted to the CDFW contract manager on time.

(A) Quarterly reports summarizing activities and results to date were submitted to the CDFW contract manager by deadlines in 2015-2016.

(B) The Year 1 (2015) annual report was submitted to the contract manager by the February 1, 2016, deadline. This final completion report summarizes Year 1 (2015) and 2 (2016) activities and final analysis, results, and conclusions from the project and fulfils the final reporting deliverable.

(C) A copy of the project database, in Microsoft Access format, was delivered to the contract manager, along with a supporting document defining the data tables and fields and relationships among tables.

(D) Presentations about the project were given by SWFSC staff at several venues:

   a. IEP Biotelemetry Project Work Team meeting (September 2015)
   b. Mokelumne River Fish Hatchery - Hatchery Coordination meeting (October 2015)
   c. Pacific States Marine Fisheries Commission Steelhead Management meeting (March 2016)
   d. IEP Winter Run JPE subteam meeting (September 2016)
   e. Bay-Delta Science Conference (November 2016)

Summary and conclusions

The main objective of this project was to develop new methods to detect PIT-tagged juvenile salmonids in large open channels, and two successful approaches were developed: (1) raft-mounted hydrofoil arrays deployed at stationary locations, analogous to rotary-screw traps, and (2) a modular flexible antenna array that can be towed by two small vessels or deployed at stationary structures such as pile dikes. These two designs represent major advances in array designs and performance in challenging habitats and allow for versatile approaches to detecting tagged fish across a range of situations.

Along with the pair-trawl array and existing antennas for smaller or shallower channels or for special structures, these new designs now make it physically possible to detect PIT-tagged fish in all of the channel types present in the Central Valley and Delta, from tributary and mainstem rivers to interior Delta channels to the lower Delta and upper estuary, although methods at locations in the lower Delta where salinities exceed about 0.5 ppt currently will be limited to the pair-trawl array. While these array designs allow for detection that may be sufficient for determining route use and passage timing of tagged fish, robust estimation of survival or abundance will require developing study design and analytical methods to deal with detections rates that are likely to be low (e.g., raw detection rates of 1.5-8% across release groups for the arrays on the Mokelumne and San Joaquin in this study, and detection of 2-4% of fish known to be alive at Bonneville Dam by the pair-trawl in the upper Columbia River estuary) and may violate assumptions for traditional mark-recapture analysis using simple dual-array installations as was done as a preliminary approach in this study. One promising approach would be to pair PIT tag and acoustic receiver arrays, as was done in Task 5, and use releases of double-tagged fish to model detection probability by the PIT tag arrays; once detection models were fit across the range of conditions affecting detection at the array location, survival and abundance of PIT-tagged only fish could be estimated using Bayesian mark-recapture models that incorporated the detection model as auxiliary information (Russell Perry and Dalton Hance, USGS, personal communication). Similarly, robust analysis of PIT tag detection data will require developing methods to address detection of live tagged fish versus tagged fish that have been eaten by predatory fishes; approaches have been developed to filter acoustic detection data for predators (SJRGA 2012) that might be adapted for PIT tag data as one possible solution.

Additionally, fine-scale fish behavior and habitat use in large channels in the Sacramento and San Joaquin rivers and Delta is not well understood and this information would be very helpful for the most effective choice and placement of PIT tag arrays. Results from this study indicated that the released juvenile Chinook salmon and steelhead smolts were in the upper water column at the locations in the deeper channel areas where the arrays were placed, and also that lateral distribution varied with location given the difference in detection between upstream and downstream arrays at both sites. However, additional data are needed to assess these vertical and horizontal distribution patterns across a wider range of habitats and locations, and to determine whether fish concentrate in certain areas that could result in high detection, how behavior and habitat use varies with flow and tidal conditions, etc. These questions could be addressed by deploying various types of PIT tag arrays across habitat types and locations or by using acoustic receivers or radio telemetry to assess fine-scale habitat use and behavior.

While the prototype hydrofoil arrays were successful as proof-of-concept and achieved detection rates potentially acceptable for some purposes, several aspects could be improved. First, the hydrofoil antennas suffered a large drop in current when deployed, which resulted in read range and total detection area (due to dead zones between adjacent fins) being reduced by more than 50%. This reduced in-water performance of the prototype hydrofoil antennas is believed to be the result of insufficient separation (air space) between the antenna coils and the surrounding water or interactions between adjacent hydrofoils that affected dynamic tuning because the fin positions were not rigid or fixed with respect to one another. Further testing is needed to determine what is needed to improve performance, whether revising antenna configuration or materials, designing antennas to achieve maximum current in air at exciter level 3 so that the exciter level can be increased to compensate for a decrease in current in water, or revising the mounting system so positions of the individual antennas are fixed relative to one another. Second, the hydrofoils were too buoyant to maintain vertical position when submerged to their full depth without the addition of ballast sleeves. Different materials or dimensions need to be tested to reduce buoyancy; further field tests using releases of tagged fish with either dual-coil fins or raising the fins to different depths could be used to determine the minimum length needed to correspond with vertical distribution of fish, where use of a shorter fin, if warranted, would reduce the buoyancy issue. Third, the final anchoring configuration on the San Joaquin arrays was sufficient to hold their position and orientation through the tidal fluctuation in river height and reversal of flow but required spring lines to shore (which increased navigation hazard and would not have been possible if arrays had been farther from the shore) and also increased the accumulation of debris under the rafts. Securing the rafts to a fixed point, such as a piling, might be superior. Finally, increasing the horizontal detection span would improve the detection rate in large channels and could be achieved in a couple ways. The existing rafts could be deployed side-by-side or apart but along the same cross-section of the channel, though the antennas would have to be synchronized between rafts to prevent interference. Alternatively, the number of hydrofoils per raft could be increased to create a wider detection span. This would require strengthening the suspension trolley and raft deck, increasing the floatation of the raft, and possibly enlarging the entire raft.

The flexible antenna is a major advancement in the construction of FDX antennas. The most common FDX antennas used in streams and rivers are 6 m wide by 0.9 m tall (interior dimensions) and constructed out of rigid 10-cm diameter PVC or HDPE. The typical pass-through read range for these antennas with 12-mm tags is about 0.90 m in air. The flexible antenna is 2.5 times taller (2.4 m) and 1/5 the diameter (2 cm) as traditional pipe antennas and has a pass-through read range of 1.0 m (in air). Flexible antennas are versatile and can be used in a variety of settings and deployment strategies. In addition to the towed and fixed applications in large channels described above, the antennas can also be used in smaller streams and rivers where conventional rigid pipe antennas are currently used. They are much easier to transport, handle, and deploy than those constructed out of rigid PVC or HDPE and have versatile applications. Cost is similar between the flexible antenna ($1,200 for armored cable, $2,000 for submersible enclosure, and approx. $400 for CANBUS cable and connectors = $3,600 total) and conventional rigid antennas (e.g., Biomark 20-ft HDPE pipe antenna: $2,320 for antenna and $937 for submersible enclosure = $3,257).

This project successfully developed production models of the armored flexible antenna cable and submersible reader enclosure. Now users can order these components from the manufacturer and assemble a modular antenna array on their own. However, two aspects of further refinement are planned. First, the full production armored cable was less flexible than the hand-built hose antennas, so a second version of the cable with more flexible filler rods will be tested to improve pliability. Second, to increase sampling depth, testing of a 12 antenna array with antennas attached on their long sides will be conducted. This should allow for increased detection of deeper migrating species like Chinook.

In conclusion, this project produced two new antenna designs for detecting PIT-tagged fish in large open channels, which along with existing antenna designs make it technically possible to detect tags in all of the channel types present in the Central Valley and Delta. Further research and development is needed to refine several aspects of the new array designs, particularly to achieve full electrical performance of the hydrofoil antennas in water, and to identify study designs and analytical approaches to accurately estimate detection probability, survival, and abundance of PIT tag detection data produced by arrays in open channels. Also, development of study designs for full life-cycle monitoring will need to address different array designs needed to target different life stages, for example a combination of hydrofoil raft arrays to detect juveniles and bottom-mounted swim-over antennas to detect adults. Thus, application of PIT tags is currently feasible for certain research and monitoring questions, such as route use and passage timing, that do not necessarily require robust estimation of detection probability, but determining the feasibility of full-scale monitoring to estimate survival and abundance throughout the system will require further research to develop a study design and analytical framework before the effort and cost of such a monitoring program can be estimated.

References

Bilski, R., J. Shillam, C. Hunter, M. Saldate, and E. Rible. 2013a. Emigration of Juvenile Chinook Salmon (*Oncorhynchus tschawytscha*) and Steelhead (*Oncorhynchus mykiss*) in the Lower Mokelumne River, December 2011 through July 2012. East Bay Municipal Utility District, Lodi, California.

Bilski, R., J. Shillam, C. Hunter, M. Saldate, and E. Rible. 2013b. Emigration of Juvenile Chinook Salmon (*Oncorhynchus tschawytscha*) and Steelhead (*Oncorhynchus mykiss*) in the Lower Mokelumne River, December 2012 through July 2013. East Bay Municipal Utility District, Lodi, California.

Burnham, K. P., and D.R. Anderson. 1998. Model selection and inference: a practical information-theoretic approach Springer-Verlag. New York.

Clark, K. W., M. D. Bowen, R. B. Mayfield, K. P. Zehfuss, J. D. Taplin, and C. H. Hanson. 2009. Quantification of pre-screen losses of juvenile steelhead within Clifton Court Forebay. Technical Report. California Department of Water Resources.

Faulkner, J. R., Widener, D. L., Marsh, T. M., Smith, S. G. and Zabel, R. W. 2016. Survival estimates for the passage of spring migrating juvenile salmonids through Snake and Columbia River dams and reservoirs, 2015. Report of the National Marine Fisheries Service to the Bonneville Power Administration, Portland, Oregon. Available at www.nwfsc.noaa.gov/publications/scipubs.

Lady, J.M., and J.R. Skalski. 2009. User 4.7 User-Specified Estimation Routine. Prepared for the Bonneville Power Administration. Contract No. 39987. http://www.cbr.washington.edu/analysis/apps/user

Ledgerwood, R. D., J. W. Ferguson, B. A. Ryan, E. M. Dawley, and E. P. Nunnallee. 2004. A surface trawl to detect migrating juvenile salmonids tagged with passive integrated transponder tags. North American Journal of Fisheries Management 24:440-451.

Ledgerwood, R. D., L. B. Way, A. S. Cameron, B. A. Ryan, B. P. Sandford and G. M. Matthews. 2005. Detection of PIT-Tagged Juvenile Salmonids in the Columbia River Estuary using Pair-Trawls, 2002. Internal report of the Fish Ecology Division, Northwest Fisheries Science Center. Available from: www.nwfsc.noaa.gov/publications/scipubs/index.cfm. (2005).

Ledgerwood, R. D., A. S. Cameron, B. P. Sandford, L. B. Way, and G. M. Matthews. 2006. Detection of PIT-Tagged Juvenile Salmonids in the Columbia River Estuary using Pair Trawls, 2003 and 2004. Internal report of the Fish Ecology Division, Northwest Fisheries Science Center. Available from: www.nwfsc.noaa.gov/publications/scipubs/index.cfm. (December 2006).

Marvin, D. and J. Nighbor, editors. 2009. 2009 PIT tag specification document. Report of the Pacific States Marine Fisheries Commission to the PIT tag Technical Steering Committee. Gladstone, Oregon (www.ptagis.org/resources/document-library/ptagis-program-documents).

Michel, C. J., A. J. Ammann, S. T. Lindley, P. T. Sandstrom, E. D. Chapman, M. J. Thomas, G. P. Singer, A. P. Klimley, and R. B. MacFarlane. 2015. Chinook salmon outmigration survival in wet and dry years in California's Sacramento River. Canadian Journal of Fisheries and Aquatic Sciences 72: 1749-1759.

Morris, M. S., Webb, L.N., Bentley, P. J., Borsky, A. J., Sandford B. P., and R. D. Ledgerwood. 2015. Detection of PIT-tagged juvenile salmonids in the Columbia River estuary using a pair-trawl, 2015. Report of the National Marine Fisheries Service to the Bonneville Power Administration, Portland, Oregon. Available at www.nwfsc.noaa.gov/publications/scipubs.

Newman, K.B., and P.L. Brandes. 2010. Hierarchical modeling of juvenile Chinook salmon survival as a function of Sacramento–San Joaquin Delta water exports. North American Journal of Fisheries Management 30(1):157-169.

PSMFC (Pacific States Marine Fisheries Commission). 2016. The Columbia Basin PIT-Tag-Information System (PTAGIS). Online interactive database, Pacific States Marine Fisheries Commission, Gladstone, Oregon (available via the internet at www.psmfc.org/pittag).

Perry, R.W., J.R. Skalski, P.L. Brandes, P.T. Sandstrom, A.P. Klimley, A. Ammann, and B. MacFarlane. 2010. Estimating survival and migration route probabilities of juvenile Chinook salmon in the Sacramento–San Joaquin River Delta. North American Journal of Fisheries Management 30(1):142-156.

Prentice, E.F., T.A. Flagg, and C.S. McCutcheon, 1990. Feasibility of using implantable passive integrated transponder (PIT) tags in salmonids. American Fisheries Society Symposium 7:317-322.

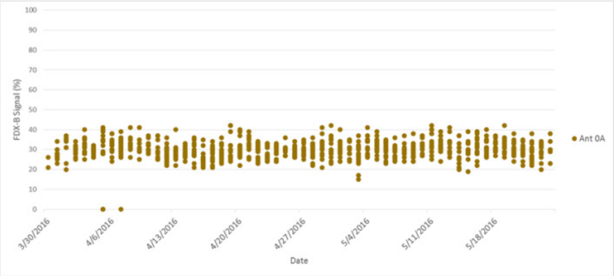
SJRGA (San Joaquin River Group Authority). 2012. 2011 Annual Technical Report: On Implementing and Monitoring of the San Joaquin River Agreement and the Vernalis Adaptive Management Plan: Prepared by San Joaquin River Group Authority for California Water Resource Control Board. 339 p. Available at http://www.sjrg.org/technicalreport.

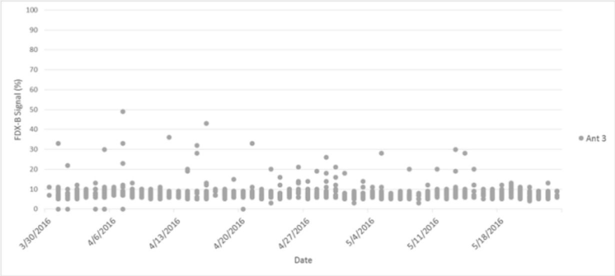
White, G.C., and K. P. Burnham. 1999. Program MARK: Survival estimation from populations of marked animals. Bird Study 46 Supplement, 120-138.

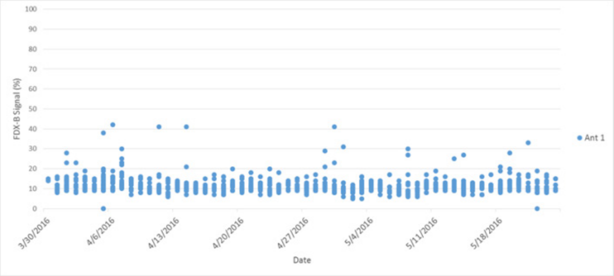
Appendices

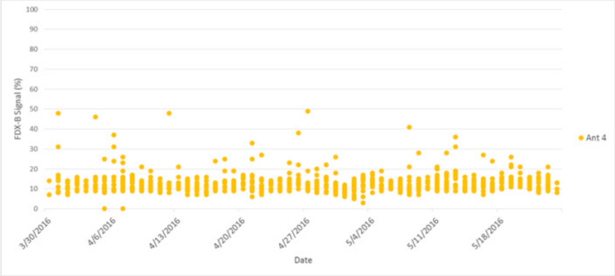
Appendix A: FDX-B Signal (noise) plots for individual antennas in the Mokelumne and San Joaquin arrays.

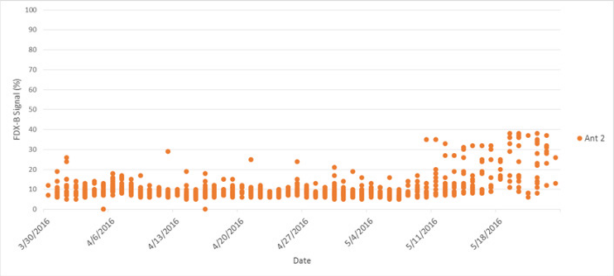
Mokelumne upstream array. Data were screened to remove records affected by the firing of the VTT. Refer to Figure 7 for identification of antenna codes.



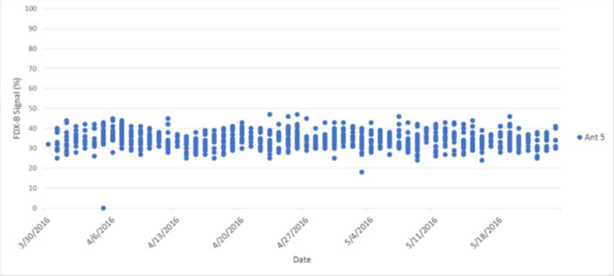


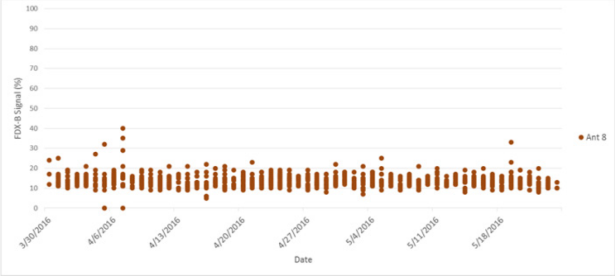


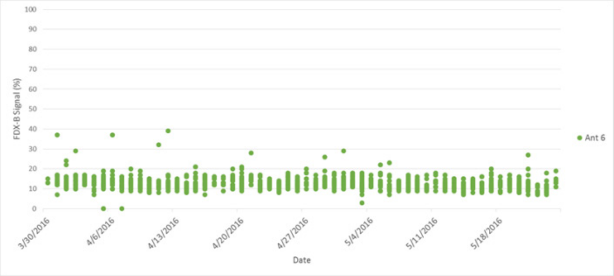


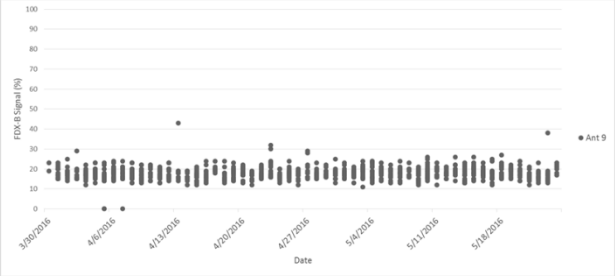


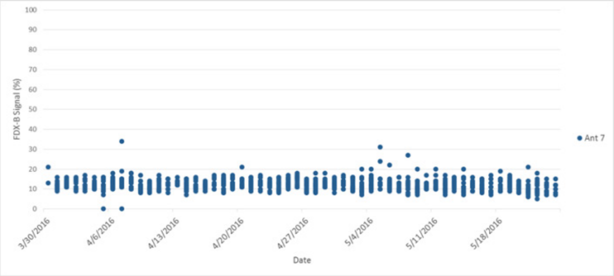
Mokelumne downstream array. Data were screened to remove records affected by the firing of the VTT. Refer to Figure 7 for identification of antenna codes.



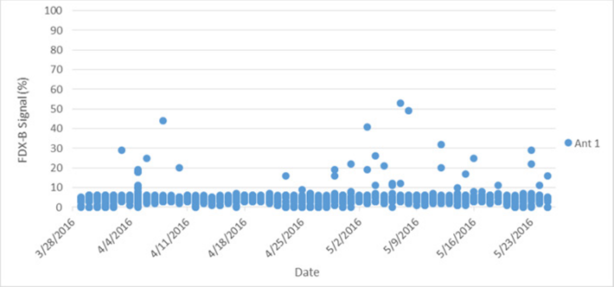


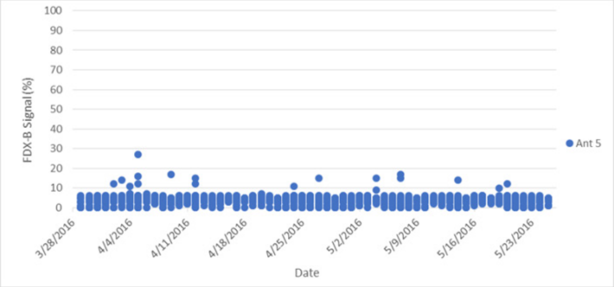


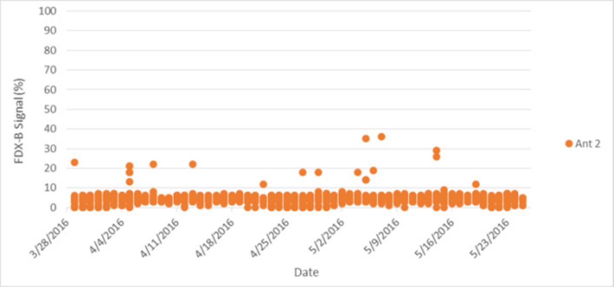


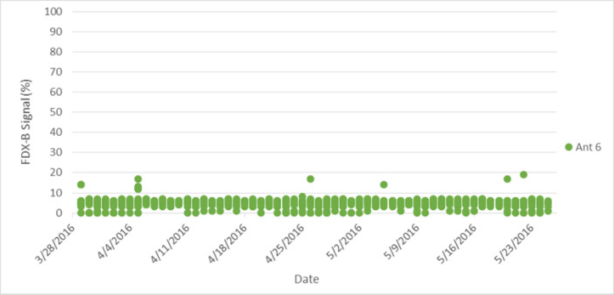


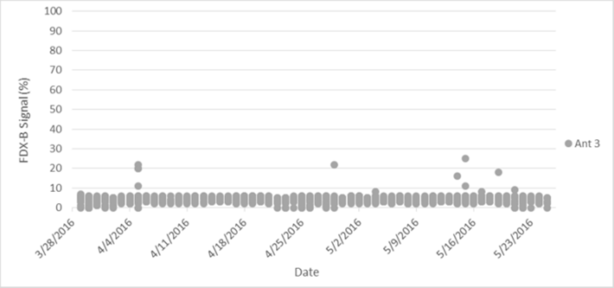
San Joaquin upstream array. Data were screened to remove records affected by the firing of the VTT. Refer to Figure 14 for identification of antenna codes.

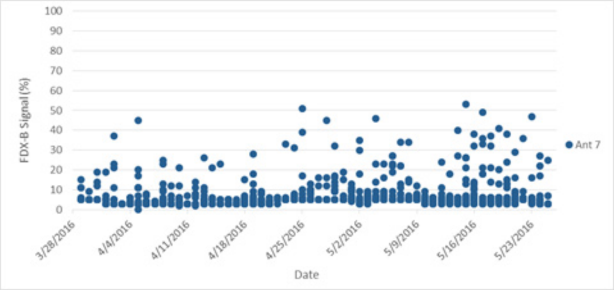


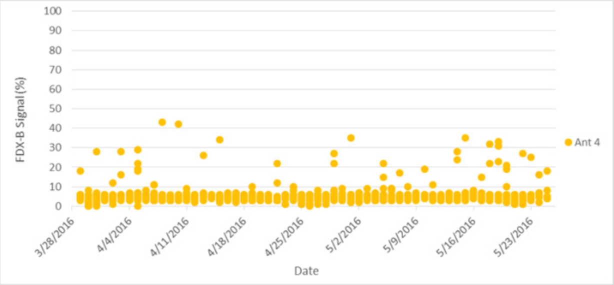




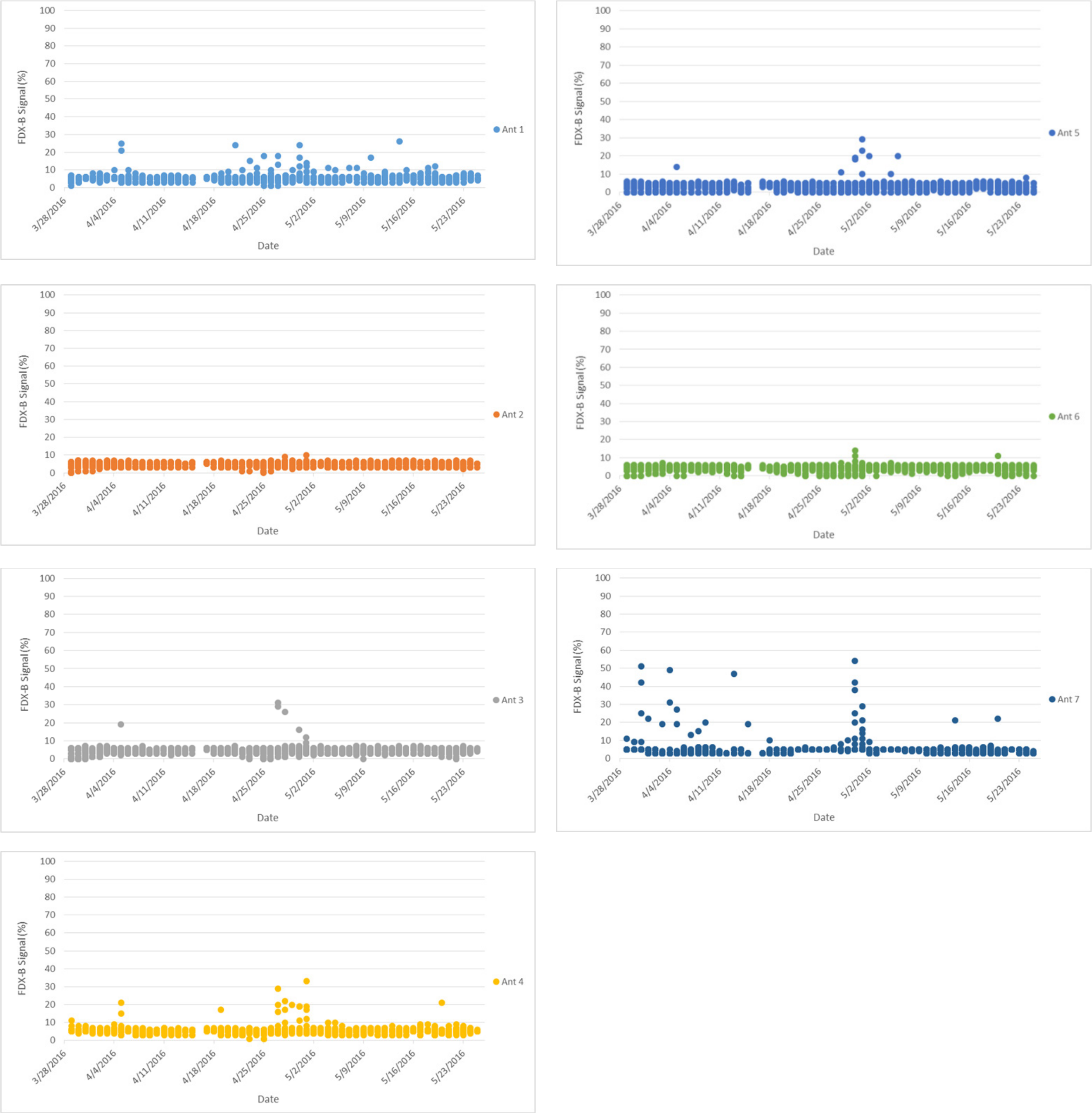








San Joaquin downstream array. Data were screened to remove records affected by the firing of the VTT. Refer to Figure 14 for identification of antenna codes.



Appendix B. Flexible antenna cable development

In 2016 NWFSC began testing a new antenna constructed with a manufactured cable. The goal for this antenna was to reduce the labor costs and time associated with the building of traditional flexible antennas made of flexible hose. Also, it was our goal to both increase the durability and electronic performance of the antennas overall. Early testing showed the manufactured cable performed well in dry-air and deployed tests. When deployed, the manufactured cable antennas supported higher currents than traditional flexible antennas. On average they were 1-1.5 amps higher in water and equivalent to the traditional antennas in dry-air tests. Read range tests were consistent between the two antennas types. There was no difference in electromagnetic interference between antenna types.

Manufactured cable antennas are more rigid than the traditional flexible design, which makes them more difficult to work with, including storing them on deployment vessels. However, they are more durable than the traditional flexible hose design. The new cables are also heavier than the traditional antennas and sit lower in the water column. If the array becomes too heavy and sags away from the surface it can introduce an unwanted sampling bias. We experimented with weighing down our array to achieve a greater depth profile and maximize the sample area of the antennas. It was shown that when antennas drop too far below the surface, fish can swim over them without being detected. Therefore, fish traveling higher in the water column could be potentially missed by the array, skewing the results.

Moving forward, care will need to be taken to mitigate the weight and flexibility concerns of the new cable design. Electronically they are comparable, if not better than the current design and they are far more durable.

Wire testing

The goal of this phase of development was to design a custom cable that could be purchased off-the-shelf and utilized as a flexible underwater antenna cable. Previously, NWFSC Point Adams Research group has hand built antenna cable comprised of three 10 AWG Type II litz wires that were inserted into 1” nominal outside diameter tubing. Although this custom built antenna cable worked well, it was difficult to construct, labor intensive and experienced some leaks that lead to antenna failure.

In order to determine appropriate wire construction parameters to develop design criteria for a custom cable, NWFSC conducted 108 wire tests to determine appropriate wire size, wire type, insulation properties, spacing and orientation. These tests were conducted at our NOAA Pasco facility, utilizing a Biomark 24V IS1001 reader, a 3.05 m x 3.05 m (10’ x 10’) antenna structure and a Biomark SST-1 Passive Integrated Transponder tag (PIT). The following table (Table B.1) is a summary of the findings from the testing summarized in Appendix C (Tests 2-88), which shows the average antenna current for each layout and wire insulation type and corresponding read range. Figure B.1 is a diagram of the wire spacing layouts and orientation of the wires. Finally, the next figure B.2 shows the antenna test apparatus used for this testing.

Table B.1. Wire insulation material, wire layout, amps and average read range.

Wire Insulation.	Wire Layout	Current Average for Test	Read Range Average
PVC	1	10A	40.38”
PVC	2	9.4A	37.38”
PVC	3	9.7A	40”
PVC	4	9.75A	40.75”
FEP	1	10.25A	42.38”
FEP	2	10.33A	42.83”
FEP	3	10.03A	42.83”
FEP	4	10.23A	42.3”

Wire layout

Figure B.1. Wire layout and spacing.

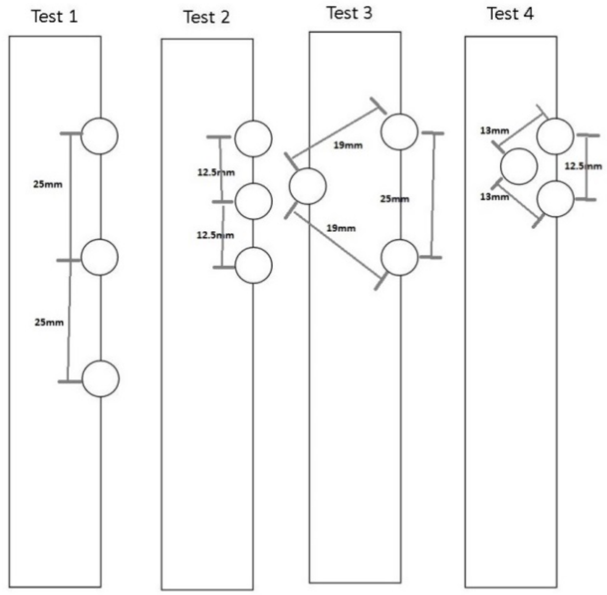


Figure B.2. Testing wire configurations at the Pasco Field Station.

Results

These tests showed that antenna current was affected by antenna wire insulation properties, wire spacing and orientation (flat versus triangular, Appendix C). This information was used to design specifications for engineering drawings which were used to manufacture an off-the-shelf cable which would reduce labor costs associated with antenna construction, produce antennas which were nearly identical in electrical properties and reduce the possibility of water intrusion and antenna failure.

- Wire Jacket material - there is a consistent increase in current going from PVC to FEP while keeping all other variables constant. The average increase in activated antenna current was 5.3%. This result is assumed to be due to the dielectric properties of the insulation. Typical PVC insulation has a dielectric constant range from 3.5-8, while PTFE insulation has a dielectric constant of 2.1. The higher the dielectric constant of the insulation, the larger the resulting molecular polarization of the insulation which results in AC resistance (Hyat, 1958).
- Although a comparison of jacketed to non-jacketed Type II litz wire was conducted, the tests provided erroneous results due to the litz structure breaking down (the wire bundles unraveled) when the PVC jacket was removed. Litz wire provides numerous benefits for increasing the total Q-factor of an inductive antenna at frequency. This is partially driven by the careful winding pattern of the individual strands of wire. When the insulation of the litz wire was removed, the

litz wire unwound. The pattern of winding was lost and resulted in the loss of benefits from the litz. Additionally, some strands were damaged when the PVC jacket was removed, which leads to a slight increase of reactance (Hund and DeGroot 1925).

- The results for testing the separation between windings (layout 1 vs 2, and 3 vs 4) was mixed, however, when wires were touching (tightly bundled) there was a definite degradation in current and read range. This result suggests that separation must exist between windings, perhaps due to noise induced from inter-winding arcing.
- The results appear to indicate that a flat wire layout would be preferred, but the difficulty in designing a flat antenna cable does not seem to warrant the slight added benefit from this wire layout.

In addition to determining the above wire specifications, an attempt was made to determine if a copper wire could be used in lieu of litz wire to reduce cost. The results from this test (Table B.2) suggest that the equivalent copper wire would be too large to function as a floating antenna array without considerable buoyancy added to the cable.

Also note that during the round of testing standard copper 6awg wire there was high noise (test 49-88). The current readings were not affected by this noise, but the read range was drastically impacted. Another set of tests were done (89-92) which confirmed that the noise was external and not generated by the change in wire.

Table B.2. Wire type comparison (litz vs copper)

10 awg litz vs 6 awg Cu:
Test 2-4 (PVC litz, layout #1) I_{ave} = 10.00, Test 74 (bare Cu, layout #1) I_{ave} = 8.00, ΔI_{ave}: 20%
Test 90 (bare Cu, layout #1) I_{ave} = 8.2, R_{ave} Test 94-96 (FEP litz, layout #1) I_{ave} = 10.27, ΔI_{ave}: -25.24%, ΔR_{ave}: -91.94% †exciter voltage = 14v

To demonstrate the affect that wire spacing alone would have on an antenna cable, NOAA Point Adams research facility conducted several tests comparing antennas built with no spacing between wires (Figure B.3) inserted into a 1” OD pipe to wires which were spaced out using 0.25” closed-cell backer rod as a foam insert (Figure B.4). Three individual backer rods were hot-glued together to form a triangle. Each 10 AWG type II litz wires were then attached to provide equal spacing around the backer rod, and held in place by wrapping the entire structure with regenerated cellulose polypropylene film (aka, cellophane).

Figure B.3. Original flexible antenna wire configuration.

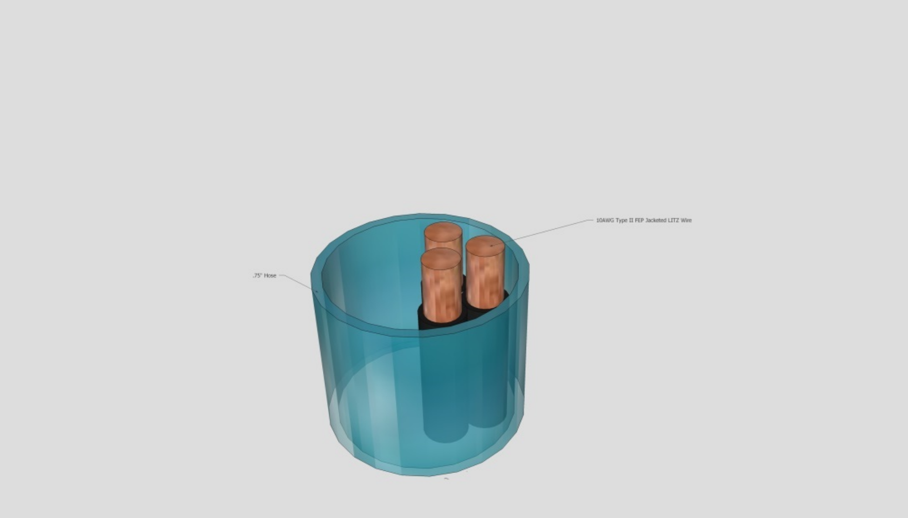
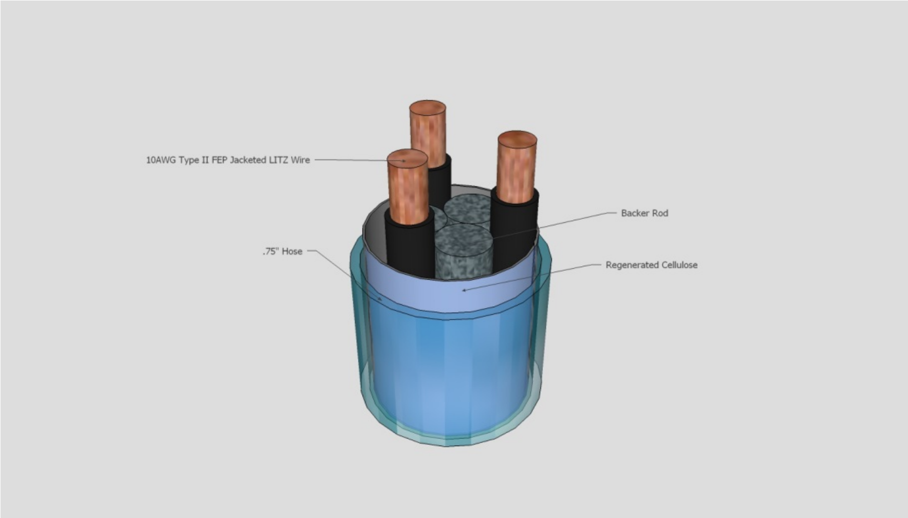


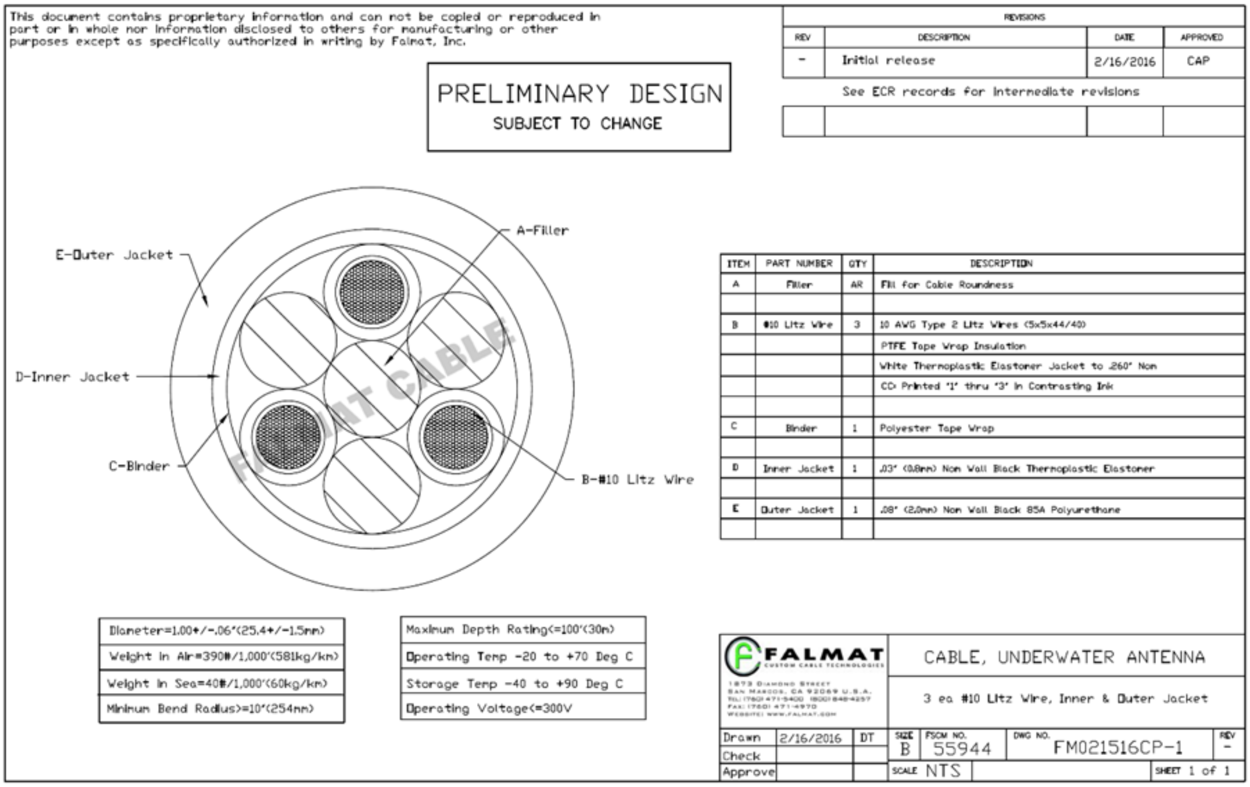
Figure B.4. Flexible antenna wire with spacer rods.



The results of this testing showed that the antenna cables constructed with backer rod had improved current and were generally more stable than antennas built without spacing or fixed wire position. Based on the results from the wire testing, which showed that a low dielectric insulation was preferable, and the spacing tests provided by the Point Adams group, a final antenna cable design was created with input from engineering staff at Falmat and New England Wire and rope.

The first cable design (Figure B.5) is comprised of three type II litz wires, over-insulated with PTFE (an FEP equivalent) insulation, and includes low-dielectric spacer rods. Additionally, an inner jacket of low dielectric thermoplastic elastomer was used to consolidate the wires and spacers, which was then over molded with 2mm of polyurethane to provide durability and waterproofing.

Figure B.5. First antenna cable design as produced by Falmat.



This document contains proprietary information and can not be copied or reproduced in part or in whole nor information disclosed to others for manufacturing or other purposes except as specifically authorized in writing by Falmat, Inc.

PRELIMINARY DESIGN
SUBJECT TO CHANGE

REVISIONS			
REV	DESCRIPTION	DATE	APPROVED
-	Initial release	2/16/2016	CAP
	See ECR records for intermediate revisions		

ITEM	PART NUMBER	QTY	DESCRIPTION
A	Filler	AR	Fill for Cable Roundness
B	#10 Litz Wire	3	10 AWG Type 2 Litz Wires (5x5x44/40)
			PTFE Tape Wrap Insulation
			White Thermoplastic Elastomer Jacket to .260" Nom
			CD: Printed "1" thru "3" in Contrasting Ink
C	Binder	1	Polyester Tape Wrap
D	Inner Jacket	1	.03" (0.8mm) Nom Wall Black Thermoplastic Elastomer
E	Outer Jacket	1	.08" (2.0mm) Nom Wall Black 85A Polyurethane

Diameter=1.00+/-.06"(25.4+/-1.5mm)
Weight in Air=390#/1,000'(581kg/km)
Weight in Sea=40#/1,000'(60kg/km)
Minimum Bend Radius>=10"(254mm)

Maximum Depth Rating<=100'(30m)
Operating Temp -20 to +70 Deg C
Storage Temp -40 to +90 Deg C
Operating Voltage<=300V

CABLE, UNDERWATER ANTENNA

3 ea #10 Litz Wire, Inner & Outer Jacket

Drawn	2/16/2016	DT	SIZE B	FSCM NO. 55944	DWG NO. FM021516CP-1	REV -
Check			SCALE NTS			SHEET 1 of 1
Approve						

Comparison tests have been conducted utilizing the Falmat cable and Point Adams hose cable. The following chart (Table B.3) shows average antenna current comparisons.

Table B.3. Antenna current comparison of hand-build hose cable traditionally used on flexible antennas and custom Falmat cable.

	Antenna Current in Amps (Exciter Level)	
Antenna Type	Water	Air
Hose	8.2-9.6 (4)	9.9-10.5 (1)
Cable	9.2-10.1 (4)	9.9-10.5 (1)

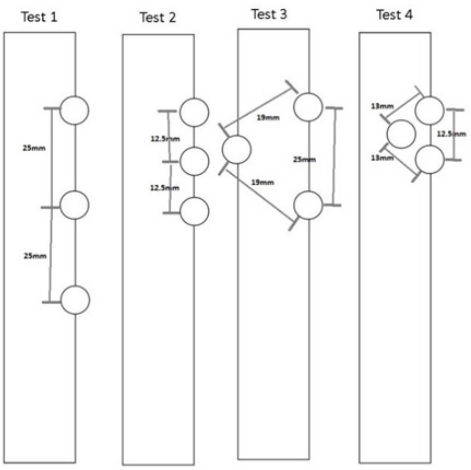
References

Hayt, W. H. Engineering Electromagnetics. New York: McGraw Hill, 1958.

Hund, A., and H. B. De Groot. 1925. Radio-Frequency Resistance and Inductance of Coils Used in Broadcast Reception. Technologic Papers of the Bureau of Standards. 19: 651-668.

Appendix C. Jacket, insulation and wire configuration test results

Figure C.1. Wire layouts used in tests (identical to Fig. B.1 but provided again for easy reference with results below).



Results

I_{ave} = average current (A), R_{ave} = average resistance (Ohms)

PVC jacket vs FEP:

Test 2-4 (PVC litz, layout #1) $I_{ave} = 10.00$, $R_{ave} = 40.8$

Test 17-20 (FEP litz, layout #1) $I_{ave} = 10.33$, $R_{ave} = 42.4$

ΔI_{ave}: -3.3%, ΔR_{ave}: -3.92%

Test 5-8 (PVC litz, layout #2) $I_{ave} = 9.4$, $R_{ave} = 37.4$

Test 17-20 (FEP litz, layout #2) $I_{ave} = 10.33$, $R_{ave} = 42.8$

ΔI_{ave}: -9.89%, ΔR_{ave}: -14.4%

PVC jacket vs FEP:

Test 10-12 (PVC litz, layout #3) $I_{ave} = 9.7$, $R_{ave} = 40.0$

Test 26-28 (FEP litz, layout #3) $I_{ave} = 10.0$, $R_{ave} = 42.8$

ΔI_{ave}: -3.1%, ΔR_{ave}: -7.0%

Test 14-15 (PVC litz, layout #4) $I_{ave} = 9.75$, $R_{ave} = 40.75$

Test 30-32 (FEP litz, layout #4) $I_{ave} = 10.23$, $R_{ave} = 42.3$

ΔI_{ave}: -4.9%, ΔR_{ave}: -3.8%

Proximity (flat – layout #1 vs layout #2):

Test 2-4 (PVC litz, layout #1) $I_{ave} = 10.00$, $R_{ave} = 40.8$

Test 5-8 (PVC litz, layout #2) $I_{ave} = 9.4$, $R_{ave} = 37.4$

ΔI_{ave}: 6.0%, ΔR_{ave}: 8.3%

Test 17-20 (FEP litz, layout #1) $I_{ave} = 10.25$, $R_{ave} = 42.4$

Test 22-24 (FEP litz, layout #2) $I_{ave} = 10.3$, $R_{ave} = 42.8$

ΔI_{ave}: -0.5%, ΔR_{ave}: -0.9%

Proximity (flat – layout #1 vs layout #2):

Test 33-36 (bare litz, layout #1) $I_{ave} = 10.4$, $R_{ave} = 39.75$

Test 38-40 (bare litz, layout #2) $I_{ave} = 9.97$, $R_{ave} = 38.5$

ΔI_{ave}: 4.13%, ΔR_{ave}: 3.14%

*Test 49,51,52 (6 awg Cu, layout #1) $I_{ave} = 10.83$, $R_{ave} = 35.5$

*Test 55-56 (6 awg Cu, layout #2) $I_{ave} = 10.85$, $R_{ave} = 29$

ΔI_{ave}: -0.18%, ΔR_{ave}: 18.3%

*Exciter voltage = 15.9

Proximity (flat – layout #1 vs layout #2):

Test 74 (bare Cu, layout #1) $I_{ave} = 8.0$, $R_{ave} = 11.5$

Test 78 (bare Cu, layout #2) $I_{ave} = 8.1$, $R_{ave} = 9.5$

ΔI_{ave}: -1.25%, ΔR_{ave}: 17.4%

Proximity (triangle – layout #3 vs layout #4):

Test 10-12 (PVC litz, layout #3) I_{ave} = 9.7, R_{ave} = 40.0

Test 14-15 (PVC litz, layout #4) I_{ave} = 9.75, R_{ave} = 40.75

ΔI_{ave}: -0.5%, ΔR_{ave}: -1.9%

Test 26-28 (FEP litz, layout #3) I_{ave} = 10.03, R_{ave} = 42.83

Test 30-32 (FEP litz, layout #4) I_{ave} = 10.23, R_{ave} = 42.33

ΔI_{ave}: -1.99%, ΔR_{ave}: 1.17%

Proximity (triangle – layout #3 vs layout #4):

Test 42-44 (bare litz, layout #3) I_{ave} = 9.73, R_{ave} = 35.67

Test 46-48 (bare litz, layout #4) I_{ave} = 9.77, R_{ave} = 36

ΔI_{ave}: -0.41%, ΔR_{ave}: -0.93%

Test 58 (6 awg Cu, layout #3) I_{ave} = 8.1, R_{ave} = 20

Test 62 (6 awg Cu, layout #4) I_{ave} = 7.9, R_{ave} = 12

ΔI_{ave}: 2.47%, ΔR_{ave}: 40%

Proximity (triangle – layout #3 vs layout #4):

Test 82 (bare Cu, layout #3) I_{ave} = 8.5, R_{ave} = 9.5 V = 12v

Test 86 (bare Cu, layout #4) I_{ave} = 8.3, R_{ave} = 7.5

ΔI_{ave}: 2.32%, ΔR_{ave}: 21.05%

*Test 83-84 (bare Cu, layout #3) I_{ave} = 10.1, R_{ave} = 16.5

Test 87-88 (bare Cu, layout #4) I_{ave} 9.8, R_{ave} = 11.5

ΔI_{ave}: 2.97%, ΔR_{ave}: 30.3%

*Exciter voltage = 14

Proximity (touching vs separated):

Test 32c,32d (FEP litz, touching flat) I_{ave} 9.45, R_{ave} = 29

Test 22-24 (FEP litz, layout #2) I_{ave} = 10.3, R_{ave} = 42.8

ΔI_{ave}: -8.99%, ΔR_{ave}: -47.59%

Test 48a-48c (bare litz, touching flat) I_{ave} 9.27, R_{ave} = 33.67

Test 38-40 (bare litz, layout #2) I_{ave} = 9.97, R_{ave} = 38.5

ΔI_{ave}: -7.55%, ΔR_{ave}: -14.43%

*Test 55-56 (6 awg Cu, layout #2) I_{ave} = 10.85, R_{ave} = 29

ΔI_{ave}: -0.18%, ΔR_{ave}: 18.3%

*Exciter voltage = 15.9

Configuration (layout #1 vs layout #3):

Test 2-4 (PVC litz, layout #1) $I_{ave} = 10.00$, $R_{ave} = 40.8$

Test 10-12 (PVC litz, layout #3) $I_{ave} = 9.7$, $R_{ave} = 40.0$

ΔI_{ave}: 3.00%, ΔR_{ave}: 1.96%

Test 17-20 (FEP litz, layout #1) $I_{ave} = 10.33$, $R_{ave} = 42.4$

Test 26-28 (FEP litz, layout #3) $I_{ave} = 10.0$, $R_{ave} = 42.8$

ΔI_{ave}: 3.19%, ΔR_{ave}: -0.94%

Test 33-36 (bare litz, layout #1) $I_{ave} = 10.4$, $R_{ave} = 39.75$

Test 42-44 (bare litz, layout #3) $I_{ave} = 9.73$, $R_{ave} = 35.67$

ΔI_{ave}: 6.44%, ΔR_{ave}: 10.26%

*Test 49,51,52 (6 awg Cu, layout #1) $I_{ave} = 10.83$, $R_{ave} = 35.5$

*Test 57 (6 awg Cu, layout #3) $I_{ave} = 11.5$, $R_{ave} = 25$

ΔI_{ave}: -6.19%, ΔR_{ave}: 29.58%

* exciter voltage = 16v

Test 50 (6 awg Cu, layout #1) $I_{ave} = 8.00$, $R_{ave} = 24.5$

Test 58 (6 awg Cu, layout #3) $I_{ave} = 8.1$, $R_{ave} = 20$

ΔI_{ave}: -1.25%, ΔR_{ave}: 18.37%

Test 74 (bare Cu, layout #1) $I_{ave} = 8.00$, $R_{ave} = 11.5$

Test 82 (bare Cu, layout #3) $I_{ave} = 8.5$, $R_{ave} = 9.5$

ΔI_{ave}: -6.25%, ΔR_{ave}: 17.39%

Configuration (layout #2 vs layout #4):

Test 5-8 (PVC litz, layout #2) I_{ave} = 9.4, R_{ave} = 37.4

Test 14-15 (PVC litz, layout #4) I_{ave} = 9.75, R_{ave} = 40.75

ΔI_{ave}: -3.72%, ΔR_{ave}: -8.96%

Test 17-20 (FEP litz, layout #2) I_{ave} = 10.33, R_{ave} = 42.8

Test 30-32 (FEP litz, layout #4) I_{ave} = 10.23, R_{ave} = 42.3

ΔI_{ave}: 0.97%, ΔR_{ave}: 1.17%

Test 38-40 (bare litz, layout #2) I_{ave} = 9.97, R_{ave} = 38.5

Test 46-48 (bare litz, layout #4) I_{ave} = 9.77, R_{ave} = 36

ΔI_{ave}: 2.01%, ΔR_{ave}: 6.49%

*Test 55-56 (6 awg Cu, layout #2) I_{ave} = 10.85, R_{ave} = 29

*Test 63-64 (6 awg Cu, layout #4) I_{ave} = 10.8, R_{ave} = 27.5

ΔI_{ave}: 0.46%, ΔR_{ave}: 5.17%

*exciter voltage = 16v

Configuration (layout #2 vs layout #4):

Test 78 (bare Cu, layout #2) I_{ave} = 8.10, R_{ave} = 9.5

Test 86 (bare Cu, layout #4) I_{ave} = 8.3, R_{ave} = 7.5

ΔI_{ave}: -2.47%, ΔR_{ave}: 21.05%

†Test 79-80 (bare Cu, layout #2) I_{ave} = 9.7, R_{ave} = 17.75

†Test 87-88 (bare Cu, layout #4) I_{ave} = 9.8, R_{ave} = 11.5

ΔI_{ave}: -1.03%, ΔR_{ave}: 35.21%

†exciter voltage = 14v

Appendix D: Submersible Reader Enclosure Development

In order to deploy a flexible antenna array, the RFID detection equipment must be collocated with the antenna for maximum antenna field development. Several reader enclosures are commercially available to house the electronics equipment near the antenna, but are lacking for several reasons mentioned below. Additionally, it was determined that the repeated deployments and recoveries onto a boat deck would require that the reader housing be fabricated from non-ferrous metal in order to provide a reasonable durability and life expectancy for the housing.

During initial testing it was determined that having a connection/plug between the Biomark IS1001 reader and the antenna cable slightly decreased the amount of current which could be developed by the antenna. In order to maximize the current, a reader enclosure needed to be designed with antenna cable penetrations that would allow a direct connection between the antenna cable and the reader.

In 2013, initial testing was done with a custom built enclosure housing that would allow for the direct connection of the antenna cable to the reader. The first reader enclosures were constructed of a mix of schedule 80 and schedule 40 Poly Vinyl Chloride (PVC) pipe and fittings; eventually this enclosure failed at the hose barbs, causing water intrusion. In 2015 a second reader enclosure was developed using liquid-tight grips and lighter PVC material that would allow for all of the previously discussed traits while reducing weight and cost. Figure D.1.

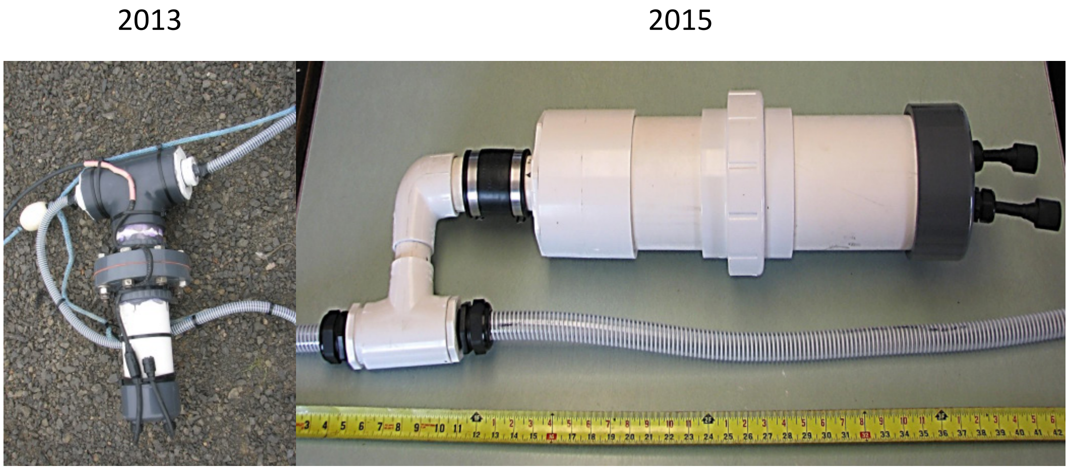


Figure D.1. Comparison of flexible antenna reader enclosures used in 2013 versus 2015.

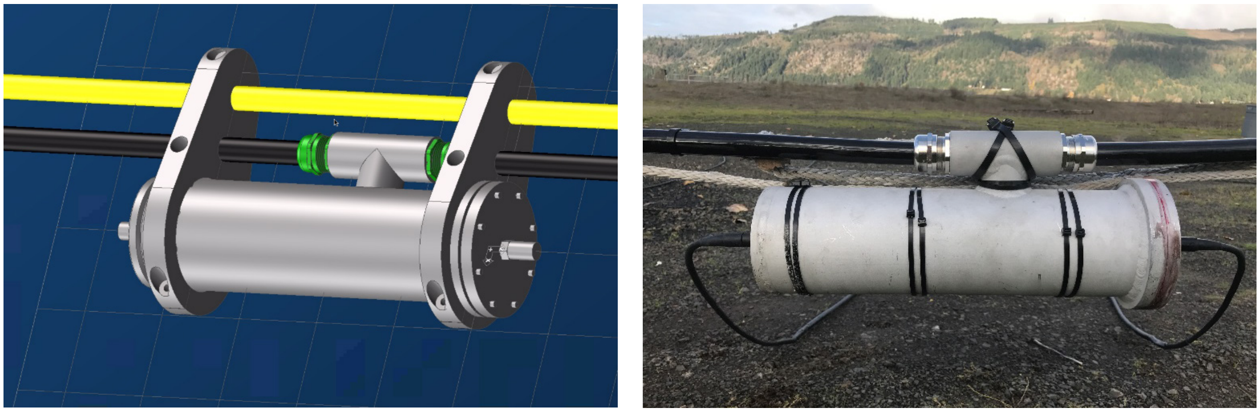
In order to provide an “off-the-shelf” enclosure, NWFSC began working with a vendor who supplies non-ferrous (aluminum) reader housings for instream deployment that could be modified with the requirements listed above. NMFS worked with the vendors engineering staff to provide a modified housing which would allow for proper flotation and connection methods previously discussed. (Fig. D.2).

Figure D.2. First prototype manufactured housing, 2016.

Several tests were performed with the NWFSC engineered reader housing, which showed that although the housing design allowed for ample antenna current, they enclosure was less positively buoyant than the PVC enclosure. An attempt was made to add buoyancy to the enclosure, but the result was not acceptable (Figure D.3). NWFSC worked with two engineering firms and issued a follow up contract for additional redesigned enclosures (Figure D.4).

Figure D.3. Buoyancy compensation for first prototype manufactured housing.

Figure D.4. Second manufactured housing, rendering and prototype used in 2016.



Appendix E. Equipment Required for Deployment of a Flexible Antenna System

- Aluminum spreader bars: 2.4 m length (2)
- Floats: F3 (2)
- Cannon ball weights: 13.5 kg (2)
- Carabiners: 80 x 8 mm (4)
- Shackles: 1.3 cm; 4 for the first antenna, 2 additional for each added antenna
- Spectra (non-stretch) line: 1 cm dia., 20 m length per antenna, 10 m length per bridle
- Tenex (non-stretch) line: 2 cm dia., 68.5 m per tow line
- CAN-Bus cable: 75 m for the towline and 7.6 m per antenna
- IS1001 Master Controller (MC)
- Antennas (1-6)
- IS1001 Reader: One per antenna
- Submersible IS1001 reader enclosure: One per antenna
- Batteries: 12V (2)
- Cable ties: 45 kg strength
- Water tight Pelican Box

Spectra line used for the antenna frames and bridles is small diameter, non-stretch line with high tensile strength. Less expensive, larger diameter, Tenex line is used for the tow lines. The bridles are 4.6 m long and serve as a transition point between the two corners of the leading antennas and the tow line. Towlines are 68.5 m long but can easily be adjusted shorter at the tow bit to regulate shape, and increase control of the array while under tow. The floats and weights are attached to the spreader bars, which maintain the width at the bridles, and orientation of the antennas in the water column. The float-end of the spreader bar should be attached to the same side of the bridle as the capsules. The spreader bars have eyes welded at the top and bottom where carabiners are used to connect the spreader bar to shackles that attach the bridle to the array.

The MC, CAN-Bus, and batteries are used to power and run the system once deployed. The CAN-Bus functions as the power and communications cable and electronically connects each antenna together at the capsule. Each 2.4 x 6.1 m antenna requires a 7.6 m section of CAN-Bus to connect adjacent antennas and provide enough slack for the cable to drift behind the antenna while under tow, avoiding electrical interference. The system is connected to the MC by running CAN-Bus from the leading antenna, up the bridle and towline to the electronics vessel. It is secured to the towline using 45 kg strength cable ties and is 7 m longer than the towline and bridle to allow for stretch while under tow. **At no point should the CAN-Bus be under strain from tow**.

The MC is powered using two 12V batteries connected in series. A watertight Pelican box is recommended to keep the MC and batteries dry in an open tow vessel. Additional equipment recommendations include: side-cutting pliers, crescent wrench (for shackles), spray silicone (for CAN-Bus connecters), electrical tape, and extra PIT tags and cable ties.

Appendix F. Cost to construct a flexible cable antenna system

Item	Qty	Unit Cost	Total
Fixed costs for one modular system/array:			
Array construction			
Spectra 3/8" - bridles & extension	1	$43.60	$43.60
Tenex 1/2"- tow line	1	$256.00	$256.00
Splicing twine	1	$10.00	$10.00
Thimbles 3/8" -bridles	9	$1.05	$9.45
Stainless clips	5	$15.00	$75.00
Sealant for capsules	2	$10.00	$20.00
Zip Ties 100 lb. 18"	20	$7.40	$148.00
Box wrenches 11/16	3	$15.00	$45.00
Solder	2	$20.00	$40.00
Electronics			
IS1001 MC	1	$4,000.00	$4,000.00
CanBUS Cable (ft)	150	$3.60	$540.00
MC rehab of existing	1	$250.00	$250.00
CANBUS connecters- MC	2	$25.00	$50.00
Heat Shrink 1/2"	5	$10.00	$50.00
Heat Shrink 1/8"	5	$10.00	$50.00
USB to Fiber optic converter	1	$300.00	$300.00
Acopian	1	$255.00	$255.00
Data Computer	1	$700.00	$700.00
Batteries (12V)	2	$200.00	$400.00
Deployment			
Aluminum bars (20 ft.)	2	$400.00	$800.00
F-3 Fenders	2	$55.77	$111.54
Cannon balls (30 lbs.)	2	$30.00	$60.00
Subtotal			**$8,213.59**
Cost for each individual antenna within array			
Reader Enclosure (WFE)	1	$2,000.00	$2,000.00
IS1001 Reader	1	$1,400.00	$1,400.00
Antenna Cable	1	$1,200.00	$1,200.00
CANBUS Connecters- Female	2	$83.00	$166.00
CANBUS Connecters- Male	2	$76.00	$152.00
CANBUS Cable (ft)	24	$3.60	$86.40
Spectra Rope Frame	1	$109.00	$109.00
Thimbles	4	$1.05	$4.20
Trawl Shackles	2	$0.94	$1.88
Subtotal			**$5,119.48**
Total cost for 6-antenna array			**$38,930.47**

Appendix G. Standard Operating Procedure for Flexible Towed Antenna Deployment

In 2015, the major components of the towed flexible antenna system were finalized and multiple deployments of various configurations were completed near Columbia River rkm 70. During these deployments, systematic procedures were established to safely deploy and operate the system. These standard operating procedures describe steps used to sample PIT-tagged juvenile salmonids in the tidal freshwater portion of the Columbia River estuary using a modular towed flexible antenna system.

Crew size and vessel needs are variable and dependent on the deployment method. A standard towed deployment, regardless of the array size, requires a minimum of two vessels and four people. The vessel that deploys and retrieves the system (electronics vessel) requires an operator and two deckhands. One deckhand becomes the operating technician once deployed. The second vessel (tow vessel), without the antenna array aboard, requires only an operator during deployment/retrieval. A third vessel and fifth person can be convenient for making adjustments and testing antennas once deployed. Radar range finding is useful to maintain distance and proper orientation between tow vessels.

To verify antenna performance while under tow a PIT tag attached to a pole is used. Each antenna should be detecting a tag 0.6 – 0.9 m in front of the antenna as well as within the entirety of the antenna itself, no “holes” should be present. Detections per tag will vary greatly given the speed of the antenna, speed of fish and orientation of the tag to the field. Given a full-duplex PIT tag will send a signal every 32ms it should be expected to detect a tag 20-30 times on a property tuned antenna.

When a stationary deployment strategy is used, only a single vessel and three people are required. During deployment, the second towline is secured to a stationary object (e.g., a piling, tree, etc.) rather than to a second tow vessel. The system is then operated much like when under tow. Again, an extra vessel is convenient for adjustments and testing, but not required. Regardless of the deployment strategy, vessels require a safe working load tow rating of at least 227 kg. The tow vessels used for developing and deploying this system were 7 m aluminum hull Workskiffs with 135 hp outboard motors.

Towed Deployment

Regardless of the array size, the system should be assembled prior to deployment, including shackling the rope frames together, attaching bridles and towlines, and connecting CAN-Bus cable to the antenna capsules. Once complete, everything should be systematically loaded into the electronics vessel in the reverse order from which it will be deployed. The objective is to facilitate a quick, tangle-free deployment. Electronic equipment, batteries, cables, and spreader bars with floats and weights attached should be loaded as well.

Deployment begins by passing one tow line (end without CAN-Bus attached), from the electronics vessel to the tow vessel, which slowly moves upstream away from the electronics vessel, pulling the towline from the top of the pile as it goes. If preferred, the electronics vessel can also control the deployment speed by reversing away from the tow vessel or stationary attachment. Once the length of the first tow line is deployed and the bridle is reached, both vessels slow to an idle, while deckhands (one on each side of the bridle) attach the spreader bar to the system using carabineers (float on capsule side and weight on the bottom). Once the spreader bar is attached, it is lowered over the front of the electronics vessel and the tow vessel resumes slowly motoring upstream. Next, the antennas are deployed in sequence over the front of the electronics vessel with careful attention not to allow the reader capsules to hit the deck as they go into the water. Reader capsules are the most fragile component of the array and care should always be taken whenever they are handled. Additionally, at no time should strain occur on the CAN-Bus cable or the connectors. When all of the modular antennas are deployed and the second bridle is reached, the second spreader bar, buoy, and weight are attached as before, and the remaining towline (with CAN-Bus) is deployed.

Half-way through the final tow line deployment, the operator of the electronics vessel should slowly start moving upstream and away from the tow vessel to begin spreading the array perpendicular to the river current. Before the system is fully deployed, ensure that the end of the towline is secured fully to the tow bit, and that the CAN-Bus cable running down the towline is not under strain. Once fully deployed, the CAN-Bus cable is plugged into the Master Controller and the system is powered on.

During deployment, attention should be given to the orientation of the CAN-Bus cable running across the top of each antenna. It should be placed on what will be the downstream side of the array under tow and the crew should ensure it does not wrap around the antennas or get entangled on a capsule. Close proximity of the CAN-Bus to the antenna will interfere with the electrical components of the system and the antenna(s) involved will perform poorly. If the array becomes twisted during deployment, continue to deploy; it is much easier to untangle the antennas and CAN-Bus once it is in the water and stretched out. This is most efficiently accomplished with the array drifting downstream from the tow vessel, while the electronics vessel motors gently upstream and adjacent to the problem area. If a third vessel is available, it can also be used to assist in the untangling. Once the system is deployed correctly, twisting and entanglement of the components should not occur. Adjustments should be made to remedy all issues before active towing begins.

Once the system is determined to be ready for towing, the electronics vessel slowly moves upriver to become parallel with the tow vessel. The goal is to create a uniform curve to the array. Optimal positioning speed for our vessels is 1000 RPM or less (slightly above idle), and optimal sampling speed is between 1200-1600 RPM under tow. This amounts to a speed-over-ground of about 1.7 kt (~2 mph). Once the system is positioned for towing, manual tuning of the antennas and data collection begins.

Retrieval of the system is in reverse order of deployment. Again, care must be exercised to avoid hitting the capsules on the deck as the antennas are pulled aboard. It is recommended that the system remain on the electronics vessel (as it was retrieved) between deployments to ensure a tangle-free future deployment.

Stationary Deployment

This system can also be deployed as a hybrid stationary array—using one vessel and a stationary attachment point for the tow line (e.g., a piling, tree, etc.) in lieu of a second tow vessel. The free end is then tended by the electronics vessel which swings out into the river current to position the array. Components and overall deployment strategies remain the same; however, in this application the crew size can be reduced to three and the system can be deployed and maintained using just one vessel. Again, a second vessel is convenient for test purposes, but not required. It is important to secure the towline high enough that it will not be covered by an incoming tide. The advantage of the stationary deployment strategy is the reduced crew size and vessel need.

In areas or times when strong river current is present, a stationary application may not be possible due to strain on the system. If the electronics vessel's RPM exceeds 1600 to maintain its position relative to the fixed location, the system will display elevated noise levels and performance will deteriorate. This is due to strain, vibration, and antenna shape changes. If this occurs, and a second vessel is available, we remove the towline attached to the stationary site and begin towing with both vessels to continue sampling.

Data management

All power and communication to and from the IS1001 readers (one on each antenna), travel via the CAN-Bus cable to the Master Controller (MC) stored on the electronics vessel. Tags and reports are stored in the MC and can be downloaded after sampling is completed using the program, Hyperterminal. Hyperterminal can also be used during sampling for a more comprehensive look at antenna functionality while under tow. For general MC set-up and node configuration, reference the IS1001 MTS User Manual found on the link below.

http://www.biomark.com/Documents%20and%20Settings/67/Site%20Documents/Technical/IS1001-MTS%20User%20Manual%202012-10-18.pdf

Master Controller and Reader Configuration

Below are the settings that we currently recommend for our towed system. The IS1001 readers have been designed and tested for use with much smaller antennas; therefore, some issues that we have encountered are beyond the scope of the user manual. We have conducted extensive testing of setting configurations to achieve the best system performance possible. MC and reader settings we recommend are:

- Node (reader) Exciter Level 1-5: Once the node serial numbers for each antenna are entered, adjust the exciter level setting to 5 for each node.
- Phase Deviation Threshold (PD) 1-65: This can only be changed to 15 using the MC front panel, unless a computer is used, in which case it can be set to 65. Using a computer, change the value to 20. The phase deviation tells the autotune function of the reader when to initiate, so when the slope value reaches the phase deviation threshold (because of antenna shape change), the

antenna begins re-tuning. The lower the phase deviation threshold, the lower the tolerance is for shape change across the antenna. Because we are in a dynamic environment, where the antennas' shape is constantly changing, we increased the phase deviation threshold manually to a higher level. Finding the correct threshold is important because if set too low, the antenna will constantly be re-tuning and tags will not be read. If it is set too high, the antenna can be severely out of shape, and therefore out of tune, and not autocorrect itself. If there is ever a question about antenna functionality, perform a full re-tune of the antenna using the menu option.

- Virtual test tags (VTT) 1-255: Set individually for each node. At the beginning of the sampling effort, it is good practice to determine the minimum VTT level that a given antenna will read. The lower the VTT, the stronger the antenna field (i.e., it can read a 'weaker' tag signal). To do this, simply turn the VTT on for an antenna, and then adjust the level down until the VTT is read intermittently, about 4-6 seconds between detections. Well-functioning antennas should have a VTT level between 5 and 10. Once determined, be sure to turn the VTT off. This process can be done manually on the MC or with a computer using Hyperterminal. Once the minimum level is established, change it back to 15 and set the VTT delay to two minutes. At this level, VTT's should be easily read across the system, giving the operator a metric to judge antenna health. One caveat to this method is that when antenna shape is changing (which is more often than not), it is common for VTT's of 15 and higher to not be read. This is likely due to the limited time the reader has to read only one tag. When the VTT is left on or a real tag is in the field, the reader has multiple chances over a short period and is much more successful at decoding the tag. Therefore, it is not recommended to use this as the sole metric of antenna performance, as there are many variables that affect the overall performance of these large antennas.
- Master Sync Mode (vs. standalone): This mode is used to provide optimal switching time between antennas so that tags moving quickly through the system can be detected.

Assessing Antennas While Under Tow

These are the parameters expected from a well performing antenna under tow.

- Current: 7.5-10 A
- Noise: 5-10%, occasional spikes into the teens are acceptable

- Reader Capacitance Value: 120-500
- Input voltage: >21.5 V DC, best if above 24V, when possible

Current and noise are the best indicators of antenna performance; a range of 7.5-11.0 A is optimal. If current is far below that range (4-5 A), it indicates a problem with the antenna and steps should be taken to bring it back to full functionality. Current levels in excess of 11.0 A will cause the reader to automatically reduce the exciter voltage to a level that will keep antenna current below this threshold to safeguard the electronics.

Noise can be highly variable depending on outside influences, though 5-10% with spikes into the high teens, in general, is an acceptable range. Noise levels consistently higher than 10% will negatively affect antenna performance and steps should be taken to remedy the cause. Typical causes of high noise include: heavy vibration from towing the system too fast, CAN-Bus interference from the array changing shape, entanglement of the CAN-Bus, outside noise sources (engines, generators, dredges, mills, aluminum boat near the antenna, etc. were noted to create noise during our tests), and water intrusion.

An external capacitor pack should be used to reach the appropriate reader capacitor value. This should be determined and tested during the antenna building phase and prior to deployment (Morris et al. 2015). A range of 120-500 allows the antennas shape to fluctuate while under tow without falling out of tune. Levels closer to 120 are desirable because the capacitor value will increase while under tow. Higher tow speeds have also correlated to higher capacitor values, which is likely because the antennas tend to get bent into a tighter “U” shape at these speeds. A fixed capacitance value of 1,023 indicates the reader cannot tune the antenna with the given external capacitance pack, often resulting from a broken solder joint. Regardless, the capsule will need to be opened to identify and correct the issue.

Input voltage should not be an issue for a 12 hour deployment if batteries are fully charged at the start of sampling. However, it is important to check that the system maintains at least 21.5V DC during sampling. The transceiver manufacturer recommends the input voltage be 4V higher than the exciter voltage to reduce noise and increase system stability. Therefore, if the exciter is level five (20V), then an input voltage of 24V should be maintained. Because of the voltage drop along the length of the CAN-Bus running from the electronics vessel to the system, we have not been able to maintain an input of

24V. If a shorter tow line is used, the CAN-Bus should be trimmed to reduce voltage drop. The array still functions at lower levels, but a higher input voltage is ideal. If the input voltage drops below 21.5 V and the antenna is at an exciter level of 5, there will not be enough input to maintain the exciter and antenna current will drop.

Common Issues and Fixes

Reduced current and high noise, are the most common issues we experience with the towed flexible antenna system. Common causes of low current are CAN-Bus entangled around the capsule or antenna, metal (vessel) near the antenna, and water intrusion. Entanglement during deployment is by far the most common issue and is easily corrected. This typically presents itself as a current drop on one antenna while the rest of the antennas in the system are functioning normally. If entanglement is not occurring, we recommend reducing the tow speed and expanding the distance between tow vessels, which will reduce the severity of the “U” shape in the array. Towing with the vessels too close together, particularly at higher speeds, causes the outside antennas to be pointed more upstream than the middle antennas. This upstream orientation does not allow the CAN-Bus to drift behind the antenna, instead causing it to lie against the antenna, reducing current. Altering the array shape should correct this issue. If these solutions do not correct the issue, water intrusion into a capsule or antenna is a possible cause. If this is suspected, we recommend removing the reader from the capsule to verify. If water intrusion has occurred, we recommend air drying the reader as soon as reasonable, and thoroughly testing it before future use.

High or inconsistent spikes in noise can also occur during deployments and are often a result of vibration from towing speed, adjacent vessel traffic, or electrical interference from an inverter or external power source. By far, the most common reason for elevated noise is vibration from high towing speeds or strong currents (in a stationary setting). If reducing the speed does not remedy the issue, change the shape of the array, as state above, and manually re-tune the antenna(s).