TITLE: NEAR FIELD EXPORT EFFECTS ON PREDATION, SURVIVAL AND ENTRAINMENT ON JUVENILE SALMONIDS

Project Manager

Alison Collins, The Metropolitan Water District of Southern California

Principal Investigators

Bradley Cavallo, Cramer Fish Sciences
Steven Zeug, Cramer Fish Sciences

Qualifications

The PIs are knowledgeable and experienced in successfully conducting studies and analyses similar to the proposed work. In the last five years, Dr. Zeug and Mr. Cavallo have published numerous peer-reviewed papers evaluating Central Valley water project operation effects on anadromous fishes. For more details on qualifications, please see attached resumes.

Purpose/Objective

A better understanding of how exports affect survival, predation and entrainment of juvenile salmonids is urgently needed. Tagging studies to date have demonstrated survival from the South Delta is very poor (SJRG 2013; Buchanan et al. 2013), but have not adequately addressed how exports influence predation, survival and entrainment. Studies have also indicated fish entrained at the Central Valley Project (CVP) have better survival outcomes than fish entrained into Clifton Court Forebay (CCF) and may be better than natural migration under some circumstances (SJRG 2013). Recognizing these findings, the Collaborative Adaptive management Team (CAMT) 2017 Workplan for Salmonids recommends accelerated actions related to preferential operation of the CVP, predator studies at the CVP and State Water Project (SWP), and improvement to salvage operations, for example evaluating predation losses at salvage. The 2017 Workplan for Salmonids also recommends operational experiments that address a broader range of export conditions (e.g. low export/high inflow and high export/low inflow).

We propose an intensive two-week study for spring 2017 (early May 2017) which will experimentally evaluate how exports influence predation, survival, and entrainment of juvenile Chinook salmon in the South Delta.

Background

Spring export management is currently based upon a conceptual model (formally articulated in the National Oceanic and Atmospheric Administration (NOAA) Fisheries 2009 Biological Opinion) where minimizing exports benefits juvenile salmonids by reducing entrainment risk and by providing beneficial “net” flow conditions in the tidal Delta. Our understanding of this conceptual model has been limited by tagging studies focused on areas of the Delta with relatively weak hydrodynamic effects from exports (e.g. Newman and Brandes 2010, SST 2017). Furthermore, recent acoustic telemetry studies in many cases have not affirmed earlier findings. For example, early coded-wire tag (CWT) studies indicated survival was best for fish remaining in the mainstem San Joaquin River (Dauble et al. 2010). In contrast, acoustic tagging studies indicate survival is very poor for both the mainstem San Joaquin River and for the Old River route (SJRG 2013; SST 2017). Acoustic tagging studies conducted in 2010 and 2011 (years with no Head of Old River Barrier (HORB)) indicated entrainment to the CVP provided the highest survival route from the South Delta. Tagged fish that were not entrained but instead migrated volitionally past the export facilities suffered very poor survival despite relatively high SJR inflows and positive OMR conditions. Intense predation mortality in Clifton Court Forebay has led to the recognition that CVP exports are preferable to SWP exports, but uncertainties remain about how the CVP should be operated to optimize near-field benefits while minimizing

hypothesized far-field indirect harms. For example: What level of CVP exports are needed to achieve benefits of preferential CVP exports? Can benefits be fully realized with a HORB in place? What are the indirect effects of operating the CVP at 4,000cfs vs. a lower export rate?

The proposed study will yield results directly relevant to the conceptual model described above, and will contribute substantially to improved water project operations and more effective fish protections. Though it would also be desirable to study export effects on juvenile salmonids entering the Central Delta from Turner Cut and Columbia Cut (for example), previous studies have shown survival to be exceptionally poor in these routes (SST 2017). As such, it would be extremely difficult to achieve necessary samples sizes to assess hypothesized export effects in these alternative routes. Furthermore, application of hydrodynamic linked biological simulation models will allow observations from this study to be applied to other Delta locations under a variety of operational conditions.

Project Summary

We propose an intensive two-week study for spring 2017 (early May 2017) which will experimentally evaluate how exports influence predation, survival, behavior and entrainment of juvenile Chinook salmon in the South Delta. Pumping rates will be altered in two day intervals between high and low export rates at the CVP and SWP (achieving an average total export rate that satisfies regulatory needs). Batches of fish, acoustically tagged with VEMCO's new predation-detecting acoustic tags (PDAT), will be released on a daily basis into Grant Line Canal about five miles east (upstream) of the export facilities. A dense network of acoustic receivers placed at key points downstream will record information on juvenile salmonid entrainment, predation mortality, and prescreen mortality during high and low exports. Movement direction and migration rate of tagged fish will also be quantified. Details of the experimental design are described further below.

The proposed work includes three tasks.

Task 1 – Project Management and Coordination. We recognize that there are many logistical aspects to the successful implementation of this study. We are actively working in parallel with all concerned parties as they develop their 2017 workplan for salmonids. We also plan to coordinate with regulatory agencies and the operators of the CVP and SWP water project facilities. These meetings will help work out the logistical and planned operations that need to occur during the proposed project.

Task 2 – Field study. This task is described further in sections below, but includes: selecting sites for receiver deployment and fish releases; deploying and maintaining receiver arrays; fish tagging; mobile surveys; and receiver retrieval.

Task 3 – Data analysis and reporting. This task is described further in sections below, but includes downloading and processing receiver data; analyzing and reporting study findings.

*Table 1. Task summary and estimated budget costs. *includes a rough cost estimate of $48,000 for VEMCO-required processing of 2D data generated by HR2 receivers in Subreach B1.*

Task	Product/Deliverable	Due Date	Task Labor Budget
Task 1. Project Management and Coordination			$21,000
Task 2. Field study		June 1st	$123,000
Task 3. Data analysis and reporting	Processed data and technical report on study findings	October 30th, 2017	$100,000*
All equipment and direct costs (excluding shipping and taxes)			$292,000
Budget Total			$536,000

The application of acoustic tags to assess near-field effects during experimental export manipulations has not been attempted previously. We are actively working with researchers from the U.S. Bureau of Reclamation (BOR, Josh Israel, Andrew Schultz, and Clarence Fullard), the California Department of Water Resources (DWR) (Kevin Clark and Javier Miranda) and seeking collaboration with other entities in order to maximize the utility of this study in 2017, share resources, and facilitate additional efforts in 2018 and 2019. We acknowledge involvement of many organizations will be necessary to successfully implement this project. To date we have had several meetings with BOR and DWR staff to discuss the concept and have received friendly review of the concept proposal form BOR's Tracy Technical Advisory Team (TATT) and the water agencies that participate in CAMT. In addition, we've discussed a coordinated effort with Clarence Fullard and Carl Dealy from the TTAT to evaluate VEMCOs predation acoustic tags to assess predation mortality of salvaged fish released in the western Delta. The study concept was also shared at the most recent (February 2017) Interagency Ecological Program (IEP) Biotelemetry Project Work Team to facilitate coordination between all of the acoustic tagging work taking place in the Central Valley and Delta area. Discussions and meetings with other researchers actively tagging fish on the San Joaquin River in spring 2017 (Pat Brandes, U.S, Fish and Wildlife Service (FWS), and Gabriel Singer, University of California Davis) are ongoing to discuss more specific coordination of shared equipment, fish release dates and locations, coordination of requested export regimes, and receiver placement (regardless of the different tagging technologies being used). Both Pat Brandes and Gabriel Singer have indicated that their studies will be completed by the first week of May, thus allowing implementation of this study and altered export regimes without concern of influencing their study objectives, design, or implementation. In addition, this study is being developed in parallel with CAMT efforts to address specific science needs and management issues related to juvenile salmonid behavior and survival in the Delta as part of their 2017 Workplan for Salmonids. To help coordinate efforts and receive CAMT input we are actively working with Bruce DiGennaro on the best way for this proposed study to be shared with CAMT. We are open to discussing with CAMT any coordinated efforts, input, or consideration that they may have of this proposed study. In addition, immediate consultation with regulatory agencies such as NOAA Fisheries are planned to discuss study questions and design, export manipulation, take considerations, and development of a proposed multi-year study following up on this work. We plan on continuing coordination with all of these entities throughout the study, analysis, and reporting.

The proposed study is now possible because of what we have learned from numerous prior studies, but also because of the present availability of PDATs (see Attachment). With traditional acoustic tags, it can be difficult to determine whether tag detections represent live juvenile salmon, or the predators that consumed them. The PDAT functions like a normal acoustic tag, but emits a different signal 5 to 9 hours after a predator consumes the tagged fish (Halfyard et al. 2017). Predation detecting tags will yield a new response variable (predation rate) while providing greater confidence estimating survival and in characterizing near-field behavioral responses to exports.

Two other elements are critical to the success of the proposed 2017 study: 1) absence of the Head of Old River Barrier; and 2) exports are altered in a coordinated fashion intermittingly between high and low export rates over a two week period.

HORB

The HORB been installed each spring since 2011. Use of the HORB is predicated upon an assumption that juvenile salmonids will experience better survival by remaining in the San Joaquin River (i.e. out of the Old River corridor). Recent studies have not supported this earlier finding. Also, the HORB effectively blocks fish (and flows) from entering the Old River route, it also prevents collection of new information necessary to assess near-field export effects.

Exports

During April and May, exports are constrained as a function of inflow from the San Joaquin River. This study does not require any particular level of San Joaquin River inflow, but does require an experimental modification of exports during a two-week period. If for example, NOAA Fisheries reasonable and prudent alternative (RPA) constrains total exports to 3,500 cfs- then this study would request that total exports be

allowed (in two day intervals) to be alternated between 4,500 and 1,500 cfs. Such operations could allow experimental higher (and lower) exports while achieving an average total export rate consistent with RPA requirements. Since fish screens at the CVP export facilities were designed to function at export rates of approximately 4,000cfs, it is critically important that the high export treatment during this experiment meet or approach this export rate. Average exports less than 2,750cfs would provide insufficient contrast in export operations, and would be inconsistent with the CAMT 2017 Workplan for Salmonids recommendation for experimenting with broader range of export conditions.

Figure 1. Approximate location for tagged fish releases, study reaches (A, B, C, D, E and F) and subarea for detailed (2-D) receiver arrays (B1). For insets for B1, red dots indicate approximate locations of HR2 VEMCO receivers.

Experimental Design

The study design is relatively simple and takes maximum advantage of predation-detecting acoustic tags and surplus VEMCO acoustic tag receivers available for 2017, which has been coordinated with Josh Israel. As indicated previously, we are actively working with Josh Israel, Andrew Schultz and Clarence Fullard (BOR-Denver) and others to share resources and to advance high priority research topics.

As shown in Figure 1, tagged fish will be released into Grant Line Canal approximately 2.5km upstream of the first study area, Reach A. Six reaches (A, B, C, D, E, and F) will be delineated, each bracketed with dual receiver arrays. Within reach B, a 2D array of HR2 receivers will be deployed subreach B1. These reaches represent a range of hydrodynamic conditions and different exposures to export effects (Table 2).

Table 2. Reach descriptions, expected survival rates, and likely number of tagged fish surviving to each reach. Survival rates estimated from per km values reported in CAMT SST 2017. Number of tagged fish surviving to each reach assumes 280 fish released. Number of fish entrained to CVP (75) and SWP (25) is a placeholder value- expected values are presently unknown.

Reach	Length (km)	Survival	Tagged fish w/ 280 released	Entrained	Description
Release	2.5	0.95	266	-	A riverine channel for fish to aclimate and assume a more natural migraiton behavior
A	1.8	0.96	257	-	A riverine channel immediately preceding entrance to the CVP
B	1.65	0.97	248	75	A semi-tidal channel which includes the entrance to the CVP
C	0.25	0.99	172	25	A semi-tidal channel bracketting the entrance to CCF
D	2.3	0.85	125	-	A tidal channel just North of the entrance to CCF; very strongly altered hydrodynamics due to exports
E	4	0.75	93	-	A tidal channel with strongly altered hydrodynamics due to exports
F	4.6	0.72	67	-	A tidal channel with hydrodynamics moderately influened by exports

Twenty tagged fish will be released each day for two weeks (Table 2). The diel schedule for these releases has not yet been determined. Without HORB, Grant Line Canal flows like a river (i.e. unidirectional) and thus tagged fish will have an opportunity to orient and will arrive to the CVP export facilities (Reach B) as naturally as possible.

Table 3. Proposed schedule of daily releases of tagged fish and export levels. Actual SWP exports will be a function of operational needs and regulatory allowances. Ideally, SWP operations will remain relatively stable for the study duration.

Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	
Fish Released	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	
CVP Exports	4,000	4,000	800	800	4,000	4,000	800	800	4,000	4,000	800	800	4,000	4,000	800	800	**EXPORT**
SWP Exports	700	700	700	700	700	700	700	700	700	700	700	700	700	700	700	700	**AVERAGE**
EXPORT TOTAL	4,700	4,700	1,500	1,500	4,700	4,700	1,500	1,500	4,700	4,700	1,500	1,500	4,700	4,700	1,500	1,500	3,100

As shown in Table 3, CVP exports during the study will alternate between 4,000cfs and 700cfs or 800cfs (dependent of facility) every two days. Exports at or near 4,000cfs are important because this pumping rate provides velocities where fish screen efficiencies are maximized. 800cfs is the minimum safe export rate at CVP. Table 3 indicates a daily averaged SWP export rate of 700cfs. We do not propose to experimentally alter SWP exports or CCF radial gates for this study. SWP exports for the spring of 2017 are unknown at this time and presumably will be determined by San Joaquin River flows and other regulatory considerations. The proposed study will yield useful information regardless of SWP operations, but relatively consistent SWP operations at some relatively low export rate would be optimal.

Detections at fixed receivers and by mobile tracking within reaches will be used to track fates and movements of tagged fish. Receiver arrays will be deployed as indicated in Figure 1 except that VEMCO receivers will be added as needed to: 1) assess within-facility predation and louver efficiency at the CVP and 2) to assess survival to salvage release for both CVP and SWP. If SWP exports are low, relatively few tagged fish are expected to enter Clifton Court Forebay. However, we will work with DWR staff to make sure VEMCO receivers are deployed to detect tagged fish salvaged at the Jones pumping plant. VEMCO receivers will also be deployed to detect tagged fish at the CVP salvage facility.

Mobile tracking will occur daily from the point of release through Reach F (approximately 17km). The primary purpose of the daily mobile tracking will be to detect mortalities or predation events not detected at fixed-location receivers located at reach boundaries.

We anticipate tagged fish occupying reach ***r*** during time ***t*** will experience one of four possible fates:

1. Entrainment: movement either toward or into the nearest export facility
2. Exit: movement into an adjacent reach away from nearest export facility
3. Predation mortality: eaten by a predator as indicated by PDAT
4. Other mortality: tagged fish does not exit the reach and the PDAT is not triggered

Like any mark-recapture study, some rules and assumptions will be necessary to allow analysis. Preliminarily, we anticipate the following:

- Tagged fish must spend at least 30 continuous minutes within a reach or to have moved through the reach in order to be considered an occupant.
    - A tagged fish moving back and forth between reaches over short periods of time (<15 minutes) will not be considered an occupant of any reach.
- For tagged fish occupying a reach for ≥5 hours, we will assume PDAT trigger indicates predation occurred within that reach.
- When a PDAT trigger occurs for a tagged fish having occupied a reach <5 hours, we evaluate fish movements and mobile tracking to identify the reach where predation is most likely to have occurred.
- Additional rules for analysis will be developed as the study develops further.

Hypotheses, Questions and Related Management Rationale

Before field study begins, we will provide specific predictions about the expected fate of tagged fish given water project operations and other factors. In the interim, we propose six hypotheses:

H_1: In reaches A, B, and C, predation mortality will be less during high exports.

Rationale: Exports have been hypothesized to slow and disorient migrating juvenile Chinook salmon. However, in reaches close to the export facilities, higher CVP exports are expected to decrease exposure to predation by increasing the rate at which fish are entrained to the salvage facilities. This hypothesis tests the idea that entrainment associated with higher exports reduces predation mortality in the near field. This hypothesis is relevant to the CAMT SST recommendation to preferentially operate the CVP and is relevant to the export restrictions specified in the RPA IV.2.1 and IV.2.3.

H_2: In reaches D, E and F, predation mortality will be significantly greater during high exports.

Rationale: Hydrodynamic conditions reaches D, E and F will be strongly impacted by experimental export operations. Unlike H_1, tagged fish in these reaches will not have the benefit of increased entrainment to avoid predation risk. As such, observing predation mortality (and other outcomes) within these reaches will allow us to test indirect effects of altered hydrodynamics which have been hypothesized by NOAA Fisheries and which are the underlying basis of the RPA actions IV.2.1 and IV.2.3.

H_3: At subarea B1 during high exports, most fish approaching the trash rack will be entrained.

Rationale: Exports have been managed to minimize entrainment of juvenile salmon. Screening facilities at the CVP export facilities were designed to operate at pumping rates of approximately 4,000 cfs. We expect exports lower than 4,000cfs will tend to reduce entrainment, but may increase predation mortality. Hypothesis H_3 addresses the mechanism underlying H_1. This hypothesis is relevant to the CAMT SST recommendation to preferentially operate the CVP.

H_4: At subarea B1 during low exports, most fish approaching the trash rack will leave the area and avoid being entrained at the CVP or be consumed by predators.

Rationale: Exports have been managed to minimize entrainment of juvenile salmon. Screening facilities at the CVP export facilities were designed to operate at pumping rates of approximately 4,000 cfs. We expect low exports will tend to reduce entrainment, but may result in increased predation mortality. Hypothesis H_3 addresses the mechanism underlying H_1. This hypothesis is relevant to the CAMT SST recommendation to preferentially operate the CVP.

H_5: During high exports, more tagged fish will survive to salvage than are estimated to survive to Delta exit via natural migration.

Rationale: Exports can result in entrainment, but altered hydrodynamics have also been hypothesized to slow and disorient migrating juvenile Chinook salmon. This hypothesis tests the idea that, for fish

reaching the vicinity of the export facilities, entrainment associated with increased exports improves through-Delta survival more than altered hydrodynamic conditions (i.e. indirect effects) harm through-Delta survival. This hypothesis is relevant to the CAMT SST recommendation to preferentially operate the CVP and is relevant to the export restrictions RPAs IV.2.1 and IV.2.3.

H_6: Elapsed time from reach entry to reach exit will not differ between low and high exports.

Rationale: Exports alter hydrodynamics and have been hypothesized to slow migrating juvenile Chinook salmon. This hypotheses tests the idea that surviving fish (those not preyed upon) will migrate more slowly during high exports than during low exports. This hypothesis is relevant to export restrictions specified in RPA actions IV.2.1 and IV.2.3.

In addition to these six hypotheses, the proposed study will yield data on several other questions. These topics are phrased as questions because outcomes are too uncertain to allow hypothesis specification.

Q_1. How do fish behave at the entrance to the CVP (subarea B1) in relation to pumping rate and tides?
Q_2. What fraction of fish entering Reach C are entrained into CCF?
Q_3. What is prescreen mortality (due to predation) and facility mortality (due to predation, impingement or entrainment) at the CVP?
Q_4. Given observed salvage of tagged fish at the CVP, does the loss calculation tool developed for Term 2a of the NMFS BiOp provide a useful prediction of the number of tagged fish entrained?

Statistical analysis

Statistical analysis will be based upon standard Cormack-Jolly-Seber survival estimation (H_1, H_2, H_5, Q_3), and also upon muli-state mark-recapture modeling where only fish of known-fates are included in the analysis (H_3 & H_4). The study design includes numerous dual arrays and daily mobile tracking will allow detection probabilities to be thoroughly evaluated, and in many cases assumed to have a value of 1. H_6 will likely utilize a generalized linear model where time of reach occupancy is the dependent variable, and where exports and other factors are covariates. Analyses for Q1 and Q2 will likely begin with visual plotting of 2D fish behavior- categories of response from these observations will be tabulated and analyzed as appropriate.

The proposed study is a novel approach, addressing numerous hypotheses. It is therefore impractical to conduct statistical power analyses for each. However, as indicated in Table 2, we anticipate a total of 257 tagged fish will enter Reach B and be available for evaluating hypotheses related to CVP export effects on predation, survival and entrainment. This sample size will allow us to statistically distinguish a 20% or larger change in predation or survival associated with the export treatment.

Source Fish

Juvenile Chinook salmon will be acquired from the Feather River Fish Hatchery in April (part of a request filed as required with CDFW in 2016). The fish will be held at a facility (TBD) and be grown to a size suitable for tagging (≥110mm, tag burden 5% or less of mass).

AT Equipment Costs (excluding taxes and shipping)

300 PDAT tags: $217,500

NOTE: These tags must be ordered at least six weeks in advance of when they are needed. A drop dead for ordering these tags for use in spring 2017 is March 7th. We are investigating if tags are ordered but not used, the percentage battery life that will remain 6 months later.

6 acoustic beacon tags: $2,000
12 HR2 Receivers: $48,960
2 VTA-180k-V5D Tag Activators: $690
High Speed RS-485 Communication Kit for HR2 Receivers: $1,120
36 VR2 Receivers: Borrow from BOR available surplus
2 VR100 and VH180 omni-directional hydrophones: Borrow from BOR available surplus

Estimated Cost
Table 1 provides an estimated budget for the total project.
The State Water Contractors, San Luis and Delta-Mendota Water Authority, Coalition For A Sustainable Delta, and State and Federal Contractors Water Agency have all expressed interested in supporting the study and contribution amounts and other potential funding partners are under discussion.

Proposed Project start date and end date: March – October 2017
The planning for this study will occur in March and April. The field work will occur over a one-month period in May during the out-migration season of the fall run Chinook salmon but before water temperatures are too warm to release tagged juvenile salmonids. The analysis, reporting, and dissemination of results will occur between June and October. A detailed report will also be produced by the end of October highlighting primary results, how this information can be used to refine the multi-year experiment, management suggestions/implications, and recommendations for future studies considered as either part of the multi-year study or future studies.

Feasibility
The study is feasible because of the experience and knowledge of the PIs, project collaborators, and because it focuses on a relatively small portion of the Delta over a relatively short period of time. Doubts about the feasibility of the study are related primarily to uncertainty about the reliability of PDATs. Predation-detecting acoustic tags are new. VEMCO has provided a datasheet describing expected tag performance (Attachment) and application of PDAT has been described in one peer-reviewed publication (Halfyard et al. 2017). Attributes of PDATs which we believe make it suitable for the proposed study:

- PDAT tags correctly identified predation events 95% of the time (i.e. very low incidence of false negatives)
- With prey fish similarly sized to the proposed study, and at water temperatures $\geq 16^{o}C$, 75% of tags triggered within 5 hours of predation, and 100% triggered within 9 hours. Receiver arrays and mobile surveys of the proposed study should allow us to account for this lag in predation detections and approximately account for where and when predation occurred.
- Zero false positives among live salmon have been observed with 15 days of tagging, 2% false triggered after 15 days, and 43% had false triggered after day 34. The proposed study is focused on short-term outcomes (<2 weeks) and thus will be unaffected by false positives occurring mostly after 4 weeks.
- For tagged prey fish that died (other than from predation), 20% of PDATs falsely identified a predation event in the dead and decomposing fish 2 to 3 days after mortality occurred. Daily mobile surveys in the proposed study will allow us to identify non-moving juvenile salmon within 2 days. Therefore our study will be able to account for any false predation detections resulting from natural mortality.

As part of our study, a subset of approximately 20 PDATs will be held for evaluation of tag retentions, survival, growth and/or predation detection. We are working with BOR staff to determine the most effective use of these tags.

Frequently Asked Questions

Q1. Is this study redundant or conflicting with other studies planned for Spring 2017?

A1. We are not aware of any planned studies which share objectives and methods proposed here. A variety of acoustic tagging studies are ongoing, but behavior, predation mortality, and entrainment in the South Delta, especially in relation to project operations, has not been a primary objective of those studies. At least two JSAT-based acoustic tagging studies are planed for the mainstem San Joaquin River in spring 2017. These studies might compliment, but will not conflict with the proposed work.

Q2. Why are study fish released into Old River when the HORB is usually in place and fish will not typically be able to access that route?

A2. Releasing fish into the Old River corridor with no HORB provides the best opportunity for evaluating near-field export effects by allowing a relatively large number of tagged fish to orient and arrive naturally in the vicinity of the export facilities. The fate and behavior of fish in response to export operations observed will have model-based application throughout portions of the Delta affected by exports. Releasing tagged fish at other locations either does not allow orientation and natural migration, or is so far away that very few are likely to survive to reach the vicinity of the export facilities.

Q3. Why not study how exports affect Sacramento River basin juvenile salmonids reaching the Central Delta via Georgiana Slough?

A3. First, numerous acoustic tagging studies have been conducted among juvenile salmonids originating from the Sacramento River basin. Much data is available on they hypothesized effect of exports, but to-date such questions have not been considered by investigators utilizing acoustic telemetry methods. Second, data which is available suggests few juvenile salmonids approach the South Delta from the Sacramento River (Zeug and Cavallo 2013). Thus, a very large number of tagged fish would need to be released, and a greatly augmented receiver array network would need to be installed from the mouth of Old-Middle River corridor all the way south to the export facilities.

Relevance to the State and Federal Contractors Water Agency (SFCWA)
SFCWA supports research that generates usable information to improve water supply reliability, including studies focused on listed fish. In addition, SFCWA has an interest in generating science to improve the RPAs and understand the mechanisms of flow-related correlations to fish survival and entrainment and seek to gain a better understanding of the direct and indirect effects of project operations. This study will evaluate the preferential operation of the CVP and provide information on the near-field effects of exports, flow, and predation on fish entrainment and survival that will provide insight into the mechanisms underpinning outmigrating juvenile salmonid survival. Data collected will assess predation mortality under high and low exports in the immediate and near area export facilities, entrainment rates under high and low exports, survival estimates to Delta exit for salvaged fish vs fish who undertake natural migration, migration rates of juvenile salmonids through study area under high and low exports, and provide entrainment estimates for the newly developed Term 2a to calculate loss of juvenile salmonids at the CVP export facility. This study will be one of the first to use new PDAT technology in a field based setting and can help inform future studies using this technology. A better understanding of mortality resulting from predation, altered behavior and entrainment under high and low export conditions will provide information that will help better manage water supply reliability while protecting listed salmonids. This study will yield data on functional relationships between exports and entrainment probability and exports and survival. Such relationships are not currently available. The absence of quantitative relationships between water project operations and fish success have prevented managers from effectively utilizing principles of adaptive management. The results from this study will contribute substantially to establishing a rigorous, structured decision making tools for determining how to best manage water project operations to achieve mutual goals of fish protection and water supply reliability.

Project Manager and contact information:

Alison Collins, The Metropolitan Water District of Southern California
acollins@mwdh2o.com
916-950-2628

Cramer Fish Sciences will lead field work, analysis and reporting.

References

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Attachment

Applications

Validating Mark Recapture Survival Models

Separating Tag Mortality from Natural Mortality

Investigations into Predator-Prey Behavior

dominance

prey selection

genetic characteristics

prey detection distance

water quality impacts on predation success

Investigating Impacts of Invasive Predators on Native Species

Trophic Energy Transfer on Reefs

VEMCO Predation Transmitter

Detect if your tagged fish has been eaten by a predator!

VEMCO predation tags permit exploration of novel questions and important research while increasing the certainty with which researchers can interpret their telemetry results.

The predation tag provides a direct measure of digestion wherein stomach acids digest a polymer. It is a superior technique to using indirect measures of activity such as acceleration.

The tag ID changes approximately 3 to 5 hours after predation and its trigger success rate is 100%.

Over the past two years, we have conducted over 140 control and experimental trials (12°C to 24°C) with an independent University research group.

Compatible with VEMCO's new HR2 receiver and the VR2W-180 kHz receiver, the predation tag supports two acoustic transmission systems (PPM and HR).

Physical Specifications

Frequency (kHz)	180
Length (mm)	12.7
Width (mm)	5.6
Weight in air (g)	0.68
Trigger Time (hrs)	3 to 5*

** Temperature dependent*

For more information, contact Dale Webber (dmwebber@vemco.com)

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PRELIMINARY - Information subject to change without notice.

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Principal Scientist

13300 New Airport Rd, Suite 102
Auburn, CA 95602
V 530.888.1443
bcavalllo@fishsciences.net

Years of Experience

- 22 years. Professional start date: May 1994

Education

- MS, Aquatic Ecology, University of Montana, Missoula MT. 1997.
- BS, Fisheries Biology, University of California, Davis, CA. 1994.

Since joining Cramer Fish Sciences in 2006, Brad has led a growing team of scientists working to help resolve some of the Central Valley's most vexing fisheries management challenges. Brad is an experienced project and team leader, a diligent listener, and a resourceful problem-solver with more than 22 years of experience working on California fish issues. Brad has provided scientific leadership on a variety of multiagency and stakeholder involved investigations including the 2012 Stipulation Study, Battle Creek Chinook Salmon and Steelhead Population Modeling, Oroville Facilities FERC Relicensing, State Water Project/Central Valley Project ESA Consultations, Feather River Hatchery Management Plan development, and the Nimbus Steelhead Broodstock Evaluation project. Brad's Central Valley salmonid expertise is demonstrated by numerous related project reports, published papers and scientific presentations. In the course of his professional career and education, Brad has attained expert knowledge of regulated rivers, particularly related to the ecology of steelhead and Chinook salmon and the potential influence of human activities through barriers, diversions, hydroelectric project operations, habitat modifications and harvest. Brad excels as a team leader, especially with complex and contentious projects requiring the application and evaluation of quantitative models for assessing aquatic habitats and fish population dynamics. Brad's project experience emphasizes linking physical models (flows, temperatures, diversions) with biological process to explore the influence of water project operations and habitat quality on salmon and steelhead populations.

Brad is currently President of Cramer Fish Sciences and is a Past-President of the California-Nevada Chapter of the American Fisheries Society.

Employment History

Principal Scientist. Cramer Fish Sciences, Auburn, CA. 2010-present.

Associate Consultant, Fisheries Scientist. Cramer Fish Sciences, Auburn, CA. 2006-2009.

Senior Environmental Scientist, California Department of Water Resources, Sacramento, CA. 2003-2006.

Environmental Scientist. California Department of Water Resources, Sacramento, CA. 1999-2003.

Fisheries Biologist. California Department of Fish and Game, Stockton, CA. 1998-1999.

Scientific Aid, California Department of Fish and Game, Rancho Cordova, CA. 1997-1998.

Selected Publications and Reports

Cavallo, B. et al. 2014. Predicting juvenile Chinook routing in riverine and tidal channels of a freshwater estuary. Environmental Biology of Fishes, 98(6): 1571-1582

Cavallo, B., J. Merz, J. Setka. 2012. Effects of predator and flow manipulation on Chinook salmon (*Oncorhynchus tshawytscha*) survival in an imperiled estuary. Environmental Biology of Fish, published online April 2012. DOI 10.1007/s10641-012-9993-5

Merz, J., S. Hamilton, P. Bergman, and **B. Cavallo**. 2012. Spatial perspective for delta smelt: a summary of survey data. California Fish and Game 97(4): 164-189.

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Delaney, D., P. Bergman, **B. Cavallo** and J. Melgo. 2014. Stipulation Study: Steelhead Movement and Survival in the South Delta with Adaptive Management of Old and Middle River Flows. California Department of Water Resources Technical Report.

Cavallo, B., P. Gaskill, J. Melgo. 2012. Investigating the influence of tides, inflows, and exports on sub-daily flow in the Sacramento-San Joaquin Delta. Available: http://www.fishsciences.net/reports/2013/Cavallo_et_al_Delta_Flow_Report.pdf

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Zeug, S.C. & **B.J. Cavallo**. 2014. Controls on the entrainment of juvenile Chinook Salmon (*Oncorhynchus tshawytscha*) into large water diversions and estimates of population-level loss. PLoS One 9(7): e101479. Doi:10.1371/journal.pone.0101479.

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Zeug, S.C., P.S. Bergman, **B.J. Cavallo** and K.S. Jones. 2012. Application of a life cycle simulation model to evaluate impacts of water management and conservation actions on an endangered population of Chinook salmon. *Environmental Modeling and Assessment* 17:455-467.

CRAMER FISH SCIENCES
An Employee Owned Consulting Company

STEVEN ZEUG, PH.D.

Senior Scientist, Science Operations Manager

13300 New Airport Rd, Suite 102
Auburn, CA 95602
V 530.888.1443
stevez@fishsciences.net

Years of Experience

- 16 years. Professional start date: May 2001

Education

- PhD, Wildlife and Fisheries Sciences, Texas A&M University, College Station, TX. 2007.
- BS, Fisheries Biology, Humboldt State University, Arcata, CA. 2001.

Dr. Zeug has a wide range of experience, having conducted fisheries investigations in a diversity of aquatic systems from headwater streams in Costa Rica to large floodplain rivers and estuaries in Texas and California. Steve's interests in fisheries biology include: river restoration, population dynamics, community interactions, and food webs. He has extensive experience with the techniques used in the measurement of aquatic communities and has conducted research on a wide range of species from gar and large river minnows to anadromous salmonids and sturgeon. Steve has authored over 25 peer-reviewed papers, multiple technical reports, and many scientific presentations related to ecology and resource management. He has a talent for quantitative analysis and guiding projects from experimental deign to communication with stakeholders and the scientific community. Steve actively leads a team of biologists in numerous projects at CFS ranging from field investigations and monitoring efforts to interdisciplinary modeling of complex adaptive management programs.

Employment History

Senior Scientist, Cramer Fish Sciences, Auburn, CA. 2010-present.

Independent Consultant, 2010.

Postdoctoral Researcher, University of California-Santa Barbara. 2007-2009.

Graduate Research Assistant, Department of Wildlife and Fisheries Sciences, Texas A&M University. 2003-2007.

Laboratory Instructor, Department of Biology, Texas A&M University, 2004-2005.

Graduate Student Mentor, National Science Foundation Undergraduate Mentoring in Environmental Biology (UMEB) Program, Texas and Costa Rica. 2002-2006.

Scientific Aid, California Department of Water Resources, Sacramento, CA. 2001-2002.

Selected Publications

Zeug, S.C., A. Brodsky, N. Kogut, A.R. Stewart and J.E. Merz. 2014. Ancient fish and recent invaders: white sturgeon (*Acipenser transmontanus*) diet response to invasive species-mediated changes in a benthic prey assemblage. Marine Ecology Progress Series 514:163-174.

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Zeug, S.C., K. Sellheim. C. Watry, B. Rook, J. Hannon, J. Zimmerman, D. Cox and J. Merz. 2014. Gravel augmentation increases spawning utilization by anadromous salmonids: a case study from California, USA. *River Research and Applications* 30:707-718.

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Zeug, S.C., D. Peretti & K.O. Winemiller. 2009. Movement into floodplain habitats by gizzard shad (*Dorosoma cepedianum*) revealed by dietary and stable isotope analyses. *Environmental Biology of Fishes* 84:307-314.

Zeug, S.C. & K.O. Winemiller. 2008. Evidence supporting the importance of terrestrial carbon in a large-river food web. *Ecology* 89:1733-1743.

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Zeug, S.C., K.O. Winemiller & S. Tarim. 2005. Response of Brazos River oxbow fish assemblages to patterns of hydrologic connectivity and environmental variability. *Transactions of the American Fisheries Society* 134:1389-1399