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Managing Water in the West

Delta Cross Channel Electrical Barrier (Pre-Study)

Research and Development Office
Science and Technology Program
Final Report ST-2017-539F-01

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14. ABSTRACT Mokelumne River fall-run Chinook Salmon contribute to a significant portion of the overall returning adult spawners in Central Valley's San Joaquin River system, the success of Mokelumne River salmon relies heavily on hatchery produced introductions from the Mokelumne River Fish Hatchery.The Delta Cross Channel (DCC) gates may provide a stimulus attracting attracting adult Mokelumne River origin fall-run Chinook salmon, resulting in straying from their prenatal spawning grounds into the Sacramento River system. In an effort to promote the continued operation of the DCC and meet South Delta water quality standards, an instream electrical barrier system (e-barrier) is proposed for installation to minimize movement of upstream migrating Chinook salmon from the Mokelumne River to the Sacramento River through the DCC. The purpose of this portion of the study was to attempt to quantify movement patterns of fish through both Snodgrass Slough and Deadhorse Island Cut. Using a DIDSON sonar 1,198 acoustically detected target sized fish (>400mm) were identified. Of those traces 726 fish moved towards the Mokulumne and 472 towards the Sacramento River. Roughly 13% of the fish traversing from the Sacramento to the Mokulumne did so against the current while 85% of the fish moving from the Mokulumne to the Sacramento were swimming against the current

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Delta Cross Channel Electrical Barrier (Pre-Study)

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Executive Summary

Fall run Chinook Salmon (*Oncorhynchus tshawytscha*) have experienced significant declines in escapement over the last century and have been listed as a species of concern. Mokelumne River fall-run Chinook Salmon contribute to a significant portion of the overall returning adult spawners in Central Valley's San Joaquin River system. Though abundance of spawning adults in the Mokelumne River have recently rebounded, the success of Mokelumne River salmon relies heavily on hatchery produced introductions from the Mokelumne River Fish Hatchery.

Coded wire tag data from the Central Valley Constant Fractional Marking Program (CFM) suggests a portion of hatchery released Mokelumne River fall-run Chinook Salmon do not return to their prenatal system, but stray into Sacramento River, and ultimately, tributaries thereof. The Delta Cross Channel (DCC) gates may provide a stimulus attracting attracting adult Mokelumne River origin fall-run Chinook salmon, resulting in straying from their prenatal spawning grounds into the Sacramento River system. In an effort to promote the continued operation of the DCC and meet South Delta water quality standards, an instream electrical barrier system (e-barrier) is proposed for installation to minimize movement of upstream migrating Chinook salmon from the Mokelumne River to the Sacramento River through the DCC.

The purpose of this portion of the study was to attempt to quantify movement patterns of fish through both Snodgrass Slough and Deadhorse Island Cut. The study had been proposed for three years, but due to changes in funding priorities it was decided the S and T program would cease funding the study following data collection in year two and CVPIA at that point in time would provide continued funding for the project. Due to funding cuts CVPIA elected not to fund the remainder of the study at this time; so while data was collected for years one and two, only the methods and a draft summary were developed for year one of the study. That data is what is presented in this study.

Two approaches were utilized to describe fish movement through the proposed study area. A DIDSON acoustic unit was used to look at movement of fish through Dead Horse Island Cut and a pair of Biosonics Split beam units were used to esonify the water through Snodgras Slough. High levels of debris reduced the utility of the split-beam sonar so only the DIDSON data from Deadhorse Island Cut was used for this portion of the study. Netting was used to generate fish species makeup and to capture salmon to be implanted with acoustic tags. Netting resulted in the capture and tagging of one salmon, though it was never detected at any of the acoustic receivers. Acoustic receivers did detect six salmon from another study, one of which used Dead Horse Island Cut to enter the Sacramento River. Following the application of an algorithm to remove debris traces in the DIDSON data, the initial 70,099 traces was reduced to 1,198 target sized fish (>400mm). Of those traces 726 fish moved towards the Mokulumne and 472 towards the Sacramento River. Roughly 13% of the fish traversing from the Sacramento to the Mokulumne did so against the current while 85% of the fish moving from the Mokulumne to the Sacramento were swimming against the current.

While this is only preliminary data, further in depth analysis of this dataset, and an analyses of the year two dataset should provide a good set of baseline information on fish movement patterns through this reach should in the future some sort of barrier again be examined.

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INTRODUCTION:

California's Central Valley fall-run Chinook Salmon (*Oncorhynchus tshawytscha*) have experienced declines in abundance over the last century (Yoshiyama 1998; Moyle 2002), punctuated by alarmingly low escapement in recent years (Lindley et al. 2009). As a result, Central Valley fall-run Chinook Salmon have been listed as a species of special concern under the Endangered Species Act. Mokelumne River fall-run Chinook Salmon contribute to a significant portion of the overall returning adult spawners in Central Valley's San Joaquin River system, and though abundance of spawning adults in the Mokelumne River have recently rebounded, the success of Mokelumne River salmon relies heavily on hatchery produced introductions from the Mokelumne River Fish Hatchery (East Bay Municipal Utility District [EBMUD]; Bilski and Rible 2011). Coded wire tag data from the Central Valley Constant Fractional Marking Program (CFM) suggests a portion of hatchery released Mokelumne River fall-run Chinook Salmon do not return to their prenatal system, but stray into Sacramento River, and ultimately, tributaries thereof (Kormos et al. 2012). It is also possible Sacramento River fall-run Chinook salmon that have entered the Mokelumne River use the DCC to return to their natal system. Though there are many pathways upstream migrating salmon could take to stray into the Sacramento, experimental Delta Cross Channel (DCC) gate closures in 2010 and 2011, which resulted in reduced straying into the American River by reportedly ≥ 50%, suggest traversing through the DCC likely contributes to straying. The DCC and associated gates, located in Walnut Grove, CA, operate to maintain salinity standards at Central Valley Project and State Water Project export pumps by drawing fresh water from the Sacramento River into the South Sacramento-San Joaquin Delta (Delta) via the Mokelumne River (Figure 1). Open DCC gates and diverted Sacramento River flows may provide a positive stimulus attracting adult Mokelumne River origin fall-run Chinook salmon, resulting in straying from their prenatal spawning grounds into the Sacramento River system and major tributaries (*e.g.*, American River). Some straying is natural and generally perceived as beneficial, as it promotes genetic diversity (Quinn 1993; Marston et al. 2012). However, straying as a result of anthropogenic influences or inordinate levels of straying may contribute to poor returns of adult fish to the Mokelumne River, impacting genetic integrity and hatchery operations.

In an effort to promote the continued operation of the DCC and meet South Delta water quality standards, an instream electrical barrier system (e-barrier) is proposed for installation to minimize movement of upstream migrating Chinook salmon from the Mokelumne River to the Sacramento River through the DCC. The current study does not seek to quantify straying rates, as a function of origin, through the DCC. Instead, efforts will be focused on the evaluation of e-barrier technology to determine the efficacy of reducing salmon movement through the DCC. To test the effectiveness of the barrier system and acquire data to meet outlined project objectives, a multi-component sampling regime and data collection effort will be completed across several years to compare movement of adult salmon with and without the electrical barrier in operation. Data collected during this first-year effort will be part of a multi-year baseline effort for before and after comparisons. The main objectives will focus on collecting data on adult salmon movement patterns in proximity of the DCC confluence with the Mokelumne River. During future project efforts, an on/off (control/impact) schedule for barrier operation will be in place to allow for a comparison of e-barrier effects.

The first objective was to estimate the proportion of adult fall-run Chinook Salmon traversing either Snodgrass Slough or Dead Horse Island Cut (Figure 1) as a means to move from the Mokelumne River, through the DCC, and into the Sacramento River during peak migration. We attempted to collect data on the abundance of adult salmon (# of fish per unit time and/or volume) traversing either stem of the DCC using hydroacoustic sampling to provide a baseline estimate for comparisons against data collected in future years following e-barrier installation. Hydroacoustic data will also help to ascertain if the selected installation location is most appropriate, and will provide useful information on temporal (both diel and seasonal) differences in migration of adult salmon. Secondly, we were hoping to compare the aforementioned estimates compared to the number of salmon enumerated in the mainstem Mokelumne River at Woodbridge by EBMUD during peak migration to provide an estimate of the total percentage of adult salmon moving out of the Mokelumne River, through the DCC, and into the Sacramento River. Our third objective was to track movements of individual adult Chinook Salmon traversing both the north and south channels of the Mokelumne River (see Figure 1) to assess migration pathways. Baseline data on more precise movement patterns of individual adult salmon, employing acoustic telemetry, will permit an estimation of the proportion of salmon from the north and south channels of the Mokelumne River that choose to move through the DCC (using either Snodgrass Slough or Dead Horse Island Cut) or stay in the mainstem Mokelumne River. Acoustic telemetry data compared before and after barrier installation will also permit an assessment of the e-barrier effects on adult salmon milling and migration timing, and if the e-barrier is re-routing adult salmon to other migratory paths aside from the mainstem Mokelumne River.

Lastly, we attempted to quantify behavior of adult fall-run Chinook Salmon. Hydroacoustic and acoustic telemetry data will provide estimates on proportion of adult salmon moving from the Mokelumne River to the Sacramento River and large-scale migration patterns, but will not permit an evaluation of the behavioral response of adult salmon in close proximity to the e-barrier.

METHODS:

Each year of the study effort capture of adult salmon to facilitate acoustic telemetry and/or species presence, as well as echosounder and DIDSON camera (Dual frequency identification sonar; DIDSON sampling, will be completed over a short window intended to coincide with their peak spawning migration. Adult fall-run Chinook Salmon generally enter the lower Mokelumne River as early as August, but peak migration and spawning efforts typically occur in September/October and November, respectively (Bilski and Rible 2013; Marine and Vogel 1994; Setka 1997). Focusing sampling efforts across the period of peak migration will maximize sampling efficiency (# of fish captured or observed per unit time). Based on historic runs as well as recommendations from EBMUD biological staff, echosounder, DIDSON, and acoustic telemetry equipment were transported to the study site in September and subsequently set-up, calibrated, and tested. Sampling occurred September 21 – October 28, 2015. Ultimately, it was revealed that the peak migration of fall-run Chinook Salmon in the Mokelumne River occurred later in 2015 than the historical average. However, due to regulatory restrictions, sampling was required to be completed November 13, 2015. By the end of October, only one salmon had been captured.

Hydroacoustic data collection—Hydroacoustic (Split-beam Echosounder and DIDSON) sampling was used in an attempt to quantify the abundance of adult salmon traversing both Snodgrass Slough and Dead Horse Island Cut. This technology is a common means to monitor migrating salmon (Cronkite et al. 2007), and is advantageous because it is non-invasive, permitting observation of large numbers of fish without causing handling stress, damage, or mortality. Hydroacoustic equipment transmits pulses of sound through the water. When the pulse encounters an object, such as a fish, an echo is reflected back to the transducer. Based on the time it takes to receive this echo, and the strength of the returning sound wave, this information can be processed to provide and estimation of the number and size of targets passing through the field of the hydroacoustic equipment (Split-Beamor DIDSON). The echosounders (BioSonics, Inc., Seattle, Washington) use a split-beam transducer that detects based on range and time. The DIDSON (Sound Metrics Corporation, Bellevue, Washington) is a sonar unit that transmits sound waves through the water, and when these waves encounter an object (*e.g.*, fish), echoes returned to the unit. The data is recorded and is converted to digital images in post-processing software. Unlike the split-beam echosounder, the DIDSON is a multibeam unit that can produce an image that, visually, allows easier identification/separation of fish/non-fish targets. Hydroacoustic data were collected throughout the duration (24h/d) of the sampling effort.

Hydroacoustic systems were set-up near the confluence of Snodgrass Slough and the Mokelumne River, and near the confluence of Dead Horse Island Cut and the Mokelumne River (Figure 2 and Figure 3). Power was supplied from a nearby business (Giusti’s Place, Walnut Grove, CA) for equipment installed at Snodgrass Slough, and minimal maintenance was required to maintain equipment operation at this site. Conversely, equipment installed at the DHI cut was powered with a combination of solar panels, batteries, and a gas generator. Side-looking echosounders were erected close to shore and on opposite banks, and aimed perpendicular to the channel bank to maximize channel coverage, a common orientation employed for enumeration of riverine salmon (Enzenhofer et al. 1998), and were deployed in straight channel locations with uniform channel bottom to improve coverage and accuracy (Burwen et al. 1998; Enzenhofer and Cronkite 2000). A DIDSON was installed at the confluence of the Dead Horse Island Cut and the North Fork of the Mokelumne River (Figure 3).

Netting—Hydroacoustic sampling is unobtrusive, as it does not require the physical capture of fish. However, data acquired using these methods may not easily permit determination of different species of fish. The abundance of larger fish species that could potentially be confused (based on target strength) with adult salmon, including native steelhead (*Oncorhynchus mykiss*), large native cyprinids (*i.e.*, Sacramento Splittail, *Pogonichthys macrolepidotus*, Sacramento Pikeminnow, *Ptychocheilus grandis*), and catostomids (Sacramento Sucker, *Catostomus occidentalis*), and non-native cyprinids (*i.e.*, Common Carp, *Cyprinus carpio*), are reportedly relatively low in abundance in the lower Mokelumne River in comparison to adult salmon during migration. Nonetheless, they are present, and an estimation of the proportion of species of large fish traversing the barrier will be necessary for data post-processing (Workman 2004). To quantify species presence, and ultimately apply these proportions to the hydroacoustic data to evaluate the numbers of salmon in the study site, trammel nets were originally planned to be fished upstream of each hydroacoustic station sample site at regular intervals, particularly near the Dead Horse Island Cut where the DIDSON was located. However, heavy boat traffic during the study period precluded sampling in this location. In turn, this prevented determining the proportion of species making up fish > 400 mm. As a result, DIDSON data is reported only as total numbers of targets (*i.e.*, fish) within this size class. At other locations, trammel nets were attended while drifting downstream, and all fish captured using this method were counted, identified to species, and immediately returned to the river in close proximity to their point of capture.

We hoped to capture upstream migrating Chinook Salmon with floating trammel nets (see Hallock et al. 1970), a technique proved effective for large fish in large river channels (Guy et al. 2009). We planned to use fish captured through netting efforts for acoustic telemetry studies. Large fish (*e.g.*, salmon) that encounter the trammel net are recognized immediately as a result of disruption of floating buoys attached to the net, allowing rapid recovery and removal. Trammel nets were designed and developed based on the head width of adult salmon in an effort to minimize extraneous entanglement and gilling. Netting efforts were completed, almost daily (during ebb tides and daylight hours, per permit restrictions) September 21 – October 28, 2015. Trammel nets were used in the North and South Forks of the Mokelumne River, as well as in DHI Cut, for a total of ~144 hours. Fyke nets were used in the Mokelumne for ~15 hours. During all netting efforts, water quality (*i.e.*, temperature, dissolved oxygen, and percent saturation) were monitored and recorded. Bureau of Reclamation and EBMUD ceased trammel and fyke netting in both forks of the Mokelumne River October 28, 2015. To adhere to sampling permit requirements, capture data from both sampling gears, including bycatch and across all locations, was reported twice weekly to the National Marine Fisheries Service (NMFS; J. Stuart). In addition, weekly sampling updates were made to California Department of Fish and Wildlife (CDFW; C. Purdy, C. McKibbin) and EBMUD. Updates and coordination with CDFW was completed as they were sampling for, and acoustically tagging, adult fall-run Chinook Salmon in the mainstem San Joaquin River, and there was a planned data sharing effort in place. East Bay Municipal Utility District (C. Del Real, M. Workman) were partners in data collection efforts.

Acoustic telemetry—Acoustic telemetry was intended to track individual salmon from lower reaches of the Mokelumne River, to permit estimation of the proportion of fish that use either Snodgrass Slough or Dead Horse Island Cut to move into the Sacramento River, or remain in the mainstem Mokelumne River. Acoustic receivers (~308 mm long x 73 mm diameter; Vemco Ltd., Bedford, Nova Scotia) were installed at six locations (Figure 4) and operated September 22 – October 29, 2015. Though our efforts only resulted in the tagging and release of one adult salmon, adult Chinook salmon were acoustically tagged from independent studies by CDFW and California Department of Water Resources (DWR) in the mainstem San Joaquin and Yolo Bypass, respectively. After capture, an acoustic transmitter (~9 mm height, ~29 mm length, ~4.7 g weight) was intragastrically implanted into the salmon. Acoustic transmitters were programmed to emit an acoustic “ping” every 20 s (for ~100 d). When an active transmitter is in close proximity (~400 m straight line distance) to a stationary acoustic receiver, the unique transmitter ID, date, and time are recorded. After tagging, fish were released near the proximity of the capture location. Provisions were made to provide temporary holding in a net pen if necessary (from handling stress).

Additionally, a Peterson disc tag was affixed below the dorsal fin rays. Though quantifying adult fall-run Chinook salmon straying, as a function of origin, is not the objective of this proposed research, efforts will be made to provide a better understanding of salmon straying from the Mokelumne River into the Sacramento River. A portion of central valley hatchery fall-run Chinook Salmon, including Mokelumne River salmon, are adipose-clipped and receive a coded wire tag prior to release. The coded wire tag is marked with a specific code unique to its hatchery origin, and, as part of CFM, recovered adipose clipped fish are sampled to retrieve this tag (Kormos et al. 2012). In the event any disc-tagged fish are recovered by hatcheries, and the fish is coded wire tagged, such information could be used to identify the origin of the salmon and whether straying had occurred. Peterson disc tags used in this study contain information identifying the study and providing contact information. Regional hatchery managers in the study area were informed of these activities and we requested CWT information be provided for all Peterson disc-tagged salmon.

Data Analysis—The DIDSON was nominally in operation 24 h/d and files were saved in 30 min increments. DIDSON and Echoview software (Echoview Software Pty. Ltd., Hobart, Tasmania) were used to process the hydroacoustic data. In order to evaluate the efficiency our data processing efforts, a subset of these 30-min files were used for quality control (QC) purposes (~150 min). These QC files were then used as the basis for setting software parameters to detect fish. File selection was based on the presence of fish and were intended to encompass a variety of operating conditions present during DIDSON operation. Because we are only concerned with movements of adult Chinook Salmon through the DCC, and because hydroacoustic target strength is correlated with fish size, target threshold limits will be set for post-processing to exclude all fish < 400 mm (based on minimum lengths of salmon typically encountered in the Mokelumne River; Workman 2006). The original files were first viewed, prior to any processing/filtering, to identify target-sized fish (>400 mm) passing with range of the DIDSON. Fish length (total length, mm) was estimated using measuring tools within the software, and taking the largest of three measurements that appeared to best represent the overall length of each fish. We used the information recorded from the raw data files to compare with the post-processed data to determine detection probabilities, size approximation, and the ability to separate fish from non-fish targets.

Original data files were first processed in DIDSON software to reduce the background noise and overall file size, thereby reducing processing time in the Echoview software. Parameters within the DIDSON software were based on original studies from the Kenai River, AK (Aquacoustics 2010). Afterwards, files were imported and processed in the DIDSON software before exporting text files for final analysis. Echoview parameters were based on a similar study in the Georgianna Slough, Sacramento County, CA (Horn, in draft). Software variables used for detecting targets were adjusted using the QC files, in an attempt to maximize the ability to detect fish while reducing the amount of debris detected. Variable properties within the software were saved in a template that was used to process all remaining files from the study period. A final text file was produced and exported for further filtering/analysis.

Using know fish targets from the QC files, text data was filtered in Excel (Microsoft Corporation, Redmond, Washington) to aid in separating fish and debris. Data were first evaluated to determine maximum/minimum ranges that separated fish from debris (under the various parameters exported from Echoview; *e.g.*, target strength source, time in beam, tortuosity, speed). Further filtering was based on removing the maximum amount of non-fish targets while limiting fish target loss. The overall filter values were saves and used for the remainder of the DIDSON files. This process was used to enumerate the total number of targets passing within range of the DIDSON during the study period. Likewise, overall fish length was determined by comparing fish measured (total length; mm) from the QC files with the respective information exported from Echoview. As fish tracks in Echoview tend to distort the overall length of the fish, this was a necessary step to estimate the length of targets exported in the text files. After determining overall lengths, outliers were removed from the analysis. A check of the removed values indicated 88.9% of the removed outliers were not individual fish. Instead, these were composed of large pieces of debris, schools of small fish that were grouped as a single target, or multiple large fish swimming close together (where the software could not distinguish between the two targets).

While we attempted to evaluate all fish tracks together, it was determined *post hoc* that separating upstream and downstream moving fish independently resulted in an improved detection rate. Because tidal influences result in directional flow changes between the Sacramento and Mokelumne River when the radial gates are open, velocity data from the USGS

Delta Cross Channel gauging station (downloaded from the California Data Exchange Center website [CDEC]; http://cdec.water.ca.gov/; Station ID–DLC; US Geological Survey gauge 11336600) was used to determine upstream or downstream movement of fish targets. Fish tracks exported from Echoview were paired with the appropriate velocity data. Based on the directionality of identified targets in Echoview, combined with the associated velocity data, we were able to determine when targets may have been moving upstream (opposite to the flow, regardless of destination—either towards the Sacramento or Mokelumne River). The assumption that targets moving against the flow were most likely fish, we were able to more accurately identify fish against non-fish targets in this manner. In addition to water velocity, river stage and water temperature data were also downloaded from the CDEC website to evaluate potential patterns of fish movement with environmental variables.

RESULTS:

Only one salmon was captured during trammel netting and fyke efforts near the study area. Bycatch consisted entirely of centrarchids (Appendix A). The one salmon captured through these efforts was acoustically tagged. However, it was not detected after release. Six acoustically tagged adult Chinook Salmon (from independent studies from CDFW and DWR) were detected moving through the study area. This data is summarized in Table 1. Of the six fish tracked, one used Dead Horse Island Cut to move from the Mokelumne to the Sacramento River. Though the data set is small, and results based on this data should take this into consideration, it suggests that Chinook Salmon use both Snodgrass Slough and Dead Horse Island Cut to traverse both to and from the Mokelumne and Sacramento Rivers.

High levels of floating and submerged aquatic vegetation were common throughout sampling, as was a high volume of boat traffic. Hydroacoutic units at the DHI cut were powered by a combination of solar power and, after difficulties maintaining power to equipment, a small generator. These units required significant maintenance, including moving solar panels, fueling the generator, and removing debris from tripods and buoys at least once daily. Power supply difficulties occasionally resulted in equipment powering down, which in turn required a restart and some loss of data. There was boat traffic, which was elevated on weekends, but this was much less compared to traffic through DHI Cut. The DIDSON was in operation September 23 – October 28, 2015. During this period, hardware issues/debris loads resulted in inconsistent data collection. Resultantly, only data from October 5 – October 28, 2015 was evaluated. Snodgrass slough debris loads were similar to those observed in DHI Cut. Because they were well below the water surface and did not require the use of a buoy, continuous debris removal was not required.

A total of 70,099 target tracks (fish and non-fish targets) were exported from Echoview over the evaluated time period (October 5 – 28, 2015). However, after additional filtering in Excel, a total of 310 upstream and 493 downstream fish tracks were identified. A random check of 40 fish tracks from upstream data indicated 87.5% efficiency of detecting fish. However, with downstream-moving fish tracks, positive fish identification was only 77.5%. Resultantly, an estimated 271/310 upstream tracks and 382/493 downstream tracks were estimated to be fish. Based on target identification from the original QC files, estimates suggest the template used in Echoview identified ~72.7% (24/33) of target-sized fish passing within range of the DIDSON. After filtering in Excel, the detection rate dropped to ~54.5%. This did allow us to remove an estimated ~98.9% of debris/non-fish tracks of the original 70,099 exported from Echoview. Combined with the upstream and downstream fish tracks, we estimate a total of 1,198 target-sized fish (>400 mm) passed within range of the DIDSON during the analyzed time period. Comparing exported length values to original measured lengths from unprocessed DIDSON files, exported values were 94.8% ± 23.5% (mean ± SD) of the original measured lengths. This metric was applied to the fish tracks to determine the overall distribution during the study period (Figure 5).

Fish tracks were first organized by direction of travel, with respect to the DIDSON. Fish moving toward the Sacramento River were labeled Sacramento-bound and, similarly, fish moving in the direction of the Mokelumne River were labeled Mokelumne-bound. After determining the direction of travel, fish tracks were organized according to recorded conditions at the moment of detection—temperature (Figure 6), time of day (Figure 7), river stage (Figure 8), and velocity (Figure 9). It was noted that the number of periods across different velocity conditions was not evenly distributed. For that reason, fish tracks (and destination) were also standardized to account for the uneven distribution of velocity conditions during the study period (Figure 10).

Lastly, fish tracks were organized by date. It's important to note that several periods occurred during the evaluated period (October 5 – October 28, 2015) where power supply issues or routine maintenance resulted in equipment down time. These periods occurred October 5, 9, 20, and 24–25. To estimate the total number of fish passing within range of the DIDSON over the evaluated period, total number of tracks were multiplied by the ability to discriminate between fish targets and non-fish targets (87.5% and 77.5% for upstream and downstream moving targets, respectively), and then divided by the overall detection efficiency after Echoview and text data filtering (54.5%).

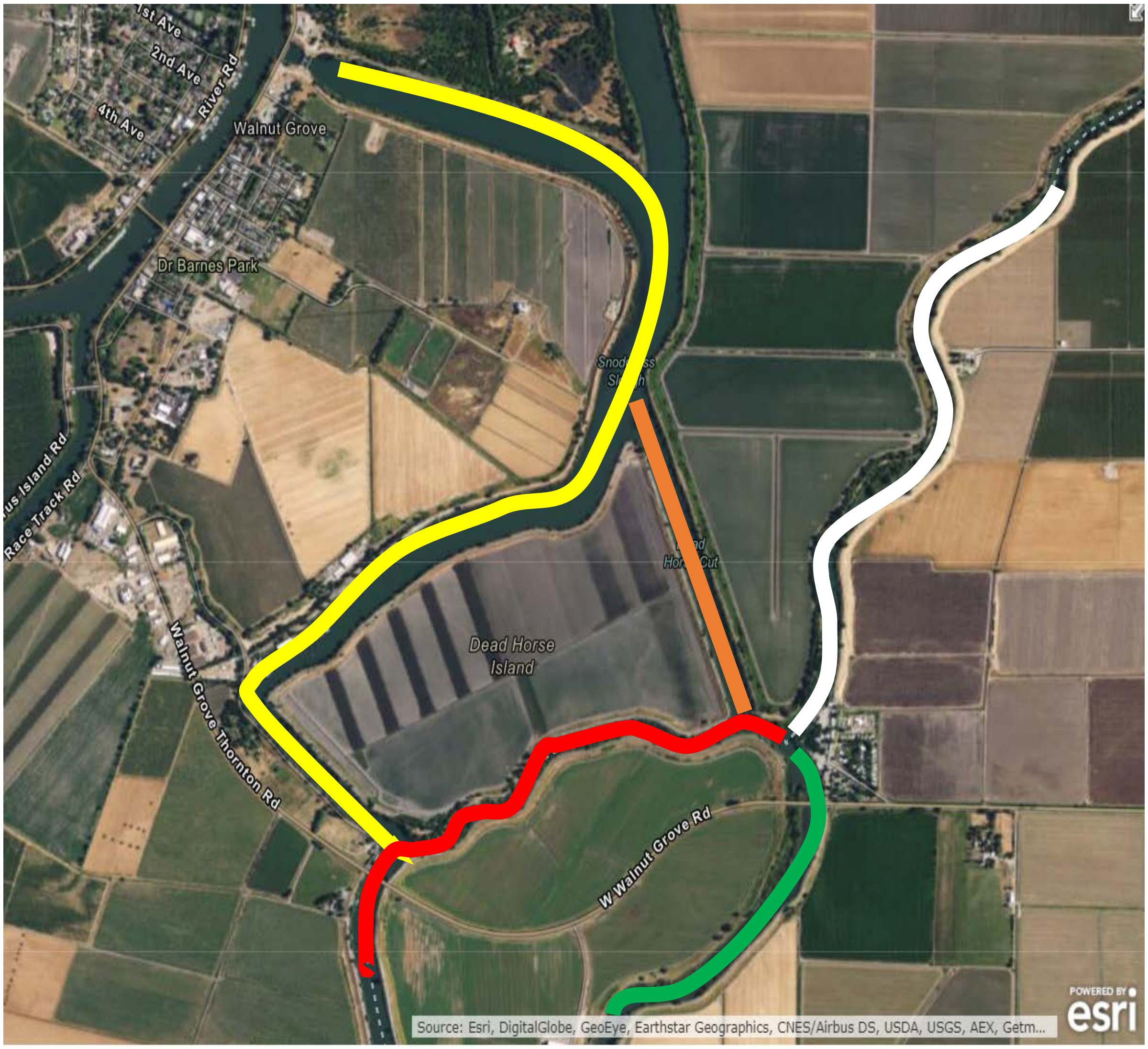
An estimated 726 of 1,198 fish moved towards the Mokelumne River during the evaluated period. Of the 726 fish moving in the direction of the Mokelumne, 629 were swimming with the flow while the other 96 were swimming upstream (during periods when water was flowing from the Mokelumne to the Sacramento River. The other estimated 472 fish were moving towards the Sacramento River. Of these, 71 were swimming with the flow when the current was moving in the direction of the Sacramento while the other 401 swam upstream, against the current. These estimates indicate ~13.3% of fish moving into the Mokelumne did so against the current while 85.0% of fish moving towards the Sacramento were swimming upstream.

DISCUSSION

As mentioned, we were largely unsuccessful at capturing adult fall-run Chinook Salmon during sampling. This is likely due, in part, to restrictions placed on the project by regulatory agencies, including, sampling only on ebb tides and during daylight hours, as well as ceasing all sampling activities after the first week of November. Figure 12 summarizes daily abundance of adult fall-run Chinook Salmon moving past our study area and up the Mokelumne River during 2015 (data from adult Chinook Salmon at the Woodbridge Dam; provided by East Bay Municipal Utilities District). This figure indicates that our restricted sampling period likely did not allow us to target a significant portion of the run.

Though hands on efforts precluded capture and subsequent tracking of adult salmon, the DIDSON data provides some useful information regarding potential patterns of fish/salmon distribution in the study area. Future efforts that require use of this area for equipment would benefit greatly from a more stable power source. Sacramento-bound fish were not observed until the latter-half of October (Figure 11). Though we cannot know whether or not these are adult salmon, they do coincide with the arrival of adult salmon at the Woodbridge Irrigation District Dam (Figure 12), ~31.7 river km upstream from the DCC. The distribution of target-sized fish (> 400 mm) at the DCC, with respect to time of day, also appears similar in distribution to Chinook Salmon passage at the Woodbridge Irrigation District Dam in 2003–04 (Workman 2004). No clear trends were present in relation to fish movement with relation to temperature (Figure 6), river stage (Figure 8), or velocities (Figure 9).

To more effectively evaluate salmon movement during future efforts, we may need to be more flexible on the project timing. Because the 2015 run occurred later than historical averages, and we were constrained by permit timelines, we were unable to effectively net and acoustically tag salmon. This precluded evaluating movement throughout the study area with acoustic telemetry. In a similar note, without a sufficient sample size of target fish within the study area, we could not determine the overall distribution of target-sized (> 400 mm) fish. As a result, we could not accurately determine the overall proportion of salmon to other species within the DIDSON data.



Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getm...

Figure 1.—Delta Cross Channel study site, depicting Snodgrass Slough (yellow), Dead Horse Island Cut (orange), the Sacramento River (blue), the north (red), south (green), and the mainstem (white) Mokelumne River. Image Source ESRI.

Figure 2—Locations and orientation of DIDSON camera (red arrow) and echosounder (yellow arrow) at the confluence of the Dead Horse Island Cut and the North Fork of the Mokelumne River during 2015 Delta Cross Channel data collection effort.

Figure 3—Location and orientation (yellow arrows) of echosounders at the confluence of Snodgrass Slough and the North Fork of the Mokelumne River during the 2015 Delta Cross Channel collection efforts.

Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getm...

Figure 4–Locations (yellow “A”) for installation of acoustic receivers to monitor movement patterns of individual adult fall-run Chinook Salmon (*Oncorhynchus tshawytscha*) straying from the Mokelumne River, through the Delta Cross Channel, into the Sacramento River, CA. An effort will be made to catch, tag, and release (“C/R”) approximately 50 adult salmon in the north and south channels of the Mokelumne River.

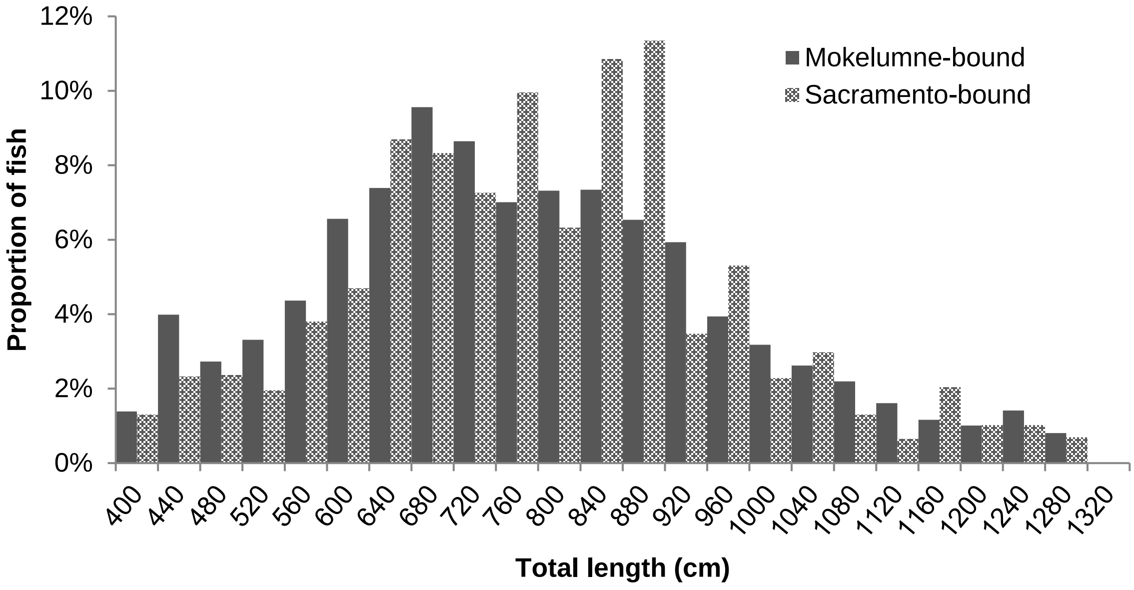


Figure 5.—Proportion of target-sized fish (>400 mm), by total length (mm), passing within range of the DIDSON camera at the confluence of the Dead Horse Island Cut and the North Fork of the Mokelumne River.

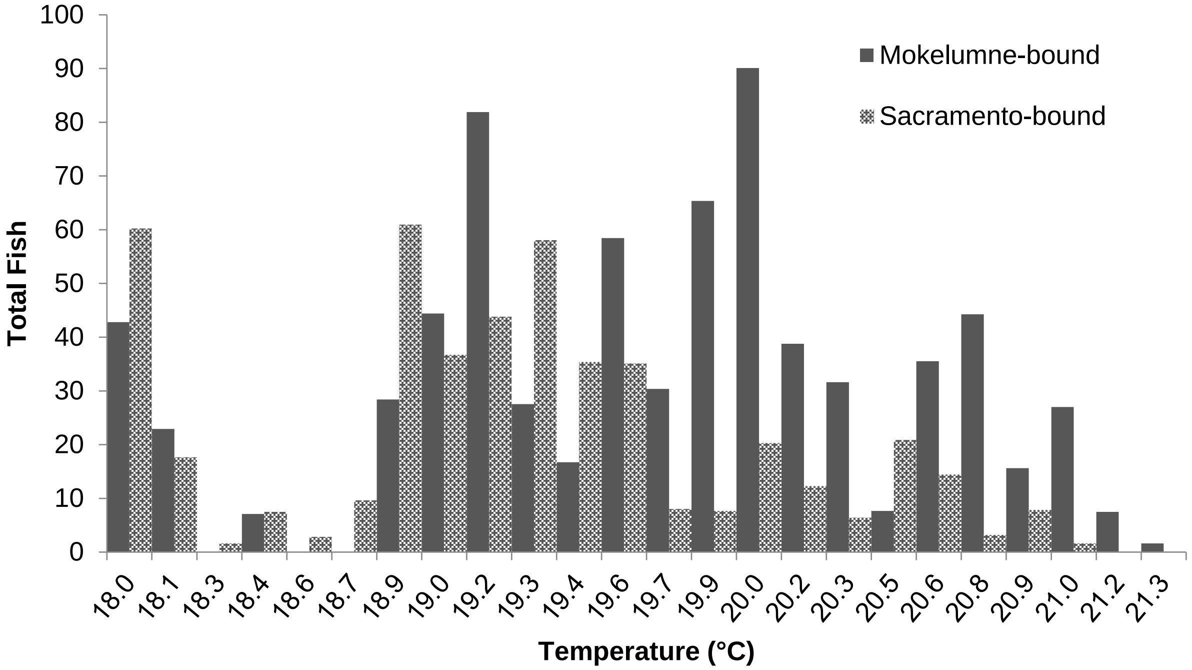


Figure 6.—Total estimated target-sized fish (>400 mm), passing within range of the DIDSON camera at the confluence of the Dead Horse Island Cut and the North Fork of the Mokelumne River.

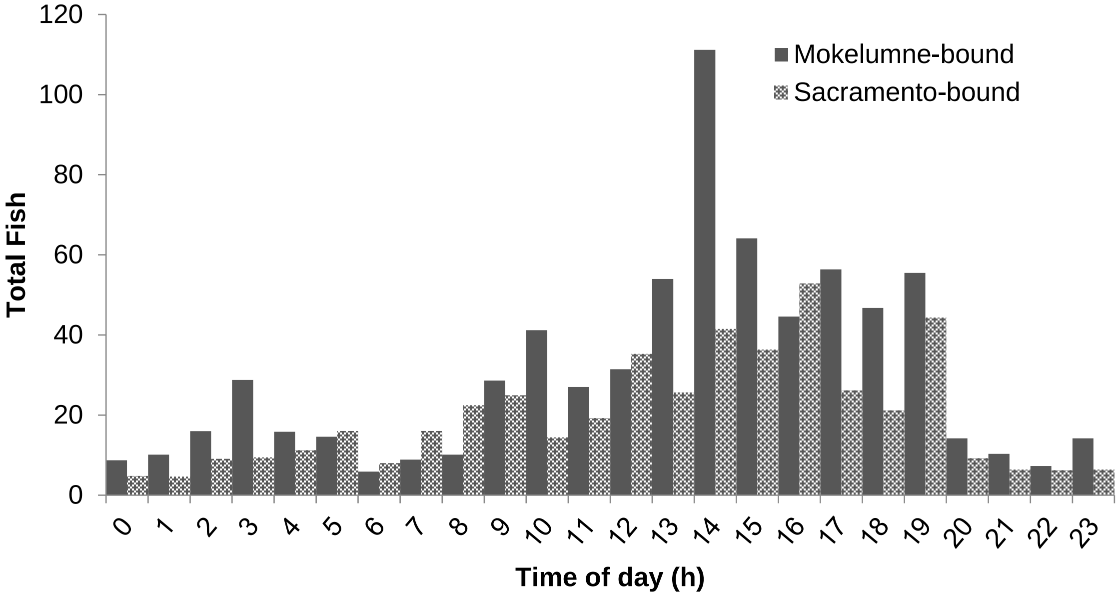


Figure 7.—Total estimated target-sized fish (>400 mm), by time of day, passing within range of the DIDSON camera at the confluence of the Dead Horse Island Cut and the North Fork of the Mokelumne River.

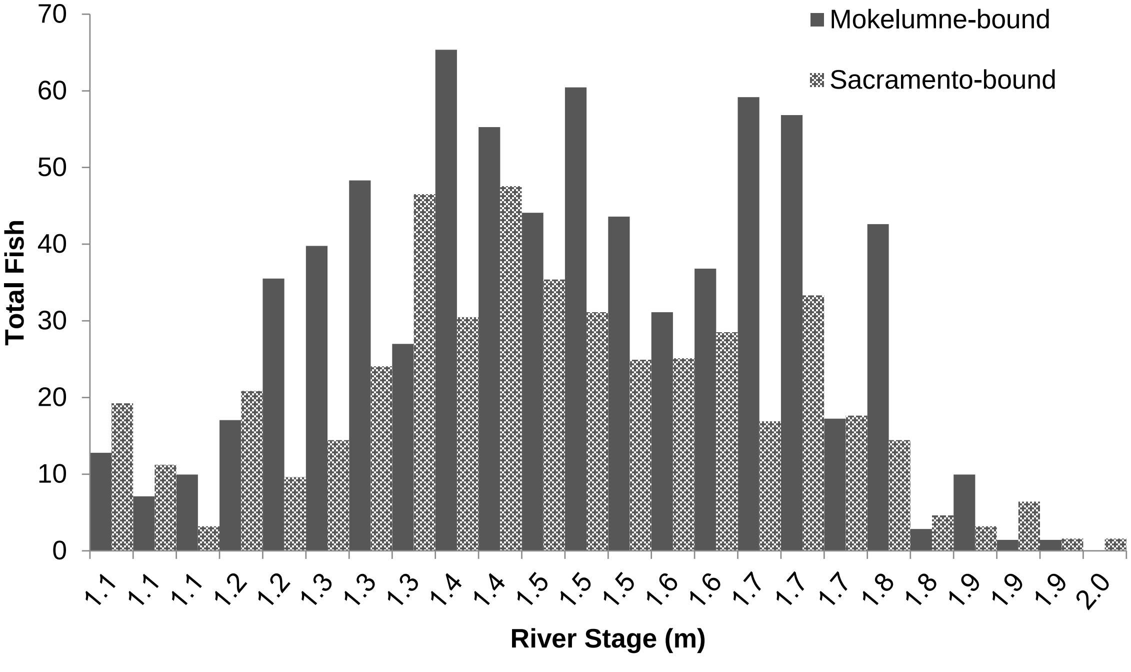


Figure 8.—Total estimated target-sized fish (>400 mm) passing within range of the DIDSON camera at the confluence of the Dead Horse Island Cut and the North Fork of the Mokelumne

River.

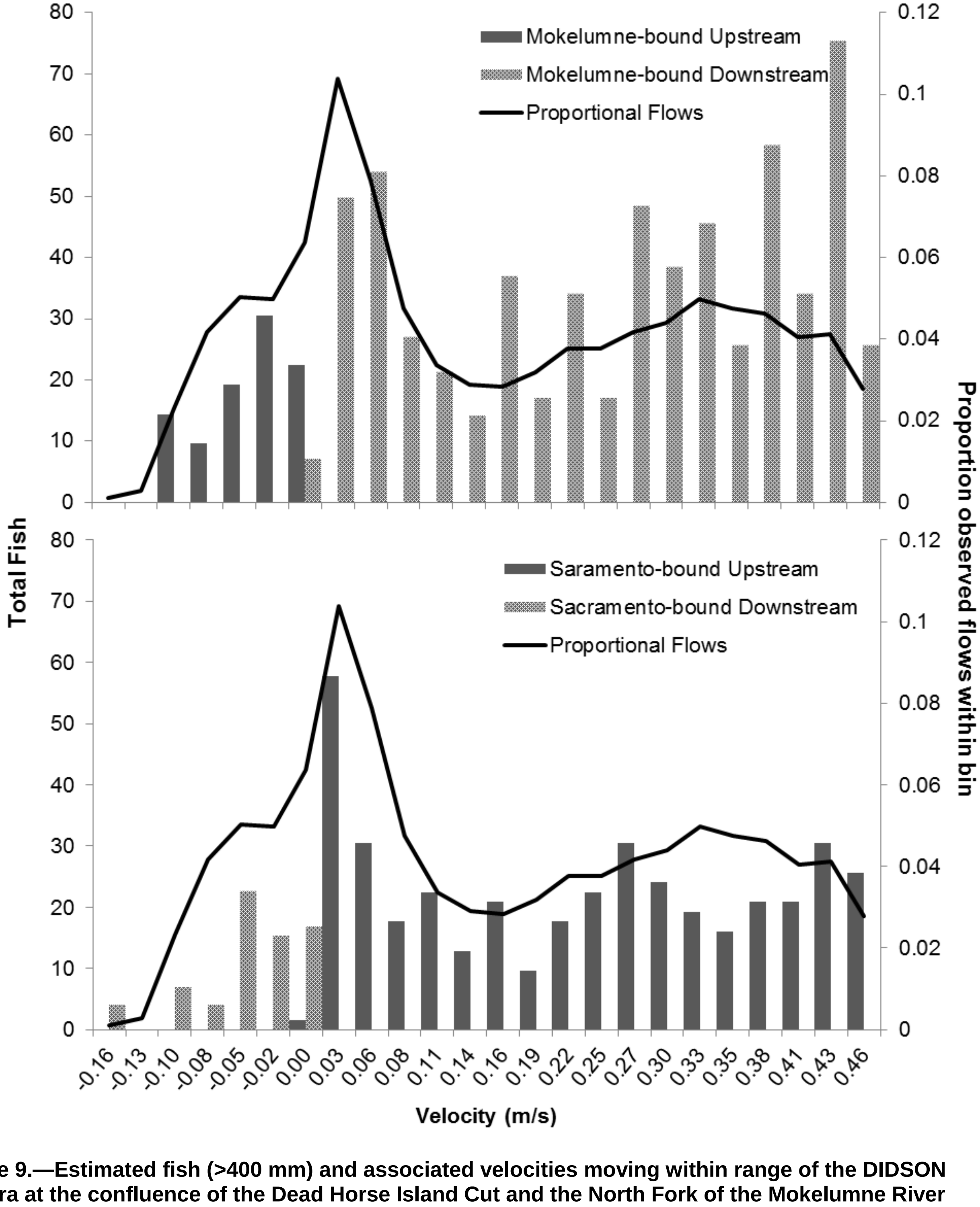


Figure 9.—Estimated fish (>400 mm) and associated velocities moving within range of the DIDSON camera at the confluence of the Dead Horse Island Cut and the North Fork of the Mokelumne River from October 5–October 27, 2015. Total proportion of observed velocities/bin indicated on secondary y-axis.

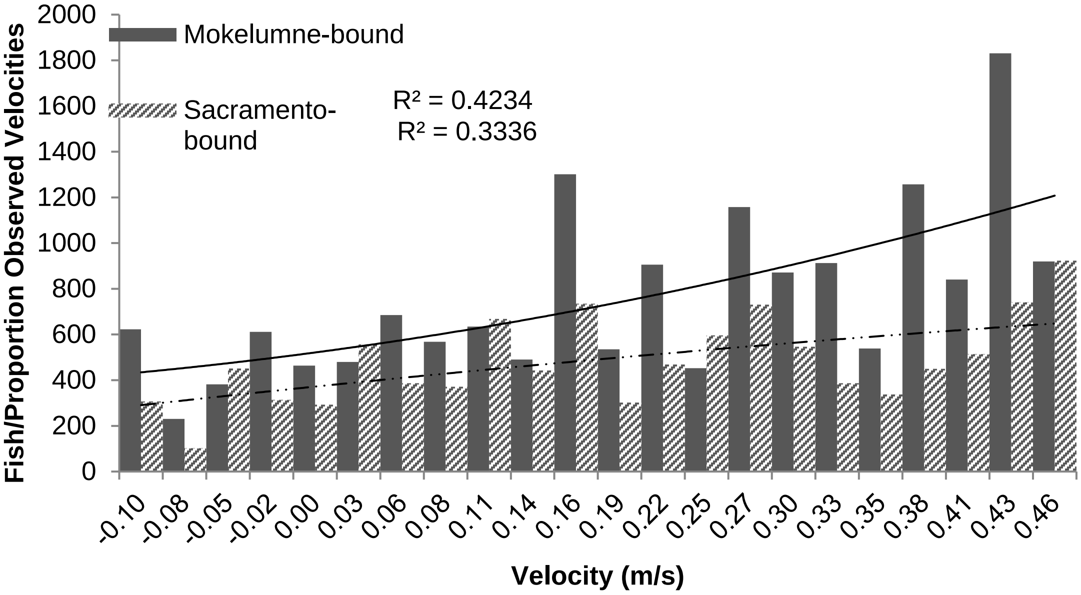


Figure 10.—Total fish/measured velocities (as a function of the measured velocities/frequency bin during the study period), passing within range of the DIDSON camera at the confluence of the Dead Horse Island Cut and the North Fork of the Mokelumne River.

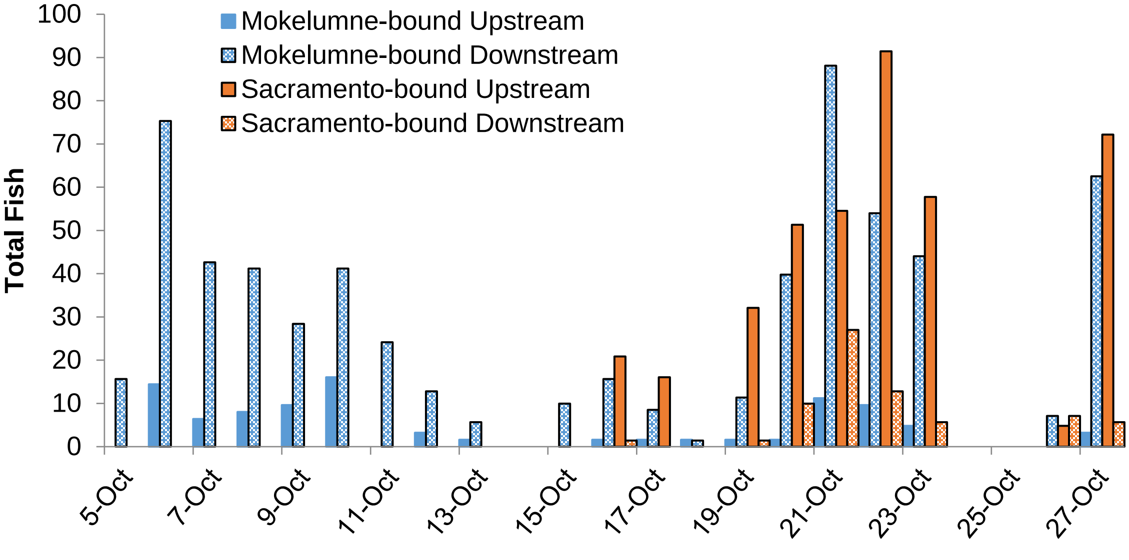


Figure 11.—Total estimated target-sized fish (>400 mm), by date, passing within range of the DIDSON camera at the confluence of the Dead Horse Island Cut and the North Fork of the Mokelumne River.

Table 1. – Release location and date/time of initial detection of six acoustically tagged adult fall-run Chinook Salmon (*Oncorhynchus tshawytscha*) within the Delta Cross Channel E-Barrier study area. Mok=Mokelumne River, Sac=Sacramento River, DFW=California Department of Fish and Wildlife, DWR=California Department of Water Resources

Acoustic #	Spp / Release Location	1st Location Time	2nd Location	3rd Location	4th Location	5th Location	6th Location	7th Location	8th Location	9th Location	10th Location
A69-1303-1010	**Chinook** (DFW) / SJR	South Mok 10/05/15 14:49:14	DHI Cut 10/05/15 16:00:26	Sac River 10/05/15 16:50:23							
A69-1303-1015	**Chinook** (DFW) / SJR	Sac River 10/19/15 15:51:27	Snodgrass Slough 10/19/15 18:16:25	North Mok 10/19/15 18:43:21							
A69-1303-1017	**Chinook** (DFW) / SJR	Sac River 10/12/15 16:37:33	Snodgrass Slough 10/12/15 17:40:10	North Mok 10/12/15 18:11:17	Snodgrass Slough 10/23/15 17:21:25	Sac River 10/23/15 18:10:53					
A69-1601-37826	**Chinook** (DWR) / Yolo Bypass	Sac River 10/19/15 22:19:48	Snodgrass Slough 10/19/15 23:29:59	North Mok 10/20/15 0:05:14	Middle Mok 10/23/15 14:56:58	Main Mok 10/23/15 15:30:01					
A69-1601-37828	**Chinook** (DWR) / Yolo Bypass	Sac River 10/11/15 18:50:40	North Mok 10/15/15 19:00:51	Middle Mok 10/15/15 19:29:56	Main Mok 10/15/15 20:31:12	South Mok 10/16/15 17:25:32	Main Mok 10/16/15 18:04:32	Middle Mok 10/17/15 19:46:34	North Mok 10/17/15 20:16:43	Snodgrass Slough 10/17/15 20:40:29	Sac River 10/19/15 16:38:26
A69-1601-6210	**Chinook** (DFW) / SJR	North Mok 10/29/15 13:38:55	Middle Mok 10/29/15 14:21:00	Main Mok 10/29/15 14:43:31	North Mok 10/29/15 18:24:42	Sac River 10/29/15 18:25:37					

REFERENCES:

Aquacoustics. 2010. Semi-automated DIDSON data analysis for the assessment of Kenai chinook salmon. Aquacoustics, Sterling, Alaska. Available: http://www.aquacoustics.com/proj_Didson-automation.html (July 2016).

Bilski, R. and E. Rible. 2011. Lower Mokelumne River Salmonid Redd Survey Report: October 2010 through March 2011. East Bay Municipal Utility District, Lodi, CA. 17p.

Burwin, D. L., D. E. Bosch, and S. J. Fleischman. 1998. Evaluation of hydroacoustic assessment techniques for chinook salmon on the Kenai River, 1995. Alaska Department of Fish and Game, Fishery Data Series No. 98-3, Anchorage.

Cronkite, G., T. Mulligan, J. Holmes, and H. Enzenhofer. 2007. Categorising salmon migration behaviour using characteristics of split-beam acoustic data. Aquatic Living Resources 20:205–212.

Enzenhofer, H. J., N. Olsen, T. J. Mulligan. 1998. Fixed-location riverine hydroacoustics as a method if enumerating migrating adult Pacific salmon: comparison of split-beam acoustics vs. visual counting. Aquatic Living Resources 11:61–74.

Enzenhofer, H. J. and G. Cronkite. 2000. Fixed location hydroacoustic estimation of fish migration in the riverine environment: an operational manual. Canadian Technical Report of Fisheries and Aquatic Sciences 2312:46p.

Hallock, R. J., R. F. Elwell, and D. H. Fry. 1970. Migrations of adult king salmon *Oncorhynchus tshawytscha* in the San Joaquin Delta as demonstrated by the use of sonic tags. State of California, Department of Fish and Game.

Horn, M. J. *In Draft*. Effects of BAFF operation of fish distribution and behavior at Georgiana Slough. Bureau of Reclamation, Technical Service Center, Denver, Colorado. Technical Memorandum No. 85-82900-14-01.

Guy, C. S., P. J. Bratten, D. P. Herzog, J. Pitlo, and R.S. Rogers. 2009. Warmwater fish in rivers. Pages 59–84 in S. A. Bonar, W. A. Hubert, and D. W. Willis (eds.) Standard methods for sampling North American freshwater fishes. American Fisheries Society, Bethesda, Maryland.

Kormos, B., M. Palmer-Zwahlen, and A. Low. 2012. Recovery of coded-wire tags from Chinook Salmon in California’s Central Valley escapement and ocean harvest in 2010. California Department of Fish and Game, Fisheries Branch Administrative Report 2012–02.

Lindley, S. T., C. B. Grimes, M. S. Mohr, W. Peterson, J. Stein, J. T. Anderson, L.W. Botsford, D. L. Bottom, C. A. Busack, T. K. Collier, and others. 2009. What caused the Sacramento River fall Chinook stock collapse? Pre-publication report to the Pacific Fishery Management Council. 57p.

Marston, D., C. Mesick, A. Hubbard, D. Stanton, S. Forstmann-Roe, S. Tsao, and T. Heyne. 2012. Delta flow factors influencing stray rate of escaping adult San Joaquin River fall-run Chinook Salmon (*Oncorhynchus tshawytscha*). San Francisco Estuary and Watershed Science 10:23p.

Quinn, T. P. 1993. A review of homing and straying of wild and hatchery-produced salmon. Fisheries Research 18:29–44.

Rich, A. 2007. Impacts of water temperature on fall run Chinook salmon (*Oncorhyncus tshawytscha*) and steelhead (*O. mykiss*) in the San Joaquin River system. Publication prepared for the California Department of Fish and Game and submitted to the California Central Valley Water Resources Control Board. San Anselmo (CA): A.A. Rich and Associates. 46 p.

Workman, M. L. 2004. Lower Mokelumne River, upstream fish migration monitoring, conducted at Woodbridge Irrigation District Dam, August 2003 through July 2004. East Bay Municipal Utility District: Lodi, CA, USA.

Workman, M. L. 2006. Lower Mokelumne River, fall run Chinook salmon escapement report, October through December 2005. East Bay Municipal Utility District: Lodi, CA, USA.

Yoshiyama, R. M., F. W. Fisher, P. B. Moyle. 1998. Historical abundance and decline of Chinook Salmon in the Central Valley region of California. North American Journal of Fisheries Management 18:487–521