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Proposal Package for Tracy Fish Facility Improvement Program

Tracy Fish Facility Improvement Program
California-Great Basin · Interior Region 10

U.S. Department of the Interior

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Proposal Package for Tracy Fish Facility Improvement Program

Tracy Fish Facility Improvement Program
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prepared by

Bureau of Reclamation
Tracy Fish Collection Facility

Bureau of Reclamation
Technical Service Center

Cover Photograph: Tracy Fish Collection Facility, Byron, California. (San Luis Delta Mendota Water Authority)

Mission Statements

The U.S. Department of the Interior (DOI) conserves and manages the Nation's natural resources and cultural heritage for the benefit and enjoyment of the American people, provides scientific and other information about natural resources and natural hazards to address societal challenges and create opportunities for the American people, and honors the Nation's trust responsibilities or special commitments to American Indians, Alaska Natives, and affiliated island communities to help them prosper.

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Tracy Fish Facility Improvement Program

J. Carl Dealy, Program Manager
Bureau of Reclamation, South-Central California Area Office
Tracy Office
16650 Kelso Road
Byron, California 94514-1909

Tracy Series Editors

Zachary A. Sutphin
Bureau of Reclamation, Technical Service Center
Fisheries and Wildlife Resources, 86-68290
PO Box 25007
Denver, Colorado 80225-0007

Connie D. Svoboda, P.E.
Bureau of Reclamation, Technical Service Center
Hydraulic Investigations and Laboratory Services, 86-68560
PO Box 25007
Denver, Colorado 80225-0007

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Movement of Fish in the Primary Channel to the Delta-Mendota Channel During Louver Cleaning

Investigators

Raymond C. Bark
Fish Biologist
Fisheries and Wildlife Resources Group
Technical Service Center
rbark@usbr.gov

Summary

The Tracy Fish Collection Facility (TFCF) was developed in the 1950's by the Department of the Interior's Bureau of Reclamation as a means to salvage fish entrained by the C.W "Bill" Jones Pumping Plant (JPP). The TFCF screens fish from the canal water, diverts them into collection tanks and transports the fish, via truck, to the confluence of the Sacramento and San Joaquin Rivers beyond the influence of the south delta export pumps. Due to the volume and rate of export pumping into the canal (up to 5,200 ft^3/s), various types of fish from the Sacramento-San Joaquin River Delta are entrained including Endangered Species Act (1973) listed fish. Native fish species found in the Delta such as Chinook Salmon (*Oncorhynchus tshawytscha*), Steelhead (*O. Mykiss*) and Delta Smelt (*Hypomesus transpacificus*) are often entrained into the canal exports therefore, it is critical that these species are effectively collected and salvaged by the TFCF. Juvenile life stages of endangered and threatened species such as Chinook Salmon (54 FR 10260, 59 FR 440, 64 FR 50394), Steelhead (63 FR 13347), and adult and juvenile Delta Smelt (58 FR12854) are salvaged mostly during the winter and spring period by the TFCF (California Department of Fish and Wildlife 2017).

Fish salvaged by the TFCF must first pass through the trash-rack structure made from thick elongated steel bars designed to keep large debris from entering the facility. The spacing of the bars for the trash-rack structure are about 2.25 inches (5.72 centimeters) apart which prevents large fish from entering the TFCF. However, all small-bodied and mid-sized fish less than 2.25 inches in width can pass through the trash-rack structure which includes all types of juvenile salmonid species. Fish that pass through the trash-rack enter the primary channel where they are guided by a louver array with 1-inch spaced (2.54 cm), angled bars, then pass into one of four bypasses feeding into the secondary channel. Once the fish enter the secondary channel, they are further guided into one of four holding tanks before being removed from the tank and loaded into a fish hauling truck.

Non-native prey fish such as Threadfin Shad (*Dorosoma petenense*), American Shad (*Alosa sapidissima*) and non-native predatory fish Striped Bass (*Morone saxatilis*), Largemouth Bass (*Micropterus salmoides*) and Bluegill (*Lepomis macrochirus*) have been the fish most frequently salvaged in recent years while numbers of ESA listed native fish (previously listed) have been declining (Aasen 2014). All these species as well as others can potentially escape downstream during louver cleaning. However, Striped Bass (*Morone saxatilis*), the top non-native predatory fish salvaged, have been found to hold within the primary channel for long periods while some eventually passed downstream of the primary channel (Wu et al. 2015) into the Delta-Mendota Channel (DMC) when the primary channel louvers were lifted for cleaning. Some of these acoustically tagged Striped Bass were also detected holding next to the primary channel guide wall where water velocities have been found to be low (Frizell and Bark 2006) and where other fish are likely to hold as well. If Striped Bass can hold for long periods in the primary channel, other entrained fish (including the ESA listed fish) may also hold and eventually escape downstream evading the TFCF salvage process altogether. The ESA listed fish that pass downstream of the primary louvers during normal operation and during louver cleaning are considered lost.

Movement of fish between the primary channel and the DMC is tied to the cleaning (and maintenance) of the primary louver panels. The louver panels are individually lifted and cleaned at least once per day (2-5 times during fall and winter) allowing fish to move downstream or upstream of the primary channel. Cleaning the louvers is necessary to ensure their effectiveness in guiding fish into the secondary channel and into the collection tanks and to minimize flow restriction to the JPP. Each louver panel (36 total) requires about 3-5 minutes to be lifted, cleaned, and then lowered back into place and occurs year-round and mostly during day and at other times when necessary. Consequently, a population of Striped Bass (as well as other fish) reside in the DMC downstream of the TFCF and upstream of the JPP. This section of the DMC is about 15 feet deep, 240 feet wide and 2 ¼ miles long - ample habitat to hold many fish.

Problem Statement

Because the primary louvers must be lifted for cleaning, movement of fish into the DMC can occur daily within the period when the louver cleaning occurs. For the entire louver array to be cleaned, a total of 108 to 180 minutes are needed which allows a lot of time for fish to escape downstream as the louvers are cleaned. The primary louvers are also cleaned from upstream to downstream, allowing fish holding near the guide wall an audio and visual cue to escape as the louver openings progress towards the apex. Fish holding in the primary louver channel may also become opportunistic and learn to escape downstream when high debris loads require multiple cleanings thus, having daily opportunities to move downstream or back upstream from the DMC. This study will determine if fish holding inside the primary channel access the DMC (or vice-versa) when the louvers are lifted for cleaning. If available, experimental groups of fish (e.g. Threadfin Shad) will be released during louver cleaning and observed for downstream escapement.

As part of this effort to determine fish movement between the primary channel and the DMC when the louver panels are lifted, I will also analyze the existing Striped Bass movement data collected from the Carbon Dioxide Predator Removal study conducted by Brandon Wu (and other TFCF staff). This study has focused on removing Striped Bass from the primary channel where several fish were acoustically tagged for each replicate to determine movement within the primary channel

during the experiment. As a secondary use of this Striped Bass movement data, I will cross-reference the CO_2 movement data with all detections of the HTI acoustic tags by the hydrophone array. Since the hydrophones (HTI) are located throughout the TFCF as well as upstream and downstream of the facility, the hydrophone array should be able to record and differentiate fish movement between the primary channel and DMC as well as in other locations within and near the TFCF.

Goals and Hypotheses

Goal:

1. Determine the extent of fish loss through the primary louver channel using an acoustic and underwater fish camera when the louvers are lifted for cleaning.

2. Determine if predatory fish holding in the DMC are accessing the primary channel.

Null Hypotheses:

1. There will be no fish from the primary channel escaping downstream into the DMC (or moving back upstream) into the primary channel when the louvers are lifted.

Materials and Methods

Test Location and Equipment

A DIDSON (Duel-Frequency Identification Sonar) camera will be the primary instrument used to determine movement of fish out of the primary channel and into the DMC or vice-versa. The DIDSON camera will be deployed immediately downstream and inside the primary channel, near the apex where fish are crowded and movement into the DMC can be clearly determined when the louvers are lifted. This study will be performed when ESA fish are present (December-June) where the duration of deployment will be approximately one week per month covering day, crepuscular, and night periods (if possible) with additional focus on periods when high debris loads require multiple daily louver cleanings.

The DIDSON camera will be mounted onto a long steel pole that will be used to lower and raise the camera from the primary channel louver deck. A rope or steel cable will also be attached to the camera's frame to ensure retrieval from the DMC. A smaller and considerably lighter "off-the-shelf" fish camera will also be used to assist the DIDSON and can be deployed at various depths using a long pole or weighted rope.

Fish Source and Care

No ESA fish from the TFCF salvage process will be caught, collected or handled for this study. However, a dip net may be used to collect a sub-sample of small-bodied fish entering the DMC from the primary channel for positive identification. All ESA fish caught in the sub-sample will be placed into a TFCF holding tank for transport and release.

Data Analysis/Interpretation

This study will determine if small-bodied fish entrained into the primary channel escape into the DMC when the louvers are lifted for cleaning or if predatory fish holding in the DMC move back into the primary channel during louver cleaning. Both scenarios negatively impact the fish salvage effort. The DIDSON camera uses sonar to capture movement of fish underneath the water's surface and will also record the louver panels being moved. Preliminary results from FY20 observed that when the louvers were lifted for cleaning, both fish and debris were flushed into the DMC at an increasing rate from upstream to downstream. Predatory fish holding in the DMC were observed feeding on small-bodied fish as they exited the primary louver channel. Fish that are not salvaged, including listed species, likely become prey to the predatory fish holding in the DMC. Predatory fish that are not salvaged, however, could become resident to the DMC and learn to move back up into the primary channel to feed when the louvers are lifted thus, impacting the salvage effort on a long-term basis. Preliminary results also observed predatory fish (Striped Bass) circling inside the primary channel at low flows, possibly either seeking to escape downstream when the louvers are lifted or hunting for prey. If this project is successful, future efforts will focus on the ESA listed fish in effort to improve the overall TFCF salvage process and methods to identify and remove predatory fish from the TFCF.

Assumptions and Limitations

The foremost limitation of the DIDSON camera is the identity of small fish captured at a distance in its video imaging. The identity of fish further away from the DIDSON camera may be less discernible due to the sonar's imaging noise (i.e. grainy imaging). The secondary commercial "off-the-shelf" fish camera captures underwater images in full color where the identities of fish are more apparent, but water turbidity can hinder the camera's capabilities. Albeit, the fish camera captured images of both Striped Bass and Bluegill staging to feed under the primary louver deck as the louvers were being cleaned in December 2019. The fish camera does have a low-light mode that helps to discern species in turbid or in dark conditions. Also, the identity of some species can be deduced using certain morphometric and physical features, but dip net collection will allow for a positive identification of the small-bodied fish entering the DMC.

Coordination and Collaboration

This research will be coordinated and conducted by one member of the Fish and Wildlife Resources Group (TSC 85-829000) with the limited assistance of one (or two) TFCF Biological Resources staff. Research project updates to the Tracy Technical Advisory Team and to interested interagency members and/or groups will be through email, phone, or power-point presentation or via a project report.

Endangered Species Issues, "Take" Considerations

No ESA fish from the TFCF salvage process will be caught, collected or handled for this study. However, the use of a dip net is requested to collect a sub-sample of small-bodied fish entering the DMC from the primary channel for positive identification. All ESA small-bodied fish caught in the

sub-sample will be placed into a five-gallon bucket and immediately released into TFCF holding tank for transport and release.

Dissemination of Results (Deliverables and Outcomes)

This study will determine if movement of fish holding inside the primary channel escape downstream to the DMC and vice-versa when the primary channel louvers are lifted for cleaning. The study will be performed during FY21 and in the subsequent year if funding is available. Data analysis and a power-point presentation will be prepared and presented to TTAT and other interested stake holders during FY21 and a TFCF Technical Bulletin or Series Report produced the following fiscal year.

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Baselines: Establishing Passive Integrated Transponder Tagging Methods in Adult Delta Smelt

Investigators

Christopher L. Hart
Fish Biologist
Tracy Fish Collection Facility
Bureau of Reclamation
Byron, CA 94514
CHart@usbr.gov

Kristen M. Towne
Fish Biologist
U.S. Fish and Wildlife Service
Lodi, CA 95240
Kristen_Towne@fws.gov

Brandon J. Wu
Fish Biologist
Tracy Fish Collection Facility
Bureau of Reclamation
Byron, CA 94514
BWu@usbr.gov

Summary

The Bureau of Reclamation's Tracy Fish Collection Facility (TFCF), located in Byron, California, was developed to collect and salvage fish from Sacramento-San Joaquin Delta (Delta) water being pumped by the Central Valley Project's C.W. "Bill" Jones Pumping Plant. Fish that are salvaged by the TFCF are hauled to designated release sites in the Delta away from the influence of the export pumps. The salvage can include a wide variety of both introduced and native fish species, including listed species such as the Delta Smelt (*Hypomesus transpacificus*; Federal Register 1993). The TFCF may potentially collect and salvage Delta Smelt throughout the year, but is usually limited to the non-summer months. The 2008 U.S. Fish and Wildlife Biological Opinion requires the Bureau of Reclamation to monitor for Delta Smelt during the months of December through July, when water is being diverted.

The Delta Smelt is a small fish, typically reaching 60–70 mm fork length (FL), endemic to the Delta. These fish typically have a 1-year life cycle and reach adulthood within 7–9 months (Moyle 2002). Delta Smelt have historically been difficult to tag because of their small size and delicate nature, so internal tags (e.g., hydroacoustic or Passive Integrated Transponder [PIT] tags) have not been used extensively (Sommer *et al.* 2011). However, technological advances have allowed for both PIT tags and hydroacoustic tags to become smaller, potentially making them a more viable option for small fish. Very few studies have attempted to implant these tags into Delta Smelt and document their findings. Although acoustic tag implantation has yet to be successful in this species, PIT tag injection has shown some promising survival and tag retention results. Wilder *et al.* (2016) reported 95% survival to 28 d in Delta Smelt injected with Biomark MiniHPT8 PIT tags. Studies in Chinook Salmon (*Oncorhynchus tshawytscha*) have reported an increase in survival by the injection method compared to surgical implantation, but that same method also increased the rate of tag expulsion (Cook *et al.* 2014). While Wilder *et al.* (2016) presented high quality initial research into this research area, it is somewhat limited in that it only assessed one implantation method (for PIT tags) and one PIT tag size. We intend to expand on this research to determine the influence of implantation technique (i.e., injection vs surgery) across a wide range of tag burdens by using PIT tags of varying sizes. Additionally, as demonstrated in Chinook Salmon, there can be a wide variability in the results of tag effect studies that employ similar methods (Towne and Brandes [in press], Ammann *et al.* 2013, Brown *et al.* 2010, Brown *et al.* 2006), indicating the importance of determining the effect of implanted tags on the fish intended for use in future TFCF studies. The present study will allow us to refine Delta Smelt tagging techniques that will become very beneficial for future facility improvement studies by developing reference and baseline material.

Problem Statement

Delta Smelt tagging techniques have not been refined or extensively studied due to the relatively recent development of tags at the present size. Therefore, there is very little information about the process and impacts to these fish. Should this research be successful in developing methods for tagging Delta Smelt, the resulting knowledge could be a valuable asset for testing TFCF efficiency with this species.

Goals and Hypotheses

Goals:

1. Determine the influence of tag implantation method (i.e., injection or surgical insertion) on survival and tag retention of adult Delta Smelt sourced from the UC Davis Fish Conservation and Culture Laboratory.

2. Evaluate the influence of tag burden on survival and tag retention of the adult Delta Smelt using a variety of PIT tag sizes.

Hypotheses:

1. Implantation via the injection method will result in lower survival of Delta Smelt post-tagging compared to both controls and fish implanted with tags via the surgery method.

2. An increase in tag burden will significantly decrease survival and tag retention for both implantation methods.

Materials and Methods

This study plan focuses on evaluating the potential for survival and tag retention to be influenced by tag implantation method and tag burden on adult Delta Smelt (*Hypomesus transpacificus*). Five hundred cultured adult Delta Smelt, roughly 70mm FL will be obtained from the UC Davis Fish Conservation and Culture Laboratory (FCCL) and transferred to the TFCF. Fish will be held inside of the Tracy Aquaculture Facility(TAF). During the course of the project, the study fish will be held at 12°C in a single 1,484-L circular tank, utilizing circulated treated Delta water. Treated Delta water has been settled, filtered, and UV sterilized. Temperature, dissolved oxygen (%), pH, total ammonia nitrogen, nitrates, and conductivity will be monitored throughout the study period to ensure proper water quality.

Approximately 50 fish will be used to develop the process and procedures, including establishing an appropriate dose of tricaine methanesulfonate (MS-222) to achieve and maintain stage III, plane 2 anesthesia for tag implantation, defined as loss of equilibrium accompanied with no reactivity and reduced gill ventilation and heart rate (Sneddon 2012). Once the process and procedures have been standardized, 320 fish will be divided to one of four groups: Surgery, Injection, Surgery Control, and Injection Control. Fish in the Surgery and Injection groups will be further divided to one of three PIT tag types: BioMark MiniHPT8 (8.4 mm), Biomark HPT9 (9 mm), and Biomark MiniHPT10 (10 mm; Biomark, Inc., Boise, ID). Each of the eight groups will have 40 fish. All fish will be held in a single tank for a 30 d holding period following tagging. The remaining 130 fish will be held as backup in case more practice fish are required than anticipated, or in the event there are mortalities during the implantation process.

The standard operating procedure will be adapted from Wilder *et al.* (2016) and Liedtke *et al.* (2012; originally developed for use in Chinook Salmon [*Oncorhynchus tshawytscha*]). Fish will be measured to the nearest 1 mm FL, weighed to the nearest 0.1 g, evaluated for condition of eyes/fins/scales, and tagged with a visible implant alpha (VIA) tag next to the dorsal insertion for individual identification in case the fish expels the PIT tag. For PIT tags inserted using the surgical method, a small incision will be made on the linea alba anterior to the pelvic girdle. Incisions will be closed with a single suture using an absorbable suture material. For PIT tags inserted using the injection method, an appropriately sized sterilized syringe/needle (MK10/N125 for HPT9 tags, and MK165/N165 for MiniHPT8 and MiniHPT10 tags; Biomark, Inc., Boise, ID) will be used and injection sites will not be sutured. During surgery, water containing MS-222 buffered with sodium bicarbonate of the same concentration will be pumped over the fish's gills to maintain sedation. The concentration of MS-222 solution will be determined by the anesthesia exploration part of the study. Fish will have 10 min to recover in water supersaturated with oxygen between 130 and 150% before being transferred to a holding tank, where they will remain for a 30 day holding period in the treated Delta water.

Fish in the control groups will be anesthetized, weighed, measured, and evaluated in a similar fashion to the tagged groups, but will not undergo surgery or injection. These fish will be subjected to the same amount and time in anesthesia and in air as those in the tagged groups, and will undergo

a similar recovery period. Fish in the control group will also be injected with a VIA tag for individual identification at the end of the holding period.

Due to the large number of fish in this study, two people will be used for tagging: one for the Surgery and Surgery Control groups, and one for Injection and Injection Control groups. Tagging will occur over a two day span, with half the fish in each group tagged on each day, for a total of 160 fish per day.

The differences in survival and differences in tag retention will be evaluated using a Fisher's exact test; groups that will be compared are detailed in Figure 1. Survival and tag retention of fish tagged on each day will be assessed for differences between them using the same tests to ensure there is no effect of tagging day. Additionally, the fish tagged by surgery will be compared to fish tagged by injection to ensure they are of similar lengths and weights using a t-test. All statistical tests will be performed in R.

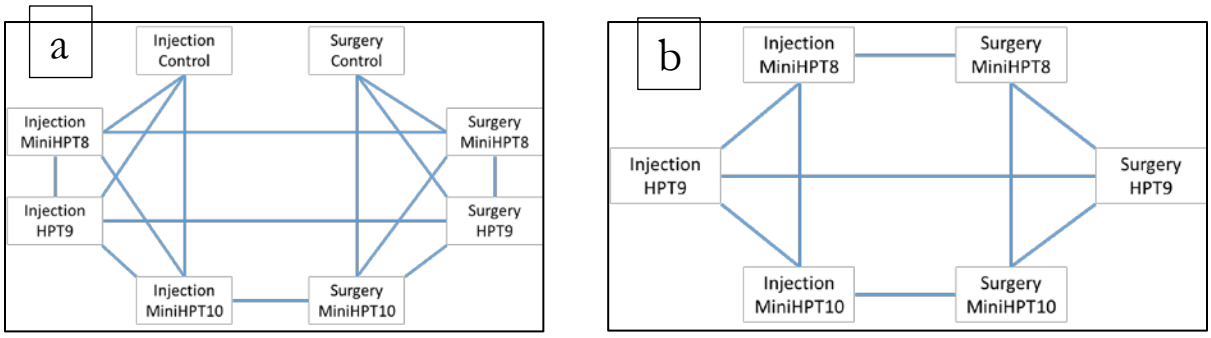

Figure 1.—Schematic of groups to be compared when analyzing differences in survival (a) and tag retention (b). A line connecting two groups indicates the difference between those groups will be assessed. Proportions will be analyzed in R using Fisher's exact test.

Assumptions and Limitations

It is assumed that the TAF will be available and fully functional for this study to be successful. Cultured Delta Smelt from the FCCL must be available due to the limited availability of wild fish stocks. It is also assumed that all personnel will be present and able to work.

Coordination and Collaboration

This research will be coordinated and conducted by the TFCF Biological Resources Section in collaboration with U.S. Fish and Wildlife Service and UC Davis. USFWS has successfully conducted comparable studies in the past and would be a valuable asset. The USFWS biologist will serve as co-PI, and assist with all aspects of the study, including study design, data analysis and report writing. UC Davis' participation is essential to the project's success by providing cultured Delta Smelt and fish husbandry.

Endangered Species Issues, "Take" Considerations

The use of cultured Delta Smelt for this project is covered under the University of California-Davis, Fish Conservation and Culture Lab (FCCL) Federal Fish and Wildlife Permit TE-027742-5 which expires June 25, 2022. A USFWS and CDFW Memorandum of Understanding will be requested prior to the study.

Dissemination of Results (Deliverables and Outcomes)

This tagging effect study was approved and funded for FY2019 and FY2020, but was not completed due to TAF upgrade and operational issues. The TAF could not produce the required post-surgery water treatment required by this study. Shortly after a major repair on the TAF ozonation machine, the main power supply failed rendering it nonoperational. Due to the high costs of replacement parts, repair has not been scheduled. Prior to the ozone failure, to create redundancy in the sterilization system, a whole facility UV system was purchased and was slated for install. Due to management involvement the installation was delayed and is estimated to be completed by late FY20. The PIT tags and required surgical supplies were purchased prior to the TAF failures.

Due to TAF upgrades and current pandemic, the tagging effect study is proposed to take place in FY2021. Data analysis and results will be shared at a Tracy Technical Advisory Team (TTAT) meeting and a Tracy Series Report will be completed the following fiscal year after the study has been completed (FY 2022). If applicable, the findings will be sent to an appropriate peer reviewed journal. The information gained will be utilized by future facility improvement studies.

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Development of Computational Fluid Dynamics Model to Assess Carbon Dioxide Injection System for Predator Removal

Investigators

James Higgs
Hydraulic Engineer
Technical Service Center, Hydraulic Investigations and Laboratory Services
Bureau of Reclamation
Denver, CO 80225
jhiggs@usbr.gov

Bryan Heiner
Hydraulic Engineer
Technical Service Center, Hydraulic Investigations and Laboratory Services
Bureau of Reclamation
Denver, CO 80225
bheiner@usbr.gov

Connie Svoboda
Hydraulic Engineer
Technical Service Center, Hydraulic Investigations and Laboratory Services
Bureau of Reclamation
Denver, CO 80225
csvoboda@usbr.gov

Summary

The Bureau of Reclamation's (Reclamation) Tracy Fish Collection Facility (TFCF; Byron, California) is located at the head of the Delta-Mendota Canal in the southern region of Sacramento-San Joaquin Delta (Delta) near Tracy, California. The purpose of the TFCF is to separate fish (salvage) from water pumped south at the C.W. "Bill" Jones Pumping Plant (JPP). Operations at the TFCF divert, collect, hold and return salvaged fish to the Sacramento-San Joaquin Delta (Delta) beyond the influence of the JPP.

National Marine Fisheries Service (NMFS) 2009 Biological Opinion and Conference Opinion on the Long-Term Operations of the Central Valley Project and State Water Project (Biological Opinion) Action Suite IV.4 specifies that Reclamation should achieve a whole facility salvage efficiency of

75% at the TFCF by reducing fish losses associated with the salvage process. Many factors, including predation by piscivorous fish, contribute to fish loss at the TFCF (Bridges *et al.* 2019). Pilot studies began in 2006 to investigate the use of carbon dioxide (CO_2) as a predator removal method for piscivorous predators such as Striped Bass (*Morone saxatilis*), White Catfish (*Ameiurus catus*) and Channel Catfish (*Ictalurus punctatus*). An initial evaluation of the use of CO_2 as a predator removal technique in the TFCF bypass pipes and secondary channel was published in 2014 using dry ice (Wu and Bridges 2014). Ongoing dry ice studies are being conducted through the Tracy Fish Facility Improvement Program to recommend an optimal CO_2 concentration for predator removals in the primary channel, bypass pipes, and secondary channel and to determine the feasibility of using CO_2 to remove predators in the primary channel (FY19 Proposal Package for Tracy Fish Facility Improvement Program).

Carbon dioxide is used as an anesthetic to force fish, including predatory fish, downstream into the holding tanks. The 2014 study demonstrated fish can be removed using a CO_2 dose of 150–350 mg/L and the dry ice method can be implemented at the TFCF. The CO_2 treatment removed significantly more fish, of all species, than the control treatment. Median length of Striped Bass collected during CO_2 treatment was significantly greater than that of Striped Bass salvaged at the TFCF during the week of testing. There was no significant difference in the median lengths of white catfish collected before and during CO_2 treatment. In comparison to current predator removal methods, this method can improve employee safety, reduce labor, reduce facility down-time, and likely increase fish survival and salvage efficiency of threatened and endangered species (Wu and Bridges 2014).

To build on current research, a Computational Fluids Dynamics (CFD) model is currently under development. A commercially available software package, FLOW-3D from Flow Science, is being used to investigate how CO_2 moves through the TFCF. At the point of this writing (June 2020) 72% of the staffdays have been expended. A solids model of the facility has been developed in AutoCAD and continues to be refined while testing it in FLOW-3D. This includes using porous objects with assigned values of open volumes in both the X and Y directions to simulate the louver bar placement. As an indicator of concentration distribution, tracers and/or buoyant particles will be included when general flow simulations appear adequate

While the pandemic has not directly interfered with progress, the confusion it created has caused delays in completing some non-time-critical tasks. This includes develop exposure guidelines which is considered to be adaptable and assist with qualitative analysis in the first year. We also need to identify 3 discharges for simulations. A meeting using Teams will be arranged in the next 2 weeks with stakeholders.

Injection of tracers and buoyant particles will be used to simulate CO_2 in a variety of areas: upstream of the trashrack, in the primary channel, at the bypass entrances, or in the secondary channel. Results may inform design of a CO_2 gaseous injector system for predator removals. Ideally, the numerical model will provide information regarding optimization of bubbler placement, application time, and application concentration to produce desired CO_2 exposure throughout the facility.

For FY21, a much more sophisticated gas transfer model will be used to simulated CO_2.

Problem Statement

Predation by piscivorous fish contributes to fish loss at the TFCF. Previous studies have shown that the application of CO_2 is an effective method to remove predators in the bypass pipes and secondary channel. A CFD model is proposed to assess flow distribution and dead zones throughout the facility, mainly the primary. Possible avoidance routes will be identified and reduced. The model may also be able to estimate CO_2 system performance based on diffuser type (e.g. line diffusers, point diffusers) and installation location. Performance of the diffuser system is based on adequate distribution of CO_2 concentrations and creation of sufficient exposure times to move predators downstream into the holding tanks for collection and removal. The volume of CO_2 used in model simulations may indicate the size of tanks needed for each field treatment. Subsequently, results from this numerical model may provide design parameters for field installation of a CO_2 gaseous injection system at the TFCF.

Goals and Hypotheses

Goals:

1. Develop exposure guidelines.
2. Assess flow distribution and dead zones throughout the facility.
3. Determine distribution of CO_2 based on diffuser type and installation location (Figures 1-4).
4. Compare variations of gas bubbler application times and sequencing to meet exposure guidelines.

Hypotheses:

1. Exposure guidelines can be identified based on previous studies and assistance from TFCF researchers.
2. Null: Flow will be evenly distributed throughout the primary and secondary channels without dead zones.
3. Null: Diffuser type and location produces the same CO_2 exposure.
4. Null: Gas bubbler application time and sequencing does not affect CO_2 exposure.

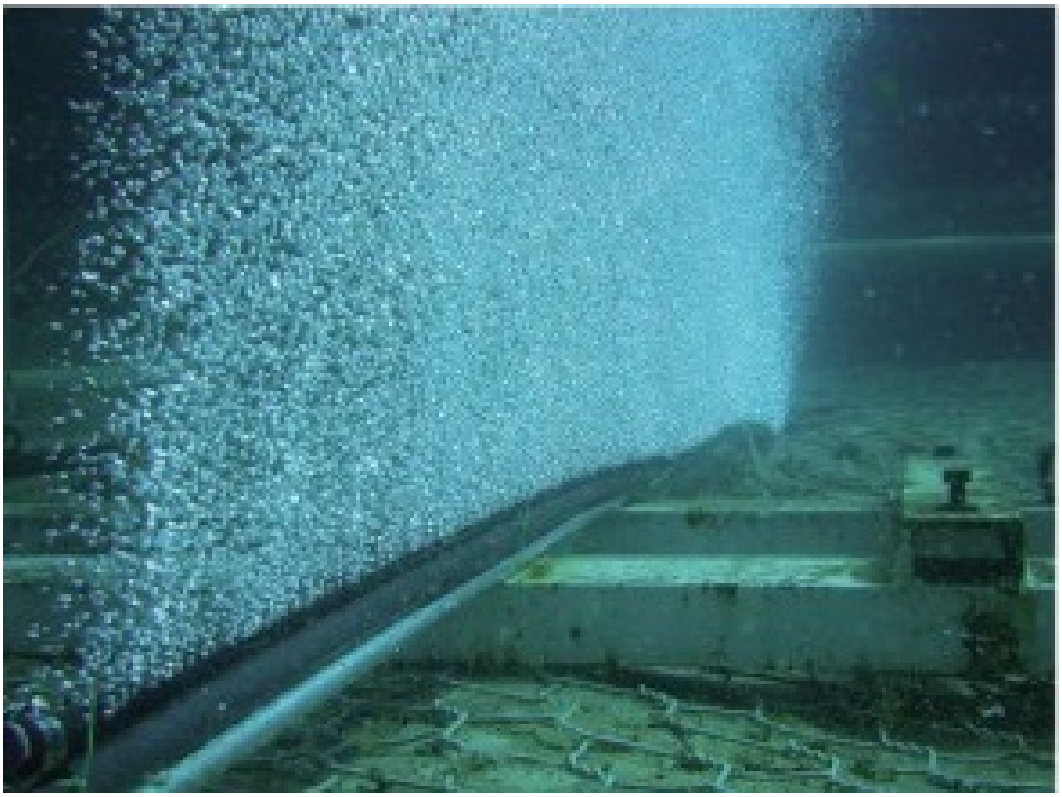

Figure 1.—Example of fine bubble linear air diffuser.

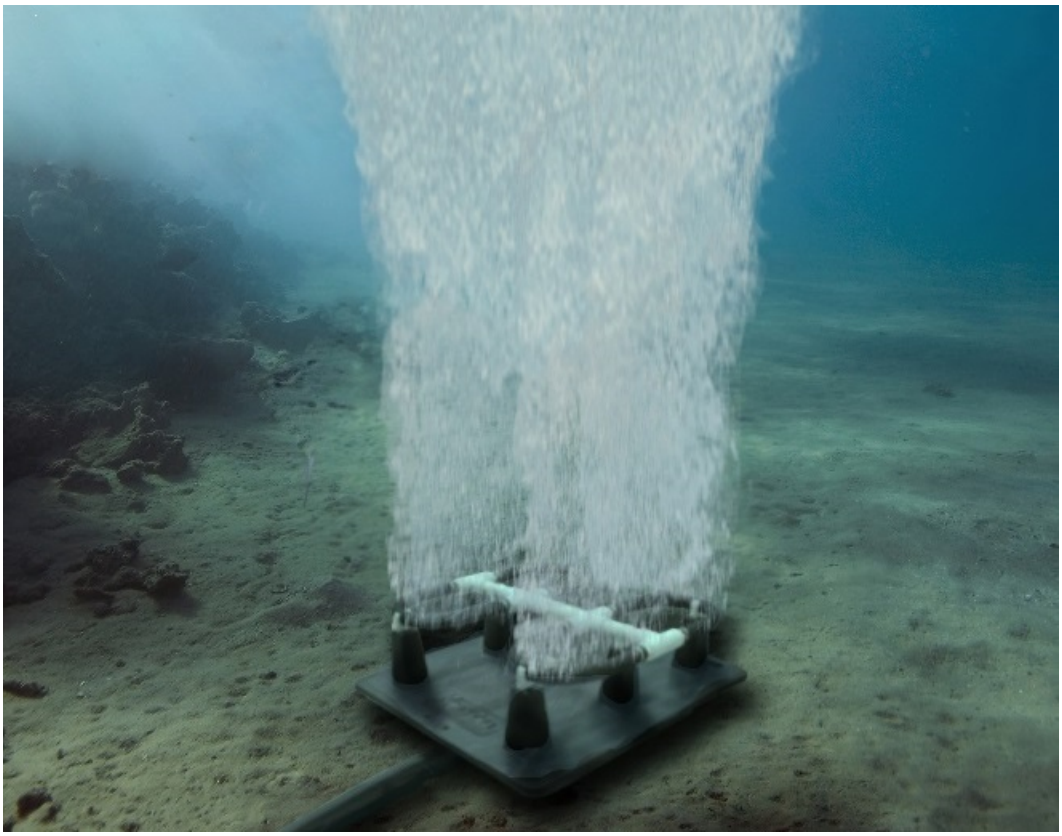

Figure 2.—Example of fine bubble point air diffuser.

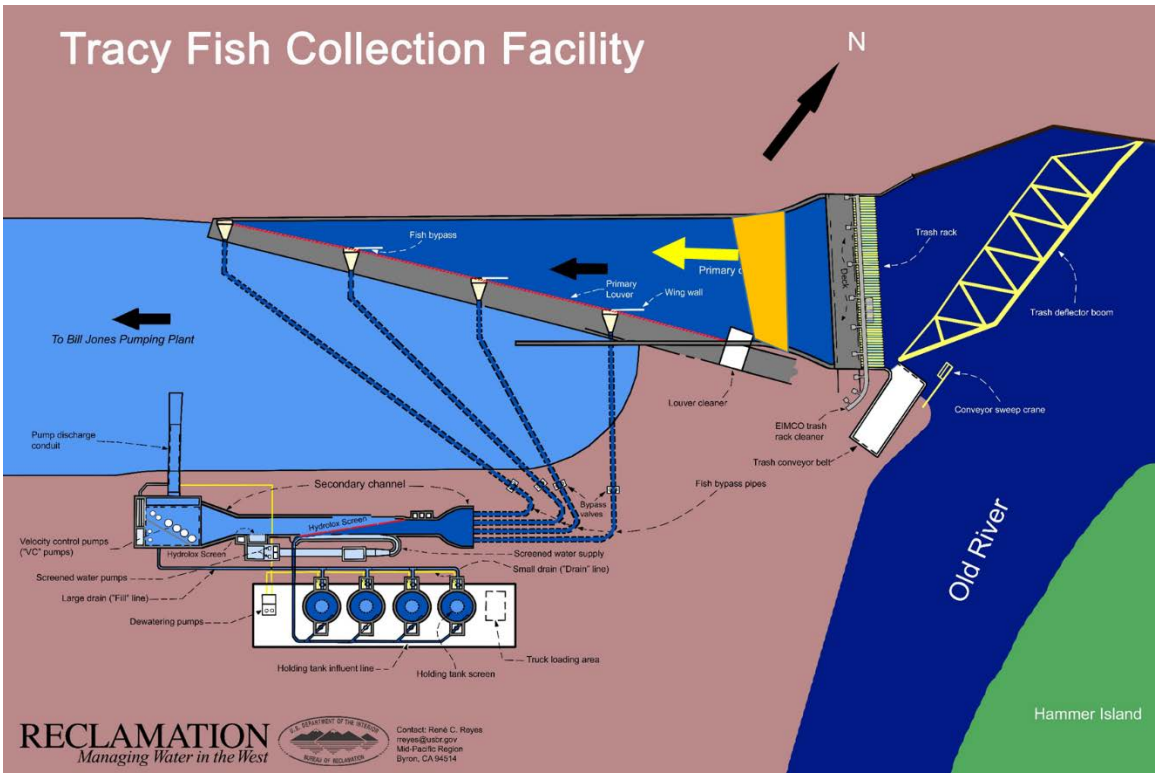

Figure 3.—Simplified image of concentrated CO_2 moving though primary channel from fine line bubblers downstream of the trashrack.

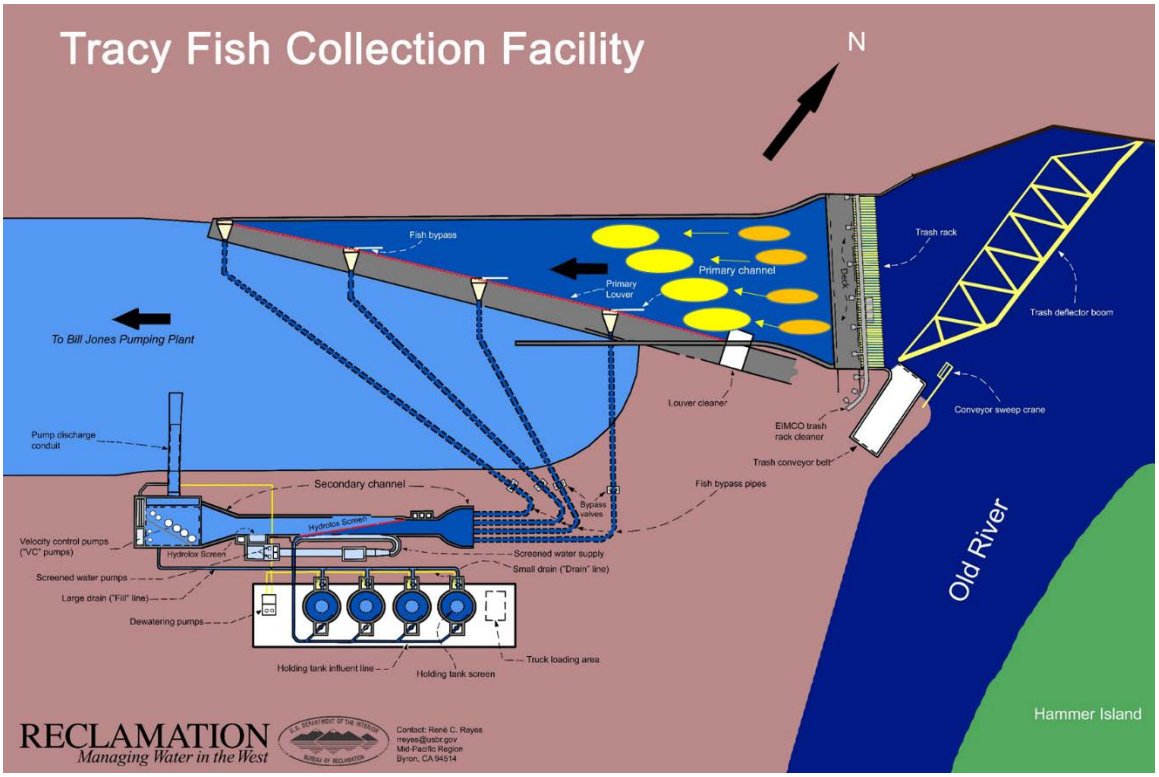

Figure 4.—Simplified image of concentrated CO_2 moving though primary channel from fine point bubblers downstream of the trashrack.

Materials and Methods

FLOW-3D by Flow Science is a computational fluid dynamics (CFD) model. The program is a finite difference, free surface, transient flow modeling system that solves the Navier-Stokes flow equations in up to three spatial dimensions. The flow equations are solved within an orthogonal coordinate mesh. The model is well-suited to the simulation of flows having a free water surface. The current version of FLOW-3D is 12.0.0.25, but the latest version of FLOW-3D at project initiation will be used.

A solids model is being created in AutoCAD 2018 for import into FLOW-3D depicting the structures in the flow field. Existing drawings of the facility will be used to create the solids model. Recent 2019 bathymetric data inside the facility will be incorporated if large deposits of sediment are identified. Bathymetric data upstream of the facility may be incorporated to add confidence to how flow enters the facility. Boundary conditions will be set based on hydraulic data from the TFCF. It is anticipated that the model will simulate 3 flow conditions which requires information on JPP rate, velocity control and holding tank pump operation, and associated water depths for a particular tidal phase. TFCF researchers will be asked to help identify the 3 flow conditions based on situations when CO2 removal may be more likely to occur. From the CFD model, flow magnitudes, distributions, and recirculation and dead zones will be identified. Simulations with tracers and/or buoyant particles can be used as an indicator of concentration distribution; however, gas transfer from the bubbles would not be modeled. Exposure guidelines developed from past research and experience in coordination with TFCF researchers.

In order to incorporate gas transfer into the CFD model, discussions with Flow Science will be required to identify appropriate FLOW-3D modules to add into the program to properly model CO2 release and to increase confidence in results. It is anticipated that various types of diffusers, locations, and application times can be simulated. Once the model is running, further refinements can be made and/or additional tasks can be added.

Year 1 Scope of Work – On track to be completed in FY20:

1. Develop CO_2 exposure guidelines and 3 simulated flow conditions to be tested (highly reliant on project personnel).

2. Develop hydraulic model for FLOW-3D

    - Develop solids model using AutoCAD 2018 or newer and import into FLOW-3D.
    - Identify flow distribution and dead zones.
    - Simulate tracers and/or buoyant particles as an indicator of concentration distribution.

Year 2 Scope of Work:

1. Incorporate gas transfer into FLOW-3D model

    - Coordinate with Flow Science on model development.
    - Utilize modules such as bubble and phase change options, density evaluation, heat transfer, drift model, neutrally buoyant probes depicting exposure history.

2. Identify optimal diffuser type, location, and application time. Estimate volume of CO2 required to meet concentration objectives.

Optional: Year 3 Scope of Work:

1. Model refinement including incorporation of chemical reaction kinetics based on water quality parameters and animating moving history probes to act more like fish.

2. Utilization of air injection in the model to improve fish recovery time, if needed.

Assumptions and Limitations

CFD modeling depends on availability of qualified staff to develop the model and computational resources to process the FLOW-3D results. If additional modules for gas transfer require more computational resources than expected, simulations may be moved to an external private server for additional cost. Reclamation has not used many of the FLOW-3D modules proposed for Years 2 and 3. Discovery of proper values for parameters and the need for calibration has not yet been evaluated. It is possible that successful gas transfer simulation cannot be achieved. Uncertainty in results will need to be estimated in order to confidently apply results to real-world conditions.

Coordination and Collaboration

Jim Higgs will be the team lead for performing the CFD development, analysis, and documentation. Bryan Heiner and Connie Svoboda will serve as hydraulic consultants. Research efforts will be coordinated with TFCF biological staff to ensure that project work compliments and advances current research. Brandon Wu and Rene Reyes will assist by providing information on previous CO_2 introduction at the facility using dry ice, developing CO_2 exposure guidance, defining TFCF operations to simulate, and providing biological expertise. If optional model refinement is desired, water quality information will be needed.

Endangered Species Issues, "Take" Considerations

No take will occur during CFD simulations.

Dissemination of Results (Deliverables and Outcomes)

After development of the CFD model in Year 1 scheduled to be complete mid October 2020, and Year 2 scheduled to be complete mid October 2021, data analysis and results will be presented at the Tracy Technical Advisory Team meeting. When the gas transfer model is integrated and final results are available, a Tracy Technical Bulletin will be completed. Data and metadata will be made available for digital archival.

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

Investigators

René C. Reyes
Supervisory Fish Biologist
Tracy Fish Collection Facility
Bureau of Reclamation
Byron, CA 94514
rreyes@usbr.gov

Brandon J. Wu
Fish Biologist
Tracy Fish Collection Facility
Bureau of Reclamation
Byron, CA 94514
bwu@usbr.gov

Zachary A. Sutphin
Fisheries Biologist
Denver Technical Service Center
Bureau of Reclamation
Denver, CO 80225
zsutphin@usbr.gov

Tien-Chieh Hung, PhD
Director & Adjunct Assistant Professor
UC Davis Fish Conservation and Culture Laboratory
Byron, CA 94514

Luke T. Ellison
Manager
UC Davis Fish Conservation and Culture Laboratory
Byron, CA 94514

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 Central Valley Project's 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, Louisiana).

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.

Reclamation replaced the secondary louvers (2.5 cm opening) in 2014 with a traveling water screen with smaller screen opening (1.5 mm width x 50 mm length). Delta Smelt larvae and juveniles were expected to be guided successfully (salvaged) to the holding tanks with this new screen. Data collected from this study will determine how velocity affect larval and juvenile Delta Smelt secondary channel efficiency. The field data collection portion of the study was completed in 2016 and funds are being requested for laboratory sample processing (10 % remaining), data analyses and report writing.

Problem Statement

The new traveling water 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) states 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 uncertain how this speed and the traveling screen interact and affect the diversion of larval and juvenile 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). All test trials were conducted during the daytime. Predator removal using carbon dioxide following protocols published by Wu and Bridges (2014) was completed before each trial. Hydrolox™ traveling water screen efficiency and participation will be calculated using the following equations:

$$\text{Efficiency} = HT/(HT + SN)100$$
$$\text{Participation} = [(HT + SN)/200)]100 \quad \text{(Eq.1)}$$

where:
HT = number of Delta Smelt recovered in the holding tank,
SN = number of Delta Smelt recovered in the sieve net behind 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. Statistical analysis will be provided by the Denver Technical Service Center and a final Tracy Series Report will be prepared by the TFCF Biological Resources Section.

Endangered Species Issues, "Take" Considerations

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

Dissemination of Results (Deliverables and Outcomes)

Field data collection and separation of samples were completed in winter 2016; laboratory data collection which includes measuring specimens, identification, and data entry is 90% complete. Data analysis is expected for FY2021. A written report is expected for FY2022. The venue for dissemination of results will be through the Tracy Series Reports. Data and metadata will be made available for digital archive. Results will be provided at TTAT and CVFFRT meetings.

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Optimal Carbon Dioxide Concentration for Predator Removals in the Tracy Fish Collection Facility Secondary Channel

Investigators

Brandon J. Wu
Fish Biologist
Tracy Fish Collection Facility
Bureau of Reclamation
Byron, CA 94514
bwu@usbr.gov

Rene C. Reyes
Fish Biologist
Tracy Fish Collection Facility
Bureau of Reclamation
Byron, CA 94514
rreyes@usbr.gov

Christopher L. Hart
Fish Biologist
Tracy Fish Collection Facility
Bureau of Reclamation
Byron, CA 94514
chart@usbr.gov

Scott A. Porter
Biological Science Technician
Tracy Fish Collection Facility
Bureau of Reclamation
Byron, CA 94514
sporter@usbr.gov

Michael R. Trask
Biological Science Technician
Tracy Fish Collection Facility
Bureau of Reclamation
Byron, CA. 94514
mtrask@usbr.gov

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 Central Valley Project's 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.

Fourteen replicates have been completed for this project during which Striped Bass removal efficiency and 96-h post-treatment survival were determined. In addition, 5 replicates have been completed during which only Striped Bass 96-h post-treatment survival was investigated. Minimal data collection occurred for this project during the FY2020 research period due to the COVID-19 pandemic. It will be necessary to complete at least 6 more replicates (at approximately 25, 125, 150, 200, 250 and 300 mg/L) to thoroughly investigate Striped Bass removal efficiency and 96-h post-treatment survival for CO_2 concentrations up to 300 mg/L. Preliminary data collected for the optimal dose investigation suggests that the CO_2 concentration that results in the highest combination of Striped Bass removal efficiency and 96-h post-treatment survival throughout the range of water temperature and water quality conditions observed at the TFCF is approximately 150 mg/L. To obtain this CO_2 concentration within the bypass pipes and secondary channel at the TFCF using current procedures, it is recommended that approximately 68.0 kg of dry ice be injected into each bypass tube for each treatment.

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 pipes 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 the optimal CO_2 concentration for the implementation of CO_2 predator removals in the bypass pipes and secondary channel at the TFCF considering removal efficiency and 96-h post-treatment survival.

Goals and Hypotheses

Goals:

1. Determine the optimal CO_2 concentration for a 15-minute exposure relative to removal efficiency and survival throughout the range of temperature and water quality conditions observed at the TFCF.

2. Estimate a single, set amount of dry ice (kg) that should be inserted per bypass pipe to approximately obtain the optimal CO_2 concentration within the bypass pipes and secondary channel at the TFCF.

Hypotheses:

1. All CO_2 concentrations will result in equal removal efficiency and survival over a 15-minute exposure period.

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. Replicates for this study will be performed in concurrence with monthly facility CO_2 predator removals at the TFCF; therefore, labor and materials costs will be split 50/50 with TFCF operations.

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 (approximately 25, 125, 150, 200, 250 and 300 mg/L for FY2021) and minimal water flow in the bypass pipes and secondary channel will be maintained for 15 minutes to increase contact time between CO_2 gas and water. Using the submersible pump, hose, and pH meter

previously described, pH will be continuously monitored throughout the 15-minute minimal flow treatment period. Carbon dioxide concentration will be measured from a water sample taken at the lowest observed pH to estimate the maximum CO_2 concentration that was achieved during each initial CO_2 treatment. After the 15-minute minimal water flow period, the number of secondary channel VC pumps in operation was adjusted to maximize (> 3.4 m^3/s) water flow in the bypass pipes and secondary channel for 15 minutes to flush lethargic fish downstream into a holding tank.

After conclusion of the 15-minute maximum flow period, water flow will be switched to an empty holding tank, minimized in the bypass pipes and secondary channel, and the process will be repeated with the insertion of approximately 136.1 kg of dry ice per bypass pipe with the intention of obtaining a CO_2 concentration of approximately 300 mg/L in the bypass tubes and secondary channel to remove any fish that may have remained after the initial CO_2 treatment. 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 CO_2 treatments. 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. The CO_2 concentration that is determined to exhibit 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.

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 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. A scatterplot illustrating the relationship between the amount of dry ice injected (kg) and the maximum CO_2 concentration obtained (mg/L) for historical CO_2 treatments performed at the TFCF will be used to recommend a single, set amount of dry ice (kg) that should be inserted into each bypass pipe at the TFCF to approximately obtain the optimal CO_2 concentration in the bypass pipes and secondary channel.

Assumptions and Limitations

It is assumed wild Striped Bass will be available and that the Tracy Aquaculture Facility will be operational and able to adequately hold this species. In addition, it is assumed that an appropriate number of personnel (4-5 individuals) will be available to perform consecutive CO_2 injections in order to determine optimal CO_2 concentration for the removal and survival of Striped Bass. Access

to appropriate safety equipment (dry ice gloves, eye protection, etc.) will be necessary to perform dry ice injections. The Biological Resources group at the TFCF will also need the ability to adjust secondary channel flow as needed for this study. It is assumed that the contract for dry ice delivery will remain active and that no other projects or studies will take priority or precedence during the FY2021 research period. Finally, it is assumed that CO_2 concentration is the only variable that affects Striped Bass removal efficiency and survival.

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

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 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 because certain species, such as Delta Smelt, exhibited a lower tolerance to elevated CO_2 levels than Striped Bass and displayed up to 70% mortality over 96 h after being exposed to 100 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 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. All fish take for this project is covered under the most recent National Marine Fisheries Service Biological Opinion as well as current CDFW Scientific Collecting Permits held by the biology staff 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.

Dissemination of Results (Deliverables and Outcomes)

Data collection and analyses will likely be completed during the FY2021 research period. Updates will be provided at TTAT and CVFFRT meetings. A draft report for peer review is anticipated to be completed by the end of September 2022. The primary deliverable will be an article published as a Tracy Series Report. 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

Investigators

Brandon J. Wu
Fish Biologist
Tracy Fish Collection Facility
Bureau of Reclamation
Byron, CA 94514
bwu@usbr.gov

Zachary A. Sutphin
Fish Biologist
Fisheries and Wildlife Resources Group
Bureau of Reclamation
Denver, CO 80225
zsutphin@usbr.gov

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 outmigrating 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 (approximately 1 h) 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 (CO_2) 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).

Sutphin and Wu (2008) 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 (from Sutphin and Myrick 2015), 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.

It was determined that operating only the oxygen system in the fish-haul trucks resulted in the highest rate of O_2 rise (0.46 mg/L per min) and likely supports the highest biomass capacity. Simultaneous operation of the compressed air and oxygen systems resulted in the next highest rate of O_2 rise (0.32 mg/L per min), followed by operation of only the compressed air system (0.05 mg/L per min). Results suggest that oxygen and aeration system capabilities of the fish-haul trucks are likely adequate for the short-duration transport of fish from the TFCF to release sites. Biomass capacity of the fish-haul trucks appears to be limited by TAN production and is estimated to be 296.7 kg. Based on this, it is conservatively estimated that the fish-haul trucks can effectively transport between 5,998 and 3,327,946 fish, depending on size. The continued use of the fish transport tables provided by Bates *et al.* (1960) is recommended. In addition, it is recommended that methods to remove excessive TAN from water or reduce ammonia toxicity during fish transport be considered.

Data collection for this project was completed during the FY2018 research period and data analysis was completed during the FY2019 research period. A draft report is expected to be produced by the end of September 2020 and a Tracy Technical Bulletin is expected to be published by the end of September 2021.

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 (from Sutphin and Myrick 2015), TAN production, and CO_2 production rates (from Sutphin and Hueth 2015). Evaluation of this 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 using 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.

Assumptions and Limitations

It is assumed that no other projects will take priority during the FY2021 research period and that there will be time develop a Tracy Technical Bulletin by the end of September 2021.

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 Issues, "Take" Considerations

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

Dissemination of Results (Deliverables and Outcomes)

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 Resident Piscivorous Fish From the Tracy Fish Collection Facility Primary Channel

Investigators

Brandon J. Wu
Fish Biologist
Tracy Fish Collection Facility
Bureau of Reclamation
Byron, CA 94514
bwu@usbr.gov

René C. Reyes
Fish Biologist
Tracy Fish Collection Facility
Bureau of Reclamation
Byron, CA 94514
rreyes@usbr.gov

Christopher L. Hart
Fish Biologist
Tracy Fish Collection Facility
Bureau of Reclamation
Byron, CA 94514
chart@usbr.gov

Kevin K. Kumagai
Senior Fisheries Biologist
HTI - Hydroacoustic Technology, Inc.
Seattle, WA 98105
kkumagai@HTIsonar.com

Scott A. Porter
Biological Science Technician
Tracy Fish Collection Facility
Bureau of Reclamation
Byron, CA 94514
sporter@usbr.gov

Michael R. Trask
Biological Science Technician
Tracy Fish Collection Facility
Bureau of Reclamation
Byron, CA 94514
mtrask@usbr.gov

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 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. Many of these techniques are largely ineffective for removing large piscivorous fish, expensive to install and operate, and are logistically difficult to implement

(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 piscivores, from this area (Wu and Bridges 2014). This suggests 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.

A total of four CO_2 treatments in the primary channel have been completed for this project. It is necessary to complete two additional replicates in FY2021 to conclude this investigation. The four treatments that have been completed include a preliminary investigation to determine if acoustically tagged Striped Bass (*Morone saxatilis*) could be influenced or moved to a desired location within the primary channel by injecting dry ice. In addition, separate investigations have been completed to determine if acoustically tagged Striped Bass could be guided into TFCF holding tanks or pushed downstream of the TFCF (where they do not have an impact on TFCF fish salvage) through an open primary channel louvers panel with CO_2 treatment of the entire primary channel. The majority of CO_2 treatments in the TFCF primary channel have been completed during 1 pump operation at the C.W. "Bill" Jones Pumping Plant (JPP) to minimize the volume of water that needed to be treated, although 1 treatment was completed during 2 pump operation at the JPP to determine if the method was feasible with increased water flows. No data collection occurred for this project during the FY2020 research period due to the COVID-19 pandemic. The two additional replicates that are necessary to complete for this project will focus on determining removal efficiency of acoustically tagged Striped Bass in TFCF holding tanks or through an open TFCF primary channel louver panel with CO_2 treatment of the entire primary channel using greater amounts of dry ice with more thorough coverage.

Preliminary results suggest that CO_2 treatment of the primary channel would be a feasible technique to remove resident Striped Bass from the TFCF during 1 pump operation at the JPP (approximately 22.7–28.3 m^3/s [800–1000 ft^3/s] water flow, approximately 0.2 m/s [0.5 ft/s] water velocity). Acoustically tagged Striped Bass appeared to exhibit an avoidance response to elevated CO_2 concentrations in the TFCF primary channel and separate treatments of the entire primary channel during 1 pump operation at the JPP removed 41.7% of acoustically tagged Striped Bass by guiding them into a holding tank and 45.4% of acoustically tagged Striped Bass by guiding them downstream of the facility through an open TFCF primary channel louver panel. No fish were collected in a holding tank during CO_2 treatment of the entire TFCF primary channel with an open primary channel louver panel (all fish that were removed were pushed through the open louver panel). It appears that CO_2 treatment of the TFCF primary channel during 1 pump operation at the JPP also results in treatment of the bypass pipes and secondary channel and likely effectively removes fish from these areas as well. Treatment of the entire TFCF primary channel with CO_2 during 2 pump operation at the JPP (approximately 45.3–56.6 m^3/s [1600–2000 ft^3/s] water flow, approximately 0.3 m/s [1.0 ft/s] water velocity) did not yield the sustained elevated CO_2 concentrations necessary to effectively guide acoustically tagged Striped Bass from the primary channel into a holding tank and there was 0% removal during this operational condition. This suggests that the use of CO_2 for the removal of piscivorous fish from the primary channel at the TFCF may not be feasible when the JPP is operating at more than 1 pump.

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). In addition, preliminary data from Wu *et al.* (In Progress) suggests that CO_2 concentrations of approximately 150 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 approximately 150 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 150 mg/L to remove piscivorous fish from the primary channel will be investigated.

Goals and Hypotheses

Primary Goals:

1. Determine if a CO_2 concentration of approximately 150 mg/L 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 CO_2 concentration of approximately 150 mg/L increases the number of piscivorous fish removed from the primary channel during a 30-min treatment period.

3. Estimate the efficiency of removal for acoustically tagged Striped Bass in the primary channel at the TFCF using a CO_2 concentration of approximately 150 mg/L 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 CO_2 concentration of approximately 150 mg/L will not increase the number of piscivorous fish species removed from the primary channel at the TFCF.

3. A CO_2 concentration of approximately 150 mg/L in the primary channel at the TFCF will have no effect on the efficiency of removal for acoustic tagged Striped Bass.

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 adopt 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 water flow and velocity in the TFCF primary channel are largely determined by the number of pumping units (1–5) being used for water export operations at the JPP, CO_2 treatment will likely occur when there is one pump operation at the JPP, which will reduce the volume of water in the primary channel that needs to be treated. If possible, CO_2 treatments will be performed when there is a slack low tide to further reduce the volume of water necessary to treat. Secondary channel velocity and flow rate will be maximized to achieve increased water velocity and flow in the primary channel bypass entrances. The maximization of secondary channel water velocity and flow will also maximize primary channel 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.

Approximately 3,629 kg (approximately 8,000 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 CO_2 concentration of approximately 150 mg/L 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 acoustically tagged fish before, during, and after CO_2 treatment of the TFCF primary channel. In addition, the use of acoustic tags and 2-dimensional tracks will allow for estimation of removal efficiency when attempting to determine if acoustically tagged Striped Bass can be pushed downstream of the TFCF through an open primary channel louver panel.

Acoustic tags will be surgically implanted in at least 10 Striped Bass (number chosen to allow for at least 10% precision) 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 Tricaine Methanesulfonate (MS-222) will likely be used as an

anesthetic. If necessary, CO_2 may also be used as an anesthetic to avoid prolonged holding periods associated with the use of other anesthetics (*e.g.* MS-222 has a minimum holding period of 21 days after treatment).

After surgical implantation of acoustic tags, Striped Bass will 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 °C well water and transported to outside 1.2-m diameter (757-L) black tanks containing aerated, 16 °C well water where they will be held at a density of up to two fish per tank. At least 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 to release, Striped Bass will be netted, 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. If possible, Striped Bass greater than 485 mm FL will be used because Striped Bass up to this length have been found to move upstream through the 56-mm spaced trash rack at the TFCF (Karp *et al.* 2017). 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 increase velocity at the primary channel bypass entrances and maximize primary channel bypass ratios to guide fish from the primary channel into a bypass pipe and, ultimately, into a holding tank. When attempting to determine if acoustically tagged Striped Bass can be pushed downstream of the TFCF into the intake canal to the JPP, the louver panel immediately upstream of bypass 4 will be lifted prior to CO_2 treatment of the primary channel.

To treat the entire primary channel, approximately 2,268–3,629 kg (approximately 5,000–8000 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 potentially be completed using 1–2 front-end loaders, 1–2 forklifts with tipping bins, 1-2 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 every 10 seconds 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.

When determining if acoustically tagged Striped Bass could be guided into TFCF holding tanks during CO_2 treatment of the primary channel, the number of piscivorous fish collected in a holding tank during the 30-min CO_2 treatment will be compared to the number of piscivorous fish collected in a holding tank during 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. A chi-square test (Minitab version 15) will be used to determine if there is a significant difference between the proportions of piscivorous fish collected in holding tanks during the 30-min fish-count (control) and CO_2 treatment. The percentage of acoustically tagged Striped Bass removed from the TFCF primary channel (collected in holding tanks) will be used to estimate the efficiency of removal when using a CO_2 concentration of approximately 150 mg/L. The proportion of acoustically tagged Striped Bass recovered in holding tanks during CO_2 treatment in the primary channel will be used along with the numbers of wild Striped Bass collected to estimate the Striped Bass 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. In order to obtain a Striped Bass population estimate using this method, it will be necessary to collect at least one acoustically tagged and one wild Striped Bass in a TFCF holding tank during CO_2 treatment of the primary channel. Two-dimensional acoustic tracks will be developed for all acoustically tagged Striped Bass and employed to investigate Striped Bass behavior in the primary channel during CO_2 treatment, which may be used to guide future research efforts.

When determining if acoustically tagged Striped Bass can be guided out of the TFCF primary channel through an open louver panel with CO2 treatment, the most downstream primary channel louver panel will be lifted while water continues to be collected in a holding tank. The continued collection of water in a holding tank is necessary since the TFCF must salvage fish whenever pumping is occurring at the JPP. Acoustic tag detections and/or 2-dimensional tracks will be used, along with the number of acoustically tagged Striped Bass collected in a holding tank, to estimate removal efficiency. The use of acoustic tag detections and/or 2-dimensional tracks will be necessary to determine the number of acoustically tagged Striped Bass removed from the TFCF primary channel through an open louver panel during CO2 treatment. In addition, the use of acoustic tag detections will verify the number of acoustically tagged Striped Bass collected in a holding tank during CO2 treatment. The number of acoustically tagged Striped Bass guided out of the TFCF through an open primary channel louver panel and the number of acoustically tagged Striped Bass collected in a holding tank will be summed to estimate total removal efficiency from the TFCF primary channel when a louver panel is lifted during CO2 treatment with a concentration of approximately 150 mg/L. The number of acoustically tagged Striped Bass guided out of the TFCF through an open primary channel louver panel and/or collected in a holding tank during the 30-min CO2 treatment will be compared to the number of acoustically tagged Striped Bass that left the TFCF through an open primary channel louver panel or were collected in a holding tank during the 30-min period immediately prior to CO2 treatment (control) to determine if the use of CO2 in the primary channel increases the total number of piscivorous fish removed. A chi-square test (Minitab version 15) will be used to determine if there is a significant difference between the proportions of acoustically tagged Striped Bass removed between the control and CO2 treatment. If

possible, the proportion of acoustically tagged Striped Bass recovered in holding tanks during CO_2 treatment of the primary channel, the proportion of acoustically tagged Striped Bass guided out of the TFCF primary channel through an open louver panel during CO_2 treatment of the primary channel, and the numbers of wild Striped Bass collected in holding tanks will be used to estimate the Striped Bass 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. In order to obtain a Striped Bass population estimate using this method, it will be necessary to collect at least one acoustically tagged and one wild Striped Bass in a TFCF holding tank during CO_2 treatment of the primary channel with an open primary channel louver panel.

Assumptions and Limitations

This project can only be completed during 1 pump operation at the JPP and 1 week notice of this pumping conditions is needed to order dry ice and have it delivered to the TFCF. One pump operation at the JPP will be necessary for a minimum duration of 2 days to complete each replicate. Tidal conditions will be considered to reduce the volume of water that needs to be treated. It is assumed that the HTI acoustic telemetry systems at the TFCF will be fully operational and an appropriate number of personnel (6-8 individuals) will be available to perform injection of dry ice into the primary channel at the TFCF. In addition, it is assumed that wild Striped Bass will be available and that the Tracy Aquaculture Facility will be operational. Access to appropriate safety equipment (dry ice gloves, eye protection, etc.) will be necessary to perform dry ice injections. The Biological Resources group at the TFCF will also need the ability to adjust secondary channel flow as needed for this study. It is assumed that the contract for dry ice delivery will remain active and that no other projects or studies will take priority or precedence during the FY2021 research period.

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 CO_2 concentrations of approximately 150 mg/L are completed in the primary channel during the normal entrainment season of these species. This is because certain species, such as Delta Smelt, exhibited a lower tolerance to elevated CO_2 levels than Striped Bass and displayed up to 70% mortality over 96 h after being exposed to 100 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. All fish take for this project is covered under the most recent National Marine Fisheries Service (NMFS) BiOp, as well as current CDFW Scientific Collecting Permits held by the Biological Resources staff 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 Series Report 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. A draft report is expected to be produced by the end of September 2021 and a final publication is anticipated by September 2022.

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Use of Predation Detection Acoustic Tags to Estimate Juvenile Chinook Salmon Facility Efficiency at the Tracy Fish Collection Facility

Investigators

Brandon J. Wu
Fish Biologist
Tracy Fish Collection Facility
Bureau of Reclamation
Byron, CA 94514
bwu@usbr.gov

Rene C. Reyes
Fish Biologist
Tracy Fish Collection Facility
Bureau of Reclamation
Byron, CA 94514
rreyes@usbr.gov

Christopher L. Hart
Fish Biologist
Tracy Fish Collection Facility
Bureau of Reclamation
Byron, CA 94514
chart@usbr.gov

Kevin K. Kumagai
Senior Fisheries Biologist
HTI-Vemco USA, Inc.
Seattle, WA 98105
kkumagai@htisonar.com

Javier Miranda
Senior Environmental Scientist
California Department of Water Resources
Sacramento, CA 95814
Javier.Miranda@water.ca.gov

Summary

The U.S. Department of the Interior, Bureau of Reclamation (Reclamation), Tracy Fish Collection Facility (TFCF; Byron, California) was designed in the mid-1950s to divert and collect fish from water destined for export by the Central Valley Project's C.W. "Bill" Jones Pumping Plant (JPP). The TFCF uses a behavioral louver-bypass guidance system in the primary channel to guide entrained fish from the primary channel into a secondary channel and a vertically rotating traveling screen (Hydrolox™, Elmwood, Louisiana) in the secondary channel to guide entrained fish from the secondary channel into a holding tank. Fish that are not successfully guided by the primary channel louvers (with 2.5-cm [1.0-in] spaced vertical slats) or secondary channel traveling screen (with 1.8-mm clear openings and 32.0% open area; Reclamation 2012) are lost downstream to the JPP (Bates and Vinsonhaler 1957, Bates *et al.* 1960). Likewise, fish preyed upon in front of or within the TFCF are also considered to be lost as they are not successfully collected in a TFCF holding tank (*i.e.,* salvaged). According to Action IV.4.1 of the 2009 National Marine Fisheries Service (NMFS) Biological Opinion on the Coordinated Long term Operations of the Central Valley Project and State Water Project (NMFS 2009), Reclamation shall undertake actions to improve the TFCF whole facility efficiency for the salvage of Chinook Salmon (*Oncorhynchus tshawytscha*) and other species so that overall survival is greater than 75.0%.

Efforts to estimate whole facility efficiency at the TFCF using acoustic telemetry have been completed previously (Karp *et al.* 2017), although data has only been collected during 1, 3, and 5 pump operation at the JPP and acoustic tags without predation detection technology were used, which made it difficult to definitively determine if predation events had occurred. In an effort to supplement efficiency and predation estimates provided by Karp *et al.* (2017), a preliminary, proof-of-concept experiment using Predation Detection Acoustic Tags (PDAT; Model 900-PD, HTI-Vemco USA, Inc., Seattle, Washington) is being proposed. Predation Detection Acoustic Tags include a fuse of digestible (polysaccharide and gelatin) material that dissolves when the tag comes in contact with digestive fluids in a predator's stomach, which creates an open circuit that alters the tag signal and indicates that predation has occurred (Schultz *et al.* 2017). During this experiment, Chinook Salmon acoustically tagged with PDATs will be released at the trash boom upstream of the TFCF and tracked to estimate participation (fish that passed the TFCF trash rack and entered the primary channel), facility efficiencies (whole facility efficiency, primary louver efficiency, and secondary screen efficiency), predation, pre-screen loss to predation (between the TFCF trash boom and trash rack), pre-facility loss to predation (upstream of the TFCF trash rack), and passage time of salvaged fish (from the trash boom to the holding tanks) under a range of pumping conditions at the JPP. In addition, PDAT trigger time will be investigated and compared to published trigger time results from Schultz *et al.* (2017).

Data collection and analyses for this project were completed during the FY2020 research period. In total, 16 replicates have been completed (3 at 1 JPP, 4 at 2 JPP, 3 at 3 JPP, 3 at 4 JPP, and 3 at 5 JPP). Preliminary results suggest that participation, whole facility efficiency, and primary channel louver efficiency of juvenile Chinook Salmon increases with increased pumping at the JPP, while secondary screen efficiency is consistently 100% at all pumping conditions. Predation and passage time of salvaged fish appears to decrease with increased pumping at the JPP. While pre-screen loss to predation (between primary louvers and TFCF trash rack) increased with increased pumping at the JPP, pre-facility loss to predation (upstream of TFCF trash rack) decreased with increased pumping at the JPP to a greater extent, resulting in a net decrease in total predation losses

with increased pumping at the JPP. It appears that increased pumping at the JPP results in faster water velocities in the TFCF primary channel, which results in increased participation (entry into the facility) and reduced passage time of salvaged fish through the facility. Reduced passage time with increased pumping reduces the amount of time that fish interact with resident predators within the TFCF and results in a reduction in predation, which further results in an increase in facility efficiency.

A draft report for editor review is anticipated to be completed by the end of September 2020, with a final publication expected by September 2021. The primary deliverable will be an article published as a Tracy Series Report.

Problem Statement

The use of PDATs potentially allows for more definitive fate determination than photonic, floy, or Passive Integrated Transponder (PIT) tags. Due to this, PDATs will be used to complete whole facility efficiency experiments at the TFCF with juvenile Chinook Salmon. Replicates will be completed at each possible JPP pumping condition (1, 2, 3, 4, or 5 pumps in operation). An expanded hydrophone array upstream of the TFCF and/or mobile monitoring may be utilized. Acoustic tag detections will be used to determine fish fate and determine where losses are occurring. This data may be used to increase accuracy in the facility loss calculation and to identify areas within or near the TFCF where reducing mortality could increase facility efficiency.

Goals and Hypotheses

Goals:

1. Estimate participation, facility efficiency, primary channel louver efficiency, secondary channel screen efficiency, predation, pre-screen loss to predation, pre-facility loss to predation, and passage time for juvenile Chinook Salmon at varying JPP pumping conditions.

2. Determine if there is a main source of juvenile Chinook Salmon loss within the TFCF system.

3. Determine if the use of PDAT tags (HTI-Vemco USA, Inc.) reduces the number of unknown fates compared to standard acoustic tags.

4. Investigate PDAT trigger time and compare to published results from Schultz *et al.* (2017).

Hypotheses:

1. Participation, facility efficiency, primary channel louver efficiency, secondary channel louver/screen efficiency, predation, pre-screen loss to predation, pre-facility loss to predation, and passage time for juvenile Chinook Salmon will not change with varying JPP pumping conditions.

2. There is no main source of juvenile Chinook Salmon loss within the TFCF system and all sources of loss reduce facility efficiency equally.

3. The use of PDAT tags will not reduce the number of unknown fates.

4. Predation Detection Acoustic Tag trigger times will not be significantly different than those published by Schultz *et al.* (2017).

Materials and Methods

Fish Source and Care

Fall-run Chinook Salmon (~100–120 mm FL; number to be determined) will be obtained from the Mokelumne River Fish Hatchery (Clements, California) or Coleman National Fish Hatchery (Anderson, California) and transported to the Tracy Aquaculture Facility (TAF). Fish will be maintained within the TAF in recirculating 711-L tanks, provided temperature controlled (at same temperature as hatchery), treated (settled, filtered and ultraviolet [UV] sterilized) Delta water, and fed at ~4% body weight per day. Water quality (temperature, pH, ammonia, nitrite, salinity, and oxygen levels) will be monitored daily. Fish will be acclimated to ambient Delta water temperature at rates less than 2°C/d prior to surgical implantation of tags and release.

Experimental Design

A release-recapture experiment using juvenile Chinook Salmon acoustically tagged with PDAT tags will be completed at varying JPP pumping conditions to determine fate and estimate facility efficiencies (whole facility efficiency, primary louver efficiency, and secondary screen efficiency), predation, pre-screen loss to predation (between the TFCF trash boom and trash rack), pre-facility loss to predation (upstream of TFCF trash rack), and passage time of salvaged fish (from the trash boom to the holding tanks) during normal day-to-day operations (*i.e.*, louver and trash rack cleaning, hydraulic changes, *etc.*).

An array consisting of 23 fixed acoustic telemetry hydrophones (HTI-Vemco USA, Inc., Seattle Washington) installed throughout the TFCF will be used along with 3 acoustic receivers (Model 290 Acoustic Tag Receivers; HTI-Vemco USA, Inc., Seattle Washington). In addition, HTI-Vemco USA, Inc. receivers/hydrophones deployed by California Department of Water Resources (DWR) in Old River and Grant Line Canal and/or mobile monitoring may be used to detect fish that swim out of the hydrophone array deployed upstream of the TFCF trash rack and potentially determine if predation had occurred outside of the facility. This may be done based on the recommendation by Karp *et al.* (2017) to perform acoustic facility efficiency studies with the installation of additional receivers and hydrophones upstream of the TFCF trash boom to reduce the proportion of unknown fates. Hydrophones installed at the TFCF were connected to one of three acoustic tracking receivers using HTI-Vemco USA, Inc. Model 690 hydrophone cables. In conjunction, this equipment was used to track fish movements in front of, within, and downstream of the TFCF, including in the secondary channel and holding tanks.

For each replicate, 10 Chinook Salmon acoustically tagged with PDAT tags will be released from the midpoint of the TFCF trash boom and tracked for up to 140 h after the end of the operational period during which they were released. This was done to adequately assign predation events since Schultz *et al.* (2017) reported a maximum trigger time of 140 h for PDAT tags. Acoustic telemetry data at the TFCF will be recorded hourly and downloaded daily and the acoustic telemetry systems will be verified to be operational throughout the experimental period. Hydraulic data (water temperature, primary channel depth, primary channel flow, primary channel velocity, secondary channel depth, secondary channel flow, secondary channel velocity, primary channel and secondary channel bypass ratios, holding tank flow, and the number of secondary channel velocity control pumps and holding tank pumps in operation) will be recorded every 30.0 min for 2.0 h, after which hydraulic data will be recorded every 2.0 h.

All collections into the holding tanks will be examined for acoustically tagged fish during each experimental period by draining holding tanks prior to the morning haul-out. Stomachs of all Striped Bass (*Morone saxatilis*) and White Catfish (*Ameiurus catus*) >300 mm FL will be examined. Any experimental fish recovered in the holding tanks will be identified through tag code procedures and/or fish length (in the event of a dead tag battery).

Fish Processing

Surgeries will be conducted at least 24 h prior to each release (following guidelines in Liedtke *et al.* 2012). Fish will be captured from TAF fish tanks using monorail nets with 6.4-mm knotless nylon mesh (40.6 cm x 40.6 cm frame, 30.5 cm depth, 1.5 m handle, Pentair Aquatic Eco-systems, Inc., Apopka, Florida) and placed in an 10-L anesthetic bath containing a 100 mg/L dose of tricaine methanesulfonate (MS-222, Argent Chemical Laboratories, Redmond, Washington), 100 mg/L of sodium bicarbonate and 5 mL of Prime® water conditioner (Seachem Laboratories, Inc., Madison, Georgia). The time until anesthetization will be recorded for each individual fish using a digital timer. After the desired extent of anesthesia is reached, the fish will be removed from the anesthetic bath, measured (FL) and weighed (g). Fish will then be moved to the surgery station and an anesthetic mixture containing 100 mg/L MS-222, 100 mg/L sodium bicarbonate and 5.0 mL of Prime® water conditioner will be dispensed, along with fresh water (if necessary), using aquarium tubing placed in the fish's mouth. Surgical tools and sutures will be sterilized in 70% isopropyl rubbing alcohol, while acoustic tags will be decontaminated using a tabletop UV sterilizer (Salon Sundry M-2009, Sunrise, Florida) with 40.0 min UV exposure time. All surgical tools will be thoroughly rinsed in distilled water prior to surgery.

Acoustic tags (307 kHz, Model 900-PD, 1.0 g in air, 6.0-mm diameter x 25.0-mm long; HTI-Vemco USA, Inc., Seattle, WA) will be activated and programmed using an HTI-Vemco USA, Inc. Model 490 LP Tag Programmer. Incisions will be made using a 3-mm depth microsurgical blade with a 15-degree blade angle (Surgical Specialties Puerto Rico, Inc., Rincon, PR) and each tag will be inserted into the body cavity of a Chinook Salmon. As was done by Karp *et al.* (2017) and recommended by Liedtke *et al.* (2012), incisions will be closed with two independent sutures (2 x 3 knot) in an interrupted pattern using 4/0 Ethicon VCP303H, taper point, RB-1, 17 mm, ½ circle, 68.6-cm, violet, coated VICRYL Plus sutures and Mayo-Hegar needle holders. A modified surgeon's knot will be used to secure each suture and sutures will be trimmed using stainless steel operating scissors. The amount of time necessary to surgically implant the acoustic tag will be recorded for each fish.

Following surgical implantation of PDAT tags, fish will be placed in 168.0-L (0.74-m diameter) black tanks containing flow-through, aerated, treated Delta water at ambient temperature. One hour prior to release, fish will be netted and transferred to perforated 18.9-L (5.0-gallon) black buckets with lids (at a density of 2 fish per bucket) containing oxygenated, treated Delta water at ambient Delta water temperature. Each bucket will be transported to the TFCF trash boom and floated in raw Delta water for final acclimation. After the 1.0-h acclimation period, fish will be released downstream of the TFCF trash boom via water-to-water transfer and tracked for up to 96.0 h.

Data Analyses:

Acoustic tag detections will be used to determine fish fate and determine where losses are occurring. The dichotomous key developed by Karp *et al.* (2017) will be modified and used to assign fates. Since PDAT tags will be used during this experiment to definitively determine if predation had occurred, it will not be necessary to develop rules (*i.e.*, cease of tag movement) to assign predation events. Equations provided by Karp *et al.* (2017) will be modified (for pre-screen loss to predation only) and used to calculate passage time (for salvaged acoustically tagged Chinook Salmon only), participation, whole facility efficiency, primary channel louver efficiency, secondary channel screen efficiency, and pre-screen loss to predation. In addition, an equation will be developed to calculate predation as well as pre-facility loss to predation. For whole facility efficiency, a low estimate (all fish of unknown fate were assumed to be predation losses) and a high estimate (all fish of unknown fate were assumed to be nonparticipants) will be provided. Likewise, a low estimate (all fish of unknown fate were assumed to be nonparticipants) and a high estimate (all fish of unknown fate were assumed to be predation losses) will be provided for predation, pre-screen loss to predation, and pre-facility loss to predation.

Assumptions and Limitations

It is assumed that results and trends of this project will be valid despite the low sample size (16 replicates of 10 fish), which was necessary due to budgetary and personnel constraints. In addition, it is assumed that no other projects will take priority during the FY2021 research period and that there will be time to develop a Tracy Series Report.

Coordination and Collaboration

This study will be coordinated with the California Department of Fish and Wildlife, Tracy Fish Collection Facility staff, HTI-Vemco USA, Inc., and DWR staff. All work will be reviewed by the Tracy Technical Advisory Team (TTAT) during progress updates on study plans and reports.

Endangered Species Issues, "Take" Considerations

Data collection for this project was completed during the FY2020 research period. Due to this, the take of wild fish, including endangered or threatened species, will not be necessary for the remainder of the project.

Dissemination of Results (Deliverables and Outcomes)

Data collection and analyses for this project was completed during the FY2020 research period. A draft report for editor review is anticipated to be completed by the end of September 2020, with a final publication expected by September 2021. The primary deliverable will be an article published as a Tracy Series Report.

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