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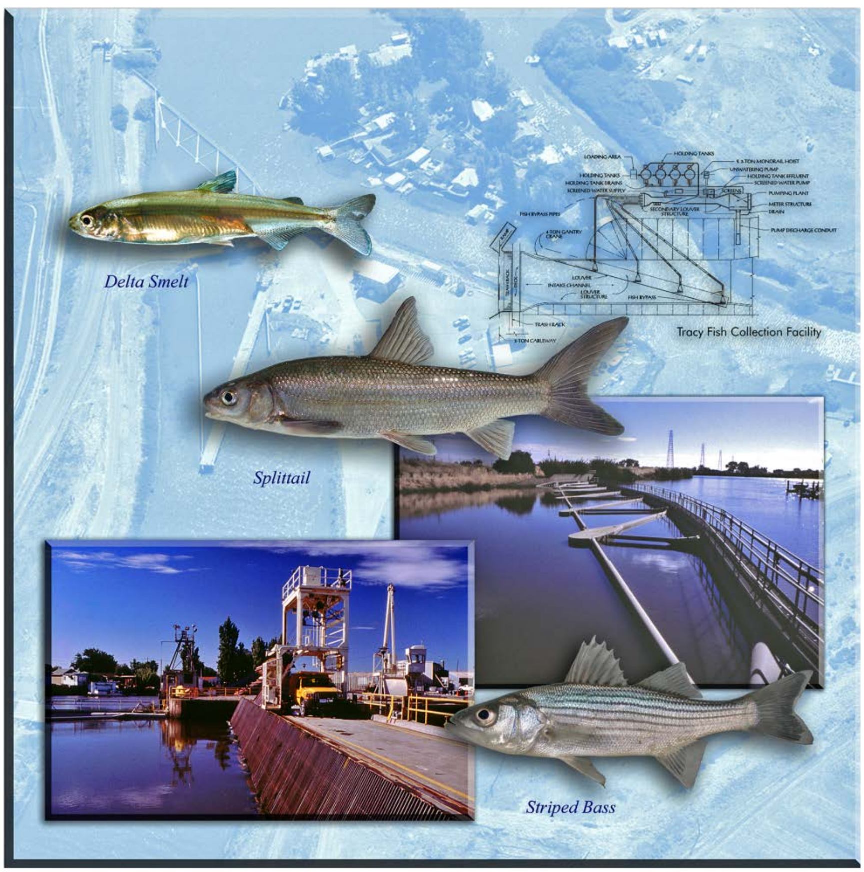
Tracy Technical Bulletin 2016-1

A Review of Fish Release Methods at the Tracy Fish Collection Facility with Recommendations for Future Operations



U.S. Department of the Interior
Bureau of Reclamation
Mid-Pacific Region and
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April 2016

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14. ABSTRACT
The Bureau of Reclamation's Tracy Fish Collection Facility (TFCF) in central California was designed in the mid-1950s to divert, collect, and return salvaged fish to the Sacramento-San Joaquin River Delta (Delta) from exported flows enroute to the C.W. "Bill" Jones Pumping Plant (JPP). Fish diverted from entrainment into the JPP are collected and held in large, circular in-ground holding tanks for up to 24 h awaiting transport and release. Truck transport from the fish facility to fish release sites in the Delta has been the standard operation since facility inception. The TFCF typically maintains two releases sites, Antioch Bridge and Emmaton, although maintenance issues and equipment failure at times allow only one to be functional. The nearby State of California Department of Water Resources fish salvage/release operation recently completed construction of a new site, are constructing two additional sites, and discussions are underway for the two facilities to begin sharing release sites. We offer several recommendations to improve current release procedures, including the alternative of developing new shoreline release tank facilities or returning to modified surface releases using water cannons and releasing into flow.

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A Review of Fish Release Methods at the Tracy Fish Collection Facility with Recommendations for Future Operations

Tracy Technical Bulletin 2016-1

by

Cathy Karp[1] and Brent Bridges[2]

[1] U.S. Department of the Interior
Bureau of Reclamation
Fisheries and Wildlife Resources Group, 86-68290
PO Box 25007
Denver, CO 80225-0007

Bureau of Reclamation
Tracy Fish Collection Facility; TO-411
16650 Kelso Road
Byron, CA 94514-1909

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

Tracy Fish Facility Improvement Program

J. Carl Dealy, Manager

Tracy Series Editors

Zachary A. Sutphin, M.S.
U.S. Department of the Interior – Bureau of Reclamation
Technical Service Center
Fisheries and Wildlife Resources Group, 86-68290
PO Box 25007
Denver, CO 80225-0007

Connie D. Svoboda, P.E.
U.S. Department of the Interior – Bureau of Reclamation
Technical Service Center
Hydraulic Investigations and Laboratory Services Group, 86-68460
PO Box 25007
Denver, CO 80225-0007

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EXECUTIVE SUMMARY

The U.S. Department of the Interior, Bureau of Reclamation Tracy Fish Collection Facility (TFCF) in central California was designed in the mid-1950s to divert, collect, and return salvaged fish to the Sacramento-San Joaquin River Delta from exported flows enroute to the C.W. "Bill" Jones Pumping Plant (JPP). Wild fish diverted from entrainment into the JPP are collected and held in large, circular in-ground holding tanks for up to 24 h awaiting transport and release. Truck transport from the fish facility to fish release sites in the Delta has been the standard operation since facility inception. The TFCF typically maintains two releases sites, Antioch Bridge and Emmaton, although maintenance issues and equipment failure at times allow only one to be functional. The nearby State of California Department of Water Resources fish salvage/release operation is currently using their new Curtis Landing fish release site and older Horseshoe Bend site, and is constructing two additional sites (J. Miranda, 2016, personal communication). Discussions are underway for the two facilities to begin sharing release sites.

Fish release methods have included both surface and underwater releases. The surface release was originally used, but was converted to underwater releases that moved fish away from the shore and deep under water. However, the underwater system has problems with clogging, fish remaining in the pipe, pipe turbulence, and predators keying in to the fish releases. Unfortunately, fish survival after release has not been studied at the current release sites with the current operating procedures.

We offer several recommendations to improve the current release procedures including: reconsidering surface releases using water cannons to deter predators, altering release schedule among all available release sites so that predators don't become accustomed to a release site, and developing new shoreline release tank facilities that would release fish at night (on the outgoing tide). Improvements at the fish facilities should be incorporated as well to help ensure fish survival, including installing oxygen systems in the fish holding tanks, developing methods to remove debris, developing procedures to collect juvenile fish in the spring in multiple holding tanks simultaneously to reduce through-screen losses, and develop methods to hold and release piscivorous fish removed from the facility.

INTRODUCTION

The C.W. "Bill" Jones Pumping Plant (JPP) and the Tracy Fish Collection Facility (TFCF) were designed to export water from the Sacramento-San Joaquin river delta (Delta) and salvage (*i.e.*, divert and collect) fish from the entrained flow, respectively. These facilities are part of the U.S. Bureau of Reclamation's (Reclamation) mid-Pacific Central Valley Project (CVP). Entrained fish are diverted through the TFCF into large, below-ground, holding tanks where they are counted and released back to the Delta by truck transport. Fish release sites are considered far enough away that salvaged fish do not immediately return to the TFCF. The purpose of this review is to describe the current fish salvage and release process, and then discuss a few alternative fish transport/release concepts, as requested by National Marine Fisheries Service in their Biological Opinion and Conference Opinion on long-term operations of the CVP and State Water Project (NMFS 2009). It is not known if current release methods at existing release sites are successful, as both short-term and long-term survival rates following release are relatively unknown.

Current Salvage Operations

The TFCF may salvage millions of fish annually, consisting of more than 50 freshwater and estuarine species (California Department of Fish and Wildlife annual salvage reports, https://www.wildlife.ca.gov/Conservation/Delta/Salvage-Monitoring). These include larvae through the adult life history stages of many diverse forms. Diverted fish are typically held in the holding tanks (up to 70,000 L [18,497 gal)] for up to 24 h, where they are then truck transported (9,800 L [2,589 gal] tank) to one of two release sites (Antioch Bridge and Emmaton, see Figure 1) at least once daily. These sites are about 32–40 km (20–25 miles) away and a salvaged fish run typically occurs in the morning (0730 h) and evening (2030 h), followed by an approximate 45–60 min truck transport. The number of fish transported depends on the amount of water exported and the abundance of fish in the south Delta. Entrained fish and debris (*e.g.*, Brazilian pondweed [*Egeria densa*], water hyacinth [*Eichhornia crassipes*] wood fragments, Asian clam [*Corbicula fluminea*] peat fibers, and sand) are loaded together into the transport truck tank and released together. Some debris is removed at several points in the salvage process (*e.g.*, trash boom, trash rack, primary channel louvers, and secondary channel traveling screen) but efficient debris removal methods have not been incorporated into the fish salvage process to ensure that debris and fish are not truck transported together.

Several facility procedures help improve the survival of salvaged fish during truck transport. First, transport trucks are completely filled to reduce water oscillating back and forth in the truck tank during transport. Secondly, each truck is outfitted with diffuser stones for separate oxygen and compressed air systems. The air system was designed to be used continuously, while the oxygen system was designed to be used when needed for transporting high densities of fish. Finally, a salt solution of about 8 ppt is added to the truck prior to the addition of fish to reduce transport induced osmotic stress (*i.e.*, the salt in the water prevents fish from losing blood salts through gills when stressed). Adding salt was determined to be essential to help fish recover from handling and transport when the facility first opened in 1957 (Bates *et al.* 1960, Raquel 1989).

Survival of salvaged fish after release is not well known and is possibly size, species, and season specific. A release site predation observation study was conducted in 2007 and 2008 using a variety of techniques and gear types (Miranda *et al*. 2010a). Using DIDSON underwater video, Miranda *et al*. (2010a) concluded that predation was occurring, more so in the summer and fall when more prey sized fish were being released, more predatory sized fish were observed in the area, and that predatory fish tended to remain near the release site when the number of fish being released was consistently high. Salvaged fish were also vulnerable to bird predation when released during the daylight hours (double crested cormorants [*Phalacrocorax auritus*]) were observed feeding on fish at the pipe outlet in DIDSON video, Miranda et al. 2010a). While predation was documented to occur, the study was not able to determine how significant a problem it is for specific species of fish.

Release Sites and Methods

The method of choice for releasing salvaged fish has historically been to use truck transport from the TFCF to shoreline release sites (Figures 1 and 2, upper left). The original design of the TFCF included barging experiments to return fish to the Delta, but logistic difficulties made this form of transport impractical (United States Department of the Interior 1957). Trucking fish to the release sites was selected as the optimal method for releasing salvaged fish due to cost, flexibility in the location of release, and minimal time needed for completion.

The original method for releasing TFCF salvaged fish was to empty the truck into an open chute down to the water during the day for a surface release (Figure 2, upper right). Sometime in the late 1960's - early 1970's, the release sites were converted from a chute to a pipe (Figure 2, lower) so that the salvaged fish could be released underwater, offshore, and more directly in tidal currents to assist with their distribution. A major disadvantage of this method was that operators could no longer see what was happening to the released fish.

The TFCF currently uses two fish release sites (Emmaton and Antioch; Figure 1) and both are used daily except when a site breaks down. In the event that multiple truckloads of fish are released each day, then each release site may be used more than once. The nearby Department of Water Resources (DWR) Skinner Delta Fish Protective Facility also uses truck transport to release

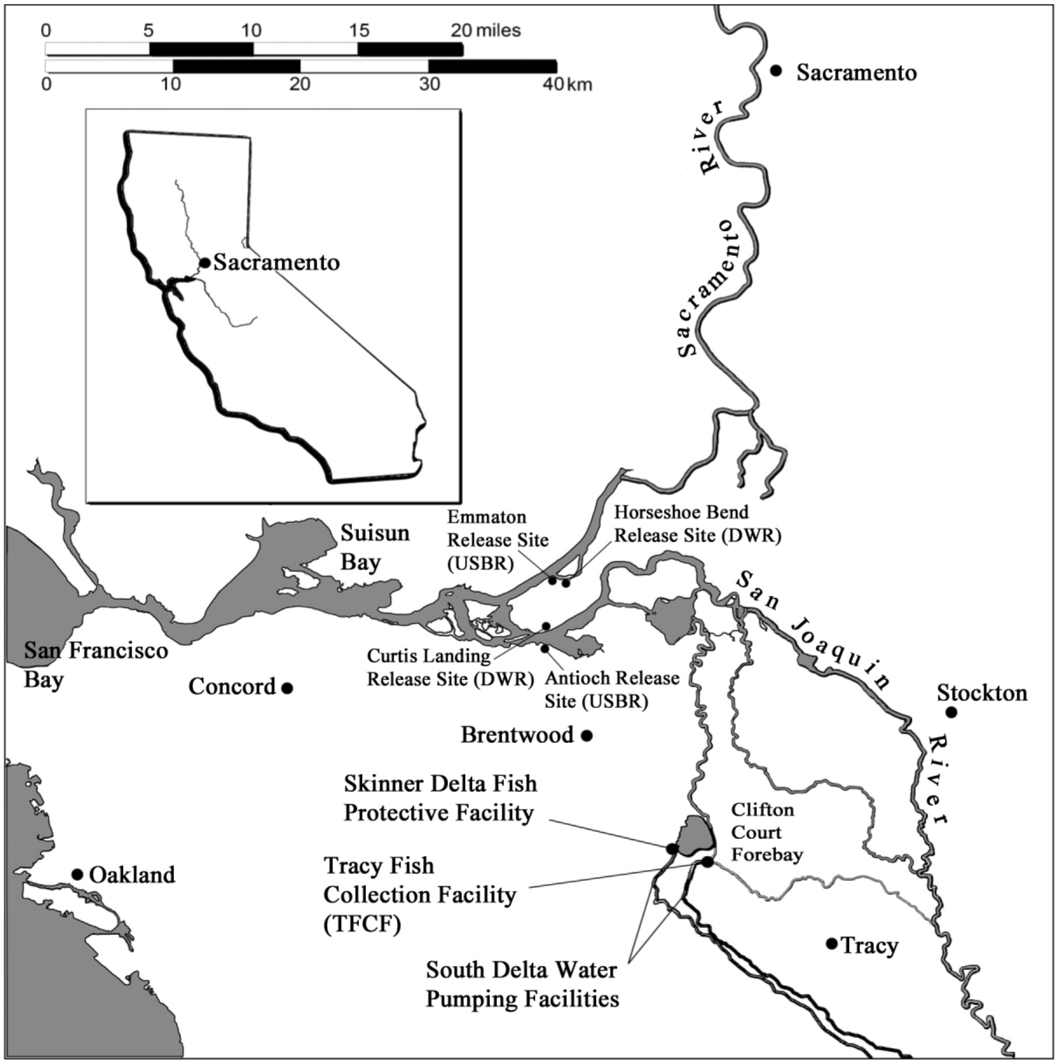

Figure 1.—Location of the Tracy Fish Collection Facility and the Antioch and Emmaton release sites, Sacramento-San Joaquin Delta, CA.

salvaged fish at nearby release sites. They currently use Curtis Landing and Horseshoe Bend release sites (see Figure 1) which will become shared with Reclamation's operations in the near future (J. Dealy, 2016, personal communication).

Both current TFCF fish release sites share a similar design. Many of the design parameters to optimize fish survival were very similar to those used in the early years on the Columbia River system (Dawley *et al*. 1992). A 30 cm (12 in) diameter steel pipe extends from shore out to deep water (see Figure 3). This allows fish to travel from the truck to an offshore underwater release. Release pipes currently extend approximately 30 – 46 m (100 – 150 ft) from shore and the outlets are approximately 3 – 9 m (10 – 30 ft) deep (depending on tide and site location). The pipe outlet is supposed to remain off the bottom so that debris does not block the exit of the pipe and fish are quickly dispersed with channel flow.

Figure 2.—Fish transport truck (upper left), old chute for surface release system (upper right), and current system of transport truck connected to site release pipe for underwater release (lower).

Water pumps (about 757 – 1,514 L/min, 200 – 400 gpm) are housed in separate pipes parallel to the fish release pipes, and provide water to rinse out the truck and release pipe. Pump intakes are screened with a perforated screen (6.4 mm [0.25 in] holes).

Operators use a standard technique for releasing fish at a release site. The transport truck backs squarely to the release pipe and a 25.4-cm (10-in) diameter flexible pipe is attached to the truck tank and inserted into the 30.48-cm (12 in) diameter release pipe. Delta water is added to the release pipe before and during the fish release. When ready to release fish, the operator opens the gate valve on the rear of the truck. An inclined slope was graded into the truck parking space to assist with draining the truck tank. The tank empties quickly at first, but the drain rate slows as the truck tank empties. As water travels down the release pipe, a standing wave forms as it hits standing water inside the pipe. Video of the release process showed some turbulence inside the pipe where debris and fish are mixed together in the standing wave (Mefford 2008). However, Miranda *et al*. (2010b) found that adult delta smelt (*Hypomesus transpacificus*) and juvenile Chinook salmon (*Oncorhynchus tshawytscha*) had high survival under lab conditions, even when released with debris. These fish were greater than 60 mm (2.4 in) fork length and it is not known how well smaller-sized fish would survive this process. Currently, with the existing CVP release sites, some fish and debris remain in the pipe due to either inadequate rinse flows and/or the pipe being too horizontal (Miranda *et al*. 2010b). After releasing the fish, the truck tank can be filled again to allow a second full-tank release. This process helps move fish through the release pipe when completed. Ideally, fish should be flushed out of the pipe, the pipe outlet should be off the channel bottom, and the hydraulic jump should extend past the end of the pipe (with as little debris as possible in the release). Release times are scheduled primarily according to facility needs and not tidal stage or fish behavior.

Emmaton Release Site

The Emmaton release site was previously known as the Sherman Island site and is located near Horseshoe Bend along Sherman Island (see Figure 1). This site allows fish to be released into the Sacramento River and was completely rebuilt in 2003 with two fish-release pipes and two water-pump pipes (Figure 3). These four pipes are supported by pilings already being used to support a water-quality sampling station. The longer of the two fish release pipes extends further offshore and has rinse water (about 1,514 L/min [400 gpm]) available. This pipe has a steeper slope than at Antioch which promotes emptying of debris but some turbulence occurs and fish may get stranded within the pipe. Water velocity inside the full pipe is approximately 0.2 m/s (0.7–0.8 ft/sec) when the pipe is rinsed out with the 1,514 L/min flow. Larger fish have been observed leaving the truck after the majority of the water has emptied. Fish leaving the truck tank late rely on the rinse water to push them out of the release pipe.

The Emmaton site is unique in that it has a second, shorter release pipe, but it does not have rinse water available (other than flushing from the truck tank directly). This short pipe was designed for times when large amounts of debris needed to be unloaded without risking plugging the longer pipe. The shorter pipe has never been used because the truck exit cannot properly align with the pipe. Emmaton is generally used for the early morning release (about 0730 h) as it is considered too remote and unsafe for the fish operators to use at night (J. Imai, 2016, personal communication). Piscivorous fish have a variety of habitat to use at this site, including the release pipes, pilings, riprap, and shoreline vegetation (Figure 3).

Figure 3.—Emmaton fish release site.

Antioch Release Site

The Antioch Bridge release site is located along the San Joaquin River on the south-side of the Antioch Bridge (see Figure 1). The shoreline and release-site pipes are shorter and have a gentler slope relative to the Emmaton site, but are not held off the bottom by pilings (Figure 4; Miranda *et al.* 2010a). Predator habitat in the area consists of shoreline vegetation, release and pump pipes, and a fishing wharf located about 61 m (200 ft) downstream. Public access for anglers exists at other agency release sites, but angling may be more frequent at the Antioch site due to the proximity of the fishing pier. It is unknown if the public fishing pressure helps reduce the amount of predation that occurs at this site.

The Antioch release site was improved in the early 1980's and again more recently by extending the pipe into deeper water. This site has problems with clogged pipes because of the low grade. A 30.48-m (100-ft) long, 30.48-cm (12-in) diameter PVC plastic pipe was added onto the end of the existing 25.9-m (85 ft) steel pipe. The PVC pipe was laid along the river bottom. Over time the PVC pipe became covered in sediment, leaving the exit of the pipe below ground level. A large scour hole developed at the end and it periodically filled with debris from the fish truck. The condition of the release pipe was discovered in approximately 2011 when the operators could no longer get fish and debris to flow through the pipe because water was not moving fast enough to push the debris before settling. A diver was hired to inspect the release pipe and remove the PVC section. This allowed the short metal section to continue to function and remain a few feet off the bottom (repairs were made at that time).

Figure 4.—Antioch fish release site.

The Antioch Bridge site is used at night because it is located within the city of Antioch and considered safer by the operators. Fish collected in the daytime at the TFCF are released at night at this location around 2000–2100 h. This site is scheduled for replacement in the near future as funds become available (J. Dealy, 2016, personal communication).

Future Release Sites Currently Being Planned

Reclamation and DWR have recently collaborated to improve and standardize the design of release sites to meet the requirements of the NMFS (2009) Biological Opinion. Design parameters for a release site are largely the same as before, but more water will be used to flush the release pipe. The Biological Opinion requires the two fish salvage facilities to use six release sites instead of the current two. Utilizing multiple release sites to minimize the buildup of predators is not a new concept (Herdman 1995). Reclamation and DWR plan on sharing six release sites instead of maintaining six independent sites for each agency. Both agencies will use the same release site each release to help overwhelm the predators at that site and to encourage fish predators to abandon the other sites in between releases.

Recently, DWR's Curtis Landing Site was upgraded with state-of-the-art technology for a pipe release to improve survival of salvaged fish (J. Dealy, 2016, personal communication). This site includes a 21.3-m [70-ft] fish release pipe made of stainless steel to insure a smooth transfer for release of fish from the transport truck to the Delta. Also included is a screened 19.8-m [65-ft] long intake pipe that houses a submersible pump to collect flush water. The fish release pipe is flushed with approximately 5,943 L/m (1570 gpm) of Delta water. This discharge will theoretically push the hydraulic jump past the end of the release pipe, reduce turbulence inside the pipe, and ensure a complete flush of fish and debris out of the pipe. Department of Water Resources is currently building two additional fish release sites on Sherman Island. As per NMFS (2009) Biological Opinion, these sites and Reclamation's sites will be used interchangeably so that all fish releases will use a single site for a set period of time. A draft Memorandum of Understanding for coordinated use of the release sites has been completed (J. Dealy, 2016, personal communication).

Salvage and Release Process Complications

Mixed Species and Mixed Size Assemblages

Salvaged fish are held and transported in mixed species and size assemblages. An even wider range in body size occurs when piscivorous fish (primarily striped bass) are removed from the primary or secondary channel and added to the holding tanks for release. Holding multiple species of varying sizes in a confined space may increase the likelihood of predation and stress within the holding and truck tanks.

The TFCF was designed to separate small from large fish using water velocity and swimming performance (*i.e.*, trash rack spacing and water speed through rack keeps large fish out but pulls small fish in), but not designed specifically to separately handle and transport predator and prey groups once these fish have passed through the trash rack (Rhone and Bates 1960). Water velocity within the facility is the mechanism that forces fish through the facility into the collection tanks. Larger and presumably stronger fish (in particular striped bass) are able to maintain themselves in the primary and secondary channel and bypasses (Wu *et al*. 2015; Karp *et al*. in prep, Bridges *et al*. 2016) because the primary and secondary channel velocities are below their swimming performance. Striped bass and other predatory fish that pass through the primary channel louver system into the Delta Mendota Canal may survive and possibly move upstream into the primary channel when the louvers are lifted for cleaning. Some of these fish become too large to pass through the trash rack and may remain in the primary channel.

All sizes of striped bass are periodically observed in the holding tanks, but the very largest individuals are rarely collected. Larger striped bass are routinely collected from the secondary and primary channels during predator removal events and can be held and trucked to the Delta separately if required. However, there are no permanent procedures in place to routinely truck large (*i.e.*, predator) and small salvaged fish separately.

Large Numbers of Fish

During flood years, the number of juvenile splittail (*Pogonichthys macrolepidotus*) and common carp (*Cyprinus carpio*) may be extremely high in the holding tanks and fish truck tank (*e.g.*, year 2006 on the California Department of Fish and Wildlife's Salvage Monitoring website www.dfg.ca.gov/delta/apps/salvage). During these times, salvage and fish release operations both need to be modified to help ensure fish survive. Firstly, oxygen needs to be delivered to the holding tanks to keep fish alive when water is flowing to a different holding tank (as during the 30-min fish count and when the main tank is used to hold fish awaiting the trucking process which may last up to several hours). Secondly, procedures need to be developed to address removal of two or three truckloads of fish from one holding tank during times of high fish entrainment. Typically, the running total of fish stored in a holding tank is monitored every two hours and fish are diverted to a new, empty holding tank once the main holding tank has reached truck tank capacity.

Excessive Amounts of Debris

Excessive amount of debris collected with salvaged fish is perhaps the biggest obstacle preventing the safe relocation of these fish back to the Delta. Debris, regardless of type, interferes with the fish-handling component of TFCF operations. While aquatic debris collected with salvaged fish may mechanically harm them as they pass through the salvage process, debris can significantly clog the fish-count and transport buckets, the holding tanks, fish-transport trucks, and release pipes (Figure 5). Fish mortality is visible once equipment clogs and fish become stranded. In addition, the quantity of debris entering the holding tanks, and not the number of fish, often dictates when and how often loads are transported to release sites.

Debris accumulation in the holding tanks and transport trucks occurs year round and methods could be developed to remove this debris. Distinctive types of debris are present during different seasons and special removal efforts are needed for each type. Water hyacinth grows quickly all summer but is not commonly seen in large amounts at the TFCF until late fall and winter when cold temperature and increased river flow transports the material to the facility. Summer and fall months are dominated by Brazilian pondweed, a submerged, rooted plant that quickly grows during the summer months when turbidity is low. This plant is easily fragmented by boat operation once it grows long enough to reach the surface. Water hyacinth and pondweed drift to the facility continuously. Both plant types can be removed in part by the trash racks and secondary channel traveling screen. Fragments of wood, clam shells, and sand move along the bottom and will need a different type of removal method that takes advantage of the high density of this material. It may be possible to use the new secondary channel traveling screen to remove much of the floating debris.

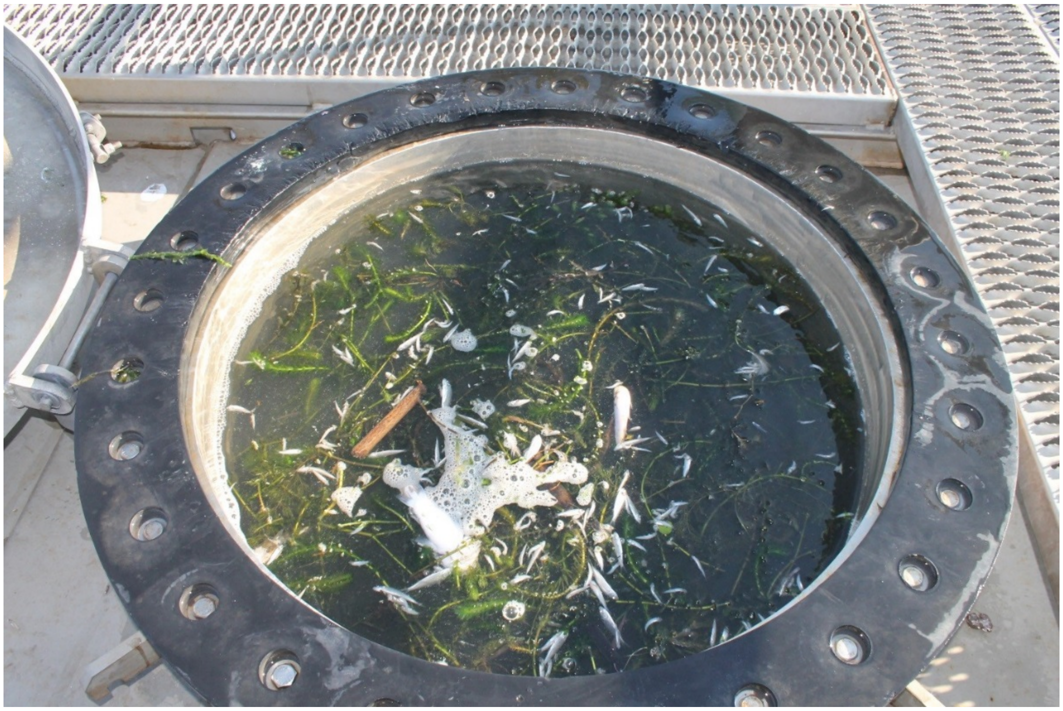

Figure 5.—Debris inside TFCF fish-transport truck.

Frequency of Fish Release

The TFCF salvages and releases fish daily or more often as determined by presence of threatened and endangered species, high numbers of fish, and high debris loads, but the current process may not be optimizing survival. Retaining salvaged fish in the large concrete holding tanks for long periods is considered detrimental by the regulatory agencies, and three operating criteria exist for when to release fish (Bates *et al*. 1960, U.S. Fish and Wildlife Service 1994, National Marine Fisheries Service 2004).

1. Fish may not be held more than 8 h when Delta smelt are present.

2. Fish may not be held for more than 12 h when salmonids are present.

3. For all other species, fish may not be held more than 24 h.

While these rules are generally followed, some are difficult to adhere to such as releasing fish every 8 or 12 h. Typically, fish salvaged during the day are released at dusk, while those salvaged overnight are released at dawn. The TFCF operation revolves around personnel schedules which makes it difficult to change operations quickly to meet criteria when the type or number of fish salvaged changes quickly. Recently, Karp and Lyons (2014) found that adult delta smelt had very high survival (97 percent after 96 h post-experimental holding) in the holding tanks. Therefore, the 8 h criteria may be overly conservative. In addition, Reyes *et al*. (2012) found that two holding tanks could be used at the same time to collect fish so that the through-screen and tank-swirl speeds could be reduced to help improve the survival of the smallest fish. Holding tank screen mesh size could be temporarily reduced in size to prevent the loss of juvenile delta smelt. This is accomplished by wrapping Nitex mesh around the holding tank screens. This style of operation could potentially improve holding tank survival of the smallest and weakest fish salvaged during the larval/juvenile fish season.

Predator Removals

Piscivorous species (in particular striped bass) enter the TFCF with other fish daily. Striped bass accumulate in front of the trash rack, behind the trash rack within the primary channel, and within the bypass tubes and secondary channel (Wu *et al*. 2015, Karp *et al*. in prep). Of these locations, striped bass can only be easily removed from the secondary channel, although studies are underway to move striped bass through the primary channel and bypasses using CO_2 (B. Wu, 2016, personal communication). However, no formal predator removal process has been established by operations. Another idea is to consider opening a portion of the trash rack in the spring to allow “resident” large striped bass an opportunity to leave the facility.

Techniques for collecting, holding and handling the predator fish need to be addressed. Predator fish could be stored in their own holding tank until ready for release. This will allow operators or researchers to place all large striped bass collected from research studies, predator removals, or the 30 min fish counts into the isolated tank. No debris would be present with these fish, as they are hand sorted. Each week (or more frequently if needed) this tank could be transported to a release site separate from that used for general salvage. Methods could easily be developed to feed these fish while they await transportation.

Specific Problems with the Current Pipe-Release Program

1. There are only two release sites per agency and each site is used daily (unless one site is inoperable). Reclamation and DWR do not share release sites unless there is an emergency. Unfortunately, the optimal number of release sites to achieve optimal low predator abundance at a fish release site is unknown.

2. Currently, fish are released at least once daily and the releases are not scheduled around an incoming or outgoing tide or when predation may be minimal (*e.g.*, during the night). Scheduling fish releases on the tide might increase survival as released fish could move with the tidal flow away from the immediate area. However, scheduling night work is generally more expensive than, and not as safe as, day work.

3. The current system replaced surface releases with underwater releases to reduce possible surface predation and to move fish away from the shore and underwater. However, predation of salvaged fish exiting the release pipe was documented by Miranda et al. (2010a). Using DIDSON video, they observed striped bass and Sacramento pikeminnow (*Ptychocheilus grandis*) holding at a pipe exit, preying on the released fish, and movement of shoreline species swimming towards the released salvaged fish once they exited the pipe (Miranda *et al*. 2010a). Releasing fish further offshore only made the situation more difficult to monitor. In addition, the infrastructure necessary for multiple long pipes provides holding habitat for predator species.

4. Release pipes may clog when debris load is high, and some released fish are subjected to passage through a restricted release pipe and may remain in the pipe. This problem isn't easily observed until fish and/or debris begin backing up in the transport truck.

5. Maintenance of the fish release sites has not been adequate due to a lack of labor, funds, or complexity of the problem (*i.e.*, broken underwater pipe and pumps).

6. Post-release survival is not known for most/all salvaged fish including the smaller fish, such as juvenile delta smelt, longfin smelt (*Spirinchus thaleichthys*) and juvenile striped bass 20–40 mm (0.8–1.9 in) FL, although injury may not be significant for these small fish based on tests conducted in spillway models (Bestgen *et al*. 2008)

Alternative Concepts to the Current Shoreline Pipe Fish Release Process

Below is a description of major types of large-scale fish movement and release operations, and additional new concepts.

Use of Net Pens or Small-Scale Transport to Disperse Fish

Net pens are being used to experimentally test if acclimating hatchery-reared Chinook salmon smolts to Delta conditions after truck release will improve their survival to adulthood (Fishery Foundation of California 2014). In this system, hatchery raised juvenile fish are truck transported to one of several sites, depending on the hatchery and fish stock, and transferred to net pens (each 2.4 m [8 ft] wide, 4.6 m [15 ft] long, 3.7 m [12 ft] deep, 0.6 cm [0.25 in] mesh; [Figure 6]). The net pen platform has multiple bays of nets, with nets weighted at the corners to maintain their shape.

Figure 6.—Net pen structure used to receive, acclimate, and release hatchery fish.

Net pen releases are being used in the Delta at Eddo's Harbor on Sherman Island and other sites. Pens are moored at the Eddo's Marina facilities and towed downstream to the receiving area in the San Joaquin River. Here, fish are transferred from transport trucks to pens using a combination of rigid and flexible pipe (see Figure 6). After receiving the fish, the pens are slowly moved downstream on the north side of the channel toward the Antioch Bridge and released after 1 – 4 h of acclimation on the ebb tide (Figure 7). During this time, the Fishery Foundation crew angles for striped bass to assess the predator density, and delays fish release until they reach an area of relatively few striped bass captures.

There is some indication that fish acclimated in net pens show higher survival rates as compared to smolts released directly from hatcheries (based on recoveries of coded wire tags in returning Chinook salmon adults [Palmer-Zwahlen and Kormos 2013]). However, the issue of straying in released transported fish, as observed in other transported fish programs, is of concern.

The biggest benefits net pens provide are that they allow fish to acclimate to Delta water conditions with no predation pressure, can be set up quickly and used seasonally, and can be used for large numbers of fish. This is helpful for fish that are not reared in Delta water, such as hatchery fish that have grown in clear spring water in single species/size culture conditions. However, fish collected at the

Figure 7.—Releasing acclimated hatchery Chinook salmon smolts.

TFCF are acclimated to Delta water, are usually held with varying amounts of aquatic debris in mixed size and species assemblages, and the relatively small numbers would probably make the net pen releases cost prohibitive.

Debris fouling and holding fish in multi-species and multi-size assemblages would complicate fish release and potentially survival. Daily releases may be impacted by severe weather conditions or times when large debris is moving through the Delta. In addition, fish releases would need to take place during daylight hours due to human safety concerns and when predation is more likely to occur, and scheduling this effort on the ebb tide would be complicated and unrealistic. Labor cost per fish released would also be high when salvage is low. Since the TFCF salvages few threatened and endangered fish on a daily basis, it is probably less expensive to find a method that requires less labor but has many of the same advantages as net pens.

Use of Barges or Large Transport Tank to Disperse Fish

Large capacity fish-holding barges are used to move fish through dams and reservoirs in the lower Columbia River. The Corps of Engineers juvenile fish transportation program in the lower Columbia River was implemented in the 1970's/early 1980's to assist with outmigration of juvenile salmonids past mainstem dams (Ward *et al*. 1997). Fish are collected at bypass facilities at Lower Granite, Little Goose, and Lower Monumental dams on the Snake River, loaded onto trucks (13,249 L [3,500 gallon]) and barges (up to 567,812 L [150,000 gal]), and transported up to 460 km (286 mi) downstream below the lowest dam in the system River (Marsh *et al*. 2015; USACE 2015). Truck and barge loading criteria for Columbia River smolt transport targets 2.3 kg (5 lb) fish per L (gal) inflow for barging and 0.2 kg (0.5 lb) fish per L (gal) of water in the trucks.

At each facility except Lower Granite Dam, larger salmonid smolts (*e.g.*, steelhead [*O. mykiss*]) and debris are separated from smaller fish using horizontal bar racks or graders into separate barge holds to reduce stress (Congleton *et al.* 2000) and increase survival (Sanford *et al*. 2012) from mixing fish sizes and species. Debris levels are low and most debris is removed. The barges use a pump system to circulate river water through the holding tanks to both maintain adequate water quality and to offer local water for imprinting. Tow boats are used to move the barges through the river and may take from 79–96 h to reach the general release area. Barge riders accompany the fish transport to monitor barging operations and water quality (temperature and dissolved oxygen levels). Schedules are arranged so that barged fish are released at a randomly selected location about 4.8–8.0 km (3–5 mi) downstream of Bonneville Dam at night to minimize predation. The fish are released by gravity when plungers over the release orifices are raised. Truck transported fish are released through the Bonneville Dam Second Powerhouse juvenile salmon bypass outfall with water cannons in use to deter avian predators (Nelson Big gun sprinkler mounted on the end of the outfall pipe; Figure 8). Prior to that modification, trucked fish were driven to a boat ramp below Bonneville Dam where the truck was loaded onto a barge and moved to the center of the river for fish release.

Figure 8.—Fish release of salmonid smolts at the Corps of Engineer Bonneville Dam Second powerhouse bypass outfall (photograph courtesy of U.S. Army Corps of Engineers).

Truck and barge transport of juvenile salmonids in the lower Columbia River is used to mitigate for the effects of the lower Snake and Columbia River dams on threatened and endangered fish populations. Improvements over the years have increased return rates of barged fish relative to those bypassed and returned directly to the river, although return rates continue to be variable and are influenced by a multitude of complex factors (Congleton *et al*. 2000; Muir *et al*. 2006; Anderson 2009; McMichael *et al*. 2011; Smith *et al*. 2011; Rechisky *et al*. 2012). Some data suggests that fish barged later in the spring have higher survival which may in part be related to size of smolts at release (D. Holecek, 2016, personal communication). Straying by returning adults is another issue potentially associated with barging as fish do not have the full exposure to river conditions for imprinting (Keefer *et al*. 2008). Delayed mortality, return rates of barged juvenile salmonids, and unintended impacts to other species remains a subject of intense research (Marsh *et al*. 2015).

Barging's biggest attributes are that it would allow fish to acclimate to Delta water conditions before release, allow fish to recover from transport/handling induced stress, accommodate a large number of fish at one time, move fish away from shore where there is hopefully less predation, and accommodate night releases. This method is helpful for moving very large numbers of fish long distances because a barge can move fish faster than towing a net and requires fewer operators. This method is also beneficial in that it could be used nearly every day of the year and would not be as limited by weather or fog as the net pens.

At the TFCF, as with net pens, trucks would still be needed to deliver fish to a barge anchored near Antioch or Rio Vista for barging to be affordable. The cost and time it takes to drive a boat from the TFCF out to these release areas would likely be cost prohibitive in terms of man hours and fuel, particularly when few fish are being salvaged. A cost estimate would need to be completed to compare daily costs of barging to the pipe release method. Differences would include cost of two barges, mooring, loading infrastructure, maintenance, personnel, etc. Barging costs would increase if fish were released more than once a day, regardless of weather conditions. Labor costs per fish released will also be extremely high when few fish are salvaged. Also, as mentioned above, fish salvaged at the TFCF are held in multi-species complexes with varying amounts of aquatic debris, and some sort of sorting procedure would have to be implemented to separate fish by size and to remove debris.

Automated Shoreline Release

An automated shoreline release site may improve success of shoreline salvaged fish releases. Operators would release trucked transported fish during the daytime into a shoreline tank that holds and acclimates salvaged fish until they are released automatically at night according to tide stage. Night releases would be optimal as fewer visual predators would be present and automated releases based on the tide stage would help to disperse the fish. This setup would allow multiple transport trucks to deposit their fish in one tank during the day for a single night release.

The shoreline tank would be similar (but not identical) to the holding tanks at the fish facilities. Delta water would continually be pumped through the tank from a screened water pump to keep fish alive until release. The screened pump intake, and shoreline tank flow-through discharge would be close to shore for easy maintenance. Fish release outlets would be close to shore, but away from the pump intake.

Several automated shore release sites may still be needed to prevent predator accumulation at any one site; however, the number of sites needed to prevent predator fish from accumulating at a release site is not known. Both the federal and state fish facilities could release fish at one site continuously and then move on to the next site the following day. In the event that a huge number of fish are salvaged, multiple release tanks would be used each day until the large influx of salvaged fish subsides. This condition is likely to happen on flood years when juvenile common carp and splittail enter the salvage systems. Each site would have variable speed pumps so that the amount of water flowing through the tank could be regulated. When a tank is not scheduled for a fish release it would remain dry to prevent algae from accumulating.

The biggest advantage to this concept is that predator impacts could be minimized. All fish truck releases could be completed during daytime if the regulatory agencies allowed and if the holding tanks at the fish facilities were allowed to accumulate fish more than the regulated 8 h for delta smelt and 12 h for salmonids (with oxygen). Day releases may be possible with the incorporation of water cannons. Presumably, less in-water infrastructure (*e.g.*, pilings or release pipes) would be needed. All equipment would be on shore, or very close to shore for easy access. This would reduce concerns of logs and boats damaging the infrastructure. During times when multiple truckloads of fish are being held and acclimated, releasing higher numbers of salvaged fish at the same time may help overwhelm predators residing in the area. While it would be impossible to eliminate all predation, releasing salvaged fish outside of avian and fish predator activity times would theoretically reduce the number of fish lost to predation. In addition, releasing fish on an incoming or outgoing tide would allow for more rapid dispersal of the salvaged fish. Currently, fish releases are not coordinated with tide stage. The automated release would be designed to not require personnel be present during fish releases. The lack of sizeable in-water infrastructure together with tidal effects should keep aquatic debris and predator fish refugia to a minimum.

The shoreline tanks would need to be engineered to withstand flood as well as low water conditions. Ideally, the tank bottom should be situated just above the level of the Delta to allow complete draining, but not so high that the water is exiting the tank too fast. The tank should be allowed to fill by Delta water (one way check valve) in the event that the Delta did flood.

Automated Shoreline Release with Multiple Release Points

The automated shoreline release system has several advantages as discussed above, but the cost for infrastructure may be higher than the traditional pipe release sites. The main cost of each shoreline release site would include the land lease or acquisition, infrastructure (buildings, pumps, pipe, and electricity) and tanks. To reduce cost, we could have multiple sites near each other to share some of the infrastructure. Ideally, the outfalls would be far enough apart that resident predators would not key in on the operation. Again, incorporation of water cannons could be considered if necessary.

Many of the existing pipe release systems could be converted to this style of operation to reduce infrastructure cost. Water supply from the existing release systems could provide water to large tanks, and pipes could be run along the shoreline to allow for multiple release locations. The main advantage to this setup is that operators could deliver fish in the day when it is safer for the operator, and the fish could be released at night when it is safer for them to disperse.

Boat Ramp Release Sites

Boat ramps allow optimal safe passage for trucks down to the shoreline, provide a slope for the tank to completely empty, are inexpensive to build, and can be used for other purposes than just releasing fish. The main disadvantages are that fish are typically released in the daytime along the shoreline where predation is likely and the water currents may not promote quick dispersal of the fish. Unlike most aquaculture or hatchery fish releases, salvage fish releases have debris mixed with the fish. This problem has complicated the fish release process as a large quantity of water is needed to rinse out the trucks. This style of release is more tailored for the predator removal releases because all the debris is removed prior to placing the fish in the truck tank.

Predator Fish Release Site

A release site exclusively for predator fish is needed for both Reclamation and DWR fish salvage facilities. Hundreds of striped bass were removed from the secondary channel in the past during routine predator removals (Liston *et al*. 1994). When this occurred, these fish were transported directly to the release sites either with the small salvaged fish or by themselves when highly abundant. Today, fewer predators are collected; therefore, they are added to the holding tanks with the salvaged fish. There is concern that releasing predator fish with smaller fish at the same release site may be promoting predation on the smaller salvaged fish.

Having a separate site for predators would help separate potential predators from salvaged fish. The release location needs to be discussed with the regulatory agencies and recreational fishing industry. Options to consider include releasing large predatory fish to local ponds in the immediate area (cities of Tracy and/or Brentwood) to inspire youth to fish. Predatory fish could also be released at boat launch sites in the Delta, into Bethany Reservoir, or the Delta Mendota Canal for fisherman to catch, or released at a specially built site in the Delta. The main improvement that can be made with the predation removal program is that predatory fish (*i.e.,* large striped bass) should not be added to the fish collected in the holding tanks to prevent them from eating those fish.

DISCUSSION

Live fish transportation is a common procedure used worldwide in aquaculture, aquarium, and fish management industries. For fish to be successfully moved they must be captured, loaded, transported, and unloaded. Each step involves potentially stressful events and the methods commonly used are often designed for the specific life stage of fish (larval, juvenile, or adult) because the amount of mechanical stress a body can handle is size dependent. Since fish transport and release occurs around the world, we can use what is known to improve the existing pipe fish release program at the TFCF, recognizing that conditions at the TFCF are very different due to aquatic debris and mixed species/sizes of salvaged fish.

While fish have been released at the TFCF fish release sites since 1957, no investigation on fish survival after release has occurred, primarily due to logistical problems. Technologies available at this time to conduct such studies include use of radio or acoustic telemetry, PIT (passive integrated transponder) tag, and/or coded wire tag technology. Programs already evaluating salmon and steelhead movements in the Delta may be the most appropriate groups to collaborate with to test long-term fish survival using several release methods.

The Corps of Engineers juvenile fish transportation program separates fish by species/size as they've found transporting fish in mixed species reduces overall success of the effort (D. Holecek, 2016, personal communication). This would be difficult to complete at the TFCF because multiple species, sizes of fish, and types of aquatic debris are usually present in the collection tanks. Minimally, holding predator fish separately from prey sized fish should be considered when releasing the striped bass after the predator removals. In addition, during periods of high fish entrainment, two holding tanks could be used at the same time to collect fish and more than one truck could be used to transport fish to the release site.

Furthermore, storing fish longer in the holding tanks and releasing fish less frequently may reduce the likelihood of predator fish keying in to the transport truck release schedule at the release site.

RECOMMENDATIONS

Our recommendations for improvements to the fish release program include:

1. Estimate success of fish releases using telemetry studies of resident fish prey and predators, and review Chinook salmon and steelhead survival study information to Chipps Island. Also, evaluate salmonid survival through the release process to Chipps Island once release site sharing has begun. Install PIT tag readers on all fish release pipes so that both fish salvage facilities can do long-term survival studies and collaborate with others already evaluating salmonid movement in the Delta. This program should consider evaluating day/night releases, release site locations, shore/pipe releases, and acclimated/non-acclimated releases.

2. Install a working oxygen system in the holding tanks.

3. Develop procedures to use the secondary channel traveling screen to optimize debris removal, and try to develop methods to remove debris from the holding tanks prior to fish removal.

4. Develop methods to ensure fish move through the release pipes while awaiting modifications to existing release sites and construction of new facilities.

5. Coordinate with DWR to share the release sites currently operational with the eventual expansion to six sites. Discuss altering the frequency of fish salvage release either by reducing the number of releases each day or using one site once every few days. This will help identify problems with this technique. Begin the release site sharing program by slowly adding release sites and monitor predator abundance over time. Start by sharing (and exclusively using) only one release site for a period of time when salmon and steelhead are not present. Add an additional release site to share every few weeks. Adding release sites slowly over time will help us evaluate how rotating through release sites influences predator density at the release pipe. Use an acoustic camera to evaluate fish predator density at the end of the fish release pipes as the release site sharing program begins.

6. Discuss feasibility of sorting small from large salvaged fish, within and between facilities. If determined feasible, different release sites could be used for the different size classes. Work with the fishery regulatory agencies to determine what should be done with the large striped bass removed from the secondary channel and bypasses. How should we hold and release them? Should long-term movement studies be conducted with these fish?

7. Evaluate survival of juvenile Delta smelt and other small species or life stages after they pass down a release pipe containing a hydraulic jump versus a pipe release when the pipe is full of water. This information is needed to determine if the existing fish release sites are impacting the smaller fish that are salvaged in the spring and early summer. Include evaluation of effects of narrowing the release pipe underwater to increase the flushing water velocity.

8. Discuss the idea of a shoreline holding/acclimation tank fish release system. It is not known if this idea would improve fish survival but could be considered as a fish release option for salvaged fish.

9. Discuss feasibility of returning to a surface release in flowing water while employing water cannons like those used in the Corps of Engineers Columbia River juvenile fish transportation program to deter avian and surface fish predation (see Figure 6).

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