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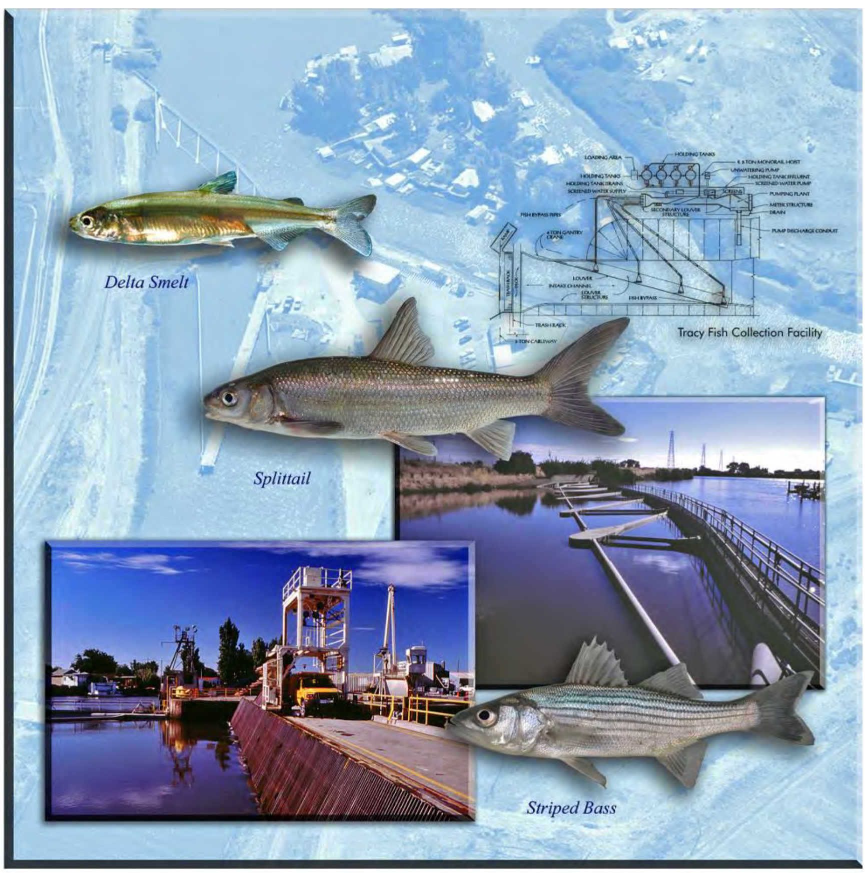
Tracy Series Volume 43

Effects of Hydraulic Conditions on Salvage Efficiency of Adult Delta Smelt at the Tracy Fish Collection Facility



U.S. Department of the Interior
Bureau of Reclamation
Mid-Pacific Region and
Denver Technical Service Center

February 2016

1. REPORT DATE *(DD-MM-YYYY)*
February 2016

2. REPORT TYPE

3. DATES COVERED *(From - To)*

4. TITLE AND SUBTITLE
Effects of Hydraulic Conditions on Salvage Efficiency of Adult Delta Smelt at the Tracy Fish Collection Facility

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Zachary A. Sutphin and Connie D. Svoboda

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Bureau of Reclamation, Technical Service Center
Hydraulic Investigations and Laboratory Services, 86-68460
PO Box 25007, Denver, CO 80225-0007

8. PERFORMING ORGANIZATION REPORT NUMBER
Volume 43

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Bureau of Reclamation,
Tracy Fish Collection Facility
16650 Kelso Road, Byron, CA 94514

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Available from the National Technical Information Service (NTIS)
Operations Division, 5285 Port Royal Road, Springfield, VA 22161

13. SUPPLEMENTARY NOTE

14. ABSTRACT
Mark–and–capture experiments were conducted to evaluate effects of hydraulic and environmental conditions on salvage efficiency of adult delta smelt (*Hypomesus transpacificus*) at Bureau of Reclamation's Tracy Fish Collection Facility. A second order polynomial model explains a significant relationship between primary velocity and primary channel efficiency ($P = 0.001$), and the derivative of the polynomial equation [the maximum point of the graph (slope = 0)] where primary channel efficiency is optimized was equivalent to a mean channel velocity of 2.37 ft/s. Analysis of a multiple linear regression model indicates trashrack differential accounts for some of the ability to predict primary channel efficiency of delta smelt ($P < 0.05$). Water temperature, turbidity, time of day, and total number of non-experimental fish salvaged during data collection were not significant predictors. Data collected within Chinook salmon facility operational criteria (data isolated from the full data set), and modeled with linear regression, suggests adult delta smelt salvage efficiency may be maximized by increasing mean secondary channel velocity to maintain a primary bypass ratio near 1.6. Also, results of this "In-Criteria" data set suggest maintenance of conditions in the primary channel that minimize primary trashrack differential can improve adult delta smelt salvage efficiency.

15. SUBJECT TERMS
Delta smelt, louver efficiency, Tracy Fish Collection Facility

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
				63	Zachary A. Sutphin Connie D. Svoboda
a. REPORT	**b. ABSTRACT**	**a. THIS PAGE**			**19b. TELEPHONE NUMBER** *(Include area code)* 303-445-2141 303-445-2152

Tracy Fish Facility Studies
California

Effects of Hydraulic Conditions on Salvage Efficiency of Adult Delta Smelt at the Tracy Fish Collection Facility

Tracy Series Volume 43

by

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U.S. Department of the Interior
Bureau of Reclamation
Mid-Pacific Region and
Denver Technical Service Center

February 2016

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COVER

Fish photography by René Reyes, Tracy Fish Collection Facility, Tracy, California.
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EXECUTIVE SUMMARY

Mark–and–capture experiments were conducted between 2003 and 2008 to evaluate effects of hydraulic (*e.g.*, primary channel velocity, primary bypass ratio, secondary channel velocity, secondary bypass ratio) and environmental conditions (*e.g.*, diel period, turbidity, temperature, debris loading, and total number of fish salvaged during data collection) on salvage efficiency of adult California Endangered Species Act listed delta smelt (*Hypomesus transpacificus*) at the Bureau of Reclamation's Tracy Fish Collection Facility (TFCF), a southern Sacramento-San Joaquin Delta facility intended to salvage fish prior to entrainment loss into the Delta Mendota Canal. The complete data set ("Full-Range") was collected to determine if hydraulic conditions outside of facility criteria can be utilized to promote increased salvage efficiency of delta smelt. For further interpretation, data collected when the facility was operated within Chinook salmon criteria ("In-Criteria") was isolated for analyses.

Across all sampling efforts mean (± standard deviation (SD); Full-Range data set) TFCF primary channel (PE; n = 67), secondary channel (SE; n = 56), and whole facility efficiency (WFE; n = 67), were 30 % (± 19 %), 67 % (± 17 %), and 23 % (± 16 %), respectively. Averaged across year of sampling a second order polynomial model explains a significant relationship between primary velocity and primary channel efficiency ($P = 0.001$), and the derivative of the polynomial equation [the maximum point of the graph (slope = 0)] where primary channel efficiency is optimized was equivalent to a mean channel velocity of 2.37 ft/s. No significant relationship exists between primary bypass ratio and primary channel efficiency. Analysis of a multiple linear regression model indicates trashrack differential (difference in water level before and after trashrack at the head of the primary channel, generally increasing with increasing debris load) accounts for some of the ability to predict primary channel efficiency of delta smelt ($P < 0.05$). Water temperature, turbidity, time of day, and total number of non-experimental fish being salvaged during data collection were not significant predictors. Secondary velocity and secondary bypass ratio were not significantly related to secondary channel efficiency.

Data collected that was within the facility operational criteria generally utilized when delta smelt are present at the facility (In-Criteria data set), and modeled with simple linear regression, suggests when operated within these conditions adult delta smelt salvage efficiency may be maximized by increasing mean secondary channel velocity in order to maintain a primary bypass ratio near 1.6. Also, results from this In-Criteria data set suggest maintenance of conditions in the primary channel that minimize primary trashrack differential can improve adult delta smelt salvage efficiency. When these conditions were met, mean (± 1 SD) PE, SE, and WFE were 39 % (± 18 %), 65 % (± 18 %), and 29 % (± 14 %).

INTRODUCTION

Water resource management, and corresponding structures (*i.e.,* dams and canals) and facilities (*i.e.,* pumping plants), have become central as a means to support anthropogenic and agricultural development throughout California's Central Valley and beyond (Nichols *et al*. 1986). Such development has resulted in gradual effects on the fish fauna of the Sacramento-San Joaquin Delta (SSJD), contributing to an altered aquatic ecosystem which has promoted changes in fish assemblages, as well as immediate effects, such as entrainment losses of fish at water diversion facilities (Nichols *et al*. 1986, Brown *et al*. 1996, Kimmerer 2008). The Bureau of Reclamation's (Reclamation) Tracy Fish Collection Facility (TFCF), located in the southern SSJD (Figure 1; Byron, CA), was designed and developed to salvage fish entrained in Delta Mendota Canal flows, thereby mitigating for entrainment loss by reducing pump-induced mortality at the down-canal Bill Jones Pumping Plant (JPP; Bates and Visonhaler 1956, Brown *et al*. 1996, Bowen *et al*. 1998).

Operations at the TFCF typically result in the salvage of millions of fish annually, with the ultimate goal to transport and release salvaged fish to the central SSJD, and outside of the immediate influence of southern SSJD water pumping facilities (http://www.dfg.ca.gov/delta/apps/salvage). Though there are a multitude of native and non-native species salvaged at the facility, delta smelt (*Hypomesus transpacificus*), a pelagic fish endemic to the SSJD, are of great concern to biologists and water resource managers (Bennett 2005). Once plentiful in the SSJD, they have experienced precipitous declines in abundance in recent decades, contributing to historically low population indices and a listing status of endangered under the California Endangered Species Act in 2010 (Radtke 1966, Moyle *et al*. 1992, CDFG 2010). Water export facilities and conveyance structures have been cited as contributing to the current state of delta smelt in the SSJD (Moyle *et al*. 1992, Bennett 2005, Kimmerer 2008). Though the ESA deems fish salvaged at the TFCF as lost from the population (USFWS 2008), research activities under the Tracy Fish Facility Improvement Program aim to promote fish populations by improving health and survival of fish throughout all major TFCF components and identifying facility conditions that maximize salvage efficiency (http://www.usbr.gov/mp/TFFIP).

The TFCF is a multi-component facility consisting of a series of louvers, evenly spaced (23.4 mm openings) vertical slats that permit water conveyance while creating turbulence that behaviorally deters fish, and bypasses, which guide fish from a primary channel to a secondary channel, and ultimately into a holding tank, where they are maintained until truck transport (Figure 2; Bowen *et al*. 1998, Bowen *et al.* 2004). Referenced data and anecdotal evidence suggests there are various biotic (*i.e.*, predation) and abiotic (*i.e.*, diel period, water quality) factors that can influence salvage efficiency at the TFCF (Bowen *et al*. 1998, Bowen *et al*. 2004, Bridges *et al*. *In Draft*). However, success of louver-type systems is dependent on fish swimming speed and facility hydraulics

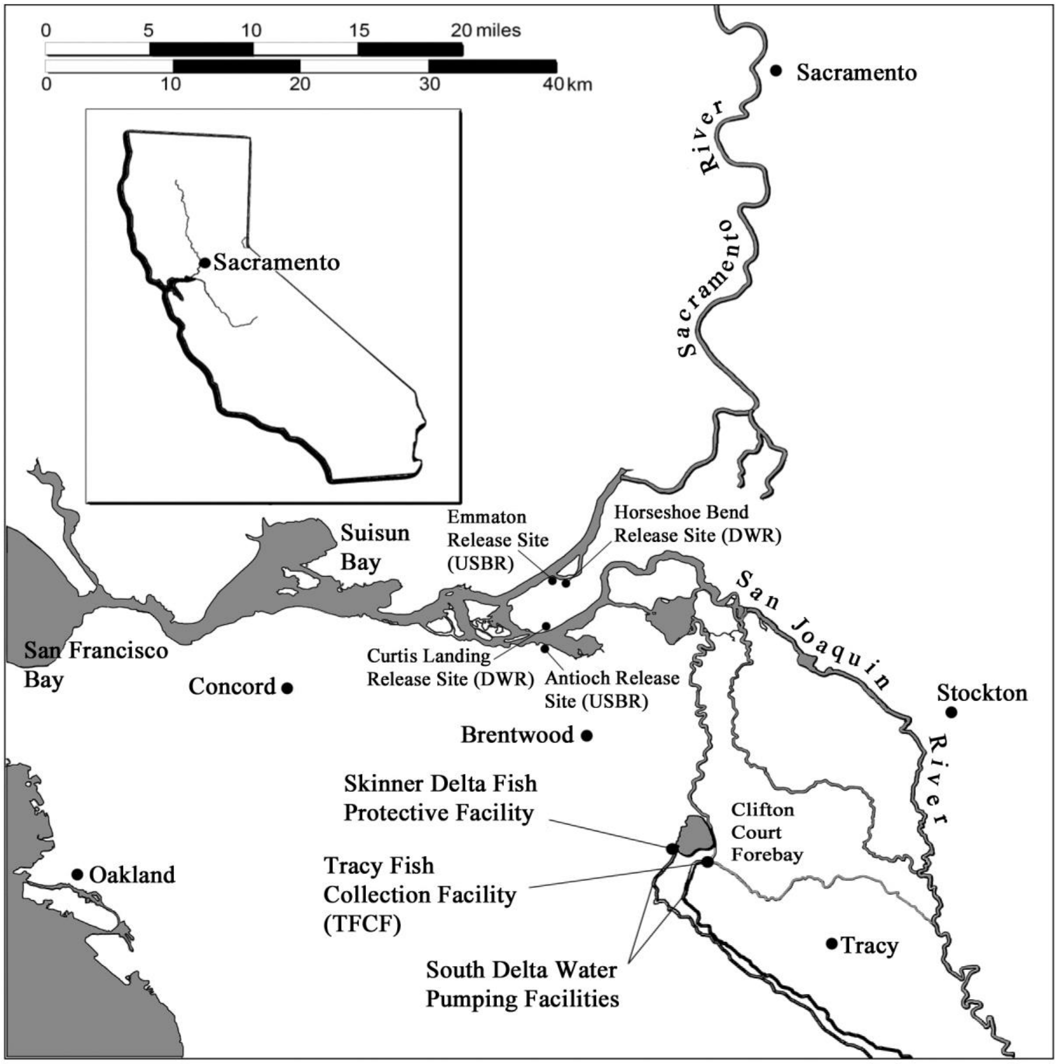

Figure 1.—Map of California's Sacramento-San Joaquin Delta (SSJD) and the location of the United States Bureau of Reclamation (USBR) owned Tracy Fish Collection Facility and fish release sites, and the California Department of Water Resources (DWR) owned Skinner Delta Fish Protective Facility.

(*i.e.*, approach velocity; Bates and Visonhaler 1956, Bates 1960). As a result, hydraulic conditions, such as channel velocities and bypass ratios (primary bypass entrance velocity to primary average channel velocity, secondary bypass entrance velocity to secondary average channel velocity)), are likely to affect TFCF fish salvage efficiency (Bates *et al*. 1960, Sutphin and Bridges 2008). This has management-level implications; because of the variables mentioned, hydraulic conditions at the TFCF, within limits, are generally the most easily manipulated. If optimal facility hydraulic conditions that promote maximum salvage efficiency can be determined for species of concern (*i.e.,* delta smelt) at the TFCF, then operations can be managed at the facility to achieve these conditions and better mitigate for losses of entrained fish.

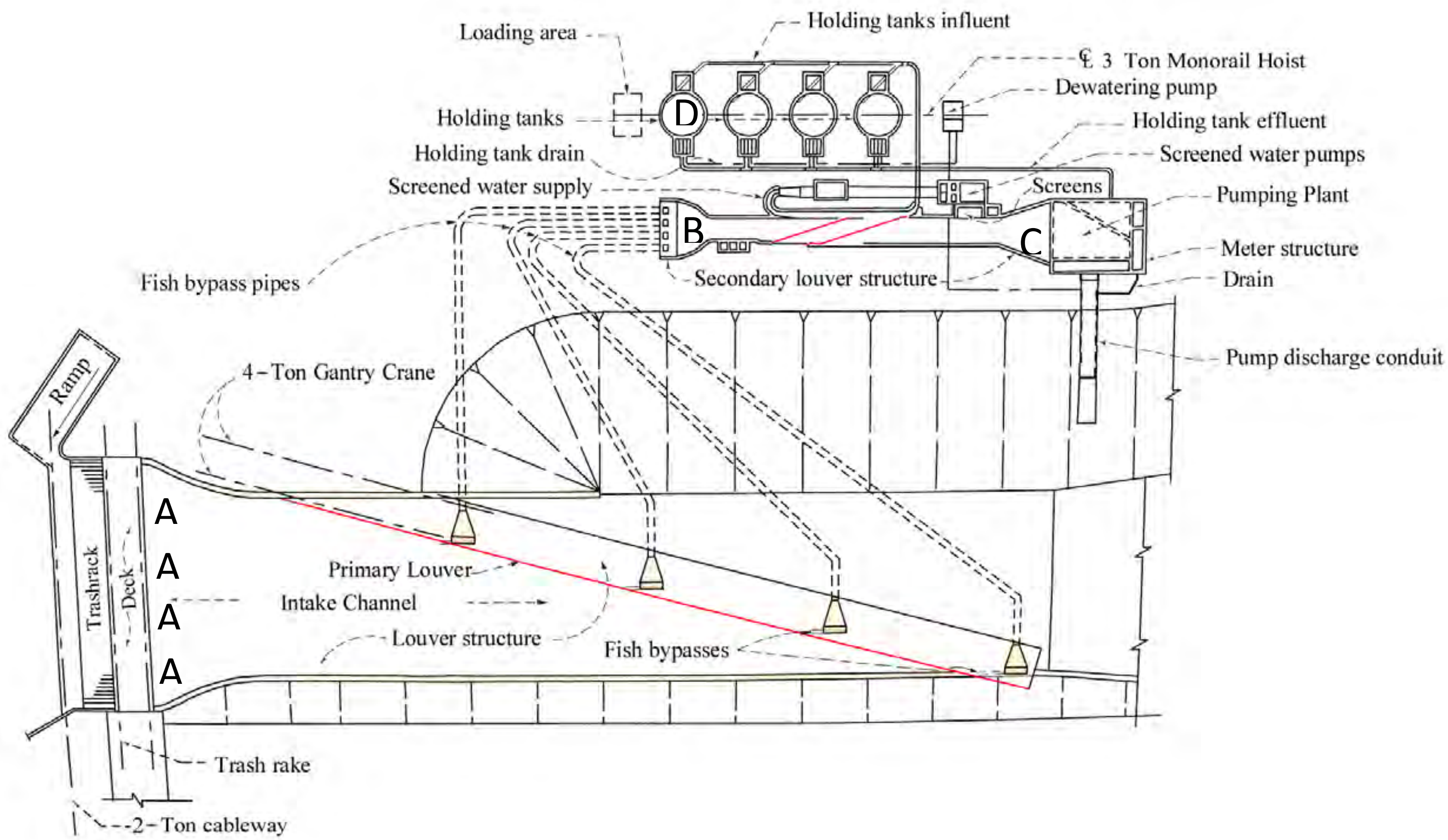

Figure 2.—Schematic drawing of the Bureau of Reclamation's Tracy Fish Collection Facility (Byron, CA) where adult delta smelt (*Hypomesus transpacificus*) facility efficiency evaluations were conducted. Red lines depict the primary and secondary louvers, and yellow areas highlight the primary channel fish bypasses. The four unique fish release locations in the primary channel are denoted by "A", and the single fish release location in the secondary channel is denoted by "B". Following releases in the primary and secondary channel, fish were typically recaptured downstream of the secondary louvers in a sieve net (location "C") or in a fish holding tank (location "D").

Currently, when delta smelt are present at the TFCF, Chinook salmon operational criteria is utilized as there is no operational criteria specifically designated for delta smelt. However, to date, no research has been completed to determine if this is suitable, or if conditions outside of this criteria could provide improved conditions to promote increased salvage efficiency of delta smelt. Therefore, the primary objective of this study was to evaluate effects of varying hydraulic conditions on salvage efficiency of adult delta smelt across multiple years (2003 – 2008) to encompass a wide range of environmental and operational conditions at the TFCF. For the sake of this study, this was termed the “Full-Range” data set. To better understand delta smelt salvage efficiency, and hydraulic effects, when the facility is operated under Chinook salmon operation criteria, data collected under such conditions was isolated from the Full-Range data set and analyzed independently. For the sake of this study, this was termed “In-Criteria”. In addition to attempting to recommend operational criteria to promote delta smelt salvage, the summarized efforts may also be useful for developing better estimates of overall facility loss and population level effects of such losses.

METHODS

Adult delta smelt mark-and-capture experiments were conducted at the TFCF in 2003, 2005, 2006, and 2008 to evaluate effects of facility conditions on salvage efficiency. Mark Bowen (former Reclamation Fish Biologist) was the project lead for experimental design and data collection efforts and this work follows many of the same protocols in past reports (Bowen *et al*. 1998, 2004). All data reported in this document and used for analyses were a result of his coordination efforts with TFCF and Reclamation’s Technical Service Center (Denver, CO). Tracy Fish Collection Facility operations were reported in English units because criteria and facility operators use these units. All other values were reported in metric units. Supplementary descriptions of TFCF facility components, not included in this report, are available in Bowen *et al*. (1998, 2004). To facilitate comprehension of the multiple data collection efforts across multiple years included in the report, Table 1 provides a summary of dates, times, and experimental and environmental conditions for all sampling efforts.

Operations at the JPP were not altered, and considered normal, during the course of this study. However, facility operations were adjusted in order to examine a broad range of hydraulic conditions that could be manipulated to facilitate delta smelt salvage if ultimately deemed appropriate. Though there is no data or specific record of predator removal activities conducted during these data collection efforts, it is assumed, based on historic efforts and TFCF personnel recollection, that secondary predator removals were completed at the initiation of each day of testing following procedures outlined in Sutphin *et al.* (2014).

Table 1.—Dates, times, number of fish released per replicate, and environmental and facility conditions during field evaluations for primary, secondary, and whole facility efficiency of adult delta smelt (*Hypomesus transpacificus*) at the Tracy Fish Collection Facility (Bureau of Reclamation; Byron, CA)

Dates	Times	Replicates (n)	Primary Released Fish (#)	Secondary Released Fish (#)	Temperatures (°C)	Fish Length (mm; mean ± SD)	Primary Velocities (ft/s)	Primary Bypass Ratios	Secondary Velocities (ft/s)	Secondary Bypass Ratios
Nov 10 – 12, 2003	1001 – 2030	10 (6 d / 4 n)	176 – 180	39 – 40	14.4 – 15.0	68.2 ± 10.1	2.97 – 3.57	1.02 – 1.55	2.56 – 3.42	0.94 – 1.64
Nov 15 – 18, 2005	1049 – 1500	13 (13 d / 0 n)	76 – 80	29 – 30	14.4 – 15.0	68.8 ± 6.2	3.11 – 4.19	0.66 – 1.14	2.62 – 4.00	0.44 – 1.37
May 19, 2006	1005 – 1225	6 (6 d / 0 n)	100	30	20.0	69.5 ± 7.5	1.54 – 1.98	1.10 – 1.42	1.10 – 1.26	1.14 – 1.33
Nov 27 – 30, 2007	1239 – 2017	18 (12 d / 6 n)	75	20	11.3 – 12.4	60.5 ± 8.1	2.33 – 2.89	1.42 – 1.66	2.53 – 3.11	1.26 – 1.63
January 17, 2008	1331 – 1448	4 (4 d / 0 n)	130	0	7.8	68.4 ± 6.4	1.13 – 1.16	3.10 – 3.39	2.48 – 2.71	1.25 – 1.33
March 11, 2008	1250 – 1500	4 (4 d / 0 n)	130	0	14.1 – 14.6	69.9 ± 5.2	1.19 – 1.26	1.42 – 2.46	1.10 – 2.45	1.50 – 1.82
March 28, 2008	1230 – 1310	3 (3 d / 0 n)	130	0	15.1 – 15.2	NA	1.15 – 1.17	1.40 – 1.48	1.01 – 1.03	1.46 – 1.70
Dec 15 – 17, 2008	0823 – 1117	9 (9 d / 0 n)	100	40	8.0 – 9.2	69.2 ± 11.6	0.45 – 0.91	1.62 – 4.33	0.55 – 2.59	1.18 – 2.88
Totals or Range	0823 – 2030	67 (57 d / 10 n)	75 – 180	0 – 40	7.8 – 20.0	60.5 – 69.9	0.45 – 4.19	0.66 – 4.33	0.55 – 4.00	0.44 – 2.88

Fish Source and Care

Adult delta smelt, cultured and supplied by the University of California Davis Fish Conservation and Culture Lab (FCCL; Byron, CA), were maintained in Reclamation’s Tracy Aquaculture Facility (TAF) in black cylindrical tanks, provided continuous flows of aerated SSJD water, and supplied satiation rations of a commercial fish food (BioKyowa 1000; BioKyowa Inc., Cape Giradeau, MO) during holding. Prior to testing, delta smelt were provided an external mark, using a photonic marking gun (Sutphin 2008; New West Technology, Santa Rosa, CA), to permit identification of each unique release group of experimental fish. Following marking procedures, smelt were provided 1–3 d recovery before initiation of testing.

Experimental Procedure

For each experimental replicate, two uniquely marked groups of adult delta smelt were released: immediately downstream of the trashrack at the most upstream end of the primary channel (location “A” on Figure 2), and at the most accessible upstream end of the secondary channel (location “B” on Figure 2). Fish were released uniformly across the primary channel at four evenly distributed locations behind the trash rack deck. This release pattern was used because it was not known where wild fish enter the facility through the trashrack. Fish were only released at one, mid-way location at the front of the secondary channel due to its narrow width. Number of fish released per replicate, as a function of sample date(s), changed each year due to the number of fish available from the FCCL (see Table 1).

Methods for release and recovery of test fish were similar for all years. For all replicate releases of smelt, a sanctuary dip-net was used to permit water-to-water transfer of smelt from holding tank to black 19-L buckets, after which fish were transported (< 100 m), lowered to the water surface, and gently poured from the bucket into each channel. Test fish were recovered from the holding tank (location “D” on Figure 2) or behind the secondary louver array (location “C” on Figure 2) typically every 20 min during an hour long experimental period. Delta smelt were recovered from holding tanks using standard TFCF holding tank sampling methodology (see Sutphin *et al*. 2007), and were deemed fish that were successfully salvaged. Fish were recovered downstream of the secondary louver array using a sieve net (2-mm mesh; 2.4 × 2.8 m opening), and were deemed fish that passed through the secondary louvers and were not successfully louvered (not successfully salvaged). Two secondary sieve nets were utilized to ensure this location was continuously sampled during testing. No similar sieve net was available downstream of the primary louvers to collect fish passing downstream because the louver structures large size. Following capture, all delta smelt were enumerated and measured for fork length (mm). Releases of fish directly into the holding tank, as well as immediately upstream of the secondary sieve net, were completed intermittently to estimate sampling efficiency at these two locations. Water quality data was recorded semi-continuously throughout data collection using a YSI multi-probe (YSI Inc., Yellow Springs, OH) installed downstream of the trashrack on the north side of the primary channel.

Hydraulic Measurements and Calculations

Hydraulic parameters were calculated from data collected at the TFCF during the test period. Preferably, hydraulic data was directly recorded from facility instrumentation. Due to equipment failure or calibration issues, there were occasions when hydraulic data needed to be estimated.

Water depths in the primary and secondary channels were measured with permanent ultrasonic water level sensors. Primary channel velocity was measured with a ChannelMaster Acoustic Doppler Current Profiler (ADCP, model H) installed in the primary channel (Teledyne RD Instruments, Inc., San Diego, CA). When the primary channel flow meter was not operational, the primary channel velocity was estimated. The pumping rate from the JPP was obtained and the primary average channel velocity at the TFCF was estimated by dividing the pumping plant flow rate by the cross-sectional area of the channel (measured primary channel depth x primary channel width).

Secondary channel flow rate was calculated as the sum of the flow rates measured by the 4 bypass pipe flow meters. Secondary channel velocity was calculated from the secondary flow rate and flow area (water depth times channel width). When the bypass flow meters were not operational, secondary channel velocity was estimated. The secondary channel flow rate is controlled by a bank of low head velocity control (VC) pumps positioned at the downstream end of the secondary channel. Secondary channel discharge was estimated from VC pump ratings when the flow meter was not available. Secondary average channel velocity was calculated as the estimated secondary channel discharge divided by the cross-sectional area of the channel (measured secondary channel depth x secondary channel width). During some tests, a Boogie Dopp acoustic Doppler velocity profiler (Nortek USA, San Diego, CA) or Marsh McBirney velocity meter (Hach Company, Loveland, CO) was used to more accurately measure secondary channel velocity.

Bypass ratio, defined as the ratio of bypass entrance velocity to average channel velocity, was calculated for both the primary and secondary channels. Bypass entrance velocity was calculated using bypass flow and dividing by the cross sectional area of the bypass entrance. All bypasses were of set width (0.5 ft), but depth was influenced by tide. Water depth between the trashrack and primary louvers was used for the primary BR calculation and water depth upstream of the first secondary louver panel was used for the secondary BR calculation. Bypass ratios must be greater than 1.0 to achieve facility criteria.

TFCF Efficiency and Participation Calculations

Holding Tank Efficiency (HTE)

Holding tank (Figure 2, label "D") efficiency quantifies percentage of fish released directly into the holding tank that are recovered when the tank contents (*i.e.*, fish, debris, and water) are drained into a fish haul-out (or count) bucket and then transferred and released into a fish count station for processing. This is the final process that occurs at the TFCF to transfer salvaged fish from holding tank to transport truck. Holding tank efficiency was used as both a quality control measure, to ensure no gross errors were made during operation of the holding tank screen or haul-out bucket, as well as to provide an overall estimate of HTE that could be used when calculating primary and secondary channel efficiency. The HTE used when calculating primary and secondary channel efficiency was the mean of all HTE across all sampling dates. To quantify HTE, 10 – 25 uniquely marked adult delta smelt were released into the holding tank using the same bucket release method described above. This effort was conducted to coincide with fish releases in the primary and / or secondary channel for most replicates completed between 2006 and 2008. Holding tank efficiency was not evaluated during 2003 and 2005 sampling.

Secondary Channel Sieve Net Efficiency (SNE)

Secondary sieve net (Figure 2, label "C") efficiency was evaluated sporadically throughout testing, and was evaluated by inserting 20 (May 2006, n = 6; November 2007, n = 1) or 10 (January 2008, n = 4) adult delta smelt immediately upstream of the sieve net during standard sampling procedures described above. The percentage of fish retained in the secondary sieve net following a full sampling period provides an estimate of SNE. The mean estimate for SNE was used to provide a more precise estimate of primary and secondary channel efficiency. The SNE used when calculating primary and secondary channel efficiency was the mean of all SNE across all sampling dates.

Whole Facility Efficiency (WFE)

Whole facility efficiency quantifies the percent of fish released at the head of the primary channel that are ultimately recovered from a holding tank using a haul-out bucket. Fate of fish that do not make it to the holding tank can include: lost to predation, lost through primary or secondary louvers, lost in holding tank, swam out of the TFCF through the trashrack, or stayed in the TFCF during the experimental period.

$$\text{WFE} = (\text{H}/\text{IP}) \times 100 \qquad \text{Eq. (1)}$$

Where:

H = Number of fish recovered from a holding tank
IP = Number of fish inserted into the primary channel

Primary Channel Efficiency (PE)

Primary channel efficiency quantifies the percentage of fish released in the primary channel that make it to the secondary channel. Historic equations assumed 100% capture efficiency in the TFCF holding tank and secondary sieve net. However, HTE and SNE estimates determined during the current effort, as well as data reported by Wu and Bridges (2014), indicates this is not a valid assumption. Since the current data collection effort permitted estimates of HTE and SNE, these values can be incorporated to provide a better estimate of PE:

$$\text{PE} = [(\text{H}/\text{HTE}) + (\text{S}/\text{SNE})]/\text{IP} \times 100 \qquad \text{Eq. (2)}$$

Where:

S = Number of fish recovered in the sieve net

Secondary Channel Efficiency (SE)

Secondary channel efficiency quantifies the percent of fish released at the most upstream section of the secondary channel that move downstream through the secondary channel and are ultimately captured in a holding tank. This value estimates how well the secondary louvers are functioning. Fish holding in the secondary channel, secondary bypass, or lost to predation are removed from the SE because these fish did not have a chance to participate in the test.

$$\text{SE} = [(\text{H}/\text{HTE})/((\text{H}/\text{HTE}) + (\text{S}/\text{SE}))] \times 100 \qquad \text{Eq. (3)}$$

Secondary channel efficiency can also be estimated for fish released in the primary channel. This equation is identical to that of Equation 3, but for fish released in the primary channel (not the secondary channel). The majority of this report references SE with regards to secondary released fish. However, SE of primary released fish is included in Appendix 1 for comparison.

Secondary Channel Participation (SCP)

The secondary channel participation calculation provides a measure of how many fish participated in the test, thereby providing the level of precision available in the SE measurement. In addition, this measurement indicates how channel velocity influences the number of fish guided downstream after release. Since the secondary channel is a closed system, it can be assumed the percentage of fish not captured in the holding tank or sieve net were either lost to predation or took up residency in the secondary channel.

$$SLP = [(H + S)/IS] \times 100 \qquad \text{Eq. (4)}$$

Where:

IS = Number of fish inserted into most upstream section of secondary channel

Statistical Analyses

Since there is no specific TFCF delta smelt operational criteria, the facility is currently operated within Chinook salmon criteria when delta smelt are present. A significant portion of the efficiency data was collected (46 of 67 total replicates) with at least one of the facility hydraulic conditions (Table 2) outside of Chinook salmon criteria. As a result, the data was assessed in its entirety (Full-Range) to evaluate if conditions outside of normal criteria would provide better operational conditions to promote salvage of smelt, and also assessed when the facility was operated within Chinook salmon criteria to ascertain salvage efficiency under these hydraulic conditions.

Table 2.—Tracy Fish Collection Facility operational criteria. Chinook salmon operational criteria is currently utilized when delta smelt are present at the facility.

Season	Begin	End	Mean Primary Channel Velocity (ft/s)	Primary Bypass Ratio (unitless)	Mean Secondary Channel Velocity (ft/s)	Secondary Bypass Ratio (unitless)
Chinook Salmon	[A] Nov. 1	May 31	NA	≥ 1.0	~3.0	1.6
	[B] Feb	May	NA	≥ 1.0	3.0 - 3.5	≥ 1.0
Striped Bass	[A] June 1	Oct 31	NA	≥ 1.0	~1.0	1.2
	[B] June 1	Aug 31	NA	≥ 1.0	1.5 - 2.5	≥ 1.0

[A] Operational criteria as defined by National Marine Fisheries Service 2009 Biological Opinion.
[B] Operational criteria as defined by Water Rights Decision 1485.

Facility efficiency data was typically collected over a narrow range of environmental and hydraulic conditions during each individual data collection effort (see Table 1 and Appendix 3, Figure 1). As a result, all analyses were conducted by averaging across year. To evaluate effects of hydraulic (*i.e.*, bypass ratio and mean channel velocity) and environmental conditions (*i.e.*, diel period, turbidity, temperature, *etc*.) on adult delta smelt efficiency, scatter plots were developed to promote post-hoc regression analyses for these relationships.

Full-Range Data Set.—The post-hoc scatter plot assessment suggested there was no discernable relationship between measured hydraulic conditions and SE (Appendix 4, Figures 1 and 2). Therefore, the majority of data analyses, and subsequent discussions, focus on effects of primary hydraulics and environmental conditions on PE. Individual second order polynomial models were used to quantify the relationship between mean primary channel velocity and primary bypass ratio on adult delta smelt PE. Multiple linear regression, incorporating turbidity, temperature, time of day, trashrack differential, and total number of fish salvaged during sampling, was used to model effects of environmental conditions on PE. Data met assumptions (normality and constant variance, $P > 0.05$) to model with regression. Independent variables were evaluated for correlation using Pearson Product Moment Correlation. A Mann-Whitney Rank Sum test was utilized to test for differences in SE for primary and secondary released fish.

In-Criteria Data Set.—The post-hoc scatter plot assessment suggested there was no discernable relationship between secondary bypass ratio and SE. Simple linear regression models were developed to evaluate effects of hydraulic conditions on PE, SE, and WFE. All statistical analyses were conducted using SigmaStat 3.5 software (Systat Software Inc., Richmond, CA) with the significance level (α) for all analyses set at 0.05.

RESULTS

Full-Range Data Set

Mean (± standard deviation) HTE ($n = 41$) and SNE ($n = 11$) were 97 % (± 6 %) and 94 % (± 7 %), respectively. The HTE suggests that, over the course of the study, there was minimal fish loss after fish entered a holding tank. Across all sampling efforts mean (± standard deviation) PE, SE, and WFE were 30 % (± 19 %), 67 % (± 17 %), and 23 % (± 16 %), respectively. Secondary channel efficiency of primary released fish (80 ± 14 %) was significantly different than that of secondary released fish (67 ± 17 %).

Averaged across year of sampling a second order polynomial model explains a significant relationship between primary velocity and PE ($P = 0.001$, Figure 3).

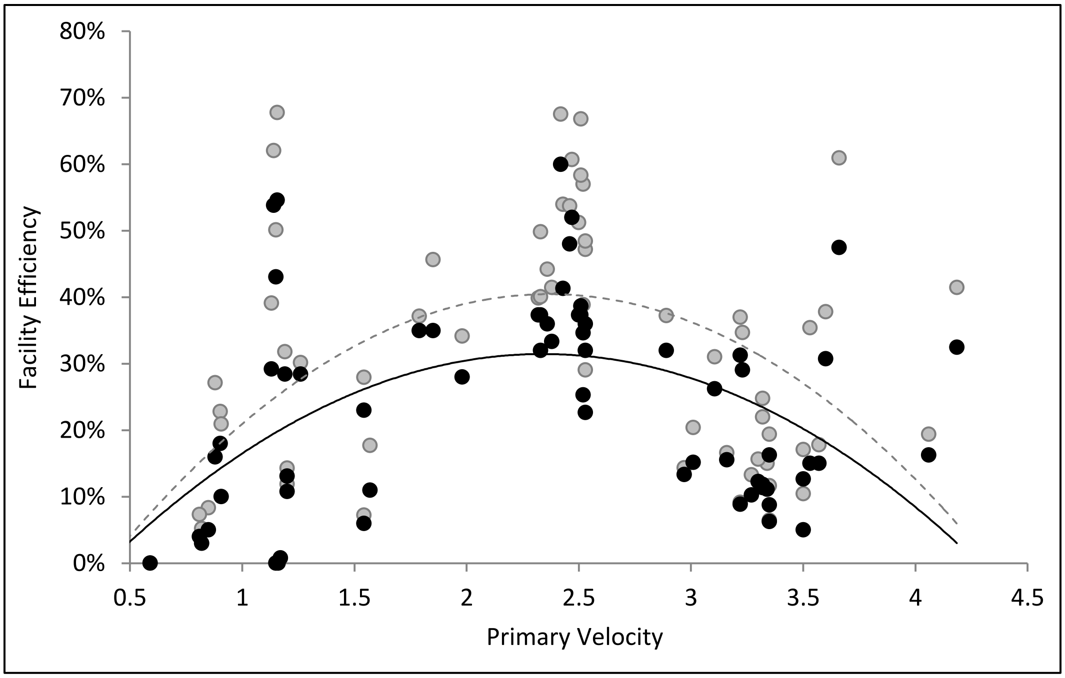

Figure 3.—Effects of mean primary channel water velocity (ft/s) on primary channel efficiency (grey circles, dotted line) and whole facility efficiency (black circles, solid line) of adult delta smelt (*Hypomesus transpacificus*) at the Tracy Fish Collection Facility (Bureau of Reclamation, Byron, CA). A second order polynomial model ($y = -0.1007x^2 + 0.4765x - 0.1735$, $R^2 = 0.27$) was used to explain correlation between primary velocity and primary channel efficiency ($P < 0.05$). The second order polynomial model used to model the relationship between primary velocity and whole facility efficiency ($y = -0.0834x^2 + 0.3901x - 0.1415$) has an $R^2 = 0.26$.

Using the derivative of the polynomial equation, the peak of the fitted line (slope = 0) where PE is optimized was equivalent to a mean primary channel velocity of 2.37 ft/s, while mean primary velocities between 1.92 and 2.81 ft/s resulted in PE values within 5% of the maximum. The same polynomial model was not significant when used to explain correlation between primary bypass ratio and PE ($P = 0.06$, Figure 4). It is important to note there is a significant gap of missing bypass ratio data between 1.7 and 3.1 that could ultimately prove influential on this relationship. Though the polynomial relationship between primary velocity and PE was significant, the fraction of variation in PE predicated by primary velocity ($R^2 = 0.27$) was low, suggesting there are likely other contributing factors that influenced PE over the course of the study. A post-hoc scatter plot assessment suggested there was no discernable relationship between measured hydraulic conditions and SE (Appendix 4, Figure 1 and 2).

Analysis of the multiple linear regression model, used to help ascertain what other measured environmental variables could have influenced delta smelt PE, indicates that, of the variables included in the model, trashrack differential (Figure 5) accounts for some of the ability to predict PE of delta smelt ($P < 0.05$). However, primary velocity and trashrack differential were positively correlated (Pearson

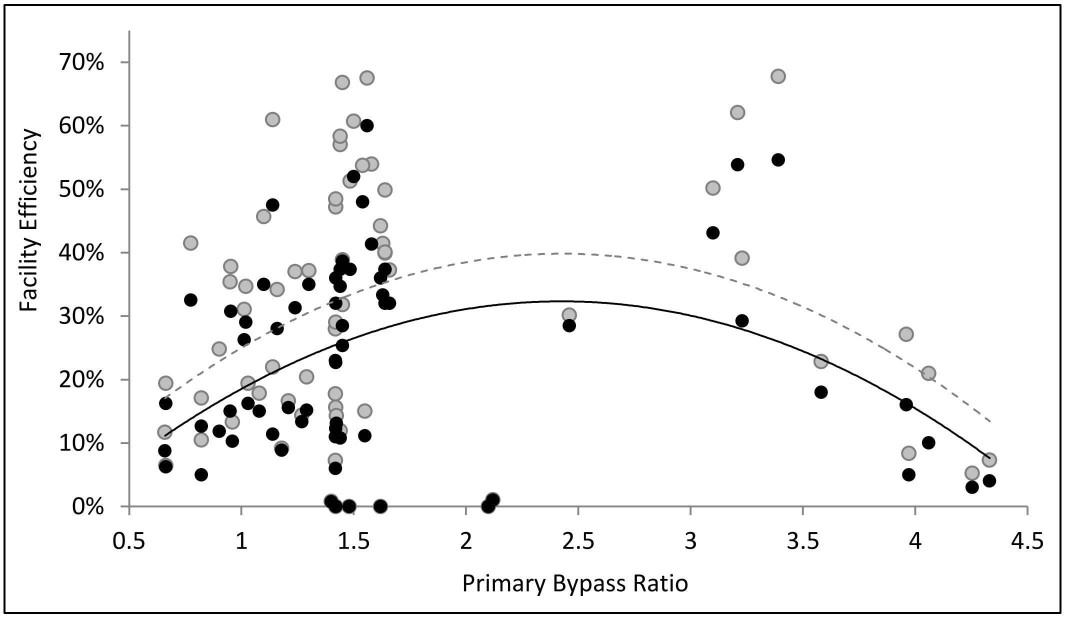

Figure 4.—Effects of primary bypass ratio on primary channel efficiency (grey circles, dotted line) and whole facility efficiency (black circles, solid line) of adult delta smelt (*Hypomesus transpacificus*) at the Tracy Fish Collection Facility (Bureau of Reclamation, Byron, CA). A second order polynomial model ($y = -0.0706x^2 + 0.3426x - 0.0313$, $R^2 = 0.10$) did not significantly explain correlation between primary bypass ratio and primary channel efficiency ($P > 0.05$). The second order polynomial model used to model the relationship between primary velocity and whole facility efficiency ($y = -0.068x^2 + 0.3297x - 0.0763$) has an $R^2 = 0.14$.

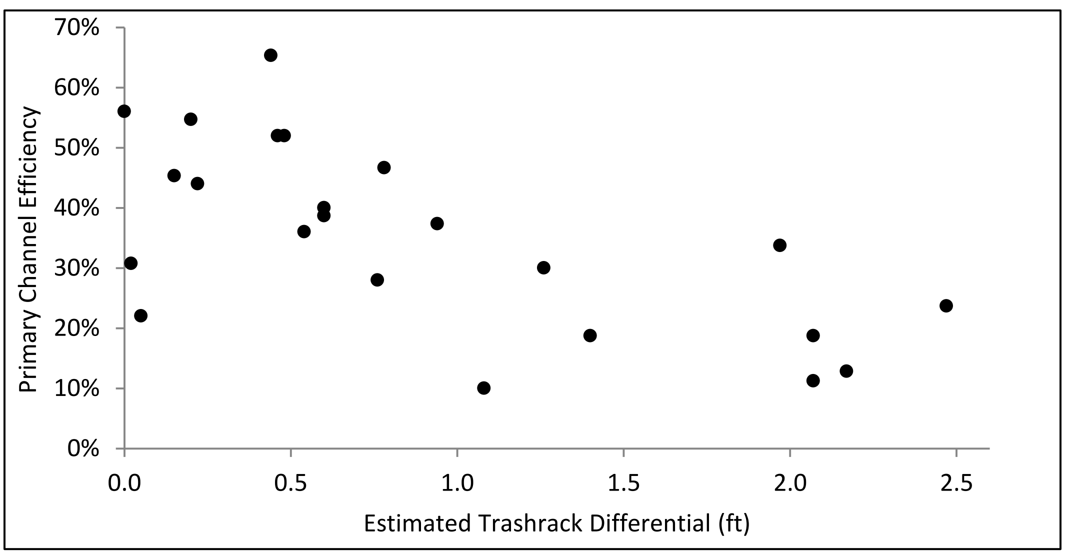

Figure 5.—Effects of primary channel trashrack differential (ft) on primary channel efficiency of adult delta smelt (*Hypomesus transpacificus*) at Bureau of Reclamation's Tracy Fish Collection Facility (Byron, CA). Of the measured environmental variables incorporated into the multiple linear regression model, trashrack differential was the only variable to explain some of the ability to predict primary channel efficiency ($P < 0.05$).

Product Moment Coefficient = 0.76, P < 0.001) making it difficult to ascertain which variable (velocity or trashrack differential) was most influential on primary channel efficiency. Water temperature, turbidity, time of day, and total number of fish being salvaged during data collection were not significant predictors (Appendix 5, Figure 1, 2, 3, and 4). Though the relationship between time of day or turbidity level and PE were not significant, when considering the multitude of other factors likely influencing PE the patterns of these data sets (Appendix 5, Figure 3 and 4) suggest they may have a slight effect on delta smelt PE. Raw data used to evaluate effects of hydraulic and environmental conditions on delta smelt PE are reported in Appendix 1 and Appendix 2.

In-Criteria Data Set

A total of 21 replicates were completed, across multiple years (Appendix 2), when the facility was operated within Chinook salmon criteria. When these conditions were met, mean PE, SE, and WFE were 39 % (± 18 %), 65 % (± 18 %), and 29 % (± 14 %). Analyses of simple linear regression models indicate, when operated within defined criteria, primary channel and whole facility efficiency of delta smelt tends to decrease with increasing velocity (Figure 6), but increase with increasing primary bypass ratio (Figure 7). Similarly, simple linear regression indicates, when operated within Chinook salmon criteria, secondary channel efficiency increases with increasing secondary velocity (Figure 8).

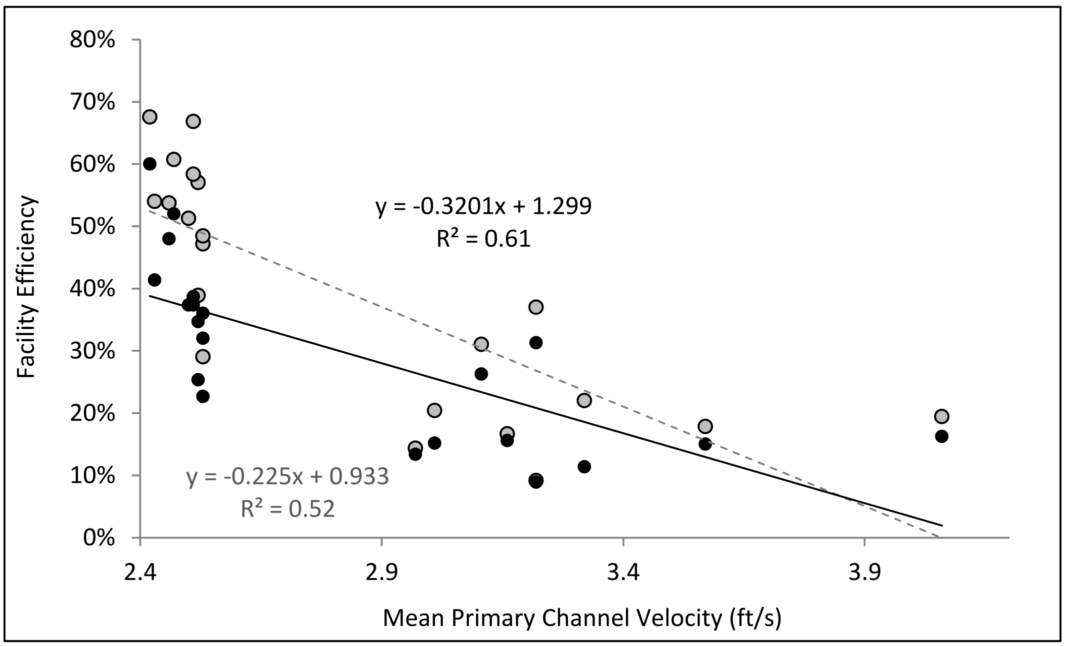

Figure 6.—Effects of primary channel mean velocity on primary channel efficiency (grey circles, dotted line) and whole facility efficiency (black circles, solid line) of adult delta smelt (*Hypomesus transpacificus*) at the Tracy Fish Collection Facility (Bureau of Reclamation; Byron, CA) when the facility is operated within Chinook salmon criteria.

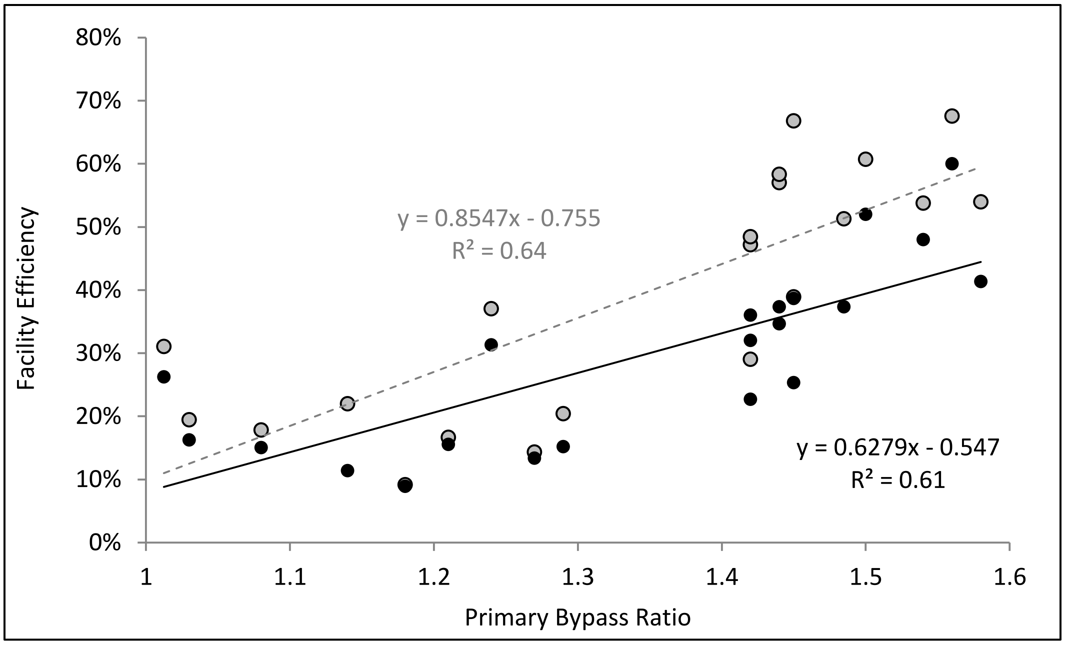

Figure 7.—Effects of primary bypass ratio on primary channel efficiency (grey circles, dotted line) and whole facility efficiency (black circles, solid line) of adult delta smelt (*Hypomesus transpacificus*) at the Tracy Fish Collection Facility (Bureau of Reclamation; Byron, CA) when the facility is operated within criteria.

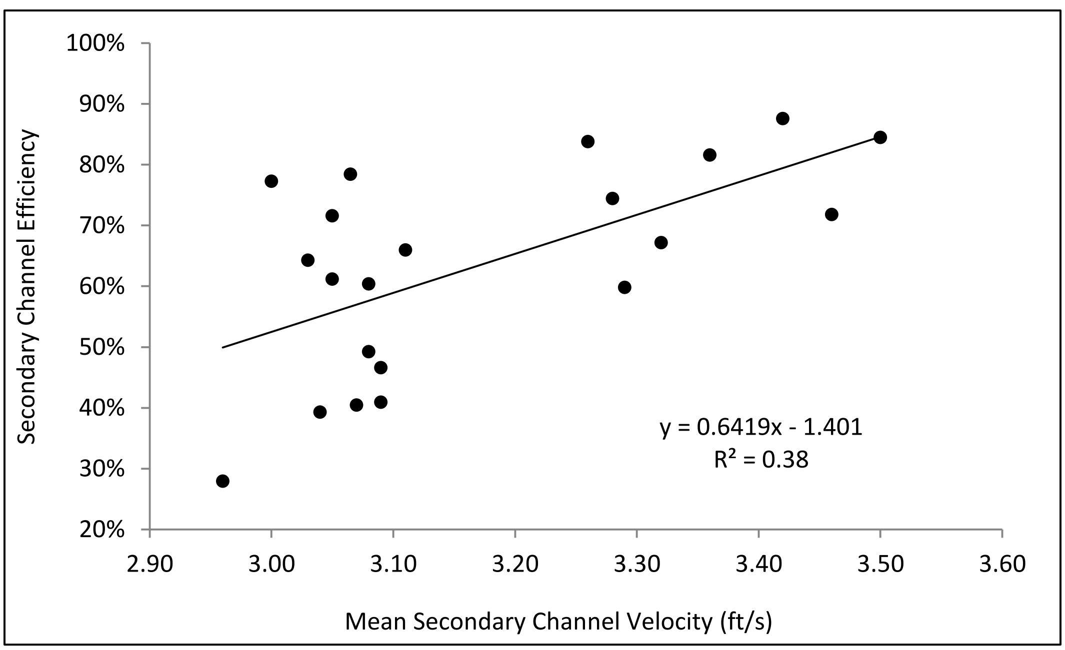

Figure 8.—Effects of mean secondary channel velocity on secondary channel efficiency of adult delta smelt (*Hypomesus transpacificus*) at the Tracy Fish Collection Facility (Bureau of Reclamation; Byron, CA) when the facility is operated within criteria.

DISCUSSION

Results of the current study suggest TFCF hydraulic conditions have an effect on adult delta smelt salvage efficiency, and these hydraulic effects are particularly evident when the facility is operated within Chinook salmon criteria. The polynomial model, describing the relationship between primary channel velocity and PE and WFE utilizing the full-range of data collected, suggests moderate water velocities between 1.9 and 2.8 ft/s promote optimal PE and WFE, whereas slower (< 1.6 ft/s) and faster (> 2.9 ft/s) velocities result in reduced PE and WFE. When the facility is operated within Chinook salmon criteria, moderate primary velocities (~ 2.4 ft/s) appear to promote elevated PE and WFE, but PE and WFE decrease as mean primary channel velocity increases from 2.4 to 4.1 ft/s.

Testing at slower primary channel velocities likely reduce the amount of fish released at the trashrack that participate in the experiment because they had the opportunity to swim out of the facility or were consumed by predators before they encounter the primary louvers. Data collected during such conditions may not be representative of the actual fish salvaging efficiency of the primary louvers, but represents a combination of louver function, fish participation, and predation. During experimentation, fish were released immediately downstream of the trashrack. If they were exposed to slower channel velocities that did not guide them downstream, there is a possibility they moved upstream through the trashrack and out of the confines of the facility (swim-out), or were able to reside in the primary channel long enough that they were not sampled in a holding tank during the designated sampling period.

The median duration adult delta smelt can sustain swimming at a velocity of 0.98 ft/s is reportedly 11 minutes (Swanson *et al*. 1998). However, some of the individuals tested by Swanson *et al*. (1998) could maintain position at this velocity for up to 360 minutes. This supports the hypothesis that at lower primary channel velocities, some of the test fish may have not participated in the experiments. If adult smelt were able to maintain position and were not guided downstream at lower velocities, these conditions also likely increased their time of exposure to piscivorous fish residing in the primary channel. Though likely temporally variant, results published by Bridges *et al*. (*In Draft*) and Sutphin (2014) indicate large (> 400 mm) piscivorous striped bass (*Morone saxatilis*) are often present in the TFCF primary channel, and Bridges *et al*. (*In Draft*) suggests predation can have a significant effect on facility salvage efficiency. Therefore, it is plausible to assume predation loss in the primary channel was more significant during low velocities.

Results reported by Swanson *et al*. (1998) suggest delta smelt are relatively poor swimmers, and susceptible to behavioral swimming failure at submaximal velocities and when transitioning to high-velocity swimming. Therefore, it is possible the lower PE observed at elevated primary velocities is, partially, a result of water velocities either exceeding the maximum swimming speed of delta smelt or exposing them to velocities requiring transition to high-velocity swimming, which ultimately resulted in test fish being swept through the louver openings. This hypothesis is supported by Swanson *et al*. (2005) whom observed increasing screen contact rates of adult delta smelt in an annular flume as water velocities increased from 0.0 to ~ 2.0 ft/s.

When assessing the full-range of data collected over the duration of the study, no significant trends were evident when evaluating effects of mean channel velocity on secondary channel efficiency (Appendix 4). However, when data was collected with all hydraulic conditions maintained within Chinook salmon criteria, secondary channel efficiency tends to increase as secondary velocities increase from ~3.0 to 3.5 ft/s. Interestingly, this is the opposite velocity effect observed in the primary channel (decreasing efficiency with increasing velocity). Our results also indicate a significant positive correlation between primary channel velocity and primary channel trashrack differential. So, perhaps increased trashrack differential drives this relationship (not channel velocity), and reduced PE and WFE as a result of increased primary velocity is a result of the correlation between primary channel velocity and trashrack differential.

Of the environmental/facility hydraulic variables measured and evaluated, trashrack differential accounts for some of the ability to predict PE of delta smelt. Increased trashrack differential, the difference in water depth upstream and downstream of the primary channel trashrack (Appendix 6, Figure 1), is a result of debris accumulation, as well as elevated primary channel velocity, on the primary trashrack causing a damming and spillover effect. Significant turbulence occurs immediately downstream of the trashrack where test fish were released. Depending on the type and magnitude of the turbulent flows, they can benefit or reduce the swimming ability of fish (see review in Liao and Cotel 2013). Flow refuging, when fish find regions of reduced or countercurrent flows, can occur when fish are exposed to turbulence. This scenario could have provided a refuge for fish released in the primary channel, resulting in reduced participation (increased swim-out) or increased time of exposure to predators, contributing to reduced PE. However, turbulent flows may also increase stability requirements, ultimately reducing swimming performance of fish (see review in Liao and Cotel 2013). Reduction in swimming performance could affect the ability of fish to swim away from flows moving through the louvers.

Differences in secondary channel efficiency of primary and secondary released fish are likely a combination of varying individual fish fitness and the rapidity at which released fish can adjust to their new environment and orient to channel flows following release. Fish released in the primary that are unknowingly compromised (injured, unhealthy, stressed) are more likely to be consumed by predators, or not possess the physical capabilities to evade increasing velocities as water is swept through the primary louvers (Mesa 1994, Mesa *et al.* 1994). As a result, the most fit individuals are more likely to make it to the secondary channel, where, once again, they are more likely to evade predation and navigate the secondary louver system. Additionally, fish released into the secondary channel are released on the water's surface and in close proximity (< 5 m) to the secondary louver panels. Given the rapid change in environment (*i.e.,* reduced visibility/increased turbidity, increased downstream velocities), from release bucket to secondary channel, it is possible some secondary released fish are immediately swept downstream and through the secondary louvers prior to adjusting to the new environmental conditions.

Appendix 7 provides a summary of results from pertinent TFCF efficiency evaluations conducted to-date for comparison to the results reported in the current study. Though perhaps on the lower range, in general it appears that primary and secondary channel efficiency of adult delta smelt is similar to those reported for other species tested, and, across all species, facility efficiency appears to have worsened from initial evaluations conducted by Bates *et al*. (1960), Hallock (1967), and Hallock *et al*. (1968). However, these comparisons hold little significance due to the wide range of efficiency values reported for most species tested at the TFCF. As indicated in the current report, this wide range in efficiency values is likely a result of variable environmental and operational conditions, but could also be reflective of the different methods used to measure and calculate facility efficiency, as well as species-specific differences in condition and swimming performance.

RECOMMENDATIONS

The current study provides evidence that there are likely a combination of known, assumed, and unknown variables, as well as hydraulic conditions and facility operations that influence fish behavior and performance and ultimately determine channel efficiency of fish at the TFCF. As a result, it can be difficult to isolate the effects of one particular variable (*i.e.,* velocities and/or bypass ratios) as a means to provide statistically significant data for recommending facility operational criteria. This approach would require controlling for these other influential variables (*i.e.*, trashrack differential, predation, *etc.*), which is generally not only impractical, but is not representative of true "typical" conditions at the facility and may also mask the importance of corresponding variables. However, if recommending facility hydraulic operational criteria is the primary objective of future research efforts, then these compounding variables should be controlled as best as possible, focusing primarily on controlling predator load in the primary and secondary channel, and maintaining debris free trashrack and louvers. Also, the extent of possible influential variables underscores the importance of standardized sampling methodology, and not only measuring these variables (to the extent possible), but also ensuring facility equipment (*i.e.*, water quality and hydraulic monitoring equipment) is functioning properly and calibrated during testing.

Delta smelt are typically salvaged from winter through spring at the TFCF, which coincides with Chinook salmon facility operational criteria (http://www.dfg.ca.gov/delta/apps/salvage). Though TFCF operational criteria follows a hybrid of multiple regulations, the general season-specific operational criteria is outlined in Table 2. Experimental results suggest operating facility hydraulics well outside of criteria likely won't improve delta smelt salvage efficiency. However, when operating within defined criteria, delta smelt salvage efficiency may be maximized by increasing the secondary channel velocity to maintain the primary bypass ratio as close to 1.6 as possible. It is important to note that there was minimal data collected when primary bypass ratios were between 1.7 and 3.1, and perhaps future sampling efforts should focus on understanding effects of primary bypass ratios within this range on adult delta smelt PE, as slightly higher primary bypass ratios may function to further improve PE.

Also, maintaining a clean primary trashrack, and, ideally, maintaining primary channel velocities between ~2.0 and 2.4 ft/s, in an effort to minimize trashrack differential may promote increased salvage efficiency of adult delta smelt at the TFCF. Primary channel velocities are controlled by pumping activities at the down-canal Bill Jones Pumping Plant, and cannot be regulated by TFCF personnel. Therefore, maintenance of suitable primary channel velocities may require alteration of pumping plant deliveries. However, considering elevated trashrack differential, which contributes to turbulent flows in the primary channel, appears to be the overriding factor driving this relationship, an alternate approach may be to evaluate means (*i.e.,* trashrack design) to minimize turbulence in the primary channel without impacting water delivery at the pumping plant.

ACKNOWLEDGMENTS

Funding for this project was provided by the U.S. Bureau of Reclamation, Tracy Fish Collection Facilities Improvement Program. The study design was improved with input from R. Silva, B. Bridges, and members of the Tracy Technical Advisory Team. A multitude of Biologists, Engineers, Fish Diversion Workers, and Technicians from both the Tracy Fish Collection Facility and Reclamation's Technical Service Center provided technical support while conducting field experiments. We thank multiple anonymous reviewers for suggestions during the editorial process that have helped to improve this document. We thank the UC Davis Fish Culture and Conservation Lab for providing adult delta smelt for testing.

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APPENDIX 1

Raw Data (Test Conditions)

Table A1-1.—Raw data collected to quantify primary, secondary, and whole facility efficiency of adult delta smelt (*Hypomesus transpacificus*) at the Tracy Fish Collection Facility (Bureau of Reclamation; Byron, CA)

		Number Fish Inserted by Location				# Primary Released Fish		# Secondary Released Fish								
Date	Time	Primary	Secondary (Sec)	Holding Tank (HT)	Sieve Net (SN)	HT	SN	HT	SN	# SN Released Fish Recovered	# HT Released Fish Recovered	Primary Efficiency (PE)	Secondary Efficiency (SE) Secondary Release	Secondary Efficiency (SE) Primary Release	Secondary Participation (SP)	Whole Facility Efficiency (WFE)
*11/10/2003	10:01	180	40	0	0	20	6	20	10	0	0	15%	66%	76%	78%	11%
*11/10/2003	11:55	179	40	0	0	22	5	28	5	0	0	16%	84%	81%	85%	12%
11/10/03	19:20	179	40	0	0	52	8	31	4	0	0	35%	88%	86%	91%	29%
11/10/03	20:30	179	40	0	0	56	8	23	15	0	0	37%	60%	87%	99%	31%
11/11/03	9:55	180	40	0	0	27	4	27	9	0	0	18%	74%	87%	94%	15%
11/11/03	11:06	180	39	0	0	28	1	29	4	0	0	17%	88%	96%	88%	16%
11/11/03	19:25	176	39	0	0	20	17	10	25	0	0	22%	28%	53%	95%	11%
11/11/03	20:30	178	39	0	0	27	8	32	6	0	0	20%	84%	77%	100%	15%
11/11/03	10:27	180	40	0	0	16	0	32	7	0	0	9%	82%	100%	100%	9%
11/12/03	14:05	180	40	0	0	24	1	28	5	0	0	14%	84%	96%	85%	13%
11/15/05	12:04	400	60	0	0	123	23	4	13	0	0	38%	23%	84%	30%	31%
11/16/05	12:34	80	30	0	0	26	6	17	12	0	0	41%	58%	81%	100%	33%
11/16/05	13:14	80	30	0	0	21	3	21	8	0	0	31%	72%	87%	100%	26%
11/16/05	16:15	80	30	0	0	13	2	19	9	0	0	19%	67%	86%	97%	16%
11/16/05	17:00	80	29	0	0	38	9	19	9	0	0	61%	67%	80%	100%	48%
11/17/05	10:49	80	30	0	0	12	15	10	3	0	0	35%	76%	44%	45%	15%
11/17/05	11:10	78	30	0	0	8	2	10	10	0	0	13%	49%	79%	70%	10%
11/17/05	11:29	76	30	0	0	9	9	10	12	0	0	25%	45%	49%	77%	12%
11/18/05	12:19	80	30	0	0	13	2	12	3	0	0	19%	79%	86%	52%	16%
11/18/05	12:24	80	30	0	0	5	0	9	4	0	0	6%	69%	100%	45%	6%
11/18/05	12:29	80	30	0	0	7	2	12	7	0	0	12%	62%	77%	66%	9%
11/18/05	16:21	80	30	0	0	4	4	14	4	0	0	10%	77%	49%	62%	5%
11/18/05	16:26	79	30	0	0	10	3	14	3	0	0	17%	82%	76%	59%	13%

Table A1-1.—Raw data collected to quantify primary, secondary, and whole facility efficiency of adult delta smelt (*Hypomesus transpacificus*) at the Tracy Fish Collection Facility (Bureau of Reclamation; Byron, CA)

		Number Fish Inserted by Location				# Primary Released Fish		# Secondary Released Fish								
Date	Time	Primary	Secondary (Sec)	Holding Tank (HT)	Sieve Net (SN)	HT	SN	HT	SN	# SN Released Fish Recovered	# HT Released Fish Recovered	Primary Efficiency (PE)	Secondary Efficiency (SE) Secondary Release	Secondary Efficiency (SE) Primary Release	Secondary Participation (SP)	Whole Facility Efficiency (WFE)
5/19/2006	10:05	100	30	20	20	35	9	26	3	18	19	46%	89%	79%	100%	35%
5/19/2006	10:32	100	30	25	20	28	5	27	1	19	25	34%	96%	84%	96%	28%
5/19/2006	11:05	100	30	21	20	35	1	21	1	20	21	37%	95%	97%	76%	35%
5/19/2006	11:45	100	30	20	20	11	6	20	3	16	20	18%	87%	64%	79%	11%
5/19/2006	12:06	100	30	20	20	6	1	24	1	17	19	7%	96%	85%	86%	6%
5/19/2006	12:25	100	30	20	20	23	4	19	5	20	20	28%	79%	85%	83%	23%
11/27/2007	12:42	75	20	10	20	39	5	15	4	18	9	61%	78%	88%	99%	52%
11/27/2007	13:03	75	20	10	0	28	9	7	10	0	8	51%	40%	75%	89%	37%
11/27/2007	13:24	75	20	10	0	29	19	13	7	0	10	67%	64%	60%	100%	39%
11/27/2007	18:05	75	20	10	0	25	5	13	7	0	10	41%	64%	83%	100%	33%
11/27/2007	18:25	75	20	10	0	24	3	13	7	0	9	37%	64%	89%	100%	32%
11/27/2007	18:46	75	20	10	0	28	1	8	9	0	10	40%	46%	96%	89%	37%
11/28/2007	15:21	75	20	10	0	24	10	9	9	0	10	47%	49%	70%	94%	32%
11/28/2007	15:42	75	20	10	0	26	15	14	7	0	10	57%	66%	63%	100%	35%
11/28/2007	16:01	75	20	10	0	28	14	8	12	0	10	58%	39%	66%	100%	37%
11/28/2007	19:37	75	20	10	0	27	5	12	8	0	10	44%	59%	84%	100%	36%
11/28/2007	19:56	75	20	10	0	24	5	10	9	0	10	40%	52%	82%	99%	32%
11/28/2007	20:17	75	20	10	0	28	8	11	10	0	10	50%	52%	77%	100%	37%
11/29/2007	12:39	75	20	10	0	17	4	13	8	0	10	29%	61%	80%	100%	23%
11/29/2007	13:00	75	20	10	0	27	8	13	5	0	9	48%	72%	77%	94%	36%
11/29/2007	13:21	75	20	10	0	19	9	9	10	0	10	39%	47%	67%	100%	25%
11/30/2007	13:56	75	20	10	0	45	4	14	4	0	9	68%	77%	92%	93%	60%
11/30/2007	14:18	75	20	10	0	31	8	5	7	0	9	54%	41%	79%	63%	41%
11/30/2007	14:41	75	20	10	0	36	3	11	7	0	10	0.54	0.60	0.94	0.48	41%

Table A1-1.—Raw data collected to quantify primary, secondary, and whole facility efficiency of adult delta smelt (*Hypomesus transpacificus*) at the Tracy Fish Collection Facility (Bureau of Reclamation; Byron, CA)

		Number Fish Inserted by Location				# Primary Released		# Secondary Released								
Date	Time	Primary	Secondary (Sec)	Holding Tank (HT)	Sieve Net (SN)	HT	SN	HT	SN	# SN Released Fish Recovered	# HT Released Fish Recovered	Primary Efficiency (PE)	Secondary Efficiency (SE) Secondary Release	Secondary Efficiency (SE) Primary Release	Secondary Participation (SP)	Whole Facility Efficiency (WFE)
1/17/2008	13:31	130	0	10	10	38	11	0	0	10	10	39%	NA	77%	NA	29%
1/17/2008	14:20	130	0	10	10	70	8	0	0	9	10	62%	NA	89%	NA	54%
1/17/2008	14:41	130	0	10	10	56	7	0	0	10	10	50%	NA	89%	NA	43%
1/17/2008	14:48	130	0	10	10	71	14	0	0	10	9	68%	NA	83%	NA	55%
5/11/2008	12:50	130	0	10	0	37	3	0	0	0	8	32%	NA	92%	NA	28%
5/11/2008	13:10	130	0	10	0	17	1	0	0	0	10	14%	NA	94%	NA	13%
5/11/2008	13:30	130	0	10	0	14	1	0	0	0	10	12%	NA	93%	NA	11%
5/11/2008	15:00	130	0	10	0	37	1	0	0	0	10	30%	NA	97%	NA	28%
5/28/2008	12:30	130	0	0	0	0	0	0	0	0	0	0%	NA	NA	NA	0%
5/28/2008	12:50	130	0	0	0	0	0	0	0	0	0	0%	NA	NA	NA	0%
5/28/2008	13:10	130	0	0	0	1	0	0	0	0	0	1%	NA	100%	NA	1%
12/15/2008	10:37	100	40	10	0	0	0	3	1	0	10	0%	74%	NA	10%	0%
12/15/2008	10:57	100	40	10	0	1	0	3	1	0	10	1%	74%	100%	10%	1%
12/15/2008	11:17	100	40	10	0	0	0	1	1	0	9	0%	49%	NA	5%	0%
12/16/2008	08:23	100	40	10	0	5	3	24	19	0	10	8%	55%	62%	112%	5%
12/16/2008	08:43	100	40	10	0	3	2	32	6	0	11	5%	84%	59%	98%	3%
12/16/2008	09:03	100	40	10	0	4	3	23	16	0	10	7%	58%	56%	100%	4%
12/17/2008	08:23	100	40	10	0	18	4	24	14	0	10	23%	62%	81%	99%	18%
12/17/2008	08:43	100	40	10	0	10	10	30	9	0	10	21%	76%	49%	100%	10%
12/17/2008	09:03	100	40	10	0	16	10	32	10	0	10	27%	76%	61%	100%	16%

APPENDIX 2

Raw Data (Environmental Conditions)

Table A2-1.—Environmental and facility conditions at the Tracy Fish Collection Facility (Bureau of Reclamation; Byron, CA) replicated testing to evaluate primary, secondary, and whole facility efficiency of adult delta smelt (*Hypomesus transpacificus*). The first two replicates completed on 11/10/2003 (denoted with *) were not used for analyses because reported secondary velocities were considered physically impossible to achieve at the TFCF, and, therefore, must be an error.

Date	Time	Temp (°C)	Turbidity (NTU)	Primary Velocity (ft/s)	Secondary Velocity (ft/s)	Primary Bypass Ratio	Secondary Bypass Ratio	Primary Channel Depth (Upstream)	Primary Channel Depth (Downstream)	Depth in Front of Trashrack	Trashrack Differential	Secondary Depth (Upstream)	Secondary Depth (Downstream)
11/10/2003	10:01	15	9.2	3.34	*5.11	1.55	0.94	NA	NA	NA	NA	NA	NA
11/10/2003	11:55	14.4	11.4	3.3	*4.83	1.42	1.02	NA	NA	NA	NA	NA	NA
11/10/2003	19:20	15	15.0	3.23	2.56	1.02	1.64	NA	NA	NA	NA	NA	NA
11/10/2003	20:30	15	12.8	3.22	3.29	1.24	1.31	NA	NA	NA	NA	NA	NA
11/11/2003	9:55	15	6.8	3.57	3.28	1.08	1.44	NA	NA	NA	NA	NA	NA
11/11/2003	11:06	15	8.2	3.16	3.42	1.21	1.38	NA	NA	NA	NA	NA	NA
11/11/2003	19:25	14.4	8.6	3.32	2.96	1.14	1.33	NA	NA	NA	NA	NA	NA
11/11/2003	20:30	14.4	8.5	3.01	3.26	1.29	1.26	NA	NA	NA	NA	NA	NA
11/11/2003	10:27	15	6.2	3.22	3.36	1.18	1.43	NA	NA	NA	NA	NA	NA
11/12/2003	14:05	15	7.2	2.97	3.50	1.27	1.45	NA	NA	NA	NA	NA	NA
11/15/2005	12:04	15	0.3	3.60	4.00	0.95	1.31	16.10	NA	NA	NA	3.60	NA
11/16/2005	12:34	14.7	2.5	4.19	3.50	0.78	1.31	16.00	NA	NA	NA	3.64	NA
11/16/2005	13:14	14.7	1.9	3.11	3.46	1.01	1.32	16.01	NA	17.27	1.26	3.74	NA
11/16/2005	16:15	14.9	1.4	4.06	3.32	1.03	1.37	17.04	NA	18.44	1.40	3.95	NA
11/16/2005	17:00	14.9	1.6	3.66	3.56	1.14	1.34	17.42	NA	NA	NA	3.82	NA
11/17/2005	10:49	14.4	5.4	3.53	3.31	0.95	1.07	15.60	NA	17.57	1.97	2.98	NA
11/17/2005	11:10	14.4	5.4	3.27	3.09	0.96	0.95	15.40	NA	17.57	2.17	2.93	NA
11/17/2005	11:29	14.4	1.9	3.32	3.42	0.90	0.44	15.13	NA	17.60	2.47	2.70	NA
11/18/2005	12:19	14.4	5.5	3.35	2.62	0.66	1.08	15.54	NA	17.61	2.07	3.30	NA
11/18/2005	12:24	14.4	5.5	3.35	2.62	0.66	1.08	15.54	NA	NA	NA	3.30	NA
11/18/2005	12:29	14.4	5.5	3.35	2.62	0.66	1.08	15.54	NA	17.61	2.07	3.30	NA
11/18/2005	16:21	14.7	3.6	3.50	3.33	0.82	1.06	16.55	NA	17.63	1.08	3.57	NA
11/18/2005	16:26	14.7	3.6	3.50	3.33	0.82	1.06	16.55	NA	NA	NA	3.57	NA
5/19/2006	10:05	20.0	5.0	1.85	1.10	1.10	1.20	21.03	20.94	21.25	0.22	9.85	9.76

Table A2-1.—Environmental and facility conditions at the Tracy Fish Collection Facility (Bureau of Reclamation; Byron, CA) replicated testing to evaluate primary, secondary, and whole facility efficiency of adult delta smelt (*Hypomesus transpacificus*). The first two replicates completed on 11/10/2003 (denoted with *) were not used for analyses because reported secondary velocities were considered physically impossible to achieve at the TFCF, and, therefore, must be an error.

Date	Time	Temp (°C)	Turbidity (NTU)	Primary Velocity (ft/s)	Secondary Velocity (ft/s)	Primary Bypass Ratio	Secondary Bypass Ratio	Primary Channel Depth (Upstream)	Primary Channel Depth (Downstream)	Depth in Front of Trashrack	Trashrack Differential	Secondary Depth (Upstream)	Secondary Depth (Downstream)
5/19/2006	10:32	20.0	5.0	1.98	1.24	1.16	1.21	21.31	21.25	NA	NA	9.88	9.77
5/19/2006	11:05	20.0	5.0	1.79	1.26	1.30	1.26	21.59	21.50	NA	NA	9.98	9.87
5/19/2006	11:45	20.0	5.1	1.57	1.22	1.42	1.23	21.68	21.53	21.60	-0.08	9.91	9.81
5/19/2006	12:06	20.0	5.1	1.54	1.21	1.42	1.33	21.62	21.45	NA	NA	9.82	9.71
5/19/2006	12:25	20.0	5.1	1.54	1.21	1.42	1.14	21.57	21.39	21.43	-0.14	9.79	9.69
11/27/2007	12:42	12.4	7.1	2.47	3.07	1.50	1.43	NA	NA	NA	NA	NA	NA
11/27/2007	13:03	12.3	6.5	2.5	3.07	1.49	1.56	NA	NA	NA	NA	NA	NA
11/27/2007	13:24	12.3	4.8	2.51	3.03	1.45	1.53	NA	NA	NA	NA	NA	NA
11/27/2007	18:05	12.2	8.0	2.38	2.53	1.63	1.31	19.27	18.88	19.87	0.60	6.51	5.94
11/27/2007	18:25	12.3	6.5	2.89	2.89	1.66	1.27	19.14	18.73	19.68	0.54	6.40	5.75
11/27/2007	18:46	12.3	6.1	2.32	2.75	1.64	1.36	19.31	18.91	19.91	0.60	6.57	5.98
11/28/2007	15:21	11.3	4.7	2.53	3.08	1.42	1.43	17.54	17.14	17.69	0.15	5.10	4.21
11/28/2007	15:42	11.6	4.7	2.52	3.11	1.44	1.42	17.59	17.61	17.79	0.20	5.15	4.32
11/28/2007	16:01	11.6	5.2	2.51	3.04	1.44	1.42	17.89	17.66	17.89	0.00	5.25	4.48
11/28/2007	19:37	12.1	5.9	2.36	2.93	1.62	1.36	NA	NA	NA	NA	NA	NA
11/28/2007	19:56	12.1	5.0	2.33	2.85	1.64	1.26	NA	NA	NA	NA	NA	NA
11/28/2007	20:17	12.1	4.7	2.33	2.86	1.64	1.26	NA	NA	NA	NA	NA	NA
11/29/2007	12:39	12.0	5.1	2.53	3.05	1.42	1.51	17.42	17.03	18.18	0.76	5.14	4.35
11/29/2007	13:00	11.9	4.9	2.53	3.05	1.42	1.62	17.41	17.02	18.19	0.78	5.12	4.17
11/29/2007	13:21	12.1	4.7	2.52	3.09	1.45	1.63	17.49	17.07	18.43	0.94	5.17	4.34
11/30/2007	13:56	11.8	3.9	2.42	3.00	1.56	1.38	18.43	18.02	18.87	0.44	5.82	5.08
11/30/2007	14:18	11.9	3.5	2.43	3.09	1.58	1.41	18.39	18.05	18.85	0.46	5.70	4.88
11/30/2007	14:41	11.7	3.5	2.46	3.08	1.54	1.45	18.17	17.90	18.65	0.48	5.58	4.76
1/17/2008	13:31	7.8	NA	1.13	2.48	3.23	1.32	20.32	20.14	NA	NA	7.47	7.03

Table A2-1.—Environmental and facility conditions at the Tracy Fish Collection Facility (Bureau of Reclamation; Byron, CA) replicated testing to evaluate primary, secondary, and whole facility efficiency of adult delta smelt (*Hypomesus transpacificus*). The first two replicates completed on 11/10/2003 (denoted with *) were not used for analyses because reported secondary velocities were considered physically impossible to achieve at the TFCF, and, therefore, must be an error.

Date	Time	Temp (°C)	Turbidity (NTU)	Primary Velocity (ft/s)	Secondary Velocity (ft/s)	Primary Bypass Ratio	Secondary Bypass Ratio	Primary Channel Depth (Upstream)	Primary Channel Depth (Downstream)	Depth in Front of Trashrack	Trashrack Differential	Secondary Depth (Upstream)	Secondary Depth (Downstream)
1/17/2008	14:20	7.8	NA	1.14	2.54	3.21	1.33	20.14	20.01	NA	NA	7.25	6.79
1/17/2008	14:41	7.8	NA	1.15	2.61	3.10	1.30	19.97	19.86	NA	NA	7.10	6.63
1/17/2008	14:48	7.8	NA	1.16	2.71	3.39	1.25	19.93	19.81	NA	NA	7.04	6.54
5/11/2008	12:50	14.1	NA	1.19	1.1	1.45	1.64	19.03	19.10	19.05	0.02	7.51	7.41
5/11/2008	13:10	14.6	NA	1.20	1.1	1.42	1.59	18.83	18.95	NA	NA	7.33	7.24
5/11/2008	13:30	14.6	NA	1.20	1.14	1.44	1.50	18.60	18.76	NA	NA	7.09	7.01
5/11/2008	15:00	14.6	NA	1.26	2.45	2.46	1.82	17.92	18.14	NA	NA	5.69	5.21
5/28/2008	12:30	15.2	11.2	1.15	1.03	1.48	1.70	19.70	19.57	NA	NA	8.12	8.05
5/28/2008	12:50	15.2	12.4	1.16	1.01	1.42	1.50	19.52	19.40	NA	NA	7.97	7.90
5/28/2008	13:10	15.1	12.4	1.17	1.02	1.40	1.46	19.36	19.25	NA	NA	7.81	7.74
12/15/2008	10:37	8.9	NA	0.59	0.56	1.62	1.35	NA	NA	NA	NA	NA	NA
12/15/2008	10:57	8.9	NA	0.45	0.60	2.12	1.44	NA	NA	NA	NA	NA	NA
12/15/2008	11:17	9.2	NA	0.45	0.55	2.10	1.44	NA	NA	NA	NA	NA	NA
12/16/2008	08:23	8.8	NA	0.85	2.48	3.97	1.18	NA	NA	NA	NA	NA	NA
12/16/2008	08:43	8.8	NA	0.82	2.59	4.25	2.88	NA	NA	NA	NA	NA	NA
12/16/2008	09:03	8.8	NA	0.81	2.52	4.33	1.22	NA	NA	NA	NA	NA	NA
12/17/2008	08:23	8.0	9.17	0.90	2.52	3.58	1.34	18.15	17.96	18.20	0.05	5.83	5.31
12/17/2008	08:43	8.0	NA	0.91	2.58	4.06	1.25	18.32	18.14	NA	NA	5.96	5.49
12/17/2008	09:03	8.2	NA	0.88	2.46	3.96	1.24	18.51	18.32	NA	NA	6.16	5.71

APPENDIX 3

Effects of Mean Primary Channel Velocity (ft/s) on Adult Delta Smelt Primary Channel Efficiency at the Tracy Fish Collection Facility as a Function of Year of Sampling

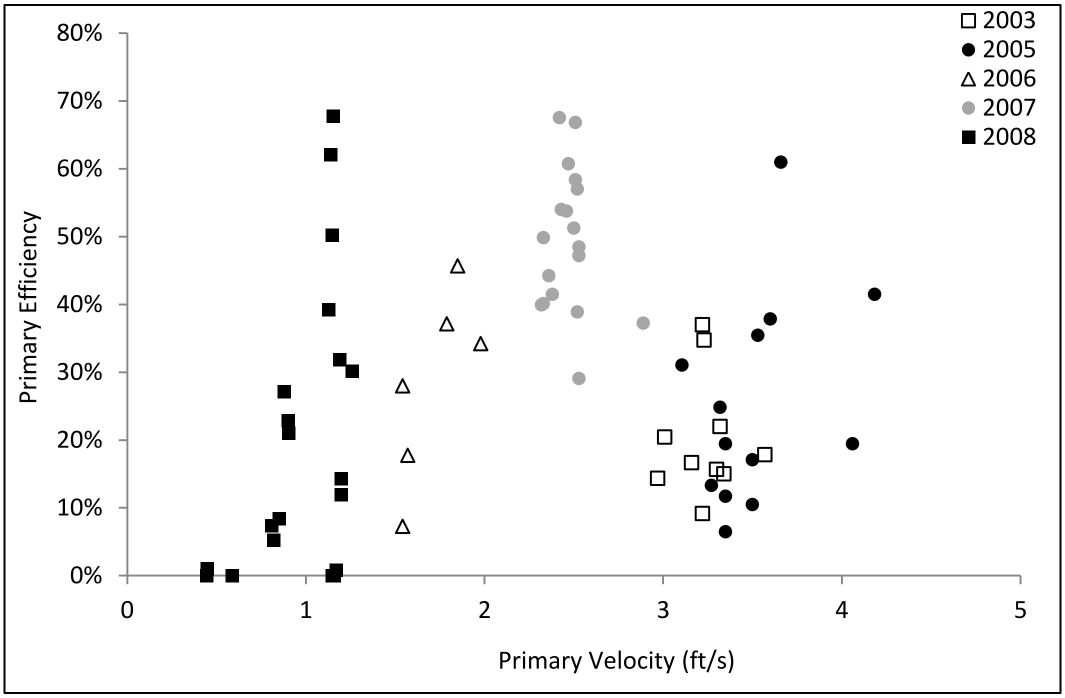

Figure A3-1.—Effects of mean primary channel velocity (ft/s) on primary channel efficiency of adult delta smelt (*Hypomesus transpacificus*) at the Tracy Fish Collection Facility (Bureau of Reclamation; Byron, CA) depicting how different hydraulic conditions were generally evaluated in different years of sampling.

APPENDIX 4

Effects of Secondary Channel Hydraulic Conditions on Secondary Channel Efficiency and Secondary Participation of Adult Delta Smelt (*Hypomesus Transpacificus*) at the Tracy Fish Collection Facility (Bureau of Reclamation; Byron, CA)

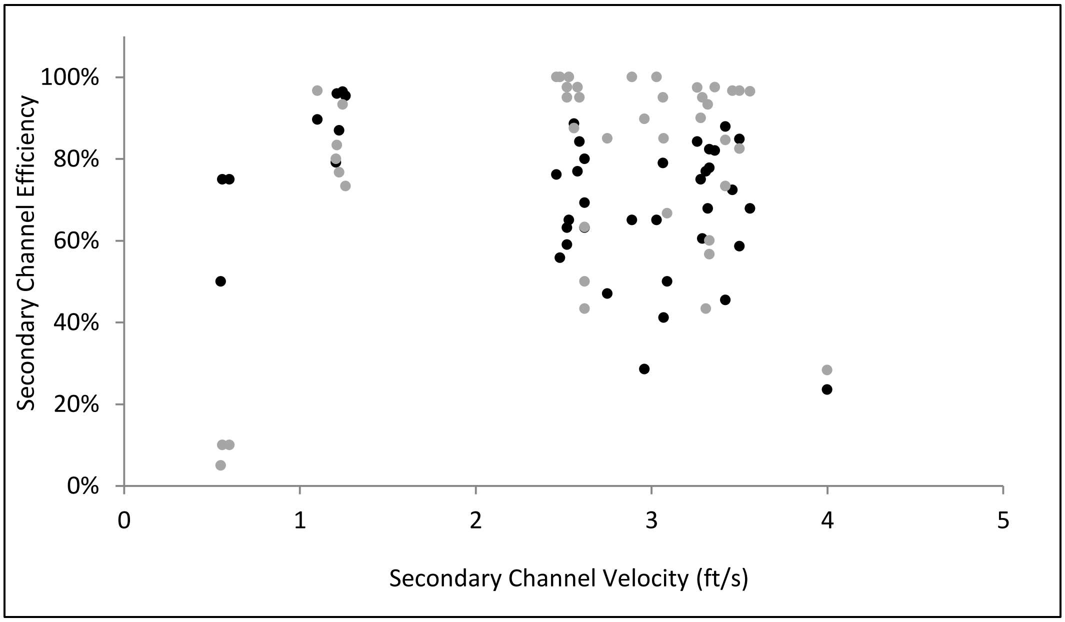

Figure A4-1.—Effects of secondary channel velocity (ft/s) on secondary channel efficiency (black circles) and secondary channel participation (grey circles) of adult delta smelt (*Hypomesus transpacificus)* at Bureau of Reclamation's Tracy Fish Collection Facility (Byron, CA).

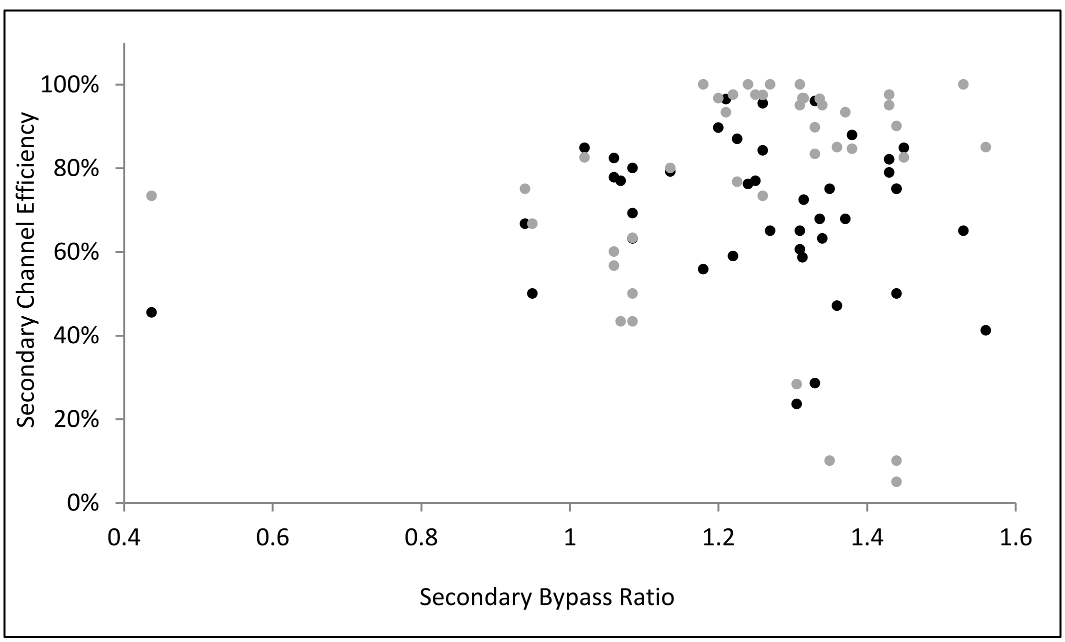

Figure A4-2.—Effects of secondary channel bypass ratio on secondary channel efficiency (black circles) and secondary channel participation (grey circles) of adult delta smelt (*Hypomesus transpacificus)* at Bureau of Reclamation's Tracy Fish Collection Facility (Byron, CA).

APPENDIX 5

Effects of Environmental Conditions During Testing on Primary Channel Efficiency of Adult Delta Smelt (*Hypomesus Transpacificus*) at the Bureau of Reclamation's Tracy Fish Collection Facility (Byron, CA)

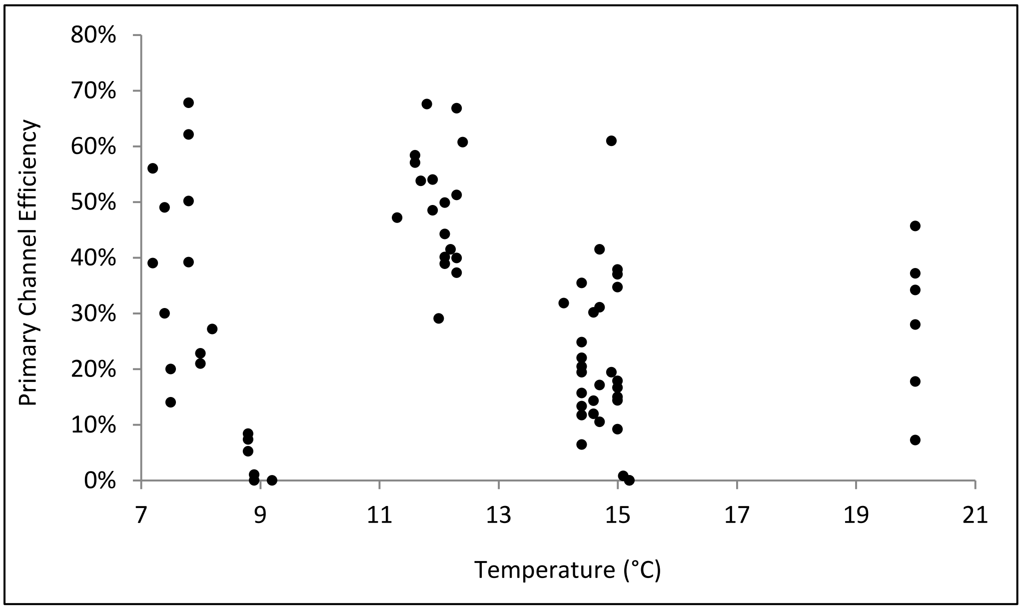

Figure A5-1.—Effects of water temperature (°C) on primary channel efficiency of adult delta smelt (*Hypomesus transpacificus*) at the Bureau of Reclamation's Tracy Fish Collection Facility (Byron, CA). When incorporated into a multiple linear regression model, temperature was not a significant predictor of delta smelt primary channel efficiency (P > 0.05).

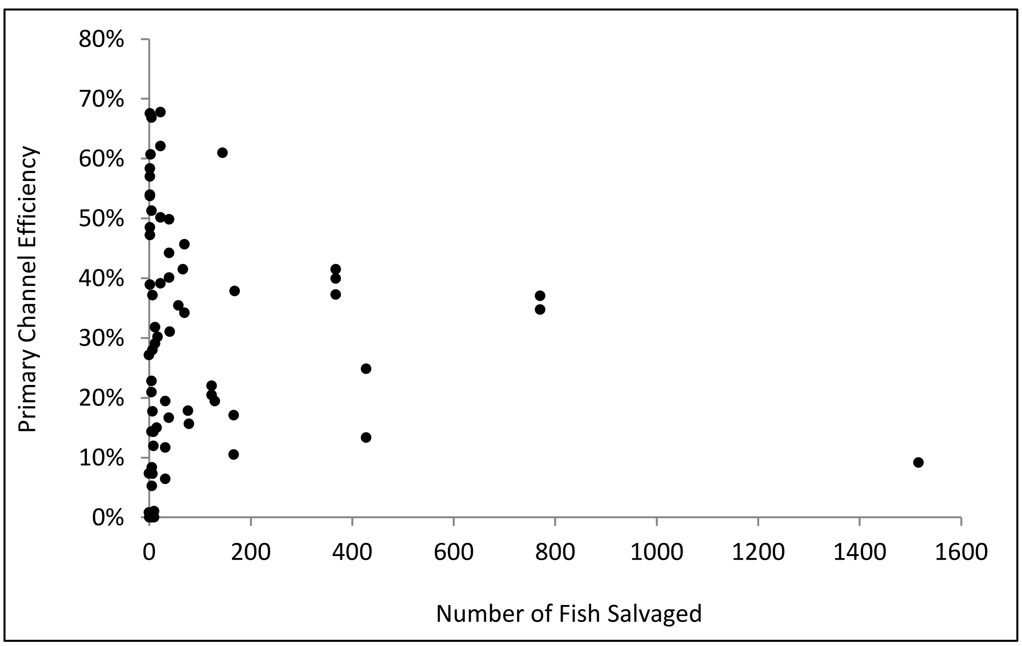

Figure A5-2.—Effects of total number of non-test fish being salvaged at the TFCF during testing on primary channel efficiency of adult delta smelt (*Hypomesus transpacificus*) at the Bureau of Reclamation's Tracy Fish Collection Facility (Byron, CA). When incorporated into a multiple linear regression model, number of additional fish being salvaged was not a significant predictor of delta smelt primary channel efficiency (P > 0.05).

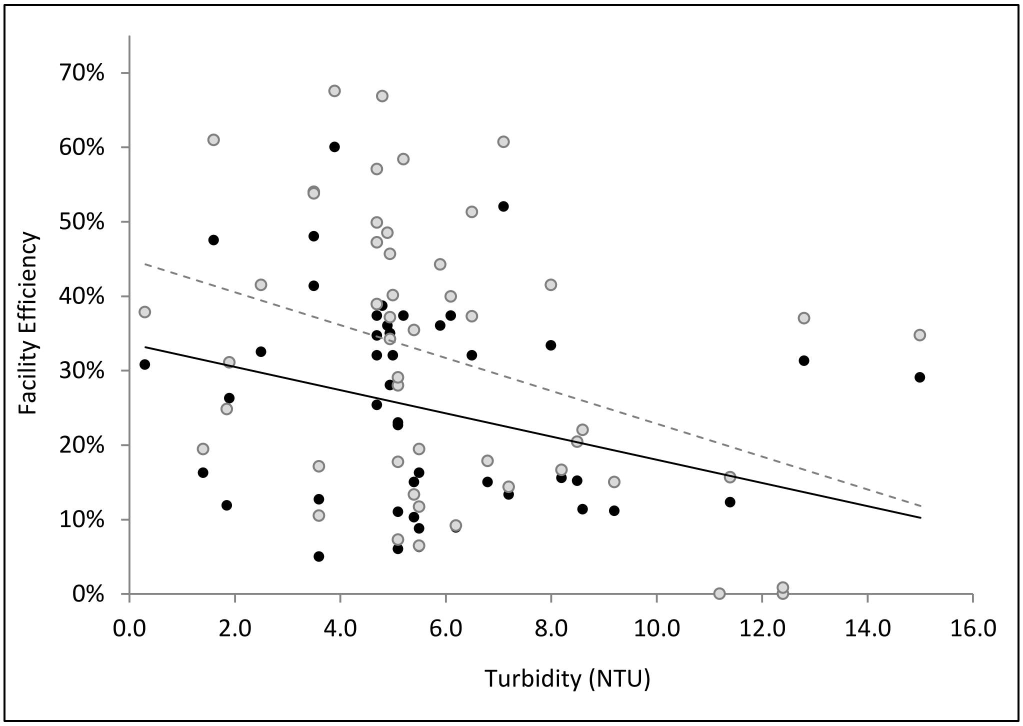

Figure A5-3.—Effects of turbidity (NTU) on primary channel (grey circles, dotted line (R^2 = 0.14)) and whole facility efficiency (black circles, solid line (R^2 = 0.11)) of adult delta smelt (*Hypomesus transpacificus*) at the Bureau of Reclamation's Tracy Fish Collection Facility (Byron, CA). When incorporated into a multiple linear regression model, turbidity was not a significant predictor of delta smelt primary channel efficiency (P > 0.05).

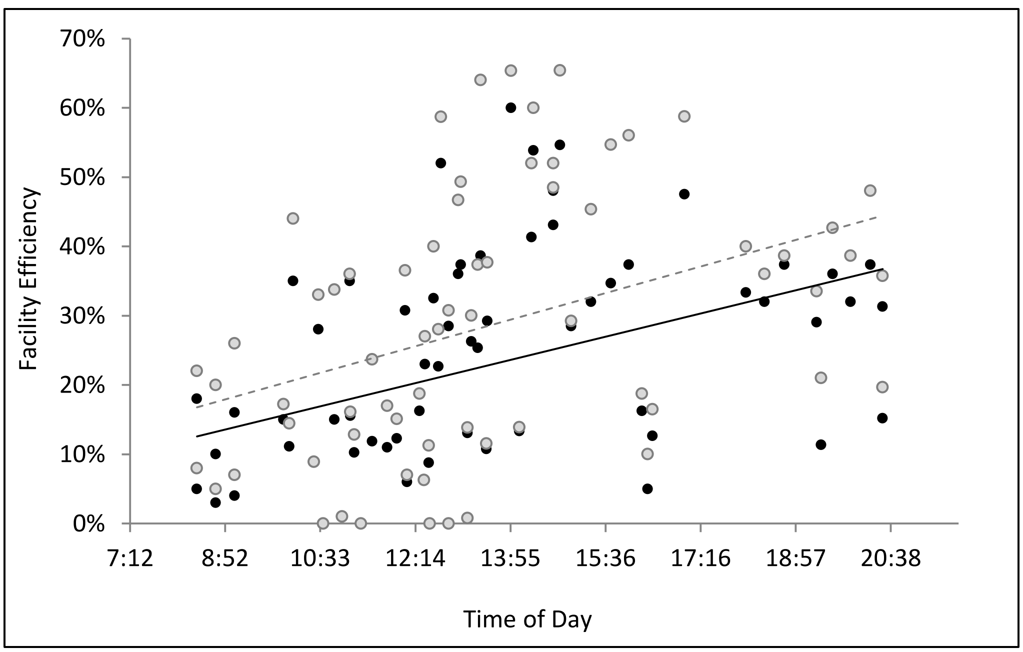

Figure A5-4.—Effects of time of day on primary channel (grey circles, dotted line (R^2 = 0.15)) and whole facility efficiency (black circles, solid line (R^2 = 0.17)) of adult delta smelt (*Hypomesus transpacificus*) at the Bureau of Reclamation's Tracy Fish Collection Facility (Byron, CA). When incorporated into a multiple linear regression model, time of day, was not a significant predictor of delta smelt primary channel efficiency (P > 0.05).

APPENDIX 6

Trashrack Differential at the Tracy Fish Collection Facility (Bureau of Reclamation, Byron, CA)

Figure A6-1.—Downstream looking perspective of the trashrack at the Bureau of Reclamation's Tracy Fish Collection Facility (Byron, CA). The image shows a significant trashrack differential, or difference in water depth upstream and downstream of the trashrack, and how such conditions create turbulent flows in the primary channel.

APPENDIX 7

Summary of Historic Tracy Fish Collection Facility Salvage Efficiency Studies

Table A7-1.—Summary of historic Tracy Fish Collection Facility salvage efficiency studies. Year is reported as the years during which data collection occurred.

Author	Year		Primary Channel Efficiency	Secondary Channel Efficiency	Species Tested	Life-Stage Tested
Bates *et al.* (1960)	1957–1959	Range	—	92–100%	Chinook salmon	juvenile (hatchery)
		Range	—	86–95%	striped bass	juvenile (hatchery)
Hallock (1967)	1966–1967	Range	75–100%	—	striped bass	juvenile (wild)
Hallock *et al.* (1968)	1967		90%	—	Chinook salmon	juvenile (wild)
		Range	2–100%	—	striped bass	larval - juvenile (wild)
Karp *et al.* (1995)	1991–1992	Range	13–82%	72–100%	Chinook salmon	juvenile (hatchery)
		Range	40–96%	30–90%	striped bass	juvenile (hatchery)
Bowen *et al.* (1998)	1993–1995	Grand Mean	—	83%	Chinook salmon	juvenile (wild)
		Grand Mean	—	82%	striped bass	juvenile - adult (wild)
Bowen *et al*. (2004)	1996 - 1997	Grand Mean	—	85.1%	Chinook salmon	juvenile (wild)
		Grand Mean	—	61.5%	striped bass	juvenile (wild)
		Grand Mean	—	65%	delta smelt	juvenile (wild)
Sutphin and Svoboda (2014)	2002	Range	—	80–100%	delta smelt	adult (hatchery)
		Range	—	77–96%	delta smelt	juvenile (wild)
		Range	—	62–100%	delta smelt	juvenile (hatchery)
[A]Sutphin (2014)	2007	Range	36–64%	41–79%	delta smelt	adult (hatchery)
Current Study **Full-Range**	2003 - 2008	Range	0–68%	23–96%	delta smelt	adult (hatchery)
		Grand Mean	30%	67%	delta smelt	adult (hatchery)
Current Study **In-Criteria**	2003 - 2008	Range	9–68%	28–88%	delta smelt	adult (hatchery)
		Grand Mean	39%	64%	delta smelt	adult (hatchery)
[A]Bridges, unpublished	2010	Range	5–31%	91–100%	Chinook salmon	juvenile (hatchery)
		Range	8–26%	56–84%	delta smelt	adult (hatchery)

[A] Sutphin (2014) and Bridges (unpublished) quantified effects of primary channel predator removal on fish salvage efficiency at the Tracy Fish Collection Facility. For appropriate comparison, only data collected before predator removal activities (deemed "normal" conditions) were included in this table. "Current Study" results are isolated by the "Full-Range", or the entire data set collected during testing, and by "In-Criteria", or the data set that was collected when all facility hydraulic parameters were within Chinook salmon operational criteria.