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Proposal Package for Tracy Fish Facility Improvement Program

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

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California-Great Basin · Interior Region 10

Prepared by

Bureau of Reclamation
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Bureau of Reclamation
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Tracy Fish Facility Improvement Program

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Disclaimer

Acronyms and Abbreviations

BiOp	Biological Opinion and Conference Opinion on the Long-Term Operations of the Central Valley Project and State Water Project
cm	centimeter(s)
CDFW	California Department of Fish and Wildlife
CO_2	carbon dioxide
ESA	Endangered Species Act
FL	fork length
ft	foot/feet
ft/s	feet per second
ft^3/s	cubic feet per second
FY	fiscal year
h	hour(s)
hp	horsepower
JPP	C.W. “Bill” Jones Pumping Plant
kg	kilogram(s)
L	liter(s)
lb	pound(s)
m	meter(s)
m^3/s	cubic meters per second
mg/L	milligrams per liter
mm	millimeters(s)
min	minute(s)
NMFS	National Marine Fisheries Service
PDATs	predation detection acoustic tags
Reclamation	Bureau of Reclamation
TAF	Tracy Aquaculture Facility
TFCF	Tracy Fish Collection Facility
TTAT	Tracy Technical Advisory Team
W	watt(s)

Symbols

°	degrees
°C	degrees Celsius
%	percent

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

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Summary

Action IV.4.1(1)(a) of the 2009 National Marine Fisheries Service (NMFS) Biological Opinion and Conference Opinion on the Long-Term Operations of the Central Valley Project and State Water Project (BiOp) mandates that the 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, has been 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.

Data collection for this evaluation was completed in fiscal year (FY) 2019. A total of four CO_2 treatments in the primary channel were completed. The four treatments that were completed include an initial 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, as well as separate investigations 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 louver panel with CO_2 treatment of the entire primary channel. Three of the CO_2 treatments in the TFCF primary channel were completed during 1 pump operation at the C.W. “Bill” Jones Pumping Plant (JPP;

approximately 22.7–28.3 cubic meters per second [m^3/s] [800–1000 cubic feet per second (ft^3/s)] water flow, approximately 0.2 meters per second [m/s] [0.5 feet per second (ft/s)] water velocity) to minimize the volume of water that needed to be treated, although 1 treatment was completed 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) to determine if the method was feasible with increased water flows.

Results suggest that CO_2 treatment of the primary channel is a feasible technique to remove resident Striped Bass from the TFCF during 1 pump operation at the JPP, although the process is not 100 percent (%) effective, is extremely labor intensive, and must be scheduled around certain uncontrollable factors (i.e., the number of pumps in operation at the JPP, tidal height, tidal direction, timing of tides, etc.). 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 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 Draft) suggests that a CO_2 concentration of approximately 185.0 milligrams per liter (mg/L) is 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 185.0 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 185.0 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 185.0 mg/L can be reasonably obtained in the primary channel at the TFCF, within 30 minutes (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 185.0 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 185.0 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 185 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 185 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 was 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 occurred when there was 1 or 2 pump operation at the JPP, which reduced the volume of water in the primary channel that needed to be treated. If possible, CO_2 treatments were performed when there was a slack low tide to further reduce the volume of water that was necessary to treat. Secondary channel velocity and flow rate were maximized to achieve increased water velocity

and flow in the primary channel bypass entrances. The maximization of secondary channel water velocity and flow also maximized primary channel bypass ratios (velocity of water going into each bypass versus the velocity of water in the channel), which promoted 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, 2,721.6–3,628.7 kilograms (kg) (approximately 6,000–8,000 pounds [lb]) of dry ice was requested to be delivered to the TFCF by the supplier (Innovative Federal Operations Group, LLC, Vista, CA) on the day before experimentation. Upon delivery, dry ice was stored in large, outdoor dry ice coolers (0.85 m^3; Polar Tech Industries, Inc., Genoa, IL) until preparation for injection. These coolers were conveniently located near the head of the primary channel at the TFCF, where injection of dry ice occurred.

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 185.0 mg/L during a 30-min treatment period, acoustic tags (Model 795-LY; HTI-Vemco USA, Inc., Seattle, WA) were used, along with an acoustic system consisting of acoustic tag receivers (Model 290; HTI-Vemco USA, Inc., Seattle, WA), hydrophones (Model 590; HTI-Vemco USA, Inc., Seattle, WA), and hydrophone cables (Model 690; HTI-Vemco USA, Inc., Seattle, WA) installed at the TFCF. The use of this technology allowed 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 allowed for estimation of removal efficiency when attempting to determine if acoustically tagged Striped Bass could be pushed downstream of the TFCF through an open primary channel louver panel.

Acoustic tags were surgically implanted in at least 10 Striped Bass (number chosen to allow for at least 10% precision) that were collected from the TFCF primary channel by angling. Striped Bass were chosen because 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 occurred up to 30 days prior to release and Tricaine Methanesulfonate (MS-222) was used as an anesthetic.

After surgical implantation of acoustic tags, Striped Bass were hand-carried to a wheeled recovery tub (228.6-L, 78.7-centimeters (cm) long x 50.8-cm wide x 57.1-cm deep) containing oxygenated 16 ºC well water and transported to outside 1.2-m diameter (757-liter [L]) black tanks containing aerated, 16 ºC well water where they were held at a density of up to two fish per tank. At least 1 week prior to release, tanks were gradually switched from well water to treated Delta water to appropriately acclimate fish. Two hours prior to release, Striped Bass were 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 occurred 1 day prior to treatment with CO_2. This was done to demonstrate and verify that Striped Bass in the TFCF primary channel would not willingly move downstream through the facility and into a holding tank within 24 hours (hr). To prevent experimental Striped Bass from moving upstream through the 56-millimeters (mm) spaced trash

rack at the upstream end of the facility, it was necessary to use only fish greater than 375 mm fork length (FL), which is the minimum size estimated by Sutphin et al. (2014) at which passage through the trash rack is restricted based on data collected at the TFCF. If possible, Striped Bass greater than 485 mm FL were 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 after being released in the primary channel, it was important to refrain from cleaning the primary louvers until after the predator removal in the primary channel was completed.

Prior to the start of CO_2 treatment, 149-watt (W) (0.2-horsepower [hp]) submersible pumps (Model 316; Carry Manufacturing, Inc., Munger, Michigan) were installed (at mid-water depth) throughout and downstream of the TFCF (i.e., in the primary channel, secondary channel, and intake canal to the JPP) to provide water samples for monitoring CO_2 and pH over time. The location, number, and configuration of submersible pumps varied based on the objective of each CO_2 treatment. Flow was maximized in the secondary channel to increase velocity at the primary channel bypass entrances and maximize primary channel bypass ratios to effectively 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 could be pushed downstream of the TFCF into the intake canal to the JPP, the louver panel immediately upstream of bypass 4 was lifted prior to CO_2 treatment of the primary channel.

To treat the TFCF primary channel, approximately 2,721.6–3,628.7 kg (approximately 6,000–8,000 lb) of dry ice was distributed and inserted at multiple locations upstream of the trash rack at the head of the primary channel. Dry ice insertion was completed using 1–2 front-end loaders, 1–2 forklifts with tipping bins, 1–2 trash rack cleaning devices, a backhoe, and manual insertion. During insertion of dry ice, all personnel were 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, were recorded from facility meters during each trial. During the initial CO_2 treatment of the TFCF primary channel to determine if acoustically tagged Striped Bass could be influenced or moved to a desired location within the primary channel, CO_2 and pH measurements were taken every 2 min from the TFCF sampling stations using 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, VA) and a pH meter (Model pH 110, Oakton Instruments, Vernon Hills, IL), respectively. During the other 3 CO_2 treatments of the TFCF primary channel, pH loggers (Model SDL100; Extech Instruments, Nashua, NH) were used to obtain pH measurements every 10 seconds. A CO_2 vs. pH curve was then developed in a laboratory setting by bubbling gaseous CO_2 (using a compressed gas CO_2 cylinder and a microbubble diffuser [MBD100; Pentair, Apopka, Florida]) into a sample of raw Delta water collected prior to each CO_2 treatment in the primary channel. The formula from the CO_2 vs. pH curve was applied to the pH measurements taken by the pH loggers to estimate CO_2 concentration.

When determining if acoustically tagged Striped Bass could be influenced or moved to a desired location within the TFCF primary channel by injecting dry ice, treatment only occurred in the north side of the TFCF primary channel. Acoustic tag detections and/or 2-dimensional tracks were used to investigate Striped Bass behavior in the primary channel during CO_2 treatment. The information obtained during this evaluation was used to guide following research efforts.

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 was 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 Fisher's Exact Test (RStudio, Boston, Massachusetts) was used to determine if there was 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) was used to estimate the efficiency of removal when using a CO_2 concentration of approximately 185.0 mg/L. The proportion of acoustically tagged Striped Bass recovered in holding tanks during CO_2 treatment in the primary channel was 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. To obtain a Striped Bass population estimate using this method, it will be necessary to collect at least 1 acoustically tagged Striped Bass and 1 wild Striped Bass in a TFCF holding tank during CO_2 treatment of the primary channel.

When determining if acoustically tagged Striped Bass could be guided out of the TFCF primary channel through an open louver panel with CO_2 treatment, the most downstream primary channel louver panel was lifted while water continued to be collected in a holding tank. The continued collection of water in a holding tank was necessary since the TFCF must salvage fish whenever pumping is occurring at the JPP. Acoustic tag detections and/or 2-dimensional tracks were 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 was necessary to determine the number of acoustically tagged Striped Bass removed from the TFCF primary channel through an open louver panel during CO_2 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 were summed to estimate total removal efficiency from the TFCF primary channel when a louver panel is lifted during CO_2 treatment with a concentration of approximately 185.0 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 CO_2 treatment was 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 CO_2 treatment (control) to determine if the use of CO_2 in the primary channel increases the total number of piscivorous fish removed. A Fisher's Exact Test (RStudio, Boston, Massachusetts) was used to determine if there was a significant difference between the proportions of acoustically tagged Striped Bass removed between the control and CO_2 treatment. It was not

possible to estimate the Striped Bass population in the TFCF system (primary channel, bypass pipes, and secondary channel) on the day of experimentation because no Striped Bass (acoustically tagged or wild) were collected in a TFCF holding tank. To obtain a Striped Bass population estimate using this method, it was necessary to collect at least 1 acoustically tagged and 1 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 evaluation could only be completed during one or two pump operation at the JPP and 1-week notice of these pumping conditions was needed to order dry ice and have it delivered to the TFCF. One or two pump operation at the JPP was necessary for a minimum duration of 2 days to complete each replicate. Tidal conditions were considered to reduce the volume of water that needed to be treated. It was necessary to collect wild Striped Bass for use during this evaluation and hold them in the Tracy Aquaculture Facility (TAF); therefore, it was necessary to maintain the TAF so that it was operational. For each replicate, it was necessary to verify the HTI acoustic telemetry systems at the TFCF were fully operational and an appropriate number of personnel (10–12 individuals) were available to perform injection of dry ice into the primary channel at the TFCF. Appropriate safety equipment (dry ice gloves, eye protection, etc.) was used when performing dry ice injections. It was necessary for the Biological Resources group at the TFCF to adjust secondary channel flow during each replicate. In addition, it was necessary to prepare and maintain a contract for dry ice supply and delivery. It is assumed no other projects or studies will take priority or precedence during the FY2025 research period and that there will be ample opportunity to prepare and finalize a Tracy Technical Bulletin for this evaluation.

Coordination and Collaboration

This study was coordinated with the TFCF biological and operations staff, Tracy Technical Advisory Team (TTAT), California Department of Fish and Wildlife (CDFW), and HTI-Vemco USA, Inc. Participation and inclusion of research-related updates were provided at regularly scheduled TTAT meetings.

Endangered Species Issues, “Take” Considerations

To minimize the risk of mortality of listed species, all attempts were made to complete research activity during seasonal periods in which listed species were not typically present at the TFCF. Despite this, 2 Chinook Salmon (*Onchorhynchus tshawytscha*; 1 fall-run and 1 spring-run according to length-at-date) and 3 Delta Smelt (*Hypomesus transpacificus*) were collected in a holding tank throughout the course of this evaluation. The number and species of fish guided out of the TFCF primary channel through an open louver panel with CO_2 treatment is unknown and could have included winter-run and spring-run Chinook Salmon, Steelhead Trout (*O. mykiss*), Delta Smelt, and other species. Based on results from Wu and Bridges (2014), it is possible that mortality of these species may have occurred because certain species, such as Delta Smelt, do

not tolerate elevated CO_2 levels as well as other fish (Delta Smelt exhibited 70% mortality over 96 hr after being exposed to 100 mg/L CO_2 for 20 min). All listed species encountered were immediately documented, processed according to current protocol, returned to the Sacramento-San Joaquin Delta (if alive), and reported to all appropriate agencies. All fish take for this evaluation was 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 have led to mortality of listed species, the cumulative lethal take of listed species for the facility would likely be much higher in the absence of predator removal activities in the primary channel at the TFCF.

Dissemination of Results (Deliverables and Outcomes)

Data collection for this evaluation was completed in FY2019 and results suggest CO_2 treatment is a feasible technique to remove resident Striped Bass (*Morone saxatilis*) from the TFCF primary channel during 1 pump operation at the Jones Pumping Plant (JPP), although the process is not 100% effective, is labor intensive, and must be scheduled around certain uncontrollable factors.

A Tracy Technical Bulletin will be the final deliverable of this study. Updates and presentations of progress will be provided internally and upon request by TTAT and other interagency technical forums. A draft report is currently being prepared, and final publication is anticipated by the end of FY2027. Information will be gained on the successes and limitations of this 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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Loss of Juvenile Chinook Salmon During Cleaning of Primary Channel Louvers at the Tracy Fish Collection Facility

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Summary

The Tracy Fish Collection Facility (TFCF) was developed in 1956 by the U.S. Department of the Interior, Bureau of Reclamation (Reclamation) as a means of salvaging fish 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). Many factors, including loss of fish through the TFCF primary channel louver array (98.1-meter [m] long x 7.0 m high with 36 louver panels [2.6 m wide x 7.0 m high] each consisting of 84 vertical louver bars [63.5 millimeter (mm) x 4.8 mm] spaced 2.5 cm apart; Reclamation 1956, Reyes et al. 2018), contribute to total fish loss at the TFCF (Karp et al. 2017, Wu et al. 2021). Loss of fish through the TFCF primary channel louver array can occur during regular facility operation or during cleaning of the primary channel louvers. To prevent excessive fish loss through the TFCF primary channel louvers due to undesirable primary channel hydraulic conditions during regular facility operation, it is necessary for the operations staff at the TFCF to clean the primary channel louvers at least once per day. Cleaning the primary channel louvers involves individually lifting and reseating each of the 36 primary channel louver panels to spray debris (i.e., submerged aquatic vegetation) off the louver slats, which creates a temporary 2.6-m wide void in the primary channel louver array that entrained fish can be lost through.

The primary channel louver array is separated into 4 sections (Sections 1–4 [from upstream to downstream]) with each section associated with a respective secondary bypass pipe intake (bypass pipes 1–4 [from upstream to downstream]) and consisting of 9 louver panels (figure 1). Since the primary channel louver array is oriented 15° to water flow in the primary channel (Reyes et al. 2018), the width of the TFCF primary channel gradually decreases as you move downstream; therefore, the rate of fish loss may be different for individual louver panels and/or sections of louver panels within the primary louver array because the probability of a fish encountering the primary channel louver array (during regular operation or cleaning) is increased as primary channel width decreases.

While the loss of fish through the TFCF primary channel louvers during regular facility operation has been thoroughly investigated with various fish species and life stages (i.e., juvenile Chinook Salmon [*Oncorhynchus tshawytscha*; Hallock 1967; Hallock et al. 1968; Karp et al. 1995; Sutphin and Bridges 2008; Karp et al. 2017; Wu et al. 2021], juvenile Steelhead Trout [*O. mykiss*; Karp et al. 2017], adult Delta Smelt [*Hypomesus transpacificus*; Sutphin and Svoboda 2016], juvenile Sacramento Splittail [*Pogonichthys macrolepidotus*; Sutphin and Bridges 2008; Karp and Lyons 2015], juvenile Striped Bass [*Morone saxatilis*; Hallock 1967; Hallock et al. 1968; Karp et al. 1995], adult Threadfin Shad (*Dorosoma petenense*; Hallock 1967, Hallock et al. 1968, juvenile American Shad [*Alosa sapidissima*; Hallock 1967; Hallock et al. 1968], juvenile White Catfish [*Ameiurus catus*; Hallock 1967; Hallock et al. 1968], and juvenile White Sturgeon [*Sinosturio transmontanus*; Karp and Bridges 2015]), the extent of fish loss that occurs when the TFCF primary channel louver panels are lifted, sprayed, and reseated for cleaning has not yet been thoroughly researched and/or directly quantified (only Karp et al. 2017 and Wu et al. 2021 briefly discuss this subject matter). Due to this, an experiment is being proposed to estimate loss of juvenile Chinook Salmon during cleaning of the primary louvers at the TFCF. Information will be gained on the extent of juvenile Chinook Salmon loss that occurs during cleaning of the TFCF primary channel louvers. This information will potentially help refine placeholder loss values used when calculating juvenile Chinook Salmon loss at the TFCF. In addition, the knowledge gained from this experiment may help determine the need for future construction and/or development efforts at the Tracy Fish Collection Facility.

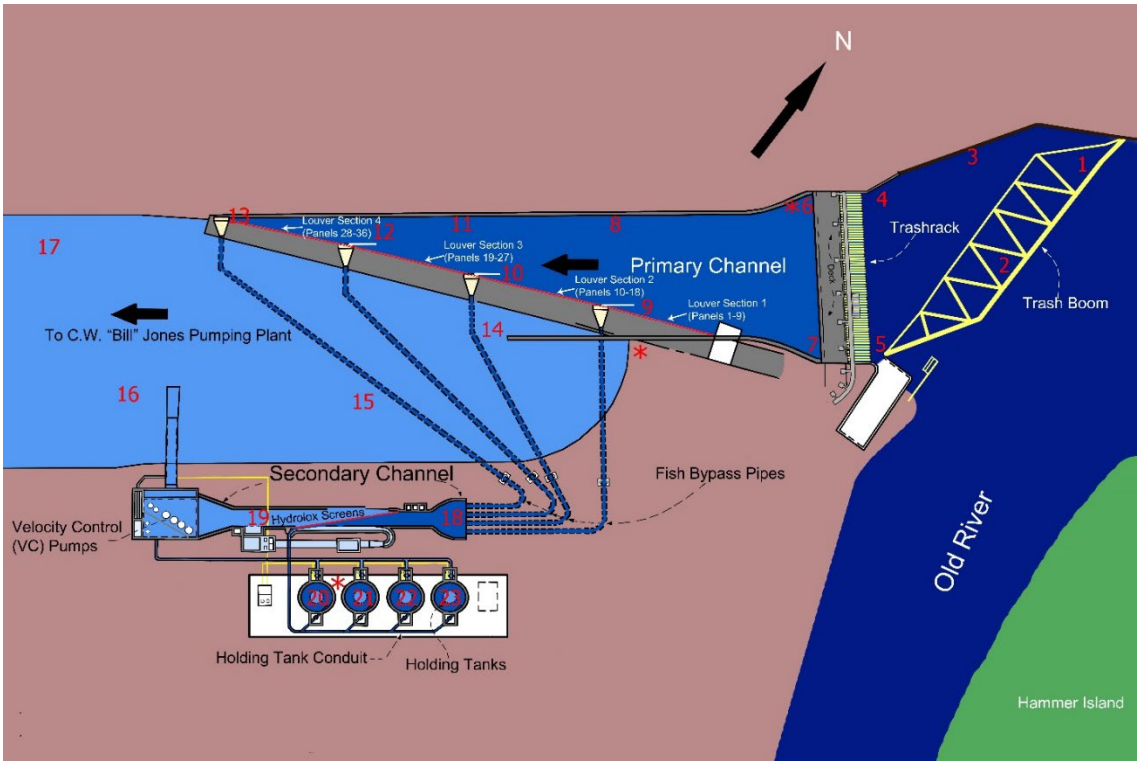

Figure 1.—Diagram of the Tracy Fish Collection Facility showing primary channel louver Sections 1–4, locations of the 23 acoustic telemetry hydrophones that will be used during this experiment (red numbers), and locations of acoustic tracking stations (red asterisks).

Problem Statement

Loss of fish through the TFCF primary channel louver array contributes to total fish loss at the TFCF (Karp et al. 2017; Wu et al. 2021) and can occur during regular facility operation or during cleaning of the primary channel louvers. While the loss of fish through the TFCF primary channel louvers during regular facility operation has been thoroughly investigated with various fish species and life stages, the extent of fish loss that occurs through the TFCF primary channel louver array when the primary channel louver panels are lifted, sprayed, and reseated for cleaning has not yet been thoroughly researched and/or directly quantified (only Karp et al. 2017 and Wu et al. 2021 briefly discuss this subject matter). Due to this, an experiment is being proposed to estimate loss of juvenile Chinook Salmon during cleaning of the primary louvers at the TFCF.

Goals and Hypotheses

Goals:

1. Estimate loss and loss rate of juvenile Chinook Salmon during cleaning of each of the 4 sections of primary channel louver panels at the TFCF (each section of primary channel louver panels consists of 9 louver panels).
2. Estimate loss and loss rate of juvenile Chinook Salmon during cleaning of each individual primary channel louver panel within each section of primary channel louver panels at the TFCF (each section of primary channel louver panels consists of 9 louver panels).
3. Estimate cumulative loss and loss rate of juvenile Chinook Salmon during cleaning of all 36 primary channel louver panels in the TFCF primary channel louver array.
4. Determine if loss and loss rate of juvenile Chinook Salmon during cleaning is significantly different among the 4 sections of primary channel louver panels at the TFCF.
5. Develop component estimates for juvenile Chinook Salmon salvage efficiency, primary channel louver efficiency (during cleaning), secondary channel screen efficiency, and passage time.

Hypotheses:

1. There will be no loss of juvenile Chinook Salmon during cleaning of the primary channel louver panels at the TFCF.
2. Loss of juvenile Chinook Salmon during cleaning will be comparable among the 4 sections of primary louver panels at the TFCF.

Materials and Methods

Loss of fish during cleaning of the TFCF primary channel louvers will be investigated using juvenile Chinook Salmon with surgically implanted acoustic tags (Model V3; 307 kHz frequency; Innovasea Marine Systems Canada, Halifax, Nova Scotia). Externally marked (i.e., photonic-tagged) juvenile Chinook Salmon will also be used during this experiment to obtain increased sample size and greater test power. Juvenile Chinook Salmon will be used as test subjects for this experiment because this species and life stage is routinely salvaged at the TFCF, and the spring and winter runs of this species are federally listed under the Endangered Species Act (ESA) as threatened and endangered, respectively (CNDDB 2022).

Juvenile Chinook Salmon will be obtained from Coleman National Fish Hatchery [Anderson, CA]), held in 1,514.2-L (400.0-gallon [gal]) circular tanks within the Tracy Aquaculture Facility (TAF), and provided recirculated or flow-through, temperature controlled, aerated, treated (filtered, settled, and UV sterilized) Delta water. Fish will be fed size No. 1 and size No. 2 starter feed (Bio-Oregon, Longview, WA) at approximately 2.0% body weight per day, although feed will be withheld for at least 24.0 hr prior to surgical implantation of V3 acoustic tags.

All releases for this experiment will be performed when ambient Delta water temperature is appropriate for juvenile Chinook Salmon (i.e., less than 20° C [Araújo et al. 2023; Moyle 2002]). In addition, all releases will be performed when the JPP is operating at high pumping capacity (i.e., when 4 or 5 JPP pumps are in operation) to maximize interaction of test fish with the primary channel louver array (Wu et al. 2021). To the greatest extent possible, all releases will be performed at comparable primary channel water depth and tidal stage so primary channel flow and velocity are similar among releases/replicates. It will be necessary to complete 3 replicates for this experiment, with each replicate consisting of a release of juvenile Chinook Salmon for each of the 4 sections of the TFCF primary channel louver array (i.e., there will be 4 releases per replicate). The order that each section of primary channel louver panels will be tested during each replicate will be randomly determined and each section of primary channel louver panels will be tested before performing additional replicates for any one section of louver panels. This approach will be necessary to develop estimates of total cumulative loss during cleaning of all 36 primary channel louver panels in the TFCF primary channel louver array by summing data from the 4 releases that a replicate consists of.

Each release will involve the insertion of 15 juvenile Chinook Salmon with surgically implanted V3 acoustic tag and 100 juvenile Chinook Salmon with a unique external photonic tag specific to that release. Experimental Chinook Salmon will be released into the TFCF primary channel (evenly distributed downstream of the TFCF trashrack) while louver panels within Sections 1, 2, 3, or 4 of the primary channel louver array are sequentially (from upstream to downstream) lifted, cleaned (using the automatic spray wash system of the primary channel louver cleaner), lowered, and reseated (figure 1). To replicate standard operating procedures, the bypass pipe immediately downstream of the louver section being cleaned will be closed prior to fish release and will remain closed for the duration of the cleaning activity for that section of louvers. Fish release and initiation of louver cleaning will occur simultaneously. The times that each individual louver panel within a section is lifted and reseated, as well as the total time for

cleaning of the entire section of louver panels, will be recorded. The time that the final (most downstream) louver panel in a section is reseated will be considered the end of the release period.

Acoustic-tagged Chinook Salmon will be followed using 23 fixed acoustic telemetry hydrophones (Model 590; HTI-Vemco USA, Inc., Seattle, WA), numerous hydrophone cables (Model 690; HTI-Vemco USA, Inc., Seattle, WA), 3 acoustic tag receivers (Model 290; HTI-Vemco USA, Inc., Seattle, WA), and 3 laptop computers (assorted models; Dell Inc., Round Rock, TX) installed throughout the TFCF (figure 1). Acoustic tagged Chinook Salmon will be tracked for the duration of the cleaning activity for the section being tested. If acoustic-tagged Chinook Salmon remain in the TFCF primary channel after the end of the replicate, it will be assumed the fish were either preyed upon in the TFCF primary channel prior to encountering the primary channel louver array or did not participate in the experiment (i.e., non-participant). Likewise, it will be assumed experimental Chinook Salmon that swim upstream through the TFCF trash rack and out of the facility did not participate in the experiment. All fish with acoustic tags collected in a TFCF holding tank within the experimental period will be recovered to verify that the tag is still in a live experimental Chinook Salmon. Any fish detected and/or recovered in a TFCF holding tank after the experimental period during which it was released will be considered non-participants. Hydrophone voltage (and potentially processed and positioned data animations) will be used to determine if acoustic-tagged fish detected downstream of the primary channel louver array were potentially lost through the 2.6-m wide void that is created when a louver panel is lifted. In addition, the timing of acoustic tag detections downstream of the primary channel louvers versus the timing of individual louver panel cleaning will be used to determine if acoustic-tagged fish were potentially lost during cleaning. The number of experimental Chinook Salmon (both acoustic-tagged and photonic-tagged) collected in a holding tank, the number of acoustic-tagged Chinook Salmon that passed downstream of the primary louver array, and the number of acoustic-tagged Chinook Salmon that were either lost to predation in the primary channel or did not participate in the study will be determined for each replicate. The proportion of acoustic-tagged juvenile Chinook Salmon lost through primary channel louvers, as well as the proportion of acoustic-tagged juvenile Chinook Salmon that were either lost to predation in the primary channel or did not participate in the study, will be applied to the number of photonic-tagged Chinook Salmon not collected in a TFCF holding tank to assign fates to those fish.

After a fate is determined for each experimental Chinook Salmon in a release group, the percentage of juvenile Chinook Salmon lost during cleaning of an entire section of 9 louver panels can be calculated using Equation 1. In this equation, fish that are either lost to predation in the primary channel or did not participate in the study are removed from the release group because fish with these fates did not have an opportunity to interact with the primary channel louver array.

Equation 1 Loss During Cleaning of Entire Section of Louver Panels = (number of Fish Lost Downstream of Primary Louver Array/[number of Fish Released - number of Fish Preyed Upon in Primary Channel or Non-Participants])*100

In addition, Equation 2 will be used to calculate a loss rate (i.e., loss per minute of cleaning) for each release group using the number of juvenile Chinook Salmon lost during cleaning of an entire section of 9 louver panels, the times that each individual louver panel within a section is lifted and reseated, and the total time for cleaning of the entire section of louver panels. In Equation 2, the amount of time for cleaning only includes durations when one of the primary channel louver panels within each section is partially or completely lifted and does not include periods when all primary channel louver panels are seated and the primary channel louver cleaner is traveling between louver panels.

Equation 2 Loss Rate (Loss Per Minute of Cleaning) = number of Fish Lost Downstream of Primary Louver Array/(Total Minutes for Cleaning of the Entire Section of Louver Panels – Minutes When All Primary Channel Louver Panels are Seated)

Assuming loss through each individual primary channel louver panel within a section of louver panels is the same, loss during cleaning of each individual louver panel within a section of louver panels can be estimated from the calculated percentage of juvenile Chinook Salmon lost during cleaning of an entire section of louver panels using Equation 3. In this equation, the loss value obtained from Equation 1 for an entire section of primary channel louver panels is divided by 9 to obtain an estimate of loss for each individual louver panel in a section.

Equation 3 Loss During Cleaning of Each Individual Louver Panel in a Section = Loss During Cleaning of Entire Section of Louver Panels/9

Total cumulative loss while cleaning of all 36 primary channel louver panels in the TFCF primary channel louver array will then be estimated for each replicate. This will be done by combining data for the 4 releases of experimental Chinook Salmon within that replicate (i.e., by combining data for each section of louver panels).

Data Analyses

For each replicate, loss of juvenile Chinook Salmon during cleaning of each section of louver panels (i.e., Section 1, 2, 3, and 4; consisting of 9 primary channel louver panels) will be estimated first and will include an estimated loss rate (i.e., loss per minute of cleaning). Loss of juvenile Chinook Salmon during cleaning of each individual primary channel louver panel within each section of louver panels will then be calculated. Total loss while cleaning of all 36 primary channel louver panels in the TFCF primary channel louver array will be estimated for each replicate by combining data for the 4 releases of experimental Chinook Salmon within that replicate (i.e., by combining data for each section of louver panels).

Depending on whether assumptions for parametric analysis are met, either a one-way analysis of variance (ANOVA) or the non-parametric equivalent (i.e., Kruskal-Wallis Test; RStudio, Boston, Massachusetts) will be used to 1) determine if there are significant differences in primary channel flow and velocity during testing of the 4 sections of primary channel louver panels that comprise the TFCF primary channel louver array, and 2) determine if loss and loss rate of juvenile Chinook Salmon during cleaning of an entire section of primary channel louver

panels is significantly different among the 4 sections of primary channel louver panels. A Tukey's Test or non-parametric equivalent (i.e., Dunn's test; RStudio, Boston, Massachusetts) will be used to identify individual sections of the primary channel louver array with significantly different primary channel flow, primary channel velocity, and/or juvenile Chinook Salmon loss estimates and loss rates.

Assumptions and Limitations

Juvenile Chinook Salmon were obtained from Coleman National Fish Hatchery [Anderson, CA]) in February and March 2026. It is assumed the TAF will be capable of keeping these fish alive, and that the fish can be reared to approximate size of 100–120 mm Fork Length for this experiment. Loss through the TFCF primary channel louvers is assumed to be comparable at all JPP pumping rates (i.e., loss estimates developed when 4 or 5 pumps are in operation at the JPP are applicable to 1, 2, and 3 pump operation as well). It is assumed that hatchery origin juvenile Chinook Salmon behave in a similar manner as wild juvenile Chinook Salmon, and that surgical implantation of acoustic tags does not affect juvenile Chinook Salmon behavior. It is also assumed the array of HTI-Vemco USA, Inc. receivers, hydrophones, and hydrophone cables that is currently installed throughout the TFCF will be maintained and operational for this experiment. In addition, it is assumed there will be sufficient opportunity to collect data (i.e., there will be adequate periods of 4 or 5 JPP pump operation for data collection), and that an appropriate number of TFCF biology and operations personnel (a minimum of 7 individuals) will be on site and available to prepare for and complete replicates for this experiment. It is also assumed no other projects, experiments, or activities will take priority during the 2026–2027 research season.

It will be assumed acoustic-tagged Chinook Salmon detected downstream of the primary channel louver array were still in live experimental Chinook Salmon upon passage (i.e., it will be assumed experimental Chinook Salmon were not preyed upon prior to passing downstream of the primary channel louver array). It will also be assumed fish that remain in the TFCF primary channel after the end of the replicate were either preyed upon in the TFCF primary channel or did not participate in the experiment (i.e., non-participant). Any fish with unknown fate will be removed from the release group for that replicate since the fate of unknown fish is either loss to predation or non-participation, and the numbers of fish with these fates are subtracted out of the denominator in Equation 1 because they do not have a chance to interact with the primary channel louver array.

Equal loss will be assumed for each individual primary channel louver panel within a section of louver panels, which will allow for estimation of loss during cleaning of each individual primary channel louver panel within a section. In addition, it is assumed total cumulative loss of juvenile Chinook Salmon during cleaning of all 36 primary channel louver panels can be adequately estimated by combining data for the 4 releases of experimental Chinook Salmon within each replicate (i.e., by combining data for each section of louver panels).

Coordination and Collaboration

This study will be coordinated with the TFCF staff (biology and operations) and the Tracy Technical Advisory Team (TTAT). Participation and inclusion of research-related updates will be provided at regularly scheduled TTAT and/or Central Valley Fish Facilities Review Team (CVFFRT) meetings.

Endangered Species Issues, "Take" Considerations

Winter run Chinook Salmon, spring run Chinook Salmon, Steelhead Trout, Longfin Smelt (*Spirinchus thaleichthys*), and Delta Smelt may be encountered during these experiments. If ESA-listed species are encountered, they will be immediately documented, returned to the Delta (if alive), and reported to all appropriate agencies. 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.

Dissemination of Results (Deliverables and Outcomes)

Juvenile Chinook Salmon were obtained from Coleman National Fish Hatchery [Anderson, CA]) in February and March 2026. A Purchase Request for Model V3 acoustic tags was submitted February 2026 specifying delivery of tags between December 1, 2026, and December 31, 2026. Data collection for this experiment will likely begin February 2027 and be completed by the end of the FY2027 research period. Data will be analyzed upon completion of data collection (i.e., during FY2027 or FY2028) and updates will be provided at TTAT and/or CVFFRT meetings. The primary deliverable will be an article published as a Tracy Series Report. A draft report for peer review is anticipated to be completed by the end of FY2028, while a final published report is expected to be posted to the Tracy Fish Facility Improvement Program website in FY2029.

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Assessment of Population Dynamics and Mitigation Methods for Golden Mussel Fouling

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Summary

Tracy Fish Collection Facility (TFCF) diverts and salvages fish from water being exported from the Sacramento-San Joaquin Delta (Delta) by the C.W. "Bill" Jones Pumping Plant into the Delta Mendota Canal. Both the TFCF and pumping plant are integral parts of the Bureau of Reclamation's (Reclamation) Central Valley Project, which provides water for agriculture and municipalities throughout the western side of the San Joaquin Valley.

Golden mussels (*Limnoperna fortunei*) were detected in the Delta and O'Neill Forebay in October 2024, marking the first detection of this species in North America. Subsequent monitoring has confirmed the presence of golden mussels in 30 locations throughout the Delta and State Water Project (CDFW et al. 2025), as well as at the TFCF (J.C. Dealy, personal communication).

The biology and life history of golden mussels are similar to those of dreissenid (quagga and zebra) mussels, with notable differences in adult size (approximately 3.0–4.5 cm for golden mussels compared to approximately 2.5–3.0 cm for quagga and zebra mussels) and the ability of golden mussels to thrive over a wider range of water quality parameters (Cataldo 2015; Karatayev et al. 2015; Morton 2015; Mackie and Claudi 2010). The impacts of golden mussel settlement on Reclamation facilities are consequently anticipated to be similar to, or even greater than, those experienced with dreissenid mussels, including flow restrictions, mechanical damage, and increased rates of corrosion (Reclamation 2021).

An assessment of system vulnerabilities at the TFCF reported the trashracks, screens, pumps, conduits, valves, and instrumentation are highly susceptible to mussel-related impacts (Reclamation 2010). Colonization on the primary louvers, bypass entrance transitions, and bypass conduits may reduce export capacity to some extent due to a reduction in open area for adequate water flow. Additionally, even minor colonization of the primary louvers could degrade fish guidance performance, and mussels on the bypass entrance transitions and bypass conduits have the potential to injure fish and reduce salvage efficiency.

Although available information suggests golden mussels will cause significant impacts to Reclamation facilities such as the TFCF (Boltovskoy et al. 2015b; Karatayev et al. 2015), this species is currently in the initial stages of establishment in the U.S. and many uncertainties exist. This proposed project will monitor golden mussel settlement at the TFCF to evaluate site-specific establishment trends and population dynamics. Specific metrics to be evaluated include seasonal cycles, periodic and cumulative settlement intensity, and colony development and growth in coordination with partnerships with state, federal and local water management agencies. These data will be valuable in informing future studies as well as strategic planning and mitigation efforts at the TFCF.

The ability to remove mussels from critical features of the TFCF may also be enhanced by the application of foul-release coatings. These structural coatings do not prevent mussel settlement but weaken their ability to adhere and reduce the effort necessary for removal. Reclamation has been investigating the effectiveness of foul-release coatings for dreissenid mussels for over

15 years and has identified several silicone-based formulations that perform well in this regard (Gulsvig and Skaja 2022). Unfortunately, all the promising coatings that were previously evaluated are no longer in production, although there are a variety of foul-release coatings currently produced that are advertised as "equivalent" in performance to previously tested coatings. These coatings are commonly used on ship hulls, and the use of silicone-based coatings for foul-release is well established (Oliveira and Granhag 2020; Townsin and Anderson 2009; Watermann et al. 1997). However, these coatings are relatively soft, and their durability or foul-release performance has not been evaluated under conditions analogous to those at the TFCF primary louvers (frequent pressure washing and exposure to debris).

This proposal continues work initiated in 2026 and expands efforts to better understand golden mussel population dynamics and evaluate potential mitigation technologies. The proposal's three primary goals are:

1. Assess golden mussel population dynamics through monitoring of settlement patterns, seasonal reproductive cycles, gonad development and correlations with water temperature. These data will improve the ability to anticipate fouling intensity and inform mitigation planning.
2. Evaluate foul-release coatings for applicability at the TFCF primary louvers, focusing on coating durability, settlement inhibition, and ease of mussel removal. Preliminary testing began in 2026, with expanded 2027 studies proposed to incorporate simulated debris exposure, high-pressure wash effects, and in-situ testing.
3. Conduct a scoping assessment of UV-C light as a non-chemical mussel mitigation tool, identifying knowledge gaps, feasibility considerations, potential treatment configurations, and opportunities to integrate UV-C with other technologies.

The proposed project incorporates laboratory investigation, in-situ studies, and multi-agency collaboration throughout the Delta. Results will support development of practical, environmentally responsible mitigation strategies and inform long-term management of golden mussel impacts at the TFCF.

Problem Statement

The golden mussel is a non-native freshwater/brackish bivalve native to Asia. It was discovered in the Delta in October 2024, the first known occurrence in North America. Adult golden mussels were also detected at the TFCF in January 2025 (J.C. Dealy, personal communication). This species is reported to be similar to dreissenid (zebra and quagga) mussels in many aspects, including prolific breeding (Boltovskoy et al. 2015a; Mackie and Claudi 2010), rapid population expansion once established in a water body (Barnes and Patino 2020; Nakano et al. 2015), and dense colony formation (Correa et al. 2015).

Both golden and dreissenid mussel larvae are planktonic, floating freely in the water column until developing to a stage where they will attach to any hard surface, including trashracks, interior surfaces of conduits, pumps, and other infrastructure that is in regular contact with raw

water (Correa et al. 2015; Mackie and Claudi 2010). Once attached to a substrate, mussels form byssal threads that secure them in place, and removal is difficult and expensive. Mitigation strategies to reduce the effort necessary to remove settled mussels from infrastructure by application of foul-release coatings have been investigated (Galhenage et al. 2022, Reclamation 2014) and may present significant labor and cost savings. However, many of the previously tested coating formulations have been discontinued by the manufacturers, and the durability and performance of currently available foul-release coatings have not been independently evaluated.

In response to the initial detection of golden mussel in the Delta, the state of California has formed the Golden Mussel Task Force and developed a comprehensive Golden Mussel Response Framework to address this invasive species threat. The framework report emphasizes the significance of impacts the golden mussel poses on ecosystems, water conveyance systems, infrastructure, agriculture, economy, and water quality (CDFW et al. 2025).

Invasive mussel fouling is a significant issue for Reclamation facilities, reducing flow capacities and functionality of equipment, potentially leading to unplanned outages and significant increases in maintenance requirements. Shell debris from mussel die-off can also be problematic, causing obstructions and degrading coatings, seals, and machined surfaces. Specific impacts on Reclamation facilities have included increase in frequency of high-temperature alarms at pumping and hydropower plants due to mussel fouling of cooling systems, flow capacity reductions and head loss from fouling at intakes, and inoperability due to shell debris clogging of small-diameter systems such as fire suppression lines. Facilities have responded to invasive mussel impacts in various ways, including installation of ultra-violet light treatments or filtration systems, dosing with copper compounds or chlorine, and a general increase in staff time for cleaning and maintenance (Reclamation 2021). Recent advances in technology such as application of ultra-violet light in the UV-C wavelengths (180–280 nanometers) have shown promise in preventing aquatic biofouling, but many logistical and operational uncertainties to full-scale implementation still exist.

Available literature suggests impacts from golden mussels will be comparable or more severe than those experienced from dreissenid mussels at Reclamation facilities (Boltovskoy et al. 2015b; Karatayev et al. 2015; Mackie and Claudi 2010; Reclamation 2021). An invasive mussel vulnerability assessment for the TFCF was conducted in 2010 and reported that features of the facility regularly exposed to raw water including the trashracks, screens, pumps, conduits, valves and instrumentation are highly susceptible to mussel-related impacts. The primary louver panels were identified as an ideal arrangement for mussel fouling, and even minor colonization could degrade the hydraulic and biological performance of fish guidance as well as export capacity to some extent. Of particular concern are the louver bypass entrance transitions and bypass conduits, as these features cannot be isolated and drained and mussel accumulation on surfaces within the facility have the potential to injure fish and reduce salvage efficiency (Reclamation 2010).

Goals and Hypotheses

Goal 1: Assess golden mussel population dynamics and correlations with water temperatures by monitoring mussel settlement, juvenile densities, and adult gonad development to characterize reproductive development, temporal patterns in spawning activity, and juvenile settlement intensity.

Although invasive mussel survival and proliferation can be influenced by a variety of environmental factors, current literature suggests water temperature as the primary driver of reproductive cycle timing and development rate (Boltovskoy 2005; Boltovskoy et al. 2015a; Nakano et al. 2015). Analyses will examine reproductive cycles synchronicity by determining whether individuals cluster around the same seasonal phase (e.g., same period of gonadal maturity) more than would be expected by chance. Practical applications of these analyses include enabling detection of changes in population trajectories, guidance for anticipated fouling intensity, and a foundation for timing mitigation strategies. Alternatively, a lack of distinct seasonal synchronization in reproductive cycles or correlation with water temperature would suggest impacts could be highly unpredictable, and a more systemic approach to mitigation may be warranted.

Data collection will be conducted monthly by TSC staff at the TFCF. Analyses will include additional population data pooled from collaborating partners throughout the Delta to capture a broader range of environmental conditions, reduce the influence of local bias or short-term events, and improve statistical power. Partnerships have been initiated with local water districts, university researchers, and state and federal agencies.

We hypothesize golden mussel reproductive maturity, spawning, and settlement are a) significantly associated with water temperatures, and b) occur in distinct synchronous seasonal peaks.

Goal 2: Determine the suitability of foul-release coatings to the TFCF primary louvers to provide recommendations regarding coatings that meet field-scale evaluation criteria and potential integration into long-term facility operations.

Assessments will address coating durability and foul-release performance. Durability testing initiated under the 2026 funding is proposed to be continued and expanded in 2027, with in-situ testing for durability and effectiveness at the TFCF primary louvers, as well as modifications to lab studies to simulate louver bar geometry, debris loading, and a high-temperature high-pressure wash systems that may be used for periodic hand-cleaning.

We hypothesize there is a) a significant difference in mean coating durability, measured as material loss, change in surface properties, or visible coating degradation, and b) foul-release performance among the foul-release coating types when exposed to conditions both simulated and empirically tested at the TFCF primary louvers.

Goal 3: Assess the feasibility of UV-C light as a potential non-chemical tool for managing invasive mussel biofouling at the TFCF.

Ultraviolet radiation has emerged as a promising non-chemical method for suppressing mussel settlement and inactivating early life stages (Stewart-Malone et al. 2015; Pucherelli and Claudi 2017). Emerging technologies in UV-C energy distribution and optimization may offer opportunities for effective system integration, but optimal design for dosing and operational integration are not well understood.

This goal is proposed to initiate as a scoping effort that will identify key knowledge gaps, define technical and operational considerations, and evaluate potential UV-C treatment configurations appropriate for TFCF infrastructure. Scoping will include evaluation of potential testing methodologies, dose-duration parameters, and logistical requirements for conducting further research. The effort will also explore the possibility to integrate UV-C with other methods (e.g. filtration, carbon dioxide) for enhanced efficiency. Outcomes will provide a foundation for determining whether UV-C as a stand-alone treatment or in coordination with complementary technologies warrants future evaluation for potential implementation at TFCF.

Materials and Methods

Population Dynamics and Water Temperature Correlations

Monitoring of golden mussel settlement will be continued from the previous project with settlement substrates of various materials and configuration currently deployed within bioboxes installed at TFCF. Two separate sets of bioboxes on shelving units, one outdoors on the secondary channel bridge and a second inside the fish collection building are currently installed and plumbed into the TFCF low-pressure system. Each shelving unit is equipped with three bioboxes, each with dimensions of approximately 10 by 10 by 42-inches. All bioboxes are covered with a small sheet of foam insulation to exclude light and buffer temperature fluctuations, and the exterior shelving unit is enclosed in foam insulation and OSB structural panels for additional protection from solar radiation and damage from weather.

Discussions with state agencies and local water managers have indicated difficulties in capturing golden mussel settlement on artificial substrates within bioboxes. Method development for settlement monitoring is ongoing and iterative testing will be conducted in 2026 to inform monitoring protocols. Initial steps include flow monitoring and automated controls to stabilize flow rates, and deployment of various substrate materials and configurations. Additional methods under consideration include manipulating substrate orientations and light exposure to exploit negative phototactic responses.

Substrates currently installed within bioboxes at TFCF include 6-inch square plates comprised of PVC, ABS plastic, aluminum, black steel, and ceramic tile (3 repetitions per material per biobox). Anecdotal evidence has suggested potential settlement preference for small, confined areas, and additional substrates with a 4-sided square configuration (4-inch by 4-inch by 1.5-inch) and a diagonal cross-piece were also included to determine if the angular areas would

be more attractive for settlement. Square samples were constructed of black steel and 3D printed with HDPE resin, with 3 repetitions of the square steel substrates per biobox and only one HDPE resin due to 3D printing constraints at the time of deployment.

Substrates are scheduled to be monitored monthly for settlement through September of 2026 under the previous TFFIP project and proposed to continue through September 2027. Specific substrate materials, design, orientation, and replicate capacity will be informed by testing conducted in 2026. Final study design is anticipated to include replicate substrates for both monthly (periodic) and annual (cumulative) settlement.
Proposed golden mussel settlement monitoring methods include:

- Digital photographs of all settlement monitoring plates will be collected on site at the TFCF for percent cover estimation.
- Settled mussels on cumulative settlement monitoring plates will be counted per size class (size classification regime to be determined).
- Periodic settlement plate monitoring will include individual settled mussel counts by size class, followed by scraping plates for dry weight measurements.

Accumulation of debris and non-mussel biofouling is expected to occur on the settlement monitoring plates. It is not anticipated that this will significantly interfere with settlement data collection entirely, but modifications to the methodology may be required. Should settlement substrates or interior surfaces of bioboxes become overwhelmed with debris and/or biofouling, monitoring may be shifted to periodic (monthly) settlement only and bioboxes will be cleaned after each data collection event.

Plankton net tows will also be collected monthly at the TFCF and shipped to the Denver TSC Invasive Species Lab for cross-polarized microscopy enumeration of golden mussel veligers. However, collaborating partners have not yet confirmed parallel plankton net tow data collection at other sites to date, and it is unknown if these data will be useful for statistical analyses.

Gonad development monitoring will also be initiated in 2026 with collaborative funding from an ongoing S&T project and will be continued in 2027 under this proposal. Samples of adult golden mussels (approximately 10–20 individuals) will be collected at TFCF monthly by TSC staff. Additional collections of adult mussels and water temperature monitoring may be conducted at various sites in the Delta in collaboration with partnered water agencies to increase sample size. Collected adult mussels will be immersed in 10 percent neutral buffered formalin and sent to the USGS Upper Midwest Environmental Sciences Center for histological assessment of gonad development. Water temperature will be measured at each sampling date at the same depth when and where the mussels are collected, and ongoing temperature monitoring at California Data Exchange Center (CDEC) stations near collection sites will be acquired.

Statistical analytical methods will depend on dataset characteristics but may include circular tests for clustering/non-uniformity (seasonal synchronicity), regression, or general additive models (water temperature correlations.)

Foul-Release Coating Assessment

Coating manufacturers have indicated availability of six different coating formulations with foul-release properties. Steel plates (6-inch square) will be applied with coatings in 2026 for preliminary durability testing under simulated spray-wash conditions in the Reclamation Technical Service Center (TSC) Hydraulics Laboratory.

Proposed continuation of coatings testing will focus on coatings that perform satisfactorily under the 2026 preliminary tests. Additional testing proposed includes:

- Modifications to coating sample spacing and orientation to wash jets to determine degradation to edge surfaces or from reflective forces, replicative of TFCF primary louver bar geometry.
- Introduction of plant fragments into the jet stream of the lab-simulated spray-wash to assess additional scouring effects.
- Exposure of coating samples to a high-temperature high-pressure wash to evaluate resistance to spot-cleaning.

Data collection for foul-release coating durability tests will include an assessment of surface damage using an optical profilometer as well material loss measurements of dry film thickness to quantify material loss.

Surface damage data obtained from optical profilometry will be converted to ordinal ratings (e.g. none, slight, moderate, severe degradation) for differentiation using the Kruskal-Wallis test followed by Dunn's post hoc tests to identify significant differences between coatings. Mean material loss in dry film thickness will be evaluated for compliance with parametric assumptions using Shapiro-Wilk tests and visual inspection of Q-Q plots; homogeneity of variance among groups will be evaluated using Levene's test. If assumptions of normality and equal variance are satisfied, differences between coating formulation in thickness reduction from spray-wash testing will be assessed using one-way-ANOVA. If parametric assumptions are not confirmed, a Kruskal-Wallis test followed by Dunn's post hoc tests will be performed to determine statistical differences in dry film thickness.

Preliminary assessments of the foul-release performance capabilities of coatings will also be conducted. A total of 6 coated samples plates per coating formulation will be deployed into the outdoor bioboxes at TFCF in 2026 two plates of each coating formulation per biobox) and evaluated monthly with digital photographs and visual counts by size class to compare settlement rates to uncoated substrates using one-way ANOVA or Kruskal-Wallis/Dunn's post hoc test per parametric data confirmation as described above for the durability testing.

Future studies are anticipated to include testing of settled mussel removal from foul-release coating sample plates at the TFCF using a portable spray-wash setup to quantify percent mussel detachment by spray-wash pressure. Durability testing results will be evaluated to refine coating formulations to progress to in-situ testing (i.e. coating samples mounted to primary louvers) for validation.

Ultraviolet C Light

Relevant scientific literature will be reviewed to summarize existing knowledge on UV-C effectiveness, dose-duration thresholds, implementation technologies, and environmental and operational limitations. Facility and operational information will be gathered and examined to identify locations where UV-C could feasibly be integrated. Considerations include power availability, maintenance, safety, and compatibility with existing operations. Environmental components such as turbidity, flow rates, and biofouling hotspots will also be assessed to determine if further investigation of UV-C as a potential mitigation tool for golden mussel fouling is warranted.

Preliminary investigations into opportunities to pair UV-C with other mussel mitigation technologies (e.g. filtration, carbon dioxide, or coatings) will also be explored to identify whether combined approaches may improve treatment efficacy. Considerations will include engineering compatibility, safety, environmental impacts, and regulatory pathways. Specific tasks include a review of existing literature, solicitation of input from industry experts, and relevant experience from ongoing golden mussel coordination and mitigation research efforts.

Lab or field-based research methodology will be explored to fill knowledge gaps and refine implementation recommendations with focus on applicability to TFCF infrastructure. Future proposals may delve further into lab or pilot-scale evaluation of UV-C for golden mussel mitigation depending on initial scoping assessment.

Assumptions and Limitations

The golden mussel population in the Delta is still in relatively early stages of establishment, and substantial uncertainty remains regarding long-term trajectories. Some aspects of the proposed monitoring, particularly those requiring seasonal or multi-year dataset comparisons may be limited by the density or consistency of mussel settlement during the project period.

Similarly, conditions specific to the TFCF primary louvers may influence the degree to which mussel fouling presents tangible operational challenges. If mean colonization intensity is low or highly variable, the benefits of implementing foul-release coatings or other structural mitigation solutions may be difficult to quantify. Coating durability testing also presents logistical challenges, as replicating individual environmental conditions experienced at the primary louvers in laboratory simulations may not accurately represent the totality of degradation factors and

interactions. Field-based evaluations of coatings are planned to validate lab-based results. These tests may be constrained by operational considerations, and opportunities to conduct testing may be affected by maintenance schedules.

Golden mussel population-scale characteristics, impacts, and mitigation strategies are the focus of multiple ongoing efforts across state, federal, and regional water agencies. As collaborative work evolves, recommendations, priorities, and available resources may shift. These changes may influence sampling frequency, site access, or the breadth of evaluations proposed. Work outlined in this proposal is designed to produce meaningful insight under a wide range of possible conditions and lay groundwork for long-term adaptive management strategies at the TFCF.

Coordination and Collaboration

Coatings Testing

Coordination will be ongoing with the TSC Materials and Corrosion group for coatings expertise. The group currently has limited capacity but has been providing expertise and guidance in obtaining coatings and refinement of analysis methods. Increased involvement in coatings testing for the TFCF by TSC coatings experts is anticipated for 2027 and potentially beyond. Collaboration is also ongoing with Pacific Northwest National Laboratory staff to obtain coating samples as well as testing methodology expertise and oversight.

Additional coordination with multiple agencies operating in the Sacramento San-Joaquin Delta regarding coatings testing is ongoing. Interest has been indicated in deploying coating sample plates in various locations, assistance with labor for monitoring, and funding support.

Gonad Development Studies

An ongoing study funded by Reclamation's Science and Technology Program will be providing resources for TSC and USGS to initiate gonad development studies in 2026. Sample collection and analysis will continue in 2027 with collaborative support requested under this proposal.

UV-C Scoping

Researchers at EPRI (www.epri.com) have been in contact with TSC staff regarding implementation of UV-C technologies to deter biofouling in various contexts. Additional collaboration may be conducted with Innovative Resources Inc. (iriproducts.com) and the University of Nevada, who have previous experience using UV-C in aquatic systems.

Endangered Species Issues/"Take" Considerations

The foul-release coatings selected for testing are non-toxic and will have no environmental impact. All tasks included in this proposal will be conducted in a manner that will not interfere with operations or cause harm to endangered species.

Dissemination of Results (Deliverables and Outcomes)

Results will be summarized in an official report and published in the Tracy Series that will be disseminated to all interested parties. The results can be shared at Tracy Technical Advisory Team meetings as requested. The results of this research will also be shared with the Reclamation Invasive Mussel Task Force, Invasive Mussel Collaborative, and all other interested invasive mussel working groups. Information will also be shared with managers at facilities that are interested in preventive control measures for golden mussels.

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