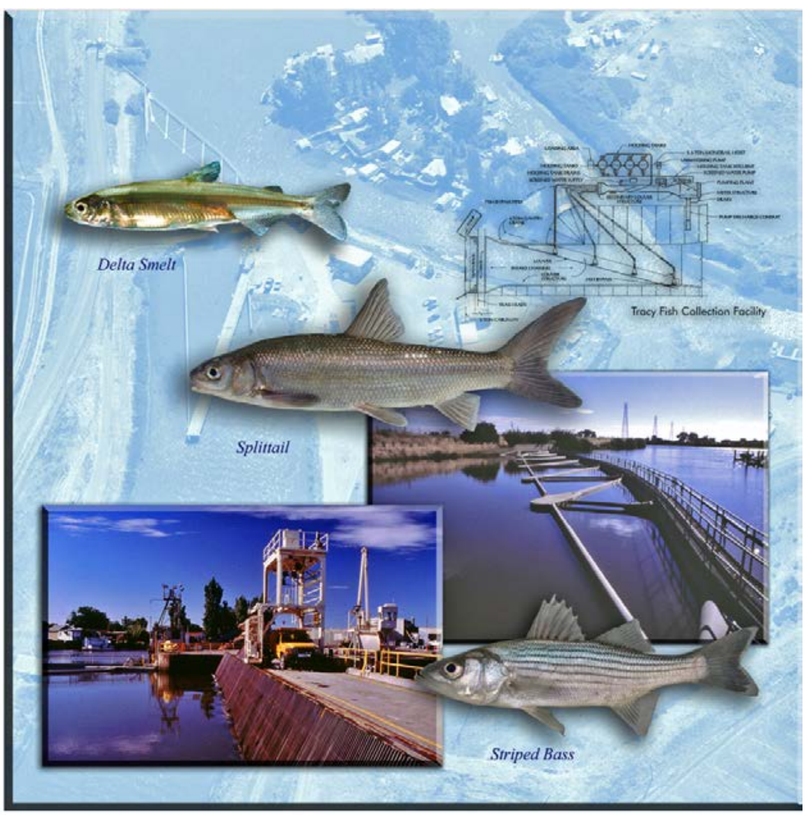
RECLAMATION

*Managing Water in the West*

# FY18 Proposal Package for Tracy Fish Facility Improvement Program




U.S. Department of the Interior
Bureau of Reclamation
Mid-Pacific Region

August 2017

# Mission Statements

The mission of the Department of the Interior is to protect and provide access to our Nation's natural and cultural heritage and honor our trust responsibilities to Indian Tribes and our commitments to island communities.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

# Tracy Fish Facility Improvement Program

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# Cover

Fish photography by René Reyes, Tracy Fish Collection Facility, Tracy, California.
Design by Doug Craft.

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# Assessing the Efficacy of a Modified Fish Salvage Release Scheme to Reduce Predation Loss of Juvenile Salmonids at the Sacramento-San Joaquin River Delta Release Sites

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## Summary

Many resident and transient species of fish to California's Sacramento-San Joaquin River Delta (Delta) have declined markedly from drought, habitat modification, water diversions, and other impacts (Bennett and Moyle 1996, Brown *et al.* 1996, Moyle 2002). The United States Bureau of Reclamation (Reclamation) Tracy Fish Collection Facility (TFCF) was built in the 1950s to divert and salvage juvenile Chinook salmon (*Oncorhynchus tshawytscha*) and striped bass (*Morone saxatilis*) in the Sacramento-San Joaquin River system from entrainment in the Delta Mendota Canal via the Jones Pumping Plant (JPP; Bates *et al.* 1960), which provides freshwater deliveries for the Central Valley Project. The fish salvage process uses a louver-bypass system which intercepts fish from entrainment and pump- induced mortality at the JPP. Though the facility was designed to salvage juvenile Chinook salmon and striped bass, all fishes— including non-native species—are captured and transported to downstream release sites in the Delta.

From 2000 to 2003, TFCF operations resulted in the salvage of roughly seven million fish per year (Reclamation 2009), including an annual average of 31,900 federally protected Chinook salmon (winter and spring runs; Federal Register 70(123):37160-37204, June 28, 2005). Since that time, annual salvage of Chinook salmon of all runs has declined to relatively low levels (Figure 1 and Table 1). The National Marine Fisheries Service's (NMFS) 2009 Biological Opinion determined that the long-term operations of the JPP adversely affects endangered winter-run and threatened Central Valley spring-run Chinook salmon, and directed Reclamation to take actions at the TFCF to increase Chinook salmon salvage efficiency and end-of-pipe survival (*i.e.*, release site predation; NMFS 2009). Though release site predation has been a concern for decades, common methods such as netting, mark and recapture, stomach analysis, other common fisheries science methods are not easily applicable to end-of-pipe and large open systems such as the Delta. Therefore, losses due to predation at release sites has not been well quantified.

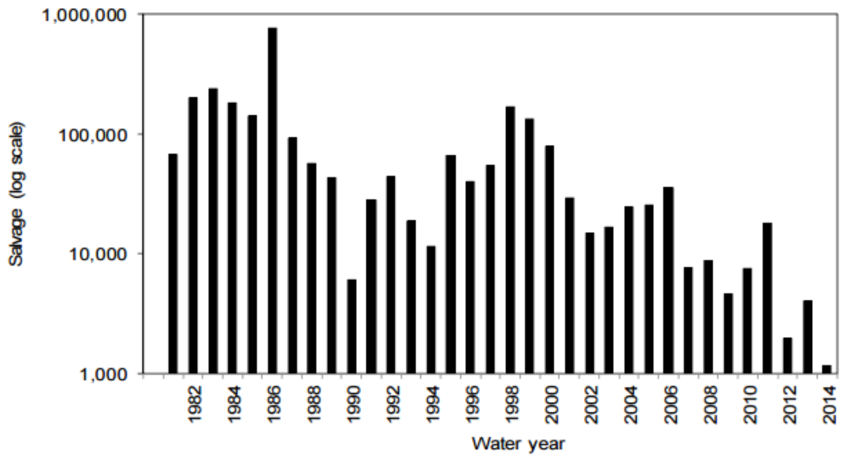


Figure 1. Annual salvage of Chinook salmon (all runs and origins combined) at the Tracy Fish Collection Facility during water years 1981-2014.

Table 1. Annual salvage of Chinook salmon (all runs and origins combined) at the Tracy Fish Collection Facility during water years 2013-2017. 2017 data is current as of 5/14/2017.

| Year | Salvage of Chinook Salmon |
|---|---|
| 2013 | 3,714 |
| 2014 | 1,264 |
| 2015 | 106 |
| 2016 | 1,383 |
| 2017 to date | 12,908 |

## Problem Statement

Survival of salvaged fish at Delta release sites is likely dependent on water temperature, seasonal predator and prey assemblage variability, diurnal behavioral changes, frequency of site-specific releases (*e.g.,* number of releases per day), tides, river discharge, and total abundance of fish in each release. Miranda *et al.* (2010) conducted a release site predation study from 2007 – 2008, which concluded predation of salvaged fish does occur at California Department of Water Resources (DWR) and other fish salvage release sites, and that predatory fishes tend to remain near the release sites when the number of fish being released is consistently high. Salvaged fish were also vulnerable to bird predation when released during the daylight hours. The study determined that predation at release could have a substantial effect on salvaged fish survival. However, the study did not attempt to estimate a precise rate of predation mortality, which is a metric that is highly sought after by regulatory agencies as well as operating agencies (Reclamation and DWR).

Quantifying release site predation is a driving research question for both TFCF and DWR operations. Because of the nature of release pipe structures (dark, inaccessible) and locations (e.g., deep-water, high-flow, turbid environments), traditional fisheries research techniques are ill-equipped to provide accurate assessments of salvaged fish predation rates at each release pipe. Concurrently, there have been few attempts to accurately define or describe the size of the predation area outside of release pipes, and those that have defined the area of study have done so based on sampling gear (Miranda *et al.* 2010, Tucker *et al.* 1998).

## Project History

From September 2016 to May 2017, we established an interagency review team consisting of fisheries biologists from Reclamation, DWR, California Department of Fish and Wildlife (CDFW), NMFS, and United States Fish and Wildlife Service. We also consulted formally and informally with the United States Geological Survey (USGS) and consulting companies ESA Biological Resources and Cramer Fish Sciences. The goal of the team was to thoroughly examine the problem of release site predation, identify past and current research that can inform future release sites studies, examine and discuss emerging fisheries research tools which can be used for release site studies, establish and vet a research ideology, and coordinate release site research with other Delta studies being conducted now and into the future. We also consulted with NMFS regarding the current Central Valley Project Biological Opinion (NMFS 2009) to ensure any research direction we take to lessen the extent of release site predation will be in line with Reasonable and Prudent Alternatives laid out in the document.

Our team identified a range of variables that, based on best professional judgement and other published and grey literature, are likely to affect salvaged salmonid survival post-release at the Delta release sites. They include, but are not limited, to the following:

- Time of day of fish releases
- Ambient light
- Water temperature
- Tidal conditions
- Abundance of released fish in haul truck

- Time since last release (frequency of releases)
- Predator abundance
- Salmon size

Our team also identified multiple avenues of research which could answer our most pertinent research questions:

1) How can we spatially and temporally define release site predation?
2) What is the current level of release site predation?
3) Can release site predation be reduced past any natural or background levels, if no elevated predation rate is discovered at end-of-pipe areas?
4) If predation can be reduced, what is the most cost-effective and easy to implement method for reducing release site predation by 50 percent?

In addition to scoping out broad scale questions regarding release site predation, our team identified a number of different methodologies which can provide answers to these questions. Reclamation and DWR staff lab and field tested some of these methodologies, including:

#### *Assessing predation loss via predation detection tags*

Much interest was focused on the use of emerging predation-detection acoustic transmitters (tags) as a tool to easily detect predation events. Many vendors are developing methods to detect predation events using sensors and triggers integrated within acoustic tags. Two main developmental avenues include dissolvable biopolymers and accelerometers, though others are investigating methods to use predator filter algorithms to identify behavioral differences between predators and prey using multi-dimensional fish tracks.

Reclamation's Technical Service Center, with assistance from DWR and ESA Biological Resources, lab tested VEMCO V5-D predation detection acoustic tags (biopolymer based) to assess the time from tagged prey consumption to predation detection signal activation. The results indicate there is high variance in the trigger "lag", which is too long (~5-30 hours; Figure 2) to accurately attribute a predation event to a predator aggregation at release sites. Pending results from a field test of these tags, it is unlikely that these tags can improve our understanding and/or definition of release site predation.

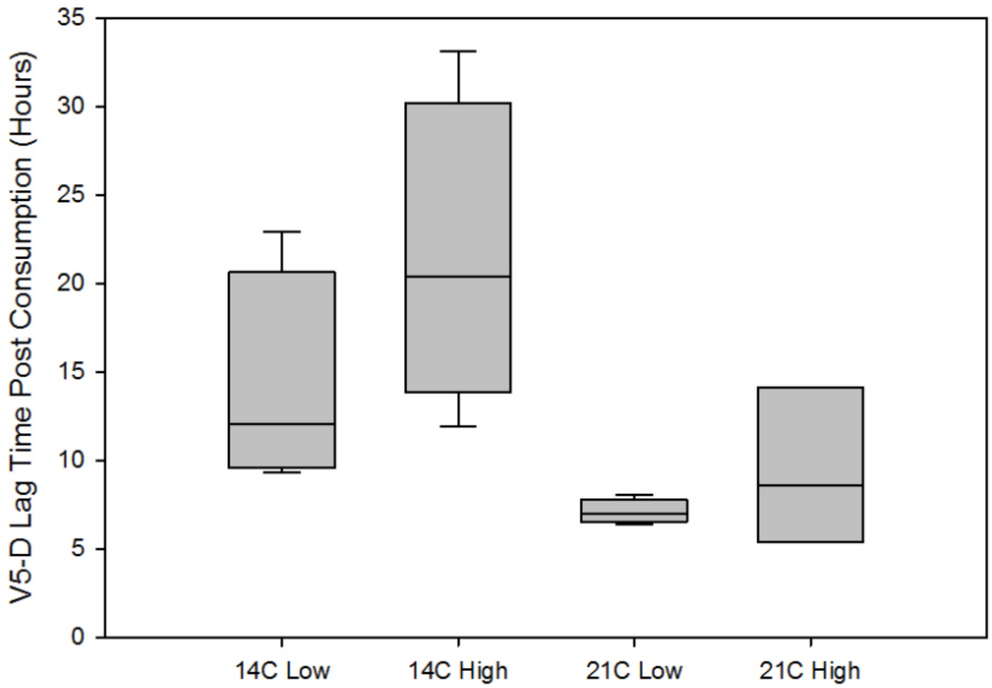


Figure 2. Lag time (hours) of V5-D (VEMCO Predator Tag) following consumption of tagged juvenile rainbow trout by adult striped bass (695-788 mm total length) at 14 or 21C. Low gut fullness (low) was defined as one rainbow trout prey item, and high gut fullness (high) was defined as 3-4 rainbow trout prey items. Four replicates were completed for all treatment conditions, except at 21C High (n = 3).

***Assessing predation using trammel nets***

Deployment of trammel nets at the release sites was proposed in the initial pilot year to examine predator diets and look for signs of predation on photonically marked Chinook salmon, which were to be added to regular fish releases. Predator total abundance was to be assessed using DIDSON camera technology, and species-specific abundances were to be estimated by assigning percent abundance of each species caught in the trammel nets to the total abundance from DIDSON data. Technical problems with the DWR pumping plant caused a lapse in salvaged fish releases and created logistical problems for assessing predation at the Horseshoe Bend release site, and we did not field test this method. However, after site visits and other testing we determined that trammel netting at the release sites would be too difficult to undertake in a large scale study, as currents can be strong, debris loads can be seasonally high, and marine mammals are occasionally present. DIDSON footage was collected during pilot phase work in spring 2017 and will be examined in late 2017 to look for patterns in predator aggregations during releases.

***Assessing predator movements at the Curtis Landing release site***

In lieu of trammel netting, we opted to evaluate predator movement at the Curtis Landing release site. We utilized existing acoustic tags and acoustic receivers available from DWR other researchers in the region. Our group externally tagged striped bass caught via hook-and-line at the Curtis Landing Release Site with VEMCO V5 acoustic transmitters in April (n = 11) and May (n = 8) 2017 (May data has yet to be downloaded from hydrophones or analyzed). We found that a large portion of tagged striped bass captured within close proximity to the release site made rapid downstream and upstream movements (> 1 km in less than one day). This is problematic for any study assessing predation with a near-field (~ 2 km upstream or downstream) acoustic arrays, as many acoustically tagged salmon could end up in predator stomachs and could be detected leaving and reentering the study area repeatedly, obscuring our interpretation of survival and predation in the near-field area using either traditional acoustic tags or predation-detection acoustic tags with long trigger times. The aforementioned results suggest that if acoustically-tagged Chinook salmon were released from the pipes, receiver placement would need to be far (> 2 km based on pilot testing and professional judgement) downstream to avoid ambiguity in data interpretation from acoustic tags (implanted in Chinook salmon) which are present in predator stomachs.

***Assessing predation using tethered feeding experiments***

To assess the effects of near-field predation from predators, we will soon (May 2017) explore the utility of Predation Event Recorders (PERs; Figure 3; Demetras *et al.* 2016) as a tool to quantify release site predation. Each PER can be tethered to a salmon and fished to capture predator ID (via camera), GPS location and time stamp of predation event, temperature and light level at time of predation, and a visual signal (strobe light) that a predation event had occurred. These may not be suitable for large scale release site studies, as the tether at the bottom of the unit (see Figure 3) is depth limited, and may not be indicative of the predation rates happening at near-bottom depths. However, other tethering setups can provide insight into predation at various water depths.

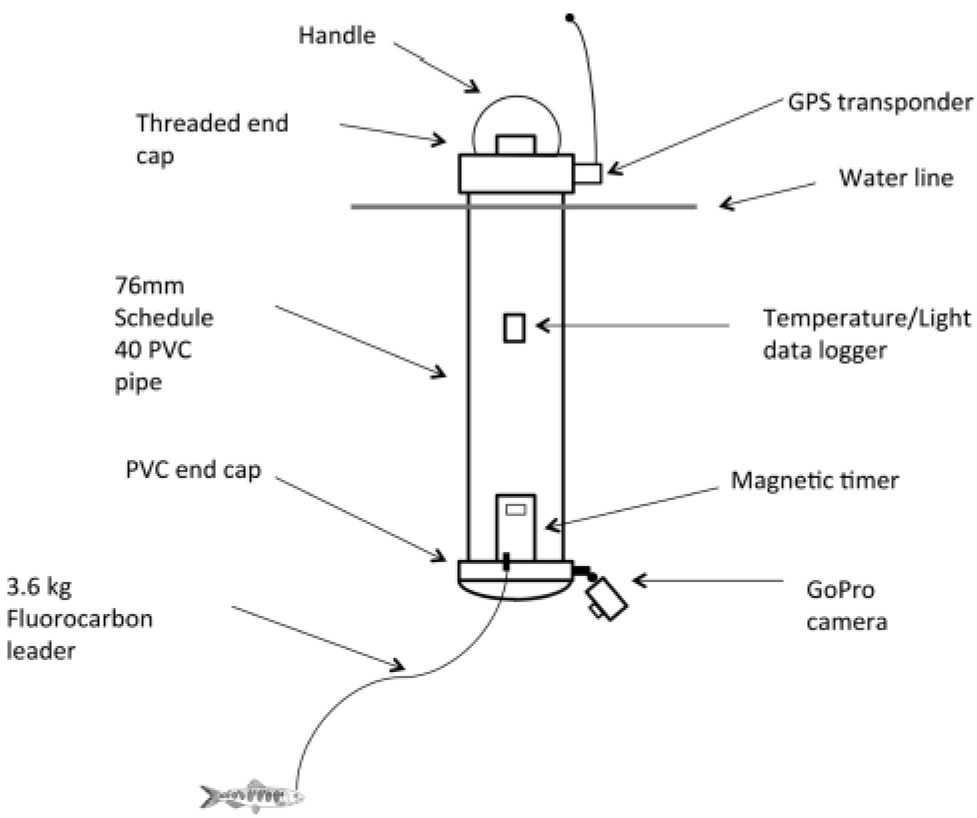


Figure 3. Schematic of a Predation Event Recorder (PER) with a baited tether. Developed by the National Marine Fisheries Service, as described in Demetras *et al.* 2016. Figure from Demetras *et al.* 2016.

### *Assessing feasibility of paired releases of Juvenile Salmon Acoustic Telemetry System transmitters*

Paired releases of acoustically tagged fish using Juvenile Salmon Acoustic Telemetry System (JSATS) acoustic transmitter tags (tags) might provide for an assessment of treatment effects at release sites by comparing current release schemes to modified schemes (e.g., rotational schedules, night/day releases, etc.). JSATS tags are small (217 mg in air, 15 mm x 3.38 mm) injectable acoustic transmitters which can be implanted into salmon at roughly 80 mm fork length. They can be used with salmon representative of sizes salvaged in late winter and early spring.

Other brands of acoustic transmitters are not available in sizes as small as JSATS tags, and published tag-body burden limitations would need to be assessed carefully if larger tags are used. In addition, the majority of acoustic studies being conducted in the Delta now and into the future will use JSATS technology. National Marine Fisheries Service Southwest Fisheries Science Center installed a JSATS receiver gate spanning the Delta at Chipps Island in 2017, and plan to do so again in 2018 and beyond. This is an ideal location to measure survival from the release sites, as it is the next downstream “pinch point.” Closer locations were considered for acoustic arrays to improve precision to detect release site mortality, however our pilot data suggests that predators move rapidly through our study area and could overwhelm our analysis and interpretation of acoustic data if they consume experimental fish.

A key challenge to the use of acoustic tags to assess the impact of release site predation mortality is that acoustic tags can only estimate survival from release location to Chipps Island (S) and cannot distinguish between predation mortality near the release site (Mp) and other sources of mortality (Mr).

$S = 1 – (Mp + Mr)$

Qualitative interpretation suggests the following:

1) The greatest probability of detecting a change in S will occur when Mp is relatively large (>0.1) and strongly affected by the treatment;
2) When values of Mp and/or S are low, a change in S will be difficult to detect regardless of how strongly the treatment influences Mp; and
3) Large values of Mr or variability in Mr will generally obscure detection of changes in S related to Mp.

Simulations can provide a way to understand the probability and impacts of treatment effects prior to performing field experimentation. We consulted with Cramer Fish Sciences quantitative biologists to run simulations to estimate release sizes needed to detect a treatment effect at Chipps Island. Results indicated that there is a large amount of uncertainty in estimates associated with a single release of a small number of fish (n = 20). This uncertainty is high enough that detecting treatment effects from single releases is unlikely.

We decided against pursuing any JSATS or other mass-releases of acoustically tagged salmon in 2018. Estimates of survival through the vicinity of our study site (Sherman Island to Chipps Island) are available from published and unpublished data (Perry *et al.* 2010; Cramer Fish

Sciences, personal communication) and can provide one variable for simulation of release sizes needed to detect a treatment effect. Initial simulations indicate that we may need at least 80-120 tags per replicate release, and possibly more if release site mortality is low, or the treatment effect is small. Our inability to know ahead of time the number of tags needed per release makes us weary of using a mass release approach, because our ability to measure a treatment effect may require hundreds of tags (costing upwards of $300,000 or more), and we won't be confident that such an investment will provide statistically defensible results. Further modeling work is required to assess adequate tag release sizes, and be assured that tag releases would be able to provide meaningful data.

## Goals

Based on our interagency working group's collective experience, best available scientific data, and results of our 2017 field research, we are proposing to conduct a feasibility and initial year of study of 1) the use of tethered predation experiments to assess release site and non-release site (*i.e.*, baseline) predation rates, 2) externally mounted VEMCO predation detection acoustic tag technology, and 3) the use of injectable JSATS acoustic tags to track salvaged fish to a downstream hydrophone array to measure survival. Using multiple lines of evidence, we think that these various technologies may be able to provide us accurate estimates of release site predation, though each technique needs to be tested before large scale studies are pursued. The 2018 feasibility study will provide data to progress towards the development of a statistically defensible study design for implementation in 2019.

### *Tethered predation experiments*

Our goal under this proposal is to develop and refine a tethering experiment that can be conducted within high-velocity environments at state and federal release sites. An extensive literature search will provide insight into past studies of riverine tethering studies. Refinement of field techniques will provide information on tether length, number of tethered prey, tethered prey loss (via lab experimentation), and number of tethering units to be used at each release site. After refinement, our goal is to conduct tethering experiments in 2018 to examine release site and non-release site predation rates of tethered fish, which we assume to be indicative of live fish predation rates. This will be conducted at the proof-of-concept level, and hope to 1) see if this is a suitable technique for current and future studies, and 2) collect enough data at this feasibility stage to determine the number of replicates and fish per location we need for statistically defensible results.

### *VEMCO predation detection tags*

Our goal for further testing of VEMCO V5D predation detection acoustic tags is to determine whether external tagging will provide for more accurate and timely signal change times (*i.e.*, lag time) than traditional surgical implantation. Current signal change times with VEMCO V5-D tags have been deemed by the project team too long to provide utility for release site experiments. However, we hypothesize that an externally attached transmitter will reduce trigger time and variability of trigger times post consumption, which may ultimately permit the use of this technology as an appropriate tool for detecting near field predation at the release pipes. External tag attachment is likely to affect swimming performance and behavior of juvenile salmon, and we plan to assess such effects in a laboratory setting.

### *JSATS downstream releases*

The concept of mass releases of acoustically tagged fish is proven and accepted, however the uncertainty of release site predation loss confounds our ability to determine the number of tags needed for each release. Our goal under this proposal is to work with quantitative fisheries biologists at Cramer Fish Sciences to run simulations of releases and determine the number of tags we may need to release per replicate in order to detect a treatment effect. This can inform a larger scale 2019 acoustic tag release project, which could take advantage of the future DWR release sites which are in close proximity to one another and would make for a good paired release study design. The tethering experiments proposed here will provide release site predation data that, to date, is unknown and will be necessary to build these simulations to get the most accurate estimates of sample size requirements.

## Materials and Methods

### *Tethered predation experiments*

May, June) at two of the four release sites. We will coordinate with state and federal operators to implement a rotational release schedule, which in theory can reduce any learned behavior exhibited by Delta predators. This proposal will assess the feasibility of this technique, and may provide accurate estimates of spatial and temporal differences in release site predation. These estimates will feed simulation models to estimate number of JSATS tags required per release and allow a power analysis to estimate the number of required replicates for future studies.

Though PERs are a preferred predation study tool by NMFS, and they were assessed in 2017 with training provided by NMFS, the depth, turbidity, and velocity at which they can be fished is limited. We propose to use a non-PERs tethering design. Our tethers will be custom built, but will resemble commercially available trotlines. They will be hook-less and will contain from top to bottom:

- Float
- Main line
- Lightweight (2lb) monofilament individual tether loops spaced every 12” and connected to the mainline via swivels (fishing at various depths)
- Lightweight anchor (5lb)

Live fall run Chinook salmon or rainbow trout (pending approval from DFW) will be used as tethered prey. Tether loops will go through gill cover and out the mouth, and then around the body of the fish. When predation events occur, the thin monofilament line will cut through and release the fish from the tethering unit (this is a similar technique that has been tested and used by NMFS). Four to eight tethering units will be fished at each of the four release sites, as well as two randomly selected non-release pipe sites. If a tether unit is set with 10 fish, soaked for 30 minutes, and contains only 2 fish at the end of the soak, then the predation rate will be assumed to be 80%. We will spend a short period of time prior to the start of the experiment refining our technique, appropriate number of tethered prey fish, soak time, and project logistics, since such tethering experiments are a novel, but simple approach to release site studies in the Delta. Tethering fish compromises their ability to swim naturally and evade predators, but still allows a comparison of predation loss between sites.

Lab studies at the TSC fisheries research center in Denver, Colorado will be conducted to assess tethered fish loss from current. We will test effects of various velocities in a test flume to provide an average rate of tethered fish loss (non-predation loss), which we will use to correct our estimates of predation loss based on water velocities at the release sites.

The rotational release site schedule will provide for "resting" periods for individual release pipes while releases are conducted at the other sites. Two release sites will change from the standard release schedule (daily releases) to releases only every 5$^{th}$ day (treatment), while one site will remain on the once daily release schedule (control). We will attempt to collect data for tethered replicates at the same tidal and diel conditions.

Excess fish salvage releases will be conducted at the two new DWR release sites to ensure the control sites don't experience higher than normal releases. The new DWR release sites will not be part of any 2018 studies, but will be the focus of future studies. Based on the recent Memorandum of Understanding (MOU) developed between DWR and Tracy Fish Collection Facility for shared release sites, this rotational release schedule is a feasible future scenario and can be easily implemented.

During the treatment release scheme, we expect to see differences in predation loss of tethered fish between control and treatment release schedules. If any Delta-wide differences in predation related to temperature, predator abundance, predator activity, or other seasonal changes occur, our control site will measure those changes and it will not be falsely attributed to the treatment. By reducing the frequency of releases, we believe that predator aggregations will decrease as a result of fewer stimuli (e.g., water pumps, truck noise, gates opening/closing) and payouts (*i.e.*, higher variability in release times creating long waits between feeding frenzies).

We also propose to conduct a natural, or baseline predation measurement by performing tethered experiments away from the assumed predator aggregations (Miranda *et al.* 2010, Kano 1987) at nearby locations with similar offshore distance and water depths (e.g., 15 m offshore and 25 m deep) as state and federal release sites. We will randomly select natural predation assessment sites by randomly choosing shoreline segments 25 m in length from ~2 km upstream of the most upstream release site to ~2 km downstream (exact distances will be assessed before the start of this project) of the most downstream release site. This will indicate whether there is a difference in predation between release sites and unaffected sites in the Delta.

Diel period may also have an influence on release site predation, so this study will also examine the effects of day vs night predation by performing exploratory night vs day tethered experiments to examine differences in predation rates. We will conduct these night experiments at the natural predation assessment sites during similar tidal conditions. This will help us quantify differences in predation as a function of diel periodicity.

#### ***Predator assemblage assessments***

At the end of each tethering month, we will spend one day performing a shoreline electrofishing survey and a second day performing a hook and line angling survey (two days per month for four months). Based on successful hook and line angling results in 2017, we believe that this methodology can accurately provide catch-per-unit-effort data for release site predators located at a variety of depths. Hook and line surveys may use either rod and reel or trotlines (hooked).

Understanding the specific predator abundance at each site will guide our release site predation reduction efforts, as we can formulate release site strategies that take advantage of specific predator feeding behaviors (*e.g.*, releases at night could be an obvious tactic if the majority of predators are daytime sight-feeders).

#### *VEMCO predation detection tags*

Discussions with a VEMCO staff biologist led to the idea of externally tagging juvenile Chinook salmon with their V5-D predation detection tag. External, versus internal, tagging may provide for significantly shortened trigger times, which may enable us to use them for release site predation studies. We propose to run a follow up lab study to the one conducted in 2017, but this time we will use smolts with pairs of tags, one surgically implanted and other externally attached with sutures. We will compare trigger times between the two tags and assess whether the reduced trigger time can provide a sufficient level of efficacy for field trials.

#### *JSATS downstream releases*

After initial sample size modeling in 2017, we propose to consult with fish biologists with expertise in survival modelling to accurately assess the number of tags we would need to release for a survival experiment. Cramer Fish Sciences has agreed to work with us to provide a table of sample sizes needed corresponding to various release site predation rates. Based on tethering experiments, which may provide accurate release site predation estimates themselves, we will have an idea of predation rates and can use that data to inform the simulations and gather the information needed to decide whether a large release of acoustically tagged fish is a sufficient method to assess treatment effects at release pipes.

#### *Schedule*

Experimental fall-run Chinook salmon or rainbow trout will be procured from a CDFW state fish hatchery by early March 2018 and stored at the Tracy Aquaculture Facility (TAF). Denver TSC staff will keep a boat on hand in a Delta marina, and will travel to the release sites to conduct tethered studies monthly for four months. Lab studies will be conducted at either the Denver fish lab or at the TAF, and will occur according to tag and staff availability, but no later than June 2018. Consultation with Cramer Fish Sciences will occur as quickly as possible following data analysis from the tethering studies. Tethered fish studies and fish assemblage assessments will take place for 7-10 days during each March, April, May, and June of 2018.

### Coordination and Collaboration

Primary coordination will be led by Reclamation TSC Fisheries and Wildlife Resources Group. Close cooperation between TFCF and DWR biologists and operational staff will be required. Collaboration with others in the region, including the CDFW, USGS, and USFWS will occur as needed.

We will continue discussions with the California Interagency Ecological Program (Steve Culberson, Lead Scientist) on whether they are moving forward with plans to monitor fish assemblages in the delta to see if we can include our release sites or use other sites they sample as reference for comparison.

## Endangered Species Concerns

The working group will use hatchery-produced Chinook salmon for release site predation experiments, from either the Feather River or Mokelumne Fish hatcheries. There will be no increased risk of incidental take of listed Chinook salmon in conjunction with this proposal, as transport and release operations will continue as usual, aside from introduction of experimental hatchery fish. Netting wild fish will not be a component of this research project. A previously established MOU regarding take of endangered species with the CDFW, and a 2017 NMFS Biological Opinion (NMFS 2017) will provide justification and authority for continued research objectives revolving around listed species. Re-initation of formal NMFS ESA consultation may be needed to include tethering as a research tool.

## Dissemination of Results (Deliverables and Outcomes)

Research updates will be provided and/or presented at regularly scheduled Tracy Technical Advisory Team (TTAT) and Central Valley Fish Facilities Review Team (CVFFRT) meetings, as the opportunities arise. The primary deliverables will be a report which quantifies predation of juvenile Chinook salmon at Delta release sites. Data collected from this study will be summarized and published as a Tracy Series Technical Bulletin as one or more nationally distributed scientific journals, such as Transactions of the American Fisheries Society, if the data warrants such publication. Results will also be presented at local and/or regional scientific conferences. Additionally, information obtained in this study will be used to improve release site protocols and will advise future release site improvements.

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# Whole Facility Efficiency Evaluation for Chinook Salmon at the Tracy Fish Collection Facility

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## Summary

The Bureau of Reclamation's Tracy Fish Collection Facility (TFCF; Byron, CA) was constructed in the 1950's to salvage fish prior to entrainment loss in the Delta Mendota Canal and pump induced mortality at the downstream Bill Jones Pumping Plant. The National Marine Fisheries Service issued a Biological Opinion (BiOp) in 2009 that "concluded the [pumping] operations were likely to jeopardize the continued existence of several federally listed species under NMFS' jurisdiction," including winter and spring-run Chinook Salmon. The National Marine Fisheries Service BiOp mandates the TFCF meet a salvage efficiency of 75 percent. Prior whole-facility efficiency evaluations have been completed but 1) these studies did not ascribe a single facility salvage efficiency estimate across operating conditions and 2) facility modifications following prior studies, including a Hydrolox™ screen in the secondary channel, necessitate further evaluation of TFCF efficiency. Proposed herein is a phased approach of TFCF whole-facility efficiency evaluation using PIT tag arrays and tagged juvenile Chinook Salmon. The use of PIT-tags/arrays presents a previously unutilized method for evaluating facility efficiency. The goals of using this technology are to address concerns from previous studies, such as low sample sizes, and identify with greater precision estimates of swim-out/participation. An initial scoping year is

proposed, followed by a second year full-scale evaluation—after a determination of the potential success of using PIT tag arrays.

## Problem Statement

Chinook Salmon (*Oncorhynchus tshawytscha*) have been declining in the Central Valley of California for some time (Yoshiyama *et al.* 1998), and are protected by the National Marine Fisheries Service (winter and spring runs-Federal Register 70(123):37160-37204, June 28 2005). Fall- and late-fall run Central Valley Chinook Salmon are considered Species of Concern (Federal Register 69(73):19975-19979, April 15, 2004). The National Marine Fisheries Service issued a Biological Opinion (BiOp) which determined that operations of the C.W. "Bill" Jones Pumping Plant (JPP) adversely affects the existence of endangered winter-run and threatened Central Valley spring-run Chinook Salmon, and directed TFCF to achieve 75 percent whole-facility salvage efficiency for juvenile Chinook Salmon (NMFS 2009; 2011). In addition, the BiOp includes an action item to reduce predation in the primary channel to ten percent or less. Also included in the BiOp is the need to more accurately quantify incidental take (*i.e.*, fish entrainment losses) associated with TFCF operations.

Concerns with previous studies correspond to the ability to appropriately provide a whole-facility salvage efficiency metric that offers a degree of acceptable precision (Jahn 2011). Previous efficiency experiments have generally relied on the ability to recover marked fish in the holding tanks (Karp *et al.* 1995; Karp and Bridges 2015; Karp and Lyons 2015; Sutphin and Svoboda 2016). The problem with traditional mark-recapture experiments at the TFCF is that it is difficult to ascertain predation and participation of test fish. Data has suggested fish may swim upstream of the trash rack, and not be screened through the TFCF or may hold in place within the facility, only to be collected after study periods have concluded (Karp *et al.*, *In Press*). On a similar note, test fish may also be predated, though without recovery of predators and the ability to recover stomach contents, past studies were unable to ascertain whether fish are lost through louvers, predated, or are merely nonparticipants (Karp and Bridges 2015; Sutphin and Svoboda 2016). Additionally, facility modifications at the TFCF have included the replacement of the secondary louvers with a Hydrolox™ screen (Vermeyen and Heiner 2016) which could have an impact on facility salvage efficiency, potentially rendering previous estimates obsolete.

## Goals and Recommendations

The objective of this proposal is initiate the development, and ultimately implement, a study design that will provide a whole-facility efficiency estimate (± standard error) for juvenile Chinook Salmon at the TFCF. This will include fish movement from the start of the facility (which will later be refined within the constraints of the BiOp, previous/ongoing studies and, accordingly, available technology) to salvage from the holding tanks. If necessary (*i.e.*, salvage estimates fall below 75 percent), we will identify additional parameters within the constraints of the TFCF operations that may influence salvage efficiency—and provide recommendations as to how facility operations might be adjusted to meet NMFS mandates.

An initial scoping period is recommended to determine the best method to evaluate salvage, predation, and participation. Similarly, it would be prudent to determine the appropriate number of fish/replicates to ensure efficiency evaluations yield a whole-facility efficiency estimate with an acceptable level of precision. Those variables contributing to facility efficiency need to be identified in order to maximize the cost/efficiency of a whole-facility efficiency evaluation.

Ongoing studies should be consulted to determine whether or not questions regarding survival upstream of the TFCF and release site survival could be answered. Previous studies suggest holding tank (Karp and Lyons 2008) and transport mortality (Sutphin and Hueth 2015) are minimal. Currently proposed studies for release site predation could address concerns regarding fish following transport and final release into the San Francisco Bay-Delta. Likewise, studies to evaluate pre-screen survival have also been proposed. If these studies successfully address these concerns, our efforts could be focused to survival within the facility (*i.e.*, from the trash rack to the holding tank), and combined with results of these studies to estimate overall survival across these areas.

## Currently Available/Considered Technologies

*Discussion of Technology Options*: Facility efficiency experiments have traditionally relied on the recapture of marked specimens in the holding tank (Karp *et al.* 1995; Karp and Bridges 2015; Karp and Lyons 2015). However, such studies often rely on partitioning of the facility in order to identify areas of fish loss (Hallock *et al.* 1968; Bowen *et al.* 1998; Sutphin and Svoboda 2014)—more recently, the use of acoustic tags has provided a finer resolution of fish behavior and fate, though estimates of facility efficiency were wide-ranging (Karp *et al.*, *In Press*). In addition, detecting loss through the louvers, predation, or non-participation (*i.e.*, fish that travel upstream away from the facility or remain within the facility after study periods conclude) is impractical with mark-recapture methods. The use of currently available technologies (*e.g.*, passive integrated transponder [PIT] and acoustic tracking) may allow finer precision in evaluating facility efficiency than has previously been available using mark-recapture techniques. As a critical component of the full-scale project study design, a primary objective of the study team in the first year scoping effort will be to determine the most cost effective and appropriate technologies for implementation.

PIT tags, on an individual basis are relatively cheap (around a few dollars each) and, as long as they remain intact, have a longevity likely exceeding that of the fish in which it is implanted. PIT tags have no battery, and the detection of a PIT-tagged fish relies on passing through or near an antenna installed in a predicted area of passage. Salmonids as small as 55 mm can be tagged with a relatively simple process using a hand-held syringe. Because of this, PIT tags offer the opportunity to test whole-facility efficiencies across a wider range of fish sizes—a critique of previous studies (Jahn 2011).

PIT-tag arrays installed at various locations within the facility could allow determination of fish fate and identify areas of potential loss within the TFCF. Proposed locations for PIT-tag arrays would largely be driven by feasibility but ideally would be immediately upstream and downstream of the trashrack, behind the primary louvers, at the downstream end of the bypass pipes leading to the secondary channel, and at the holding tank discharge pipe. The proposed double array at the trash rack could allow a directionality component to be determined (*i.e.*, fish swimming upstream of the trashrack), that would otherwise be difficult to detect with a single antenna. PIT tag antennas are generally not 100 percent efficient (Connolly *et al.* 2008; Beeman *et al.* 2012). Due to this, preliminary testing would be necessary to evaluate each antenna efficiency. Overall salvage would be determined as a function of these efficiency estimates. With PIT tag arrays, it would be difficult to determine any influence of predation/participation outside of the trash rack structure. PIT tag arrays in deep water, particularly in unconstrained areas, prove difficult to construct.

As opposed to the minimal cost of individual PIT tags, individual acoustic tags cost several hundred dollars. Acoustic tags, being battery powered, have a finite life span which can range from several days to years, depending on tag size and frequency of signal emission. On the other hand, since acoustic tags emit a signal (and not required to pass through or near an antenna, as with PIT tags), receivers are often able to detect tagged fish at a greater distance (> 100 m), in ideal conditions. Though the detection range is greater for acoustic tags, the minimum fish size for tagging is larger than for PIT tags. The size range recommended is proportional to the size of the fish, but is generally about a maximum of 6–8% of body weight in air (Brown *et al.* 1999; Chittenden *et al.* 2009). Based on Karp *et al.* (*In Press*), a nominal minimum size of 105 mm for juvenile Chinook salmon was considered ideal for currently available acoustic tags. Since these tags are larger, implantation is more difficult than with PIT tags, generally requiring a surgical procedure.

One issue with PIT tags is that detection doesn't necessarily mean the fish is still alive. It could have been consumed by a predator and subsequently be detected at an antenna array. More recent advances with acoustic tags include predation tags–tags designed to switch frequencies following a predation event whereby a polymer coating degrades in the stomach of the predator (https://vemco.com/products/v5-predation-transmitter/). While the timing of the frequency change after consumption may be variable (5–30 h; Fullard, *pers. comm.*), researchers would be able to determine the fate of test fish with a higher degree of precision than has been previously available. Tag life for the V5 predator tag (Amirix Systems Inc., Bedford, Nova Scotia) is 24–30 days. However, there is a possibility that predators, after having consumed a tagged fish, could be recovered in the holding tank prior to tag triggering and subsequent frequency change. A hydrophone in the holding tank could be used to determine the presence of any recovered and tagged fish. Actual handling of tagged fish would be required to determine whether or not recovered fish had been consumed by a predator prior to frequency change of the acoustic transmitter.

Hydrophone receivers could be installed, like PIT-tag arrays, at various locations within the TFCF to determine the fate of tagged and subsequently released fish. Acoustic receivers could be installed upstream of the trash rack, in the primary channel, in the secondary channel, in the holding tanks, and downstream of the primary louvers and holding tank/secondary discharge in the Delta Mendota Canal. Jahn (2011) identifies the area in front of the trash rack as the beginning of fish loss, as a result of "unnaturally intense predation," and there is currently "[n]o independent estimate of prescreen survival." Karp *et al*. (*In Press*) have since provided some estimates of pre-screen loss, but the range of these estimates are broad. Hydrophone placement upstream of the facility, and the potentially use of predation-event acoustic tags, could help to determine fish fate in this area.

## Year 1: PIT Tag Array Installation/Pilot-level Efforts

1. *Coordination*: An initial scoping and development period is recommended in order to ensure the study design will address the mandates outlined in the 2009/2011 BiOp. This will involve coordination with TFCF and Denver TSC biologists to plan and implement a whole-facility efficiency evaluation for Chinook Salmon. The purpose of this coordination effort will be to:

a. Determine parameters to consider for whole-facility efficiency evaluations (*e.g.*, flow, tidal influence, river stage, diel period, debris loading).

b. Discuss timing of potential study periods.

c. Review previous TFCF and State Water Project studies to identify issues or shortcomings (*e.g.*, lack of replicates, wide margins of error, fish participation) can be adequately addressed.

d. Develop a defensible study design incorporating the most suitable technologies, methods, and analyses to address the NMFS BiOp RPA.

2. *Technological Consultations*: In addition to coordination with biological staff, consultation with industry leaders in fish tracking technology will be necessary to determine installation options and constraints within the TFCF.

    a. In conjunction with Item 1 above, decide which locations of the facility (including upstream and downstream, as necessary) would need to be monitored to be able to determine fish movement.

    b. Determine the feasibility of equipment installation at these locations to adequately detect fish movement without interfering with normal facilities operations.

3. *Equipment installation*:

    a. Due to regional interests in potentially detecting the presence of salmon from the Sacramento-San Joaquin River Basin at the TFCF, as well as the potential benefit of using PIT tag arrays for facility efficiency evaluations, PIT tag arrays may be installed prior to the March–May pilot efforts in 2018.

    b. Coordinate with TFCF staff for equipment installation following consultation with industry experts and determination of antenna locations. For initial year efforts, a double array is proposed at the trash rack—one if front and one behind, and single arrays are proposed within the holding tanks. These locations will ideally provide directionality of fish movement in/out of the facility at the trash rack, and detect fish that have been recovered in the holding tanks.

    c. Antenna efficiency testing will be coordinated to coincide with fish releases (see below). Efficiency values are necessary to estimate the total number of fish passing each antenna since arrays are generally less than 100 percent effective.

4. *Fish releases for pilot level testing (contingent upon PIT tag array installation)*:

    a. Fish will be procured from either the Coleman National Fish Hatchery (Anderson, California) or the Mokelumne River Hatchery (Clements, California).

    b. We will coordinate schedules to ensure fish are obtained ahead of the study period and that fish will be of appropriate size for both tagging operations and experimental releases.

    c. Fish will be maintained at the Tracy Aquaculture Facility (TAF) in tanks supplied by aerated well or treated Delta water until study use. Tagging operations (PIT tag or acoustic tag) will be coordinated with TFCF biologists and TSC staff. Approximate fish size for this study should correspond to fish typically collected during peak salmonid seasons—1993–2015 salvage data (ftp://ftp.dfg.ca.gov/salvage/DOSS_Salvage_Tables/) in March, April, and May, 86, 92, and 102 mm (mean, spring-run wild Chinook, standardized across years, respectively).

Based on fish salvage data from 1981–2012, Chinook Salmon have been recorded at the Tracy Fish Collection Facility (TFCF) across all months, though December–July are considered the primary months of presence (ftp://ftp.dfg.ca.gov/salvage/1981-2012%20daily%20salvage%2003072012.zip). However, March–May are when the majority of salmon encounter the facility. This information will be considered prior to scheduling these releases.

d. Two periods of fish releases are proposed. One trip will be tentatively planned for March and the other in late May, early June. Ideally, this will help to account for a range of environmental and operational conditions typically present under normal facility operations during peak salmon collection periods.

   Twelve releases of 150 fish, spanning two trips (6 releases/replicates per trip) are proposed. Each of the six replicates will be staggered across a 24-h period to incorporate diel influences in salvage efficiency. One-hundred fish will be released upstream of the trashrack, and an additional 50 fish will be released below the trashrack for each release. These numbers were based on previous studies that suggest a proportion of the fish released below the trashrack are recovered in the holding tanks (Sutphin and Svoboda 2016), and fish behavior upstream of the trashrack (and participation) can be quite variable (Karp *et al., In Press*). Subsequent detection of fish released below the trashrack will help to give an indication of swimout/non-participation. Likewise, differences between salvage of these two groups of fish, in coordination with a swimout estimate, may give an indication of predation upstream of the trashrack.

5. *Data analysis*:

   Following fish releases and subsequent data analysis, biologists will determine 1) if the use of PIT tag arrays will be sufficient to determine whole-facility efficiency, and 2) the total number of fish per replicate and total replicates needed for full scale efforts proposed in Year 2–3 Full-scale Implementation based on an accepted level of precision. The NMFS should be consulted to determine what level of precision is necessary when reporting facility efficiency.

## Year 2: Full-scale Study Implementation

1. Following Year 1 Pilot-level Testing, implement a full-scale study that includes:

   a. Equipment installation/maintenance, as necessary. Additional PIT tag arrays will be considered to identify areas of potential loss within the facility, where warranted.

   b. Procurement/care of test fish following the aforementioned guidelines.

   c. Scheduled fish releases corresponding to the total number of fish/replicates determined from scoping period.

2. Analysis of the data with the appropriate metrics to determine whole-facility efficiency with the corresponding level of precision.
3. Dissemination of results: a final Tracy Series report will describe whole-facility efficiency and the associated standard error.

## Coordination and Collaboration

Study proposals will be distributed through the Tracy Fish Facility Improvement Program to state and federal agencies to ensure study designs will address the issues presented in the NMFS BiOp. Denver staff will coordinate with TFCF biologists/operations for site visits and evaluations during project development/implementation.

## Endangered Species Concerns

Incidental "take" of ESA listed Chinook Salmon, Steelhead, and Delta Smelt is possible when recovering test fish in the holding tank. Such fish will be returned to Delta waters as quickly as possible. The total number of each ESA species incidentally caught or collected during the experiment will be recorded and sent to the reporting agencies. The incidental take from this research is covered under the TFCF Section 10 permit.

## Deliverables and Outcomes

If installation of PIT tag arrays at the TFCF can be completed prior to the March–May peak juvenile salmon period, initial pilot efforts in FY18 will include preliminary releases of juvenile salmon. A summary of the findings from these releases, to include feasibility of using PIT tags for whole-facility efficiency evaluation, will be completed and presented to TFCF management. Researchers will provide an estimate of the number of fish/replicates needed to evaluate whole facility efficiency with an acceptable level of statistical confidence. Full-scale evaluation of whole-facility efficiency is proposed for Year 2–3 (FY2019). A TFCF Series report will follow whole facility efficiency evaluation in FY19.

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# Near-Field Export Effects on Predation, Survival, and Entrainment on Juvenile Salmonids

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## Summary

The greatest mortality directly associated with the Central Valley Project (CVP) and State Water Project (SWP) facility operations results from predation in areas outside the louver channels (SST 2016, CFS 2013).  These "prescreen" areas are not well understood, but studies have shown that survival can be extremely low through Clifton Court Forebay and along Grant Line Canal (Buchanan 2013, 2014, 2015, 2016).  Coordinated operations of the CVP and SWP facilities could reduce loss associated with predation mortality in Clifton Court and perhaps other locations (SST 2016). However, uncertainty remains about CVP prescreen mortality and how cumulative juvenile salmonid loss may be reduced through improving prescreen survival by decreasing distance travelled in these prescreen channels and/or increasing migration rates through these channels and the facilities. This study aims to identify the environmental drivers (i.e. export operations, migration route, prey densities, tides) influencing habitat attributes (i.e. predation mortality, flow characteristics) and their effect on salmonid migration rates, survival, and cumulative facility loss. This study will range over multiple water years to capture a series of

conditions desirable for learning about a varied set of hydrodynamic conditions and operations and reducing uncertainty regarding the relationship of prescreen loss to coordinated operations of the CVP and SWP fish facilities. Recent efforts through the Collaborative Science and Adaptive Management Program's Salmon Scoping Team and NMFS Biological Opinion to identify data gaps in our understanding of salmonid survival, the south Delta and water operations, and cumulative loss suggest these data can inform improved loss models, optimize survival for salmonids near the salvage facilities, and support water reliability through enhanced coordinated operations.

## Problem Statement

A better understanding of how exports affect survival, predation, and entrainment of juvenile salmonids is urgently needed. Recent tagging studies have demonstrated survival from the San Joaquin River through South Delta is very poor, although few fish are directly entrained into the facilities (Buchanan et al 2015, Buchanan et al 2016, SST 2016). Studies have indicated fish entrained at the CVP have better survival outcomes than fish entrained into CCF (Buchanan et al 2013, 2014, 2015, 2016). Better data on how export operations and facilities can influence mortality is needed to optimize South Delta CVP/SWP operations for water supply reliability and salmonid survival. As part of the NMFS Biological Opinion on the Long-term Operations of the CVP and SWP (NMFS 2009), Reclamation and DWR were required to improve the methodology for estimating salmonid loss as part of Term and Condition 2a. Recently, the interagency Collaborative Adaptive Management Team (CAMT) 2017 Workplan for salmonids recommended accelerated actions related to preferential operation of the CVP and evaluating predation losses at salvage facilities, yet the benefits and tradeoffs associated with such actions have not been quantified.

## Goals and Predictions

Goals:

1. Determine how exports influence juvenile salmon predation, survival, and entrainment in the Old River corridor (for fish arriving from both the east and the north) during December through April.
2. Develop an operational tool to optimize juvenile salmonid survival through the South Delta based on CVP and SWP export facility operations.
3. Validate the alternate loss equation parameters developed as part of Term and Condition 2a related to CVP prescreen loss.

Predictions:

1. Exporting a greater proportion of water through the CVP than SWP reduces combined salmonid loss due to an increased prescreen survival rate.
2. Alternate models of loss can more accurately estimate loss than the current method.
3. Combined facility loss is lower during periods of proportionally higher CVP exports.

For fish released east of export facilities (upstream)

1. Survival through the CVP is higher than survival via natural migration regardless of export rates.
2. Survival through entrainment to the SWP is not different from survival via natural migration.
3. Movement rates toward the facilities are not affected by export rates.

For fish released north of the export facilities (downstream)

1. Survival to Delta exit (Chipps Island) is independent of export rate.
2. More fish migrate south and approach the export facilities during high exports than low exports.
3. Prescreen predation mortality will be less during high exports than low exports.

## Materials and Methods

### *Task 1: Operation and maintenance of acoustic receiver array*

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) estimate within-facility predation and louver efficiency at the CVP and 2) to assess survival to salvage release for both CVP and SWP. For the within-facility array at the Tracy Fish Collection Facility, receivers will be placed to detect fish upstream and downstream of the primary louvers, in the secondary channel, holding tanks, and transport truck. HRR receivers upstream of the track rack will be used to assess behavior (predator/smolt) for comparison to tag code (predator/smolt).If a within-facility array is developed, range tests will be used to ensure receiver deployment is effective for fine scale movement measurements. If a study to assess survival to salvage release is developed, we would like to add a DWR co-investigator on this study plan, to help ensure VEMCO receivers are deployed to detect tagged fish salvaged at the Skinner Delta Fish Protection Facility. However, if SWP exports are low, relatively few tagged fish are expected to enter Clifton Court Forebay.

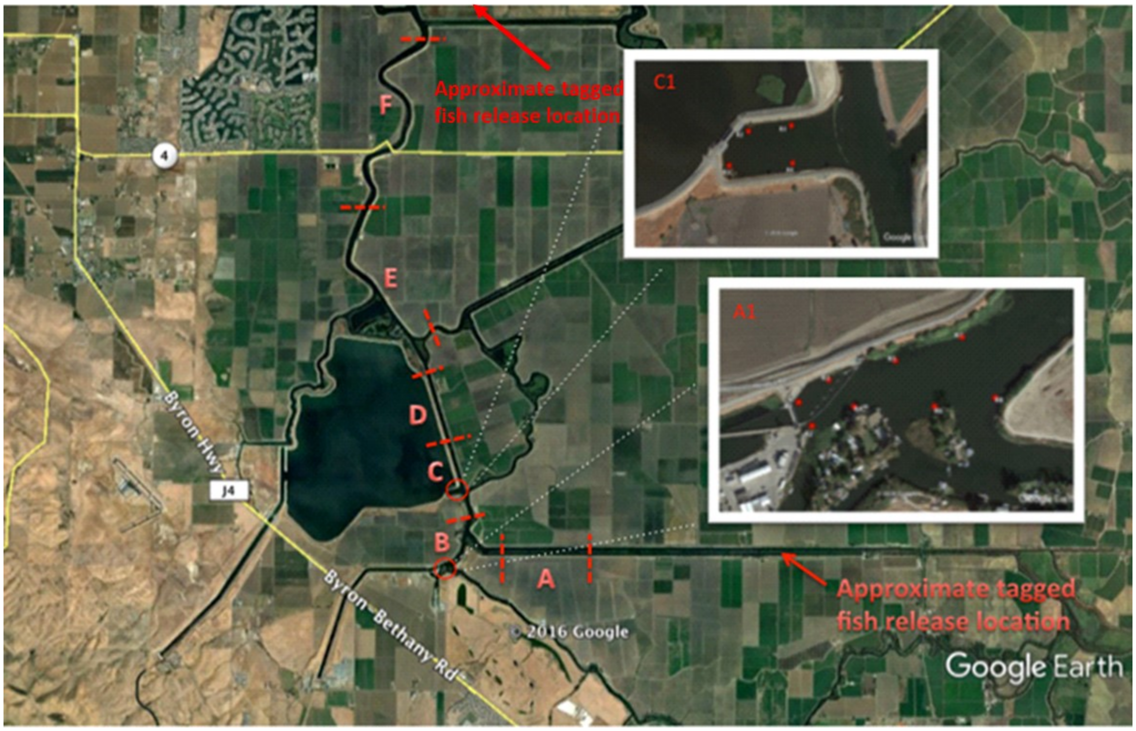


Figure 1. Approximate location for tagged fish releases, study reaches (A, B, C, D, E and F) and subareas for detailed (2-D) receiver arrays (A1 and C1). For insets for A1 and C1, red dots indicate approximate locations of HR2 VEMCO receivers.

Mobile tracking will occur for ten days after releases 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.

*Acoustic Telemetry Equipment List*

12 HR2 Receivers (Needed)

2 VTA-180k-V5D Tag Activators (USBR Supplied)

High Speed RS-485 Communication Kit for HR2 Receivers (USBR Supplied)

36 VR2 Receivers (USBR Supplied)

2 VR100 and VH180 omni-directional hydrophones (USBR Supplied)

***Task 2: Facility operation coordination***

Opportunities for varied exports between the facilities are most likely between early winter and spring (December 1 through March 1) when state and federal regulations, hydro-meteorological conditions, and water transfers are impacting export rates. More than 60% of juvenile Chinook salmon are salvaged during April and May, and avoiding study during this period for experimental operational periods may reduce cumulative loss of ESA-listed species. During this period, the NMFS and USFWS biological opinions offer a range of export and Old and Middle River (OMR) levels to be targeted depending on ESA-listed salmonid and Delta Smelt distribution and abundance. The majority of desired conditions can be met within this range, although operations with the most negative OMR flows risk being constrained the later into December a release of fish is requested. These negative OMR flow conditions are not currently feasible later than December, as the NMFS Biological Opinion's (2009) RPA limit OMR flows to no more negative than -5,000 starting January 1.

The Delta Operation for Salmon and Sturgeon (DOSS) and Smelt Working Group (SWG) technical teams hold weekly reviews of these data and ensure precautionary recommendations are made to the Water Operations Management Team. To provide coordination for this study, these teams will receive briefings on this study requesting weekly flexibility for completing releases as part of the study. These teams will provide an assessment of fishery risks to Water Operations Management Team (WOMT) with a recommendation to take the action. The Study Team will provide a review of how the fish release was implemented to each technical team.

Recent changes to the distributional and abundance monitoring efforts include the Enhanced Delta Smelt Monitoring, real-time reporting of mainstem and Delta juvenile salmon monitoring stations, expanded acoustic telemetry and tagging, and modified winter-run Chinook Salmon juvenile production estimate provide the best available information for daily export operations flexibility during periods of potentially increasing risk. Coordination on this study will be tiered to accomplish the desired releases and operational conditions:

- The Study Team will coordinate with the biological opinion technical teams regarding an annual plan with required number of seasonal fish releases
- The biological opinion's DOSS and SWG Technical Teams will assess the fish release requests, evaluate the best available information, and recommend if releases can occur which avoid increased risks to ESA-listed species
- The technical team will coordinate with WOMT to ensure operational conditions occur with the fish releases.

*Experimental Design*

Export effects will be measured as weekly stable export conditions. High exports levels achieve OMR flows between -6,250 and -3,750 cfs, low export rates achieve OMR flows between -2,500 and -1,250 cfs. Four periods will be tested annually between December 1 and March 1 until there are 2 replicates of each condition from both release locations. These periods should not be consecutive weeks, and the preference would be to achieve alternating high and low periods through the range of the study period. Two consecutive weeks is problematic because environmental variable may change among two week periods that obscure export effects.

Table 1. Annual set of experimental periods desired for both release locations between December 1 and March 1.

| **Duration** | 7-day period | 7-day period | 7-day period | 7-day period |
|---|---|---|---|---|
| **Operational Condition** | High Export Rate (>75% CVP) | High Export Rate (>75% CVP) | Low Export Rate (~50% each facility) | Low Export Rate (~50% each facility) |

This study does not require any particular level of San Joaquin River inflow, but does require an experimental modification of exports during four one-week periods between December 1 and March 1. Such operations could allow experimental higher (and lower) exports for seven days while achieving an average total 14-day daily OMR flow average fitting the RPA requirements. Since fish screens at the CVP export facilities were designed to function at export rates of approximately 4,600 cfs, it is critically important that the high export treatment during this experiment meet or approach this export rate.

We do not propose to experimentally alter SWP exports or CCF radial gate operations for this study. However, coordination would result in the best outcome, which are SWP exports that are stable and equal or less than CVP exports during experimental periods. This will assist in reducing operational variation, which frequently plagues studies attempting to investigate export operations and fish survival and movement. Adding a DWR co-investigator to adequately consider these operations in our data collection and result interpretation could be important to achieving this outcome. The proposed study will yield useful information regardless of SWP operations, although the preference is for the best outcome.

### *Task 3: Fish acoustic tagging*

*Sample size estimation*

Sufficient sample size is necessary to have groups survive past the facilities from the eastern release site and out into northern reaches. We used expected survival rates (SST 2016) and hypothesized entrainment rates to determine that each sample requires at least 144 fishes.

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 SST 2017. Number of tagged fish surviving to each reach assumes 144 fish released. Number of fish entrained to CVP (75) and SWP (25) is a placeholder value- expected value currently unknown.

| Reach | Length (km) | Survival | Tagged Fish w/ 144 released at u/s site | Predicted Entrained | Description |
|---|---|---|---|---|---|
| Release | 2.5 | 0.95 | 137 | | A riverine channel for fish to aclimate and assume a more natural migration behavior |
| A | 1.8 | 0.96 | 131 | | A riverine channel immediately preceding entraince to the |
| B | 1.1 | 0.98 | 129 | 39 | A semi-tidal channel which includes the entrance to the CVP |
| C | 1.5 | 0.97 | 86 | 18 | A semi-tidal channel which includes the entrance to CCF |
| D | 1.6 | 0.89 | 58 | | A tidal channel just North of the entrance to CCF; very strongly altered hydrodynamics due to exports |
| E | 4 | 0.75 | 44 | | A tidal channel with strongly altered hydrodynamics due to |
| F | 4.6 | 0.72 | 32 | | A tidal channel with hydrodynamics moderately influenced due to exports |
| | | | | | |
| | | | Tagged Fish w/ 288 released at d/s site | 144 | Presume that 50% move south into Reach F towards facility |
| Release | 2.5 | 0.72 | 104 | | A tidal channel with hydrodynamics moderately influenced due to exports |
| F | 4.6 | 0.72 | 75 | | A tidal channel with hydrodynamics moderately influenced due to exports |
| E | 4 | 0.75 | 56 | | A tidal channel with strongly altered hydrodynamics due to |
| D | 1.6 | 0.89 | 50 | | A tidal channel just North of the entrance to CCF; very strongly altered hydrodynamics due to exports |
| C | 1.5 | 0.97 | 48 | 7 | A semi-tidal channel which includes the entrance to CCF |
| B | 1.1 | 0.98 | 41 | 12 | A semi-tidal channel which includes the entrance to the CVP |

*Study fish*

Juvenile Chinook Salmon will be acquired from Coleman Hatchery and brought to the Tracy Aquaculture Facility (TAF) in late fall. With early coordination, FWS biologists believe they can reduce incubation temperatures and target creating surrogate juvenile late fall run Chinook ≤110mm, tag burden 5% or less of mass).

*Fish surgery training*

Fish surgeons will undergo a 3-day training session within 3 weeks of the initiation of the study annually. The initial procedure will follow Liedtke et al. (2012), and modification will be discussed and documented during the fish surgery training. Fish surgeon will perform necropsies on fish held overnight to assess their performance. A target of 80 surgeries prior to the study's commencement will be the training standard.

*Tag programming and surgery*

The study design attempts to take maximum advantage of predation-detecting acoustic tags and surplus VEMCO acoustic tag receivers available for 2018 and 2019. Predation-detecting acoustic tags are the preferred tag, so that prescreen mortality and survival can be more accurately estimated. If this technology is not available, a VEMCO tag of similar size (V5) will be used.

Fish will be tagged by surgical insertion of V5 tags into the peritoneal cavity at the TAF. Two simple interrupted stitches tied with square knots on non-absorbable sutures will be used to close the incision, and up to 3 fish will be held in 5 gallon buckets following recovery from anesthesia to ensure survival and normal swimming behavior. The duration of surgical procedures should take less than 5 minutes. Fish will be tracked from surgical table to river using standardized electronic forms. A tagging coordinator will periodically complete tagger compliance checklists and inspect each tagger to confirm the standard operation procedure is being followed. A summary of these checklists will be developed following the study and include information about the dates of inspections and general findings of the inspections. A VEMCO 180kHz receiver will be used at the surgery site to immediately verify that tags are working correctly by monitoring after tagging, through at least two transmissions, and prior to transport to the release site.

*Fish transport, holding, and release*

Over the term of the study, tagged fish will be released from two sites. 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. Also, tagged fish will be released into Old River approximately 2.5km upstream of the downstream study area, Reach F. Six reaches (A, B, C, D, E, and F) will be delineated, each bracketed with dual receiver arrays. These reaches represent a range of unidirectional and tidal hydrodynamic conditions and different exposures to export effects (Table 2). Fish will be transported to the release site at least 48 hours prior to release in a cooler by truck and acclimatized to river conditions.

Fish will be held for 48 hours prior to release. Four fish will be released every 2 hours for 3 days for a total of 144 fish from the east for each export condition. Eight fish will be released every 2 hours for 3 days for a total of 144 fish from the north for each export condition. Over the entirety of the study, it is estimated 2,304 fish will be released. Without Head of Old River barrier, Grant Line Canal flows like a river (unidirectional) and thus tagged fish will have an opportunity to orient and will arrive at the CVP export facilities (Reach B) as naturally as possible. On Old River, flows are tidal and tagged fish will have an opportunity to orient and select a direction based on a range of tidal conditions.

*Tag life study and fish health*

A tag life study will not be undertaken based on the short duration (less than 7 day) of the study. A predator-detection study will be undertaken. A subset of predator detection tags will be implanted into predators and time to signal switch measured for the study. While death is immediate, it has been shown that predation tags have a range of times (5-30hours) when the predator trigger is activated and the tag signal changes. Thus if predator tags are available, fifty will be used in the laboratory to define a distribution of trigger times, which will be applied to predation-coded detection histories to estimate predation timing. A fish health study will not be undertaken based on the favorable conditions for fish during December through the end of February.

### *Task 4: Data processing and analysis*

*Approach and methods*

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

1. Salvaged: detected as present in the holding tank.
2. Entrainment: movement either toward or into the nearest export facility
3. Exit: movement into an adjacent reach away from nearest export facility
4. Predation mortality: eaten by a predator as indicated by PDAT
5. 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:

1. 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.
2. 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.
3. For tagged fish occupying a reach for ≥6 hours, we will assume Predation detection acoustic tag trigger indicates predation occurred within that reach.
4. When a PDAT trigger occurs for a tagged fish having occupied a reach <6 hours, we evaluate fish movements and mobile tracking to identify the reach where predation is most likely to have occurred.
5. Additional rules for analysis will be developed as the study develops further. (See tag life study and fish health)

*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 multi-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 operational conditions and other factors are covariates. Analysis 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 129 or 48 tagged fish will enter Reach B or C, respectively, and be available for evaluating hypotheses related to CVP export effects on predation, survival and entrainment.

*Model Development and Validation*

Recent advances in an alternate model for estimating loss at the CVP and SWP have been made as part of the biological opinion's term and condition 2a effort (CFS 2016). This model allows for comparison of salvage observations at the CVP and SWP for considering the efficacy of preferential pumping from the CVP. Also, a simple spreadsheet model of export processes effect on survival and cumulative loss were developed at part of the 2012 stipulation study (DWR 2013). Both of these models will be validated with data from this model. Terms that will be validated include CVP and SWP prescreen mortality and CVP facility efficiency and survival. If the results from this study are shown to not be reflected in the terms' values and parameterization in these models, then changes will be made to recalibrate these models for use. The opportunity to refine these models with new information should provide a tool for predicting CVP and SWP export operation impacts on these measures and could be used to optimize for a particular metric (i.e. lower predation mortality, higher efficiency, lower cumulative loss)

### Coordination and Collaboration

San Luis Delta Mendota Water Authority and Reclamation Central Valley Operations office will receive preseason coordination briefings, as well as updates during the fish releases. This study will be coordinated with the TFCF staff, Reclamation's Bay-Delta Office Science Division, National Marine Fisheries Service, US Fish and Wildlife Service, and Tracy Technical Advisory Team (TTAT). Participation and inclusion of research-related updates will be provided at regularly scheduled TTAT and Central Valley Fish Facilities Review Team (CVFFRT) meetings.

### Endangered Species Issues, "Take" Considerations

No ESA-listed species will be handled during this study. Appropriate hatchery stocks from California hatchery sources will be coordinated with CDFW and USFWS. Permitting for this will occur approximately 9 months early to ensure fish can be brought into TAF and raised on ration to target ESA-listed fish sizes during December through April.

To achieve operational conditions across a range reflecting coordinated operations to test preferential pumping from the CVP and SWP, pumping rates may require levels greater than under the NMFS and USFWS RPAs.

### Dissemination of Results (Deliverables and Outcomes)

Regular updates will be provided at TTAT and CVFFRT meetings. Quarterly updates will be provided to the CAMT. A Tracy Series Report will be prepared and published upon completion of this study.

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# Evaluation of Hydrolox™ Traveling Screen at the Secondary Channel using Larval and Juvenile Delta Smelt

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## Summary

The Tracy Fish Collection Facility (TFCF) is located at the head of the Delta-Mendota Canal in the southern region of Sacramento-San Joaquin Delta (Delta) near Tracy, California. The facility was constructed in the 1950s to salvage fish that would otherwise be entrained by the C.W. “Bill” Jones Pumping Plant (JPP). Since inception, the TFCF used behavioral louver arrays in the primary and secondary channels that were angled 15° to the flow of water with 2.5 cm (1 in) spaced vertical slats angled 90° to the direction of flow that create a disturbance in the water and guide fish into one of four recessed holding tanks (6.1 m wide, 5.0 m deep). The system was

designed primarily for Striped Bass (*Morone saxatilis*) and outmigrating Chinook Salmon (*Oncorhynchus tshawytscha*). In June 2014, the secondary louver system was replaced with an engineered traveling water screen (Hydrolox™, Intralox LLC, Harahan, LA).

Delta Smelt (*Hypomesus transpacificus*) is a federally listed threatened species native to the Delta (Federal Register 1993) and is salvaged at the TFCF (CDFW, ftp salvage records website). The larval, juvenile, and adult life stages are reported when they are observed during fish counts and when they are detected during larval fish sampling.

With the replacement in 2014 of the secondary louvers (2.5 cm width) with the traveling water screen that has smaller opening (1.5 mm width x 50 mm length), Delta Smelt larvae and juveniles are expected to be guided successfully (salvaged) to the holding tanks. Data collected from this study will determine how velocity affect larval and juvenile Delta Smelt secondary channel efficiency. The data collection portion of the study was completed in 2016 and funds are being requested for data analyses and report writing.

## Problem Statement

As part of Reclamation's effort in attaining a whole facility efficiency of 75 % (NMFS 2009), the new secondary louvers were replaced with a traveling water screen with smaller screen opening. The new screen's efficiency in guiding Delta Smelt larvae, juveniles, and adults to the holding tanks is unknown. Furthermore, the State Water Resources Control Board Decision 1485 (*i.e.*, D-1485) and the current 2009 NMFS Biological Opinion mandate that the secondary channel be operated at salmon criteria, or 3.0-3.5 fps, between February and May, months when larval and juvenile Delta Smelt are observed at the TFCF. It is unknown, however, how this speed and the new traveling screen interact and affect the diversion of Delta Smelt to the holding tanks.

## Goals and Hypotheses

Goals:

1. Determine if secondary channel water velocity affect the salvage of Delta Smelt larvae and juvenile to the holding tank

Hypotheses:

1. Because the traveling screen has smaller opening, Delta Smelt larvae and juveniles will be diverted to the holding tank and will not be lost through the screens

## Materials and Methods

Because Delta Smelt is a protected species and wild Delta Smelt cannot be used, cultured Delta Smelt were obtained from the UC Davis Fish Conservation and Culture Laboratory (FCCL) and these fishes were used as surrogates for wild Delta Smelt. A memorandum of understanding was prepared with CDFW allowing the use of cultured Delta Smelt within the compounds of the TFCF for this study. In 2015, 3000 juveniles measuring 20-30 mm FL and in 2016, 10,000 individuals measuring 15-40 mm FL were used.

Five secondary channel velocities were tested to cover the full range of typical operations: 1.0, 1.5, 2.0, 2.5, 3.0 fps (or 0.3-0.9 mps). When secondary louvers were used in the secondary channel, the width at the upstream part of the louvers where the secondary velocity was calculated was 8.0 ft (Figure 1A). It is important to note that because of the new traveling water screen, the width of the secondary channel at the upstream point of the screen where we calculate the channel velocity is 6.5 ft (Figure 1B). Also, the angle of the new screen is more acute at 7 degrees compared with the louver system of 15 degrees. All test trials were conducted during the daytime. Predator removal using carbon dioxide following protocols published by Wu and Bridges (2014) were completed before each trial. Hydrolox™ traveling water screen efficiency and participation will be calculated using the following equations:

Efficiency = HT/(HT + SN)100

Participation = [(HT + SN)/200)]100

Where,

HT is the number of Delta Smelt recovered in the holding tank,

SN is the number of Delta Smelt recovered in the sieve net behind the screen.

The samples were picked through (summer-winter 2016) and verified that all collected smelt were cultured Delta Smelt. Bycatch of other species were separated, identified and counted. Data analysis will be completed in 2017 and a final report submitted in 2018.

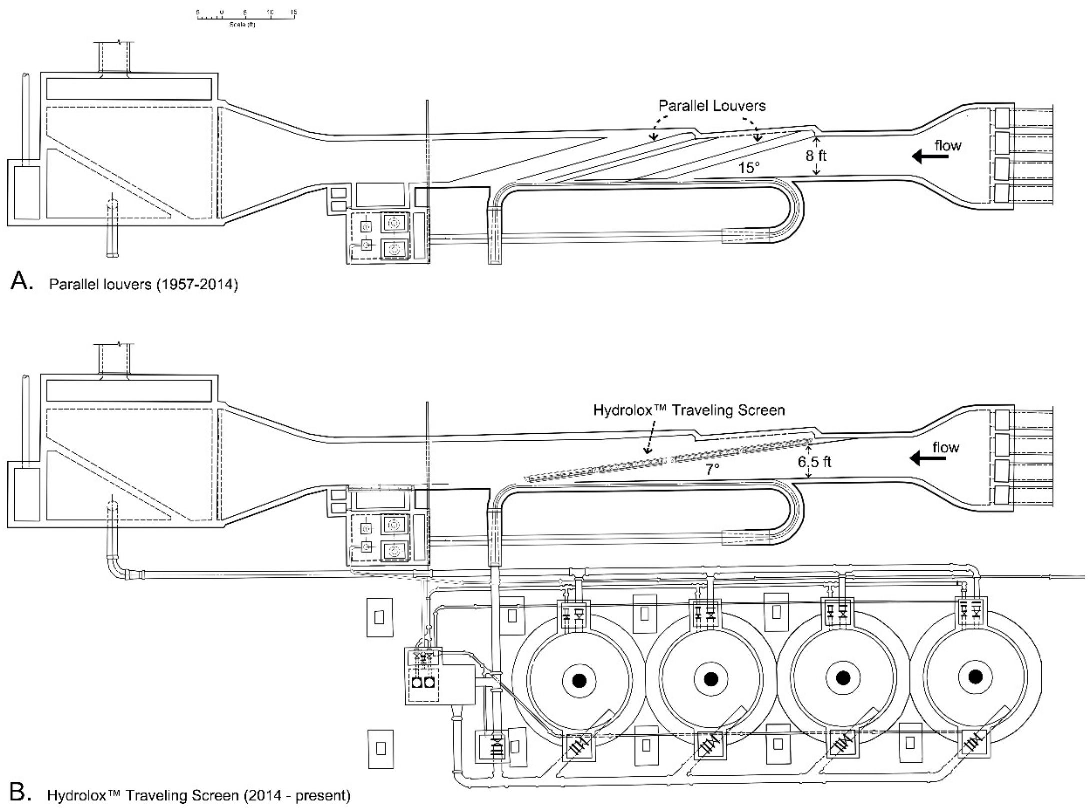


Figure 1. Secondary Channel Screen: A.) Parallel Louvers angled at 15° and 8 ft width at the upstream point of the louvers and B.) Hydrolox™ Traveling Screen angled 7° and 6.5 ft width at the upstream point of the screen.

## Coordination and Collaboration

This study was coordinated with the UC Davis Fish Culture and Conservation Laboratory. Participation and inclusion of research-related updates will be provided at regularly scheduled Tracy Technical Advisory Team (TTAT) and Central Valley Fish Facilities Review Team (CVFFRT) meetings. Analysis will be provided by the Denver Technical Service Center and a final Tracy Series Report will be prepared by the TFCF Biological Resources Branch.

## Endangered Species Issues, "Take" Considerations

Chinook Salmon (*Oncorhynchus tshawytscha*), Steelhead (*O. mykiss*), Longfin Smelt (*Spirinchus thaleichthys*) and Delta Smelt (*Hypomesus transpacificus*) were not collected during this experiment.

## Dissemination of Results (Deliverables and Outcomes)

Updates will be provided at TTAT and CVFFRT meetings.

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# Determining Optimal Carbon Dioxide Concentration for Implementation of Carbon Dioxide Predator Removals in the Bypass Pipes and Secondary Channel at the Tracy Fish Collection Facility

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## Summary

The Tracy Fish Collection Facility (TFCF) was developed in 1956 by the Department of the Interior, Bureau of Reclamation (Reclamation) as a means of salvaging fish ≥ 20 mm in length and returning them to the Sacramento-San Joaquin River Delta (Delta) beyond the influence of C.W. "Bill" Jones Pumping Plant (JPP). To improve the overall salvage process and efficiency of the TFCF it is necessary to minimize fish loss throughout the facility. Many factors, including predation, contribute to the total fish loss at the TFCF (Liston *et al.* 1994, Fausch 2000). Predators accumulate throughout the facility, including in front of the trash rack, the primary channel, the bypass pipes, the secondary channel, and the holding tanks (Liston *et al.* 1994).

Over the years, Reclamation has discussed various means of moving fish through the system (Liston *et al.* 1994, Fausch 2000). A predator removal program in the secondary channel was studied and implemented in the early 1990's (Liston *et al.* 1994) and continued through the decade. Predators were flushed into fyke nets, seined, and dip netted out during times when the secondary channel was drained. Striped Bass (*Morone saxatilis*) were the main predatory species and fish up to 700 mm TL were removed. Other abundant predators at the facility include catfish, sunfish and gobies. Stomach analyses of some of these fish have yielded, among others, Chinook Salmon (*Oncorhynchus tshawytscha*), Delta Smelt (*Hypomesus transpacificus*), and Threadfin Shad (*Dorosoma petenense*; Liston *et al.* 1994). In recent years, predator removal activities have slowed because of logistics and the length of time the facility is down to complete the fish removal effort. In 2004, an alternative predator removal method using carbon dioxide ($CO_2$) was approved for study. This method does not reduce daily salvage due to secondary channel downtime and is likely more efficient and safer for employees and fish than the historic predator removal method (Wu and Bridges 2014). An initial evaluation of the use of $CO_2$ as an alternative predator removal technique in the TFCF bypass pipes and secondary channel was completed in September 2007 and demonstrated that elevated $CO_2$ concentrations are effective for removing predatory fish from the bypass pipes and secondary channel at the TFCF. Results from this initial evaluation have been published as a Tracy Series Report (Wu and Bridges 2014), although the authors did not recommend a $CO_2$ concentration that should be used upon implementation of this method at the TFCF.

Preliminary data for the optimal dose investigation suggests that the $CO_2$ concentration that results in the removal of the greatest proportion of tagged Striped Bass, as well as highest 96-h post-treatment survival, is different for cool (< 18.0 ºC) and warm (≥ 18.0 ºC) water. During times when the water temperature was cool, the Striped Bass could survive treatment at a higher $CO_2$ concentration and the optimal dose was determined to be approximately 180 mg/L. When the water was warm, the optimal dose was determined to be approximately 65 mg/L. This is likely due to overall reduced 96-h post-treatment survival of Striped Bass during times of warm water temperature. Since optimal $CO_2$ concentration appears to be largely affected by water temperature, it will be necessary to develop optimal dose estimates for cool and warm water conditions. If possible, a temperature specific dose table will be developed.

## Problem Statement

Predation may be significant within the primary bypass pipes and secondary channel because Striped Bass continue to reside within them. Removing these fish with the historic method is dangerous for employees, likely decreases daily salvage, and likely causes damage to the fish and/or fish mortality. An initial evaluation of the use of $CO_2$ as an alternative predator removal technique in the TFCF bypass tubes and secondary channel has been completed and published (Wu and Bridges 2014), although authors did not recommend a $CO_2$ concentration that should be used upon implementation of this method. The goal of this proposal is to determine optimal $CO_2$ concentrations for the implementation of $CO_2$ predator removals in the bypass tubes and secondary channel at the TFCF considering removal efficiency and 96-h post-treatment survival. Since preliminary data suggests that optimal $CO_2$ concentration is largely affected by water temperature, it will be necessary to develop optimal dose estimates for cool and warm water conditions. If possible, a temperature specific dose table will be developed.

## Goals and Hypotheses

Goals:

1. Determine optimal $CO_2$ concentration for a 15-minute exposure relative to removal efficiency and survival for cool (< 18 °C) and warm water (≥ 18 °C) conditions.

Hypotheses:

1. All $CO_2$ concentrations will result in equal removal efficiency and survival over a 15-minute exposure regardless of water temperature.

## Materials and Methods

The optimal $CO_2$ concentration for the removal and survival of TFCF predatory fish species will be investigated by removing wild Striped Bass from the bypass pipes and secondary channel with consecutive $CO_2$ injections of increasing concentration. In order to obtain water samples for monitoring of pH and $CO_2$ concentration, it will be necessary to install a 1/5 hp pump in the secondary channel prior to the initiation of consecutive $CO_2$ predator removal replicates. The secondary channel Velocity Control (VC) pumps will be operated to achieve a secondary flow of approximately 0.57 $m^3/s$ and water flow will be initiated into an empty holding tank. Dry ice will then be injected into the bypass pipes to obtain an initial target $CO_2$ concentration (0, 50, 75, 100, 125, 150, 200, 250, or 300 mg/L).

After the predator removal effort is completed with a certain $CO_2$ concentration, the secondary channel will be flushed until the $CO_2$ concentration returns to an ambient level and another predator removal effort with a 300 mg/L $CO_2$ concentration can be performed. Preliminary data suggests that a 300 mg/L concentration is well over the concentration that is 100 percent effective (150 mg/L) at removing Striped Bass from the bypass pipes and secondary channel, therefore, any fish remaining after the first predator removal should be collected at the 300 mg/L concentration. This will allow us to determine the effectiveness of each $CO_2$ concentration tested.

Ninety-six h survival will be determined for all wild Striped Bass recovered from the initial predator removal efforts at concentrations of 50, 75, 100, 125, 150, 200, 250 and 300 mg/L. Ninety-six h survival will not be investigated for non-target species. Survival and efficiency of removal for wild Striped Bass collected during the 300 mg/L predator removal efforts that follow each tested $CO_2$ concentration will not be determined due to the fact that fish collected in this sample will be exposed to numerous $CO_2$ concentrations. Three replicates will be performed at each initial $CO_2$ concentration and the $CO_2$ concentration that is determined to have the highest combination of removal efficiency and 96-h post-treatment survival will be considered the optimal dose for implementation of $CO_2$ predator removals in the bypass pipes and secondary channel at the TFCF. Since preliminary data suggests that optimal $CO_2$ concentration is largely affected by water temperature, optimal dose estimates will be developed for cool and warm water conditions. If possible, a temperature specific dose table will be developed.

*Data Analyses*
Logistic regression will be used to determine if a significant capture-dose response exists within the range of 0–300 mg/L. A probability-capture curve will be used to determine the probability of capture within 25 percent for each $CO_2$ concentration being tested (*i.e.*, 0, 50, 75, 100, 125, 150, 200, 250 and 300 mg/L) using Probit analysis with a logit link function. A probability-survival curve will be used to determine the probability of 96-h post-treatment survival within 25 percent and verify that survival is influenced by water temperature. Contingency tables will be used to compare the proportion of fish that die within 96-h for each treatment. A scatterplot will be used to illustrate the relationships between $CO_2$ concentration, removal efficiency, and 96-h post-treatment survival. The $CO_2$ concentration at which best-fit trend lines for removal efficiency and 96-h post-treatment survival intercept (the $CO_2$ concentration at which there is the highest combination of removal efficiency and 96-h post-treatment survival) will be considered the optimal dose for implementation of $CO_2$ predator removals in the bypass pipes and secondary channel at the TFCF. Since preliminary data suggests that optimal $CO_2$ concentration is largely affected by water temperature, it will likely be necessary to develop optimal dose estimates for cool and warm water conditions. If possible, a temperature specific dose table will be developed.

## Coordination and Collaboration
This study will be coordinated with the TFCF staff, Tracy Technical Advisory Team (TTAT), and California Department of Fish and Wildlife (CDFW). Participation and inclusion of research-related updates will be provided at regularly scheduled TTAT and Central Valley Fish Facilities Review Team (CVFFRT) meetings.

## Endangered Species Issues, "Take" Considerations
Based on results from Wu and Bridges 2014, it is possible that mortality of listed species could occur if predator removals using $CO_2$ as an anesthetic are completed during the normal entrainment season of these species. This is due to the fact that Chinook Salmon and Delta Smelt exhibited a lower tolerance to elevated $CO_2$ levels than Striped Bass. The dose necessary in order to move adult Striped Bass through the TFCF bypass pipes and secondary channel may be over the concentration in which Chinook Salmon and Delta Smelt exhibited 100 percent survival. Winter-run Chinook Salmon, Steelhead Trout (*O. mykiss*), and Delta Smelt may also be collected in holding tanks and encountered during these experiments. If this occurs, these fish will be immediately documented, returned to the Delta, and reported to all appropriate agencies. In order to minimize the risk of mortality to listed species, all attempts will be made to complete research activity during seasonal periods in which salvage of listed species is not likely to occur.

Although the procedures during experimentation may lead to mortality of listed species, the cumulative lethal take of listed species for the facility is likely much higher in the absence of predator removal activities.

## Dissemination of Results (Deliverables and Outcomes)
There was minimal progress made for this project during the 2015-2016 research periods due to the fact that other projects took priority. Data will be collected to determine optimal $CO_2$ concentrations for the implementation of $CO_2$ predator removals in the bypass pipes and secondary channel at the TFCF over the next two years. Updates will also be provided at TTAT and CVFFRT meetings. A draft report for peer review is anticipated to be completed by December 2018. The primary deliverable will be an article published as a Tracy Technical

Bulletin.  Information will be gained on the successes and limitations of this alternate predator removal technique at the TFCF.  This knowledge will help guide future development and implementation of predator removal procedures at the TFCF and other fish facilities.

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# Estimation of Biomass Capacity of the Tracy Fish Collection Facility Fish-Haul Trucks Based on Oxygen and Aeration System Capabilities and Published Oxygen Consumption, Ammonia Production, and Carbon Dioxide Production Rates

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## Summary

The U.S. Bureau of Reclamation (Reclamation), Tracy Fish Collection Facility (TFCF) is located at the head of the Delta-Mendota Canal (DMC) 4 km NE of the C.W. “Bill” Jones Pumping Plant (JPP) and 15 km NW of Tracy, California, and was developed for salvaging outmigrant Chinook Salmon (*Oncorhynchus tshawytscha*) and Striped Bass (*Morone saxatilis*) ≥20 mm entrained by the JPP.  After salvage, fish are maintained in holding tanks (6 m wide x 5 m deep) until transport back to the Sacramento-San Joaquin Delta (Delta).  The schedule of fish hauling is dependent on salvage rates, debris loading, and special-status-species procedures (CDFW 2013). Prior to transport, fish accumulated in a holding tank are collected in a haul-out bucket (1544 L, 1.8 m inside diameter with a conical bottom from 0.9 m deep to 1.3 m deep) and transferred to a fish-haul truck tank (9,462 L, 4.6 m long x 2.0 m wide x 1.2 m deep).  Fish are then trucked 49.9 km from the TFCF to one of two release sites located at the confluence of the Sacramento and San-Joaquin Rivers and away from the immediate influence of south Delta pumping facilities.

Maintenance of adequate dissolved oxygen (DO), total ammonia nitrogen (TAN), and carbon dioxide levels is of particular concern during fish transport.  Dissolved oxygen levels in the fish-haul trucks can affect the success of fish transportation as low DO levels can result in respiratory stress, which can affect swimming performance, equilibrium, and survival of fish (Moyle and Cech 2004, Herbert and Steffensen 2005, Portz *et al*. 2006).  Elevated fish densities in the truck can also increase the rate of $O_2$ consumption, as well as $CO_2$ production, and cause hypoxic or anoxic conditions.  In addition, TAN can reach toxic levels in closed transport systems, as fish continuously produce TAN as a primary byproduct of protein metabolism and water consumption (Suthphin and Wu 2008).

In 2008, Sutphin and Wu reported fish density (0.3–64.5 g of fish/L) and water quality parameters of concern in the bucket and trucks generally remained within acceptable ranges throughout the period of fish transport at temperatures between 15.2–25.3 °C. Since then, new fish-haul trucks have been designed, fabricated, and are being used at the TFCF. The new fish-haul trucks must be evaluated to estimate the biomass capacity based on the oxygen and aeration system capabilities, as well as published oxygen consumption, TAN production and $CO_2$ production rates (from Sutphin and Hueth 2015). This information may be used for the potential development of updated fish transport tables, which indicate the percent of a load (up to 100 percent) that a total number of salvaged fish within a particular size class represents. Minimal progress was made on this project during the 2015 and 2016 research seasons due to the fact that other studies took precedence during this period.

## Problem Statement

New fish-haul trucks have been designed, fabricated, and are being used at the TFCF. This new equipment must be evaluated to estimate the biomass capacity based on the oxygen and aeration system capabilities, as well as published oxygen consumption, TAN production, and $CO_2$ production rates (from Sutphin and Hueth 2015). Evaluation of this new equipment will increase the likelihood that the millions of fish that are salvaged annually, including the threatened Delta Smelt (*Hypomesus transpacificus*) and endangered Winter-run Chinook Salmon (Reclamation's Tracy Fish Salvage Records 2009), are transported to release sites under appropriate water quality parameters.

## Goals and Hypotheses

Goals:

1. Measure the rate of $O_2$ rise in the new fish-haul trucks while operating the air system only, $O_2$ system only, and both the air and $O_2$ systems simultaneously.
2. Use measured oxygen production rates along with published estimates of fish oxygen consumption, TAN production, and $CO_2$ production (from Sutphin and Hueth 2015), to develop a mass balance equation to estimate biomass capacity of the new fish-haul trucks while operating the air system only, $O_2$ system only, and both the air and $O_2$ systems simultaneously.

Hypotheses:

1. The rate of $O_2$ rise in the new fish-haul trucks will not be different when operating the air system only, the $O_2$ system only, and both the air and $O_2$ systems simultaneously.
2. Estimates of biomass capacity for the new fish-haul trucks will not be different when operating the air system only, the $O_2$ system only, and both the air and $O_2$ systems simultaneously.

## Materials and Methods

The rate of $O_2$ rise in water containing 8 mg/L salt while running the air system only, the $O_2$ system only, and both the air and $O_2$ systems simultaneously will be determined with maximum gas flow through the airstones (approximately 6-8 L/min) after injecting nitrogen gas in the water to achieve a DO level of $\leq 4.0$ mg/L. Sampling will be completed during times when the Delta water temperature is warm (June-Sept.) because this condition likely results in the lowest $O_2$ dissolving rate in the water and, in combination with published estimates of fish oxygen consumption, would yield a conservative estimate of biomass capacity for the new fish-haul trucks at the TFCF.

All trials will be completed in the TFCF truck pit. Air and ambient Delta water temperatures will be measured at the beginning and end of each trial using an Acu-Rite digital thermometer and a YSI-85, respectively. The truck will be completely filled with 8 mg/L salt water and nitrogen gas will be injected into the water until a DO level of 4.0, or under, is reached (measured with a YSI-85). This will be done in order to obtain a more comprehensive rate curve for each system or combination of systems. The appropriate gas system will then be turned on. Oxygen cylinders will be set to 40 psi for all trials in which the $O_2$ system will be utilized. Oxygen and Total Gas Saturation (TGS) measurements, taken with a YSI-85 and a Sweeney saturometer, respectively, will be obtained every 2 min from the mid-water column until five measurements are recorded on the plateau of the curve. The water in the truck tank will be continuously mixed during this period using a 0.5 hp submersible pump (Tsurumi, Inc., Glandale Heights, Illinois) in order to simulate the mixing associated with water sloshing during transport.

Published estimates of fish oxygen consumption, TAN production, and $CO_2$ production rates will be used along with $O_2$ measurements to develop a mass balance equation to estimate biomass capacity of the new fish-haul trucks while operating the air system only, $O_2$ system only, and both the air and $O_2$ systems simultaneously. This information may be used in the development of updated fish transport tables at the TFCF.

*Data Analyses*
The rate of $O_2$ rise will be evaluated for each system or combination of systems using regression analysis by plotting $O_2$ concentration over time and generating a rate curve. Published estimates of fish oxygen consumption, TAN production, and $CO_2$ production will be used along with $O_2$ measurements to develop a mass balance equation to estimate biomass capacity of the new fish-haul trucks while operating the air system only, $O_2$ system only, and both the air and $O_2$ systems simultaneously.

## Coordination and Collaboration
All work on this evaluation will be coordinated with the TFCF Fish Diversion Operators, TFCF Biology staff, and the Denver Technical Service Center Fisheries and Wildlife Resources Group. Participation and inclusion of research-related updates will be provided at regularly scheduled Tracy Technical Advisory Team (TTAT) and/or Central Valley Fish Facilities Review Team (CVFFRT) meetings.

## Endangered Species Concerns
This evaluation will not involve the take of any wild fish, including species listed as endangered or threatened.

## Dissemination of Results (Deliverables and Outcomes)
Preliminary work has been performed in the investigation of oxygen rise in the new fish-haul trucks when using the air system only, $O_2$ system only, and both systems in combination (in August and September 2009, October 2011, and February, March, April and September 2014).

While progress was made on this project during the 2014 research period, data collection has not taken place since then due to the fact that other projects have taken priority. Data collection for this project is not expected to be completed until September 2017. If data collection can be completed by September 2017, a draft report is expected to be produced by December 2017.

The primary deliverable will be an article published as a Tracy Technical Bulletin. Updates will be provided at TTAT and CVFFRT meetings. Additionally, information will be gained on the successes and limitations of the fish-hauling process at the TFCF while using the new fish-haul trucks. This information will help guide future improvements to the fish transport procedures and equipment at the TFCF.

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# Feasibility of Using Carbon Dioxide to Remove Piscivorous Fish from the Tracy Fish Collection Facility Primary Channel

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## Summary

Action IV.4.1(1)(a) of the 2009 National Marine Fisheries Service (NMFS) Biological Opinion and Conference Opinion on the Long-Term Operations of the Central Valley Project and State Water Project (BiOp) mandates that the U.S. Bureau of Reclamation (Reclamation) complete studies to determine methods for removal of predators in the primary channel at the Tracy Fish Collection Facility (TFCF) with the goal of implementing measures to reduce pre-screen predation in the primary channel to ten percent or less (NMFS 2009). While a predator removal program in the secondary channel at the TFCF has been ongoing since the early 1990s, there are

few options for addressing the predator loads in the primary channel. Reclamation personnel have reviewed various means of moving predators through the TFCF system such as electricity, sound, light, and mechanical methods, although many of these techniques are largely ineffective for removing large piscivorous fish, expensive to install and operate and are logistically difficult to implement at the TFCF (Fausch 2000). The use of carbon dioxide ($CO_2$), in the form of dry ice, was recently evaluated as a predator removal technique in the bypass pipes and secondary channel at the TFCF and was found to effectively remove fish, including piscivorous predators, from this area (Wu and Bridges 2014). This suggests that the periodic use of $CO_2$ may also be efficacious for the removal of piscivorous fish from the primary channel at the TFCF. If so, the use of $CO_2$ in the primary channel could be implemented at the TFCF to meet Action IV.4.1(1)(a) of the NMFS BiOp instead of investing funds for extensive research, design, development, installation and maintenance of more complicated predator removal systems or processes.

In April 2015, a preliminary investigation was completed to determine if acoustically tagged Striped Bass (*Morone Saxatilis*) could be herded or moved to a desired location within the primary channel by injecting dry ice. To do this, it was necessary to utilize the existing hydrophone array (Hydroacoustic Technology, Inc., Seattle, Washington) in the primary channel that was previously set-up for other projects. In addition, any remaining acoustically tagged (Hydroacoustic Technology, Inc., Seattle, Washington) Striped Bass in the primary channel (approximately 11-12 fish) were used as test subjects. This preliminary investigation was completed during a slack low tide with low primary channel velocities in an attempt to minimize the volume of water that needed to be treated.

Approximately 2,268 kg (5,000 lbs) of dry ice was injected in front of the trash rack on the north side of the primary channel. Peak $CO_2$ concentrations at the north and south side of the primary channel were estimated to be 192.0 mg/L and 1.8 mg/L, respectively. Acoustic tracks of tagged Striped Bass in the primary channel showed that all fish actively avoided the $CO_2$ in the north side of the primary channel for approximately 30 mins, although this behavior could also be attributed to an avoidance response to the turbulence, disturbance, and bubbles produced during dry ice injection. Despite this, regardless of whether fish were actively avoiding high $CO_2$ concentrations in the water or avoiding the turbulence and disturbance from bubbles created by dry ice injection, acoustically tagged striped bass did show an avoidance response to dry ice injection. This suggests that the use of $CO_2$ may be effective for removing fish from the primary channel at the TFCF. Even if fish are not anesthetized by the $CO_2$ concentration achieved in the primary channel, it may be possible to move them into the bypass pipes and secondary channel where Wu and Bridges (2014) have shown they can be readily removed from the TFCF system. The higher than expected $CO_2$ concentration reached on the north side of the primary channel (where dry ice was injected) was likely due to the fact that dry ice injection was completed during a slack low tide, which ultimately reduced the volume of water that had to be treated. This suggests that depending on alkalinity, temperature of the Delta water, primary depth, tidal stage and tidal action, less ice than expected may be necessary to achieve a dose of 75 mg/L (the optimal dose considering removal efficiency and survival from the secondary channel based on preliminary data from Wu et al. [in progress]) when treating the entire primary channel.

## Problem Statement

Action IV.4.1(1)(a) of the 2009 NMFS BiOp mandates that Reclamation complete studies to determine methods for removal of predators in the primary channel at the TFCF with the goal of implementing measures to reduce pre-screen predation in the primary channel to ten percent or less (NMFS 2009). The use of $CO_2$ was recently found to effectively remove fish, including piscivorous predators, from the bypass pipes and secondary channel at the TFCF (Wu and Bridges 2014). Also, preliminary data for all water temperatures combined suggests that $CO_2$ concentrations of approximately 75 mg/L are optimal for the removal of Striped Bass from the bypass pipes and secondary channel at the TFCF, considering removal efficiency and survival. This suggests that the periodic use of $CO_2$ at a concentration of 75 mg/L may also be efficacious for the removal of piscivorous fish from the primary channel at the TFCF. Due to this, the feasibility of using $CO_2$ at a concentration of approximately 75 mg/L to remove piscivorous fish from the primary channel will be investigated.

## Goals and Hypotheses

Primary Goals:

1. Determine if a 75 mg/L concentration of $CO_2$ can be reasonably obtained in the primary channel at the TFCF, within 30 min, considering the volume of water that needs to be treated and the amount of dry ice necessary.
2. Determine if a 75 mg/L $CO_2$ concentration increases the number of piscivorous fish removed from the primary channel during a 30-min treatment period.
3. Estimate the efficiency of removal for piscivorous fish in the primary channel at the TFCF using a 75 mg/L $CO_2$ concentration over a 30-min period.

Secondary Goals:

1. Provide a population estimate of the number of piscivorous fish in the TFCF system (primary channel, bypass tubes, and secondary channel) on the day of experimentation based on the proportion of acoustically tagged striped bass recovered, as well as numbers of wild piscivorous fish collected, during $CO_2$ treatment in the primary channel.

Hypotheses:

1. The injection of $CO_2$ in the primary channel will have no effect on the $CO_2$ concentration in the water due to large water volume and water flow within this component of the TFCF.
2. A 75 mg/L $CO_2$ concentration will not increase the number of piscivorous fish species removed from the primary channel at the TFCF.
3. A 75 mg/L $CO_2$ concentration in the primary channel at the TFCF will have no effect on the efficiency of removal for piscivorous fish species.

## Materials and Methods

In order to investigate the feasibility of using $CO_2$ to remove piscivorous fish species from the primary channel at the TFCF, it will be necessary to adapt procedures described by Wu and

Bridges (2014) for the secondary channel and modify them for use in an area of the facility with a larger volume of water and greater flow.

Since the flow and velocity in the primary channel at the TFCF are largely determined by the number of pumping units (1–5) being used for water export operations at the C.W. “Bill” Jones Pumping Plant (JPP), trials will be completed when there is a slack low tide during one unit pumping operations at the JPP, which will reduce the volume of water in the primary channel that needs to be treated. Secondary channel velocity and flow rate will be maximized to achieve slightly increased velocity and flow in the primary channel bypass entrances. The maximization of secondary channel velocity and flow will also maximize primary bypass ratios (velocity of water going into each bypass versus the velocity of water in the channel), which may promote entrance into the bypass pipes and, ultimately, collection of fish in holding tanks during both the control (30-min facility fish-count performed immediately prior to $CO_2$ treatment) and $CO_2$ treatment.

The amount of dry ice needed to theoretically achieve a concentration of 75 mg/L in the primary channel was calculated based on water volume and flow, assuming that the length of the primary channel is 121.9 m (400 ft), the width of the primary channel is 25.6 m (84 ft), the depth of the primary channel is 5.2 m (17 ft), and the flow through the primary channel is approximately 25.5 $m^3/s$ (900 $ft^3/s$) when there is one pumping unit operating at the JPP. It was calculated that approximately 4,653 kg (10,258.1 lbs) of dry ice would be required to achieve a 75 mg/L concentration in the primary channel. Since dry ice injection will be scheduled to coincide with a slack low tide, it is likely that this amount of dry ice will be greater than needed because the flow through the primary channel will be reduced during these conditions. Since the main goal of this project is to determine if the use of $CO_2$ promotes the removal of fish from the primary channel, the possibility of higher than expected $CO_2$ concentrations was deemed acceptable by the authors and approximately 4,672 kg (10,300 lbs) of dry ice will be requested to be delivered to the TFCF by the supplier (Innovative Federal Operations Group, LLC, Vista, California) on the day before experimentation. Upon delivery, dry ice will be stored in large, outdoor dry ice coolers (0.85 $m^3$; Polar Tech Industries, Inc., Genoa, Illinois) until injection takes place. These coolers will be conveniently located near the head of the primary channel at the TFCF, where injection of dry ice will occur.

To determine the reaction of piscivorous fish to elevated $CO_2$ treatment in the primary channel, as well as estimate the efficiency of removal when using a 75 mg/L $CO_2$ concentration during a 30-min treatment period, acoustic tags (Hydroacoustic Technology, Inc. [HTI], Seattle, Washington, Model 795-LY) will be used, along with an acoustic system consisting of acoustic receivers (HTI, Model 290/291 ATR), hydrophones (HTI, Model 590), and hydrophone cables (HTI, Model 690), that was previously installed at the TFCF for other projects and is still being maintained. The use of this technology will allow for the production of 2-dimensional tracks of acoustic tagged fish.

Acoustic tags will be surgically implanted in at least 12 Striped Bass (number chosen based on the number of appropriate acoustic tags on hand and budgetary constraints) that will be collected from the TFCF primary channel by angling. Striped Bass were chosen due to the fact that they were the most prevalent piscivorous fish species encountered during previous predator removal studies performed in the secondary channel at the TFCF (Liston *et al.* 1994; Wu and Bridges

2014; Sutphin *et al.* 2014) and are likely the main piscivorous fish species in the primary channel as well. Surgical implantation of acoustic tags in Striped Bass will occur up to 30 days prior to release and $CO_2$ will be used as an anesthetic to avoid prolonged holding periods associated with the use of other anesthetics (*e.g.* Tricaine Methanesulfonate [MS-222] has a minimum holding period of 21 days after treatment). Striped Bass will then be hand-carried to a wheeled recovery tub (228.6-L, 78.7 cm long x 50.8 cm wide x 57.1 cm deep) containing oxygenated 16 $^{o}$C well water and transported to outside 1.2-m diameter (757-L) black tanks containing aerated, 16 $^{o}$C well water where they will be held at a density of up to two fish per tank for up to 30 days.

One week prior to release, tanks will gradually be switched from well water to treated Delta water in an effort to appropriately acclimate fish. Two hours prior release, Striped Bass will be netted (using the dip net previously described), transferred to perforated garbage cans containing approximately 37.9 L of treated Delta water and transported to the head of the TFCF primary channel for release. Release of Striped Bass into the primary channel will occur 1 day prior to treatment with $CO_2$. To prevent experimental Striped Bass from moving upstream through the 56-mm spaced trash rack at the upstream end of the facility, it will be necessary to use only fish greater than 375 mm fork length (FL), which is the minimum size estimated by Sutphin *et al.* 2014, based on data collected at the TFCF, at which passage through the trash rack is restricted. To prevent experimental Striped Bass from moving into the canal downstream of the primary louvers, it is important that the primary louvers are not lifted for cleaning after fish are introduced into the primary channel until after the predator removal in the primary channel is completed.

Prior to the start of $CO_2$ treatment, a 149-W (0.2-hp) submersible pump (Model 316, Carry Manufacturing, Inc., Munger, Michigan) will be installed, at mid-water depth, in the middle of the primary channel to provide water samples for monitoring $CO_2$ and pH over time. If possible, multiple pumps may also be installed throughout and downstream of the TFCF including in the primary channel, secondary channel, holding tanks, and intake canal to the JPP. Flow will be maximized in the secondary channel to slightly increase velocity at the bypass entrances and maximize primary bypass ratios in an attempt to guide fish from the primary channel into a bypass pipe and, ultimately, into a holding tank.

To treat the entire primary channel, approximately 4672 kg (10,300 lbs) of dry ice will be evenly distributed and inserted at multiple locations upstream of the trash rack at the head of the primary channel. Dry ice insertion will be completed using 1–2 front-end loaders, 1–2 forklifts with tipping bins, both trash rack cleaning devices, and manual insertion. During insertion of dry ice, all personnel will be required to wear appropriate personal protective equipment including, but not limited to, life jackets, harnesses, gloves, safety glasses, and hardhats.

Hydraulic measurements, including primary channel flow, primary channel velocity, primary channel depth, secondary channel flow, secondary channel velocity, secondary channel depth, holding tank flow and holding tank velocity, will be recorded from facility meters during each trial. Carbon dioxide and pH measurements will be taken every 2 min from the TFCF sampling station(s) using a submersible pump to obtain water samples, hand-held titration cells (K-1910 [range = 10–100 mg/L $CO_2$] and K-1920 [range = 100–1000 mg/L $CO_2$], CHEMetrics Inc., Midland, Virginia), and a pH meter (Model pH 110, Oakton Instruments, Vernon Hills, Illinois), respectively. Alternatively, pH loggers (Model SDL100; Extech Instruments, Nashua, New

Hampshire) will be used to obtain pH measurements while a $CO_2$ vs. pH curve will be developed, using a sample of raw Delta water collected prior to the injection of $CO_2$, to obtain a formula that will be applied to pH measurements to estimate $CO_2$ concentration.

The number of piscivorous fish collected during the 30-min $CO_2$ treatment will be compared to the number of piscivorous fish collected in the 30-min fish count performed immediately prior to $CO_2$ treatment (control) to determine if the use of $CO_2$ in the primary channel increases the total number of piscivorous fish removed from the primary channel at the TFCF. A chi-square test (Minitab version 15) will be used to determine if there is a significant difference between the proportions of piscivorous fish removed during the 30-min fish-count (control) and $CO_2$ treatment. The percentage of tagged Striped Bass recovered will be used to estimate the efficiency of removal when using a 75 mg/L concentration. The proportion of acoustically tagged striped bass recovered during $CO_2$ treatment in the primary channel will be used along with the numbers of wild piscivorous fish collected to estimate the piscivorous fish population in the TFCF system (primary channel, bypass tubes, and secondary channel) on the day of experimentation, which was a secondary objective of this study. Additional replicates (up to 2) may be performed if Striped Bass are successfully guided to holding tanks during treatment of the TFCF primary channel with $CO_2$.

If no experimental Striped Bass are collected in the holding tanks during the $CO_2$ treatment, 2-dimensional acoustic tracks will be used to investigate Striped Bass behavior in the primary channel during treatment, which will be further used to guide future research efforts. Depending on the behavior that is observed, the $CO_2$ treatment process may be modified and repeated in an attempt to effectively guide Striped Bass to the TFCF holding tanks. For example, if acoustic tagged Striped Bass are found to enter the bypass pipes but not the holding tank, it may be suggested that we perform an additional $CO_2$ treatment in the bypass pipes and secondary channel after treating the primary channel in an effort to guide fish from the bypass pipes and secondary channel into a holding tank. On the other hand, if acoustic tagged Striped Bass are determined to not enter the bypass pipes or secondary channel during $CO_2$ treatment in the primary channel, it may be suggested that we lift the louver panel immediately in front of bypass 4 prior to $CO_2$ treatment of the primary channel in an effort to guide fish from the primary channel in to the canal downstream of the primary channel where there is no impact on salvageable fish.

## Coordination and Collaboration

This study will be coordinated with the TFCF biological and operations staff, Tracy Technical Advisory Team (TTAT), California Department of Fish and Wildlife (CDFW), and Hydroacoustic Technology, Inc. Participation and inclusion of research-related updates will be provided at regularly scheduled TTAT and Central Valley Fish Facilities Review Team (CVFFRT) meetings.

## Endangered Species Issues, “Take” Considerations

Winter-run Chinook Salmon (*Onchorhynchus tshawytscha*), Steelhead Trout (*O. mykiss*), and Delta Smelt (*Hypomesus transpacificus*) may be encountered during these experiments. Based on results from Wu and Bridges 2014, it is possible that mortality of certain listed species may occur if predator removals using a 75 mg/L $CO_2$ concentration are completed in the primary channel during the normal entrainment season of these species. This is due to the fact that certain species, such as Delta Smelt, exhibited a lower tolerance to elevated $CO_2$ levels than Striped Bass and displayed up to 60% mortality over 96 h after being exposed to 75 mg/L $CO_2$ for 20 min. If listed species are encountered, they will be immediately documented, returned to the Sacramento-San Joaquin Delta (if alive), and reported to all appropriate agencies. In order to minimize the risk of mortality of listed species, all attempts will be made to complete research activity during seasonal periods in which listed species are not typically present at the TFCF.

Although the procedures during experimentation may lead to mortality of listed species, the cumulative lethal take of listed species for the facility is likely much higher in the absence of predator removal activities in the primary channel at the TFCF.

## Dissemination of Results (Deliverables and Outcomes)

A Tracy Technical Bulletin will be prepared and published upon completion of the study. Updates and presentations of progress will be provided internally and upon request by TTAT and other interagency technical forums. At the earliest, data collection is expected to take place in October 2017 and will likely continue into 2018. A draft report is expected to be produced by December 2018.

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