RECLAMATION

Managing Water in the West

Tracy Series Volume 45

Effects of Striped Bass Predation on Salvage of Adult Delta Smelt and Juvenile Chinook Salmon at the Tracy Fish Collection Facility

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14. ABSTRACT

Juvenile Chinook Salmon (*Oncorhynchus tshawytscha*) and adult Delta Smelt (*Hypomesus transpacificus*) are salvaged by the Tracy Fish Collection Facility (TFCF) and can become prey to resident non-native Striped Bass (*Morone saxatilis*). Whole facility efficiency (WFE) was estimated at low pumping rates (1 JPP pump in operation; approximately 26 m^3/sec) before and after Striped Bass were removed from the primary and secondary channels. Experiments consisted of releasing 100 marked test fish downstream from the TFCF trash rack and recording the number making it to a TFCF holding tank. In the Delta Smelt experiment, 74 Striped Bass (123 kg) were removed which increased WFE by 34.0%. In the Chinook Salmon experiment, 56 Striped Bass (161 kg) were removed which increased WFE by 35.2%. Predation rates in the primary channel during the Delta Smelt and Chinook Salmon experiments were approximately 0.5% per Striped Bass and 0.6% per Striped Bass, respectively. The Striped Bass collected in the primary channel, secondary channel, and holding tanks were size segregated, with smaller fish collected further downstream.

15. SUBJECT TERMS
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by

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Executive Summary

Water is exported south through the C.W. "Bill" Jones Pumping Plant (JPP) in the southern end of the Sacramento-San Joaquin River Delta (Delta), California, as part of the Bureau of Reclamation's Central Valley Project. The Tracy Fish Collection Facility (TFCF) serves to salvage entrained fish from the water exported by the JPP. Entrained adult Delta Smelt (*Hypomesus transpacificus)* and juvenile Chinook Salmon (*Oncorhynchus tshawytscha)* can become prey to resident, non-native Striped Bass (*Morone saxatilis)* residing inside the TFCF (Liston et al. 1994, Sutphin et al. 2014, Karp et al. 2017, Reyes et al. In Press); consequently, they are not reported in salvage. Resident Striped Bass are typically larger than 400 mm fork length and cannot leave the facility through the 5.7-cm-wide trash rack spacing. These predators depend on entrained fish entering the facility for forage and likely impact fish survival and salvage at the TFCF.

Experiments to quantify whole facility efficiency (WFE) with domestic Delta Smelt and Chinook Salmon were completed at low pumping rates (1 JPP pump in operation; approximately 26 m^3/sec) before and after removing Striped Bass from the primary and secondary channels to determine predator impact on salvage. Replicates consisted of measuring the proportion of 100 marked test fish released downstream from the TFCF trash rack that made it to the holding tank.

In the Delta Smelt experiment, adult Striped Bass were removed in increments while measuring WFE. This allowed the use of multiple linear regression to predict WFE based on three independent variables: number of predators, light level above the water's surface, and water turbidity. In the Delta Smelt experiment, 74 Striped Bass (123 kg) were removed which increased WFE by 34.0%. Predation rate in the primary channel during the Delta Smelt experiment was approximately 0.5% per Striped Bass.

In the Chinook Salmon experiment, WFE was measured across only one predator removal which reduced variability in environmental influences. In the Chinook Salmon experiment, 56 Striped Bass (161 kg) were removed which increased WFE by 35.2%. Predation rate in the primary channel during the Chinook Salmon experiment was approximately 0.6% per Striped Bass.

Striped Bass collected in the primary channel, secondary channel, and holding tanks were size segregated, with smallest fish collected further downstream. Size segregation is likely influenced by competition, water velocity, and food availability within the facility.

Introduction

The Bureau of Reclamation's (Reclamation) Central Valley Project (CVP) delivers up to three-million acre-feet of water annually for agricultural, municipal, industrial, and environmental needs in California from the Sacramento-San Joaquin River Delta (Delta) through the C.W. "Bill" Jones Pumping Plant (JPP; Figure 1). A Reclamation operated fish salvage facility, the Tracy Fish Collection Facility (TFCF), is located upstream of the JPP and functions to salvage fish entrained in exported water (Bates and Vinsonhaler 1957). Predation by piscivorous Striped Bass (*Morone saxatilis*) is a contributing factor to fish loss at the TFCF. Large (≥ 400 mm fork length [FL]) Striped Bass are able to reside in the primary and secondary channels and likely reduce the number of fish salvaged (Kano 1990, Liston et al. 1994, Gingras 1997, Moyle 2002, and Clark et al. 2009). Potential prey include threatened and endangered species such as Delta Smelt (*Hypomesus transpacificus)* and Chinook Salmon (*Oncorhynchus tshawytscha),* which are typically salvaged in winter and spring at a life stage vulnerable to predation by larger fish (California Department of Fish and Wildlife [CDFW] 2012; Figure 2). Although it is widely recognized that Striped Bass are abundant and consume native listed fish at the nearby Clifton Court Forebay (Gingras 1997, Clark et al. 2009), the abundance and impact are largely unknown at the TFCF.

The goal of this research was to investigate if large resident Striped Bass in the primary channel at the TFCF impact salvage operations enough during low pumping conditions (i.e., one JPP unit on; periodically mandated for the protection of threatened and endangered species) to warrant their removal. There are large labor and material costs to remove these fish on a regular basis; therefore, it is prudent to quantify effects of adult Striped Bass on fish salvage prior to making management level recommendations regarding removal efforts. To achieve our research goal, the project focused on accomplishing four objectives:

1. Quantify the change in whole facility efficiency (WFE) for a known number of adult Delta Smelt and juvenile Chinook Salmon released into the primary channel before and after the removal of Striped Bass.

2. Estimate predation rate on test fish (i.e., the percentage of daily salvage consumed per predator) in the primary channel.

3. Document abundance and body size of Striped Bass in the primary channel, secondary channel, and holding tank during the days of testing.

4. Record Striped Bass morphometric data and water velocity at various locations in the TFCF. Future predator removal techniques will require this background information.

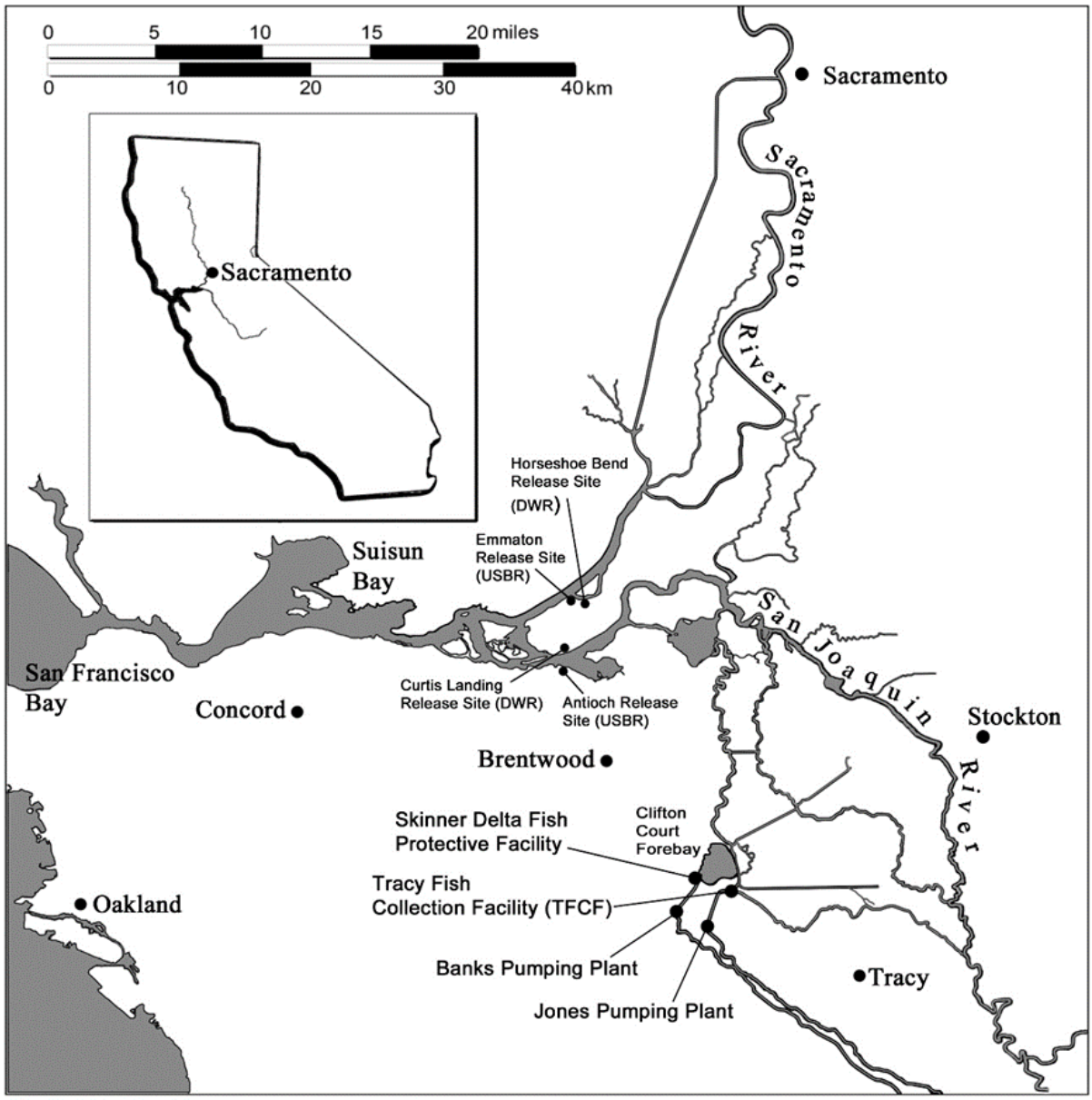

Figure 1.—Map of the Sacramento-San Joaquin Delta showing the location of the Tracy Fish Collection Facility, C.W. “Bill” Jones Pumping Plant, and the fish release sites.

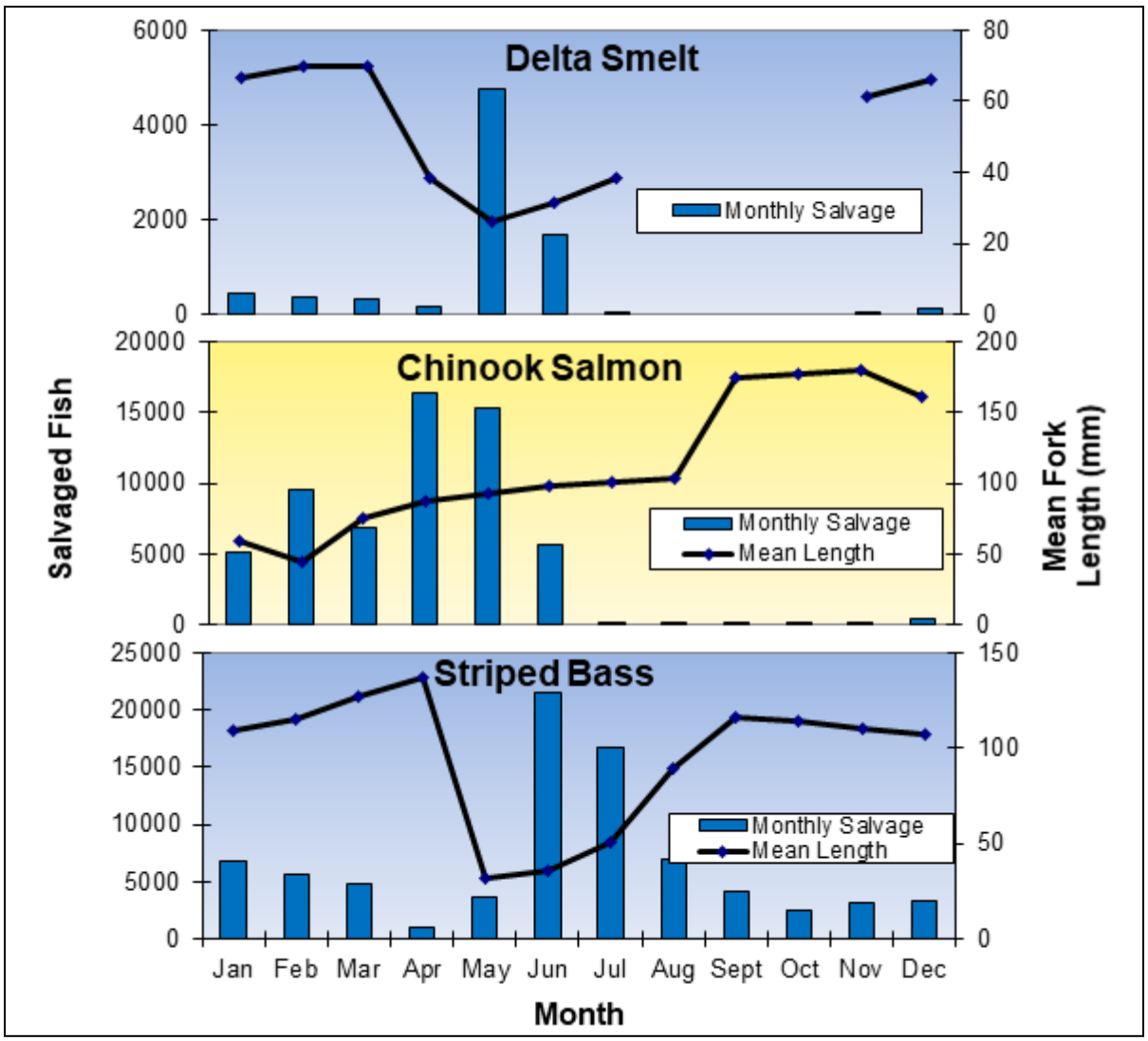

Figure 2.—Delta Smelt, Chinook Salmon, and Striped Bass average monthly abundance and body size salvaged at the Tracy Fish Collection Facility from 1993-2006 (CDFG 2007). Export pumping may be reduced during winter and spring for protection of Chinook Salmon.

Methods

Study Design

Two similar studies were used to measure the impact large resident Striped Bass in the primary channel had on WFE of prey items (i.e., adult Delta Smelt and juvenile Chinook Salmon). Both experiments used a mark-recapture technique to measure the proportion of test fish released near the front of the facility that were recovered in the holding tanks (Karp et al. 1995, Bowen et al. 1998, Sutphin 2014) and measured the change in WFE as a function of the number of Striped Bass removed from the primary channel. Experiments were separated in time to allow for recolonization of Striped Bass in the TFCF primary channel. All Striped Bass collected in the primary and secondary channel predator removals that were capable of eating experimental test fish (prey items <40% of Striped Bass length) were assumed part of the resident population (Hartman 2000). The trash rack, located at the upstream end of the primary channel, was cleaned as needed by facility operators during both experiments.

Being able to predict and control the predator population within the TFCF was important for this study. Immigration (i.e., entrainment and colonization from downstream) and emigration (i.e., swim-out or moving downstream during cleaning activity) of Striped Bass in the primary channel needed to be minimized to reduce predation-related influences that potentially change quickly day-to-day and would have introduced a large amount of variability in the data set. In addition, a method such as gillnetting was needed to quickly deplete the population of large resident Striped Bass in the primary channel.

Optimal testing conditions were satisfied by completing the tests at reduced export pumping (i.e., 1 JPP unit on, 26 m^3/s), which coincidentally occurs yearly during the winter and spring to protect threatened and endangered species. At reduced pumping, the primary louvers—which are periodically raised for cleaning—could be left in the down position for the duration of the test without clogging with debris. This prevented immigration and emigration from the canal downstream. At minimal export pumping, less prey and predator fish are typically salvaged and this condition likely encourages 'small' Striped Bass (ca., <400 mm FL) in the primary channel to leave to find forage. This condition made it more likely that there was not large influxes of small Striped Bass during the experiment. In addition, at reduced export pumping the water velocity in the primary channel was slow enough to fish gillnets safely and effectively.

The two WFE experiments did have a few differences as discussed below.

Delta Smelt

On December 16–19, 2008 a portion of the Striped Bass population in the primary channel was removed prior to each unique trial release of Delta Smelt. This study measured WFE as the predator population was reduced over the 4 d of testing.

Chinook Salmon

On April 21–23, 2009 a known number of Striped Bass were removed all at once, with Chinook Salmon WFE replicates being completed the day before and after the predator removal. This reduced the total number of days needed for testing to three, which helped minimize

environmental differences. Shorter test duration also helped reduce the chance of debris clogging the primary louvers while they were left in place.

Predator Removal

To be able to measure the impact that primary channel Striped Bass have on the salvage process, it was necessary to be able to manipulate the Striped Bass densities in the primary channel, secondary channel, and holding tank. By removing the Striped Bass from the secondary channel and holding tanks before each trial, the change in WFE was attributed to the Striped Bass in the primary channel. Specific details on how the Striped Bass were removed from each area are discussed below.

Holding Tank

Each sample collected in the holding tank was initiated with an empty holding tank. This ensured that no Striped Bass were present at the start of the test.

Secondary Channel

Striped Bass were removed from the secondary channel before releasing test fish to minimize predation taking place in this area. This helped ensure predation influences measured during the test were coming from Striped Bass in the primary channel. Striped Bass removed from the secondary channel in the first removal of each experiment were not considered part of the primary channel population as this was completed prior to the first fish release. Fish removed from additional trials were assumed to have originated from the primary channel rather than the Delta or canal downstream, because the majority of these fish were too wide to pass through the trash rack or louvers.

Striped Bass in the secondary channel were manually captured after dewatering the channel to 0.3 m deep (Liston et al. 1994, Sutphin et al. 2014). As was done by Sutphin et al. (2014), fish within the channel were removed with a beach seine and fish holding in the underground bypass pipes were captured by flushing them into a fyke net (122 cm X 122 cm entrance, 366 cm long, 6 mm mesh). Abundance was recorded for all species collected. Some morphometric information was recorded from these Striped Bass; however, sex and diet were not recorded as these fish were released back to the Delta.

Primary Channel

Striped Bass removals were completed in the primary channel by setting three gillnets (15 m long x 6 m deep, 13.6 kg mono, 13.3 cm stretch mesh) across the primary channel (25.6 m wide; Figure 3). Net size was selected based on previous fishing experience in this area using angling and various sizes of gillnets (7.6, 13.3, and 15.2 cm stretch mesh) during low pumping conditions. The two largest mesh sizes were used in 2006–2008 facility predator removals, but the 13.3-cm net collected the most Striped Bass. Stretch mesh of 13.3 cm effectively targets Striped Bass in the size range of 400–700 mm FL (McRae et al. 2012). Prior angling experience suggested smaller Striped Bass in the primary channel disappeared during low pumping conditions; therefore, gillnet activity for this experiment focused on removing only the larger Striped Bass confined to the primary channel. In addition, by exclusively using a larger mesh, rather than using multiple panes of various sizes, potential bycatch of sub-adult Steelhead (*O. mykiss*) and sturgeon (*Acipenser spp.*) was minimized.

The first four gillnet sets were completed with uniform effort to be able to estimate the total number of large Striped Bass using a depletion method (Lockwood and Schneider 2000). Additional sets of much longer duration (up to 1.25 h) were made after these four primary sets in an attempt to capture all remaining fish. One net was set perpendicular to the flow immediately downstream from the trash rack (Location 1; Figure 3), while the two other nets were set diagonally to the flow in the middle (Location 2; Figure 3) and lower primary channel (Location 3; Figure 3). All three nets were fished simultaneously for 20 min for one set. Each net was set against the north or south wall for 10 min and then shifted to the other side for the remaining 10 min because each net did not span completely across the channel. Steel structures in the primary channel (i.e., louvers and trash rack) were hit with a shovel to make noise and promote fish movement towards the gillnets. Because Striped Bass rarely survived in previous gillnet predator removals, gillnetted fish were euthanized (using 300 mg/L tricaine methanesulfonate [MS-222]) and then body morphometrics (fork length, total length, maximum width, maximum circumference, and weight), sex, and diet were recorded. Morphometrics were collected to provide site-specific body-size data to compare with structures confining the fish to the primary channel (louver and trash rack slot width), and were used to compare fish sizes collected within various components of the facility. Diet data was used to determine if test and wild prey items were consumed.

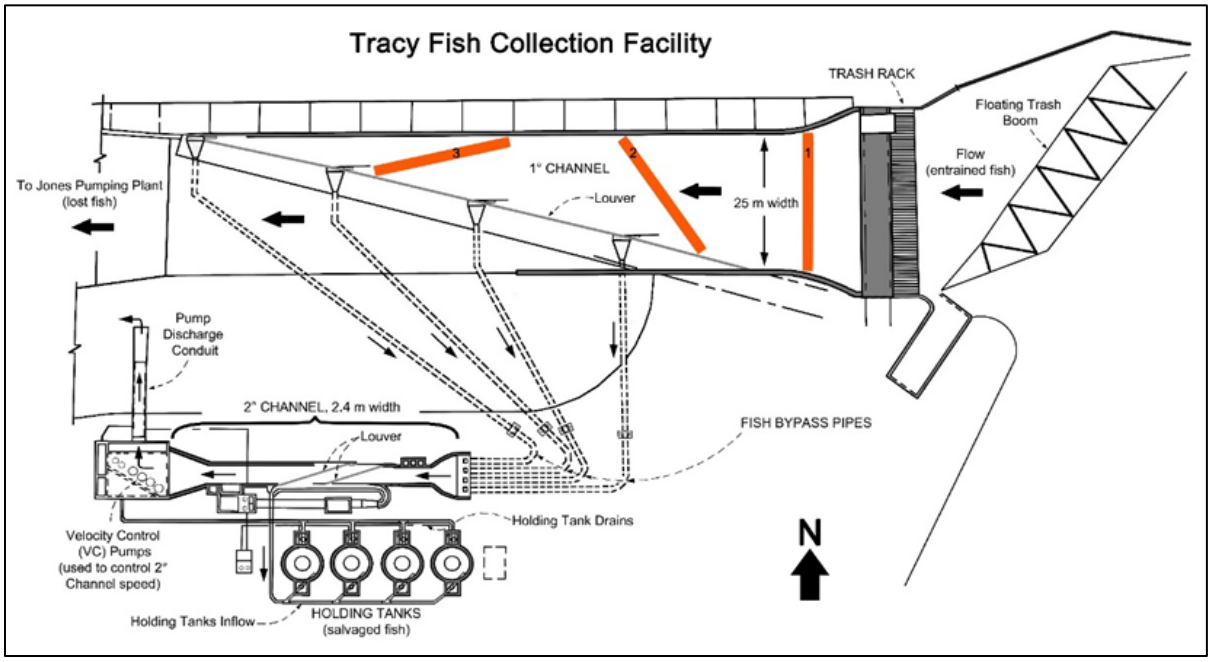

Figure 3.—Schematic of the Tracy Fish Collection Facility showing gillnet fishing locations (orange bars) used to remove Striped Bass from the primary channel.

Fish Source and Care

Adult Delta Smelt were obtained from the University of California, Davis, Fish Conservation and Culture Laboratory (FCCL; Byron, California). Juvenile Chinook Salmon were obtained from the California Department of Fish and Wildlife, Mokelumne River Hatchery (San Joaquin County, California). Both species were held indoors in a temperature-controlled recirculating

system on site at the TFCF in the Tracy Aquaculture Facility (TAF). Chinook Salmon and Delta Smelt were fed daily satiation rations of Nelson and Son's Silver Cup Salmon Crumble and BioKyowa 1000, respectively, and held on a 12L:12D photoperiod. Water temperature was matched to the hatchery from which the fish originated and was slowly manipulated (< 2 °C/d) to match Delta water temperature (8–10 °C December 2008, 19–21°C April 2009).

One week before testing, test fish were sorted, marked, and isolated in new 1.2-m diameter tanks according to release group. Fish were anesthetized (using 100 mg/L MS-222) until loss of equilibrium was reached, measured (mm FL), and externally fin tagged with a needleless injector (Biometrix System-1000; New West Technology, Santa Rosa, California). Tag solution (i.e., photonic marking solution) was injected into one of three fins (i.e., anal, caudal, and dorsal; Sutphin 2008). By using a combination of tag color (blue, pink, green, yellow, and white) and tag location, each release group could be uniquely identified. Subsamples of individual length were recorded from each group to verify that large differences were not present between tagged groups. After tagging, fish were held in 1.2-m diameter outdoor tanks at the TAF in ambient Delta water for approximately one week until they were released. Tag groups were randomly assigned to release order in each experiment.

Predation Experiment

Whole facility efficiency was estimated by releasing uniquely marked groups of Delta Smelt and Chinook Salmon at the upstream ends of the TFCF primary and secondary channels and recapturing them downstream. Test fish were simultaneously released behind the trash rack (100 total), and upstream end the secondary channel (40 total) for each replicate. Fish were recovered downstream in a holding tank or in one of two sieve nets (2.4 x 2.8-m opening, 9-m long, 3-mm mesh) used to capture test fish that passed through the secondary louvers (Karp et al. 1995, Bowen et al. 2004). Sieve nets were lowered and lifted in tandem with holding tank operation (as flow to each holding tank was switched to initiate a new replicate); therefore, sieve net and holding tank samples were treated as paired samples.

Channel water velocity largely determines louver performance (Bates et al. 1960, Meinz 1978); therefore, the primary and secondary channel velocities were routinely monitored. Primary channel velocity ranged from 0.12–0.28 m/s on the incoming tide and was controlled by the JPP. This condition was similar for each experiment. Secondary channel velocity for the Delta Smelt and Chinook Salmon tests were manually controlled with the velocity control (VC) pumps (see Figure 3) and targeted at 0.75 and 0.90 m/s respectively. Operating velocity for the secondary channel ranges from 0.9–1.1 m/s while these species are normally salvaged. The secondary channel velocity was reduced for the Delta Smelt experiment to a value that could be achieved for all trials due to the presence of high tides which limited the maximum attainable channel velocity.

Each trial was initiated by filling an empty holding tank and stabilizing the secondary channel velocity and holding tank flow. Prior to each subsequent release, the water flow was diverted to a new holding tank. At the start of each replicate, all hydraulic information (depth [m], flow [m^3/s], and velocity [m/s]), water temperature (^oC), light (PAR, µmol[photons]/s*m^2), and turbidity (NTU) data were recorded. Secondary channel depths were provided by Hydro Ranger

200 level indicators (Siemens AG, Munich, Germany) while secondary channel and holding tank flow were obtained from Panametrics DF868 flow meters (General Electric Company, Fairfield, Connecticut). Both the real-time and historical data from these meters were used to document velocity at various stations within the TFCF. Outdoor light levels above the water's surface and Delta water turbidity were measured for each fish release period using a model LI-250 light meter with a Quantum sensor (LI-COR, Lincoln, Nebraska) and a 2020 turbidity meter (LaMotte Company, Chestertown, Maryland), respectively.

During each replicate, multiple buckets were used to disperse test fish uniformly across the primary and secondary channels. Only 20–25 fish were placed into each 19-L black bucket to prevent fish from suffocating. Test fish were released once hydraulic parameters were within targeted range (i.e., ±0.05 m/s of target). Fish were released simultaneously at the trash rack and secondary channel with a water-to-water transfer. The distance between the two release sites, as well as the rate of downstream travel in the secondary channel, helped ensure that the two groups of fish had minimal contact with one another in the secondary channel. Fish released into the secondary channel were used to measure both secondary channel louver efficiency and participation. In addition, this release location helped verify that minimal predation was occurring in the secondary channel.

A new group of uniquely-marked Delta Smelt and Chinook Salmon were released every 20 and 30 min, respectively, at both release locations. The number of replicates completed between secondary channel predator removal events consisted of three for the Delta Smelt experiment and six for the Chinook Salmon experiment. The release frequency was lengthened for the Chinook Salmon experiment as this made it easier to meet regulatory criteria of using 30-min fish counts to estimate salvage. The authors realize that the release frequency for each species may not have been long enough to avoid interaction between release groups, which may have resulted in pseudoreplication. Despite this, it is assumed that significant interaction did not occur between release groups during this study.

Paired holding tank and sieve net samples were processed every 20–30 min. Test fish and large predators were euthanized (using 200 mg/L MS-222) and location, time, unique fin mark, and FL were recorded. Stomach contents of piscivorous fish in the samples were examined to account for predation of missing test fish. Wild fish entrained with test fish were identified, counted, measured, and released into a designated holding tank. Length data from Striped Bass collected in CVP salvage were recorded during the month testing occurred to compare against Striped Bass removed during each experiment.

Delta Smelt and Chinook Salmon replicates were monitored for 80 and 150 min, respectively, to ensure hydraulic parameters were as constant as possible as test fish moved through the facility. Monitoring periods were chosen based on previous experience testing these species. Delta Smelt collected after the monitoring period, but within 2 h were reported separately under the heading of 'Flush'. Since the Chinook Salmon experiment only required releasing fish over 3 days, all fish in the holding tank were monitored and reported approximately 18 h after release. The new accumulative totals were reported as 'Overnight Collection'. Fish collected after the monitoring period were reported separately to demonstrate the majority of recovered test fish came in within the designated study period.

Two types of controls were used to verify that the sieve net and holding tank bucket functioned correctly. Prior to starting each experiment, the sieve net was visually checked for holes and then tested by releasing ten test fish immediately upstream of the net. This quick test crudely measured sieve net efficiency to verify it was working properly and verify that unexpected holes had not developed in the net or around the frame (n = 5). Whenever efficiency fell below 95% (>2 fish lost per 50 released) the net was inspected, repaired and retested. Testing was limited to times when the secondary channel was operated at a fast velocity (ca., 0.9 m/s), otherwise the test fish had the opportunity to swim upstream from the net.

A second control was used to verify the holding tank bucket was not leaking. The bucket's internal drain mechanism has failed in the past, resulting in lost samples that could not be easily detected by the operator or biologist. To verify that the system was working correctly, ten tagged test fish were released into the holding tank each time the sample bucket was used to retrieve a sample. The recovery of less than 8 of the 10 control fish indicated that too much of the sample was lost and the data point could not be used. A small amount of loss was expected from test fish adhering to the tank wall or other objects in the tank, as well as impinging on the screen. Despite this, many of these missing fish can be recovered in successive samples, which verifies that the previous sample had adequately collected the control fish. For the purpose of the calculations, sieve net and holding tank efficiencies were consistently high enough to be considered 100%.

Formulas

The WFE formula (Equation 1) in this study measures the percent of fish released from downstream of the trash rack that are recovered in the holding tank. This same formula could also be used to evaluate WFE if fish were released at the floating trash boom, but for the purpose of this study, fish were released downstream of the trash rack to isolate predation influences occurring only in the primary channel. While the WFE formula provides an estimate of the number of fish salvaged, it does not provide information about where fish are lost in the system.

$$WFE = (H/I_P)100 \quad \text{(Eq. 1)}$$

where:
H = Number of fish recovered from the holding tank
I_P = Number of fish inserted into the primary channel behind the trash rack

During this study, test fish released behind the trash rack to measure WFE could be lost in four ways:

1. Swim though primary louvers
2. Eaten by predators within the facility
3. Swim upstream through the trash rack back to the Delta
4. Maintain themselves within the TFCF

Fish that return to the Delta or maintain position within the TFCF (non-participation) should not be considered lost in terms of determining how well the TFCF functions; however, without a technique to determine if this behavior occurred, it was not possible to differentiate between non-

participation, predation, and louver loss. Due to this, all fish not collected in a holding tank after release were considered lost. This was considered a valid assumption because survival studies on tagged juvenile Chinook Salmon near the fish facilities indicate that survival is nearly zero if fish choose to avoid the TFCF (SJRGA 2013). To minimize the impact of non-participation, recovery efforts were long enough to give most fish time to pass through the facility and were uniform in length to compare treatments.

The difference between the WFE estimates before and after removal of predators (L) provides a measure of how much reported salvage (i.e., fish that end up in holding tank) changes due to predator presence and, along with the known number of predators removed (P), allows for the estimation of predation loss rate (Equation 2).

$$\text{Predation Loss Rate} = L/P \quad \text{(Eq. 2)}$$

where:
L = Difference between WFE estimates before and after removal of predators (%)
P = Number of predators removed (Striped Bass)

Primary channel louver efficiency (PLE; Equation 3) measures the percent of fish released from the trash rack that make it to the secondary channel.

$$PLE = ((H+S)/I_P)100 \quad \text{(Eq. 3)}$$

where:
S=Number of fish recovered in the sieve net in the secondary channel

This calculation has many of the same limitations as the WFE; however, loss through the secondary louvers is known. The PLE estimate assumes fish not collected in a holding tank or sieve net in the secondary channel were either preyed upon or traveled through the primary louvers. This provides a conservative, low estimate because the influence of fish maintaining position within the facility or swimming away from the facility was not subtracted out.

Unlike the WFE and PLE estimates, the secondary channel louver efficiency estimate (SLE) accurately measures how well the secondary louver system functions because fish salvaged and lost can be accounted for (Equation 4). The SLE measures the percent of fish swimming downstream towards the louvers that make it to the holding tank. Fish that take up residence in the secondary channel during the trial were not included in this measurement.

$$SLE = (H/(H+S))100 \quad \text{(Eq. 4)}$$

Most fish released into the secondary channel are typically recovered after release because it is a closed system. This makes it possible to measure how many of the test fish participate. This value is known as secondary channel louver participation (SLP; Equation 5). The SLP is helpful in that it can be used to verify there are no unexpected holes in the system and enough time was allowed during the test to recover a majority of the test fish. In addition, when most test fish are recovered it confirms that little predation occurred within the secondary channel. Documenting that little predation occurred in the secondary channel was important for interpreting our results because this study focused on predation occurring in the primary channel.

$$SLP = ((H+S)/I_s)100 \quad \text{(Eq. 5)}$$

where:
I_s = Number of fish inserted into the front of the secondary channel

Analysis

All statistical analyses were completed with Minitab 15 (Minitab Inc., State College, Pennsylvania) or Excel 7.0 (Microsoft, Redmond, Washington), testing at an alpha level of 0.05. Subsamples from Delta Smelt (n = 39) and Chinook Salmon (n = 50) release groups were measured for FL during tagging to verify that groups were similar in length. Group lengths were compared using a Kruskal-Wallis non-parametric analysis of variance on ranks, as the assumptions for a parametric one-way analysis of variance (ANOVA) test could not be met (i.e., normality). If a significant difference was detected among groups, a Dunn's Multiple Comparison Test was used to identify which specific group mean lengths were different from the others. To determine if the small amount of group differences observed were evenly distributed across treatments, a Mann-Whitney U-test was used to compare body length between pre- and post-gillnetted groups.

Primary channel predator removals were evaluated independently for the adult Delta Smelt and juvenile Chinook Salmon experiments. A chi-square test was used to test for independence of gillnet location on Striped Bass catch and an ANOVA was used to determine if Striped Bass length differed across gillnet location. Striped Bass population in the primary channel was estimated using the first four sets of gillnet data using a depletion estimate (Lockwood and Schneider 2000).

Size distributions of Striped Bass collected in the primary channel, secondary channel, and holding tank were plotted for qualitative comparison. Striped Bass caught in the secondary channel during the Chinook Salmon test during pre- and post-gillnetting efforts were tested for differences in size distribution using a Kolmogorov-Smirnov cumulative distribution test. Too few Striped Bass were collected during the Delta Smelt test to make this comparison. Salvaged Striped Bass FLs, measured daily during the facility fish counts for the entire month of each experiment, were used to compare body length between the holding tanks and secondary channel with a Kolmogorov-Smirnov cumulative distribution test. Despite the use of different sampling methods, this comparison was deemed valid because all size classes of fish in the two areas were collected. Size distribution comparison between the primary and secondary channels was not possible as the gillnet selectively removed only the largest fish from the primary channel.

Experimental study designs for Delta Smelt and Chinook Salmon experiments were different, requiring separate approaches for analyzing the data. In the Delta Smelt experiment, predators were incrementally removed over several days between efficiency testing, and environmental and hydraulic conditions changed over time. To evaluate the Delta Smelt data, best subset multiple linear regression was used to identify which independent variables most reliably predict WFE. Linear regression was selected over the logistic regression because the influence on the release group (100 fish released all at once) was of primary interest and not the individual fish. In addition, the coefficients in the equation are easier for general interpretation. Independent variables of interest included primary and secondary depth and velocity, ambient light above the

water, turbidity, primary and secondary bypass ratio (ratio of water velocity inside bypass entrance to velocity in front of the bypass), bypass four entrance velocity (most downstream bypass), accumulative numbers and weight of Striped Bass removed, and wild fish salvaged during the test. To keep the sampling effort uniform between all replicates, only the data from the first 80 mins of sampling was used in the regression. Autocorrelation of the residuals were tested with a Durbin-Watson test. Mallow's Cp, which compares the bias and precision of the full model to the best subsets, was used to evaluate the regression equations and select the optimal independent variables.

In the Chinook Salmon experiment, adult Striped Bass were removed in one effort between the pre- and post-facility efficiency testing. Estimating predator impact on salvage and loss was completed by looking at the difference (±95% Confidence Interval [CI]) between mean WFE values collected with and without predators using the equations described above. This method worked well for the Chinook Salmon experiment as environmental and hydraulic conditions were generally uniform. Chinook Salmon SLE was compared using a parametric two-way ANOVA to test if the fish release locations (primary or secondary channel) or the presence of predators in the primary channel (present or absent) influenced this value.

Striped Bass morphometric data from the primary and secondary channels were plotted with best fit regression trend lines in Excel. Trend lines were used to validate that an appropriate gillnet mesh size was selected to exclusively catch only those fish confined to the primary channel and to estimate both width and weight of Striped Bass that fit through the trash rack.

Historical hydraulic data from the salvage data records were used to investigate water velocity at various points inside the TFCF as a function of JPP pumping rate and seasonal operating criteria (Striped Bass or Chinook Salmon). Water velocity inside the TFCF is highly influenced by the tide; therefore, to standardize the measurements all values were taken when the primary channel was 5.5 m (18.0 ft) deep. The velocity of water exported through the JPP and TFCF depends on the number of JPP pumping units (1–5) operating; therefore, all velocity data was interpreted based on the number of JPP pumping units in operation.

Results

Delta Smelt Experiment

Striped Bass Removed

Predator removal efforts in the primary channel resulted in the collection of 32 Striped Bass (87 kg total biomass) in 5 net sets, and all fish were too large to escape the primary channel (Appendix A). Striped Bass were not preferentially caught ($\chi^2(2,32) = 1.19$, $P = 0.55$) and average body size was not significantly different ($F(2,29) = 1.96$, $P = 0.16$) at any of the three gillnet locations. Each gillnet set progressively caught fewer fish and estimated population size (±95% CI) for Striped Bass (≥400 mm FL) in the primary channel was 34 ± 5 fish.

Overall, 39 Striped Bass ≥400 mm FL were removed from the gillnet and secondary channel removals post gillnetting, indicating that the number recovered was within the population size estimated by depletion fishing (29–39). The actual number of Striped Bass influencing predation results (74) also included those Striped Bass removed in the secondary channel because they were assumed to originate from the primary channel (Appendix B). To estimate worst-case predation scenario, it was assumed that all 74 fish were available to eat test fish. Since the first predator removal effort in the secondary channel was completed prior to releasing Delta Smelt, the total number of Striped Bass removed from the facility of all sizes was 87 fish, of which 45 were ≥400 mm FL (Appendix B).

Striped Bass collected from the primary channel, secondary channel, and holding tanks had group differences (Figure 4). Fewer Striped Bass were caught from the secondary channel on a single day than what was captured in the primary channel. With all removals combined, more Striped Bass were removed from the secondary channel than the primary channel; however, nearly two and one-half times more fish biomass was collected in the primary channel (Appendix A and B). Striped Bass removed in the secondary channel had a wider range in length than the fish from the primary channel, and were smaller overall. The size range difference was expected as the gillnets selectively captured the largest fish, while sampling in the secondary channel and holding tank captured all sizes of fish. Few Striped Bass ≥400 mm FL entered the secondary channel and holding tank in comparison with what was known to be present in the primary channel. The largest Striped Bass (739 mm FL) was collected from the primary channel. Size differences were statistically comparable between the holding tank and secondary channel groups as fish of all sizes were captured from each area. Striped Bass size distribution was significantly smaller in the holding tank than in the secondary channel ($K\text{-}S_{Test} = 0.93$, $K\text{-}S_{Crit} = 0.43$; Figure 4). Differences between holding tank and secondary channel Striped Bass length frequency during the Delta Smelt and Chinook Salmon experiments were likely due to seasonal fluctuations in Striped Bass number and size.

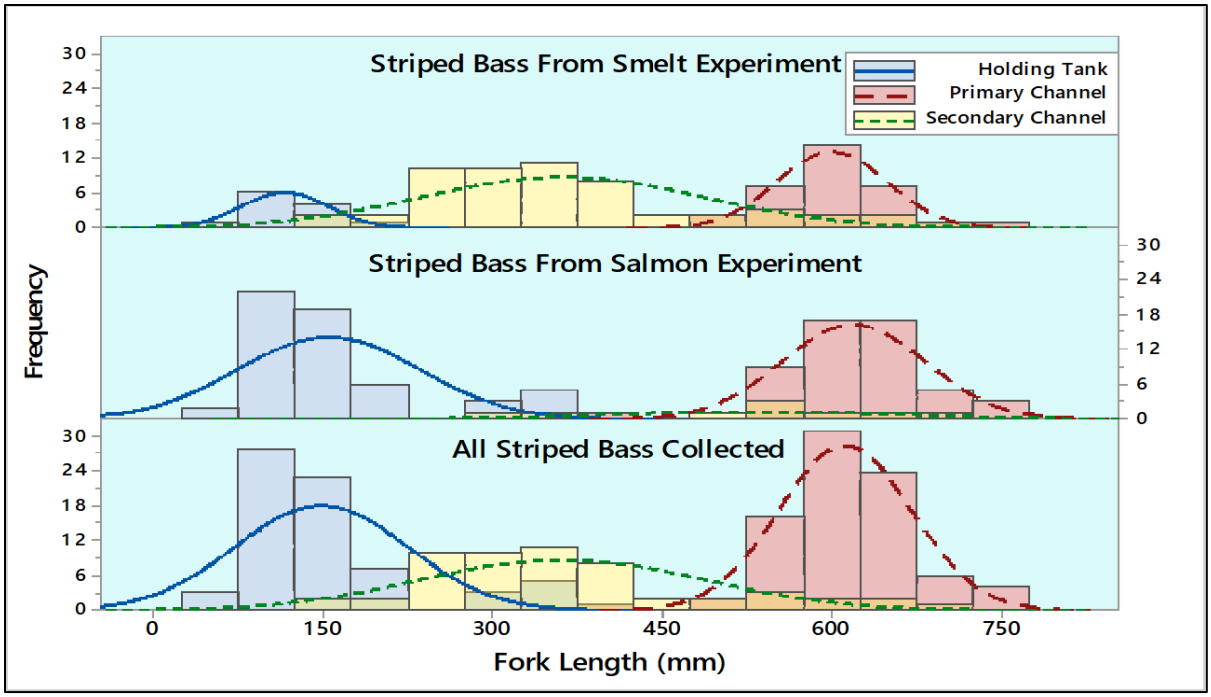

Figure 4.—Striped Bass length frequencies collected in the primary channel, secondary channel, and holding tanks during the Delta Smelt and Chinook Salmon whole facility efficiency testing at the Tracy Fish Collection Facility.

Wild Fish Salvaged

During the Delta Smelt experiment, fewer wild fish (319) were salvaged in relation to the number of test fish released (1500; Tables 1 and 2). Test fish passed through the primary channel at a higher density than wild prey, as groups of 100 fish were released at a time. Wild and test fish in the primary channel provided a prey/predator ratio that ranged from approximately 4:1–73:1 during testing. This estimate is approximate because it assumes that gillnetting was able to remove all predators and it does not take into account the actual number of fish entrained (i.e., there is loss through primary louvers). Threadfin Shad (*Dorosoma petenense*) were the most abundant wild prey item in salvage, and no wild Delta Smelt, Chinook Salmon or Steelhead were salvaged during the experiment.

Table 1.—Species and quantity of fish salvaged during the four days of Delta Smelt testing in the Tracy Fish Collection Facility primary channel to measure large Striped Bass impact on entrained fish.

	Dec 16–19, 2008 Expanded Salvage
Delta Smelt (*Hypomesus transpacificus*)	0
Chinook Salmon (*Oncorhynchus tshawytscha*)	0
Steelhead Trout (*Oncorhynchus mykiss*)	0
Striped Bass (*Morone saxatilis*)	81
White Catfish (*Ameiurus catus*)	16
Channel Catfish (*Ictalurus punctatus*)	37
American Shad (*Alosa sapidissima*)	80
Threadfin Shad (*Dorosoma petenense*)	510
Bluegill (*Lepomis macrochirus*)	112
Splittail (*Pogonichthys macrolepidotus*)	0
Prickly Sculpin (*Cottus asper*)	50
Yellowfin Goby (*Acanthogobius flavimanus*)	73
Inland Silverside (*Menidia beryllina*)	9
Total	**968**

Table 2.—Striped Bass estimated abundance, number of test fish released and number of wild fish recovered during the four days of Delta Smelt testing in the Tracy Fish Collection Facility primary channel. The ratio of prey/predator ranged from 4:1–73:1 during testing.

	Total Prey/Predator During Testing	Striped Bass Assumed Present	Delta Smelt Released	Wild Fish Salvaged During Test
Trial 1	4.2	74	300	12
Trial 2	6.6	48	300	15
Trial 3	28.8	11	300	17
Trial 4	72.6	7	300	208
Trial 5	–	0	300	67
Total			**1500**	**319**

Striped Bass Diet

Diet data, collected from 31 of the 32 gillnetted Striped Bass, revealed that 17 fish were empty and 14 contained wild or test fish. Of the 14 Striped Bass that contained wild or test fish, 7 contained only wild fish, 5 contained wild fish and test fish, and 2 contained test fish only. The high incidence of wild fish eaten is expected since wild fish are continually present at a low density and gut data reflects feeding over an extended period. Gillnetted fish sometimes regurgitate their food; therefore, of those fish with food in their stomach (i.e., maximum predation case scenario), the average (± SD) number of Delta Smelt consumed per Striped Bass was 1.0 (±1.2). Average number of Delta Smelt consumed per Striped Bass in all was 0.5 (±1.0). During the three-day smelt experiment, only 510 Threadfin Shad and 73 Yellowfin Gobies (*Acanthogobius flavimanus*) were salvaged. Both shad and gobies are common prey items for Striped Bass (Nobriga and Feyrer 2008); therefore, test fish were a large fraction of potential prey items.

Change in Salvage and Predation Rate on Delta Smelt

Adult-sized Delta Smelt provided by the FCCL averaged 61 mm FL (1.5 mm SD) and were approximately 4 mm smaller than the size historically salvaged (66 mm FL; see Figure 2 and Appendix C). There was no significant difference in body size between the twelve tagged Delta Smelt release groups (Kruskal-Wallis, n = 39, H = 11.04, $P = 0.44$).

More Delta Smelt were salvaged after predators were removed from the primary channel, and few additional test fish were recovered after the 80 min sample period (Figure 5 and Appendix D). While an increase in WFE was seen between pre- and post-gillnet groups (16.7%; Appendix D), this difference does not adequately indicate the amount of predation that occurred during each trial because predators were removed slowly over time. Multiple regression was a better tool for predicting the amount of predation based on a known number of predators removed. This technique was especially useful since environmental conditions change daily and could be used to help reduce error in the estimate.

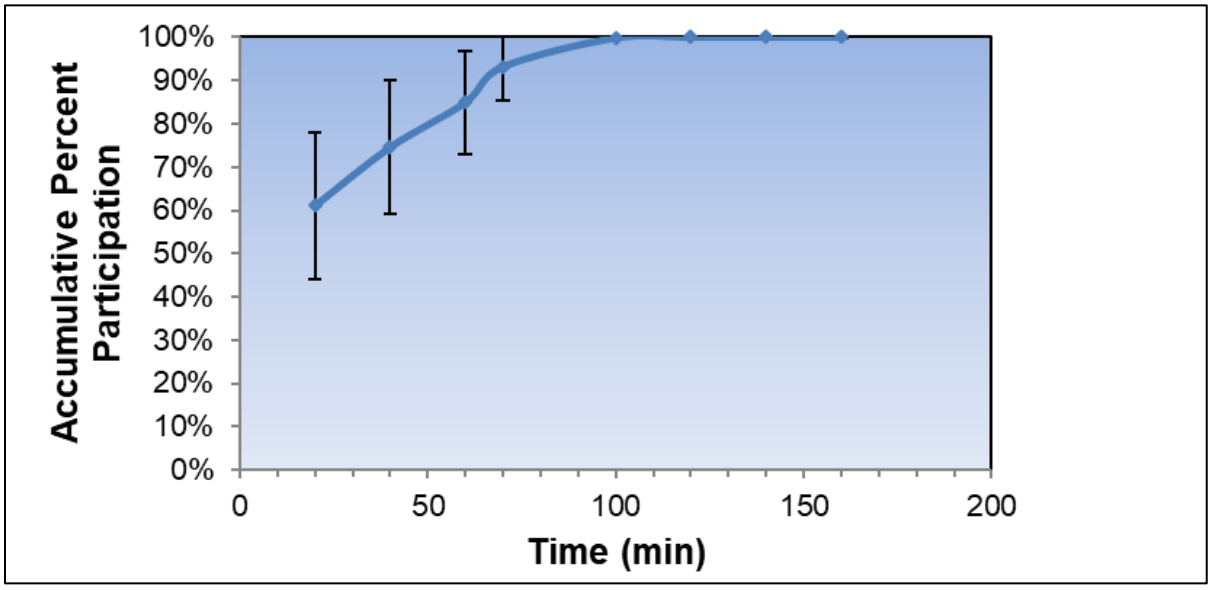

Figure 5.—Accumulative average participation of Delta Smelt released behind the trash rack that traveled to the secondary channel. (Data points represent geometric means with 95% CI).

Best subset linear regression was used to predict Delta Smelt WFE using independent variables (Appendix E). Three independent variables were identified that explained a significant proportion of the variance in WFE ($F(3,11) = 10.38$, $P = 0.002$; Appendix F). The independent variables that best predicted WFE were the number of predators present ($P = 0.001$), water turbidity ($P = 0.056$) and light level above the water's surface ($P = 0.006$, Equation 6). Turbidity was included in the model as it was on the borderline of being significant. These three independent variables explained 66.8% of the variability in WFE estimates (Appendix F) and provided 20.8% more explanatory power than just using the number of predators alone (Equations 6 and 7; Appendix F). The estimated rate of change for the conditional mean of WFE with respect to predation, when turbidity and light were fixed, was between 0.25 and 0.67%. The predation coefficient was 0.46 (Appendix F), which suggests that the predation rate during the Delta Smelt experiment was approximately 0.5% per Striped Bass. The maximum change in

WFE (34.0%) was estimated by multiplying the known number of predators influencing the test (74) by the predation coefficient (0.46).

$$WFE = 10.3 - 0.46P + 4.95T - 0.057AL \quad \text{(Eq. 6)}$$
$$r2(adj) = 66.8\%$$

$$WFE = 28.6 - 0.33P \quad \text{(Eq. 7)}$$
$$r2 = 46.0\%$$

where:
P = Predators present in primary channel
T = Delta water turbidity (NTU)
AL = Ambient light above water (µmol/s*m^2)

Many of the independent variables were not used in the analysis due to multicollinearity. For example, primary and secondary depth were strongly correlated with the number of predators present as predator removal occurred over several days as tide levels slowly dropped. In addition, primary channel velocity, bypass #4 intake velocity, and water surface differential on the trash rack were all correlated and could not be used together in the model. Fortunately, the hydraulic conditions were tightly controlled in this experiment and this allowed us to see the influence of light and turbidity on predation. Using the average turbidity and light levels during the experiment, the predicted WFE values were graphed based on a known number predators in the primary channel (Figure 6).

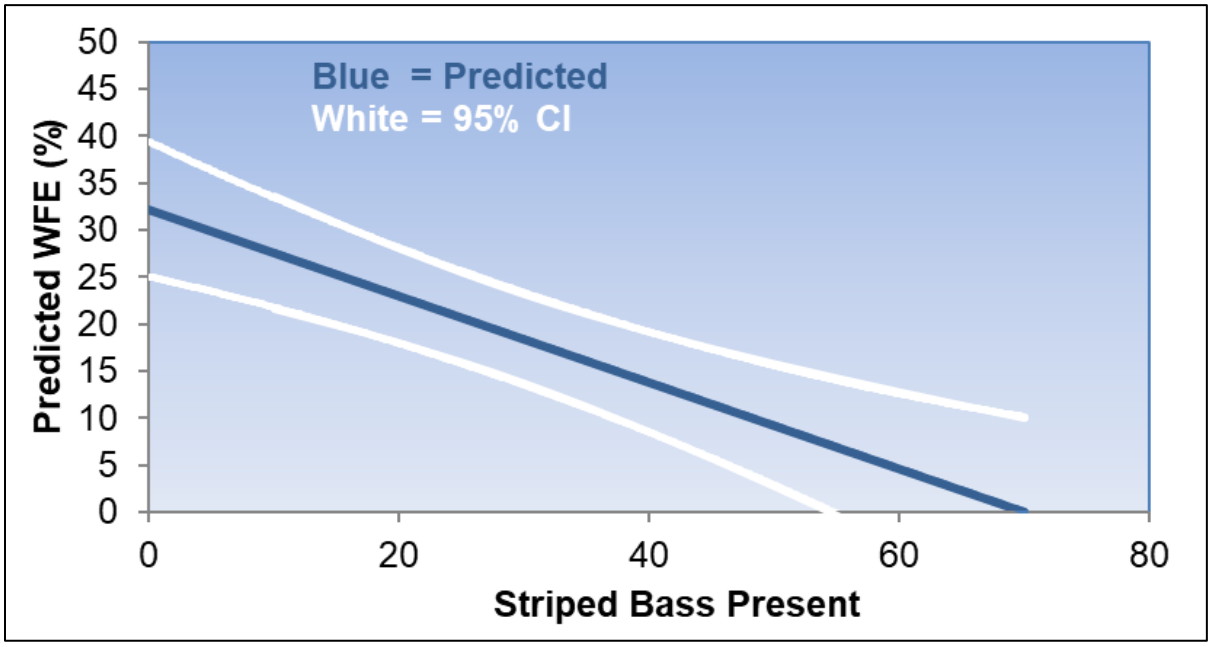

Figure 6.—Predicted whole facility efficiency (WFE) for a release of 100 Delta Smelt when 1 Jones Pumping Plant unit is in operation (Equation 6). Mean turbidity (7.1 NTU) and light (234.5 µmol/s*m^2) levels measured during the experiment were used as constants.

Delta Smelt SLE was not significantly different between those released at the trash rack and at the head of the secondary channel (ANOVA, F(1,28) = 0.21, P = 0.65; Appendix D). Trying to

predict SLE based on the variables measured (Appendix E) was not successful. Best subset regression did not reveal any combination of variables with a $r^2_{(adj)}$ above 34%. This result was expected as secondary velocity and bypass ratio were standardized in all trials and these two factors are known to influence the SLE (Bates et al. 1960, Ducharme 1972, Meinz 1978, Bowen et al. 2004). The mean (± 95% CI) SLE for all Delta Smelt trials was 69.5 ± 4.9% (13.8% SD, n = 30). Delta Smelt participation for those fish released at the head of the secondary channel was nearly 100% for all trials, indicating that very little predation occurred within the secondary channel and fish entering the secondary channel were not taking up residence. Some of the early secondary channel release trials completed before gillnetting indicated that more than all the fish were recovered (ca., 2%). Since it is not possible to recover more than was released, this indicates that the fish were not counted accurately into the buckets, which introduced a small amount of error into the data.

Chinook Salmon Experiment

Striped Bass Removed

In the Chinook Salmon experiment, 52 Striped Bass (156 kg) were removed in 6 gillnet sets in the primary channel (Appendix G). Fish were not preferentially caught ($\chi^2(2,52) = 1.65$, $P = 0.44$) and average body size was not significantly different ($F(2,49) = 0.44$, $P = 0.65$) at any of the three gillnet locations. No population estimate for the Striped Bass confined to the primary channel could be provided because gillnet catch did not decline linearly over time. This method likely failed in the Chinook Salmon experiment because the louvers and trash rack were not hit with metal objects (i.e., shovel) until the later gillnet sets, which caused a spike in catch. Out of all gillnetted Striped Bass, only one was small enough to leave the primary channel upstream through the trash rack.

Striped Bass were removed from the secondary channel prior to releasing test fish each day. Fewer Striped Bass were caught from the secondary channel than the primary channel. As was found in the Delta Smelt experiment, Striped Bass removed in the secondary channel had a wider range in body length than primary channel fish (see Figure 4 and Appendix H). Striped Bass size distributions were different between those captured in the secondary channel and holding tank (Kolmogorov-Smirnov, $K\text{-}S_{Test} = 0.89$, $K\text{-}S_{Crit} = 0.49$). This comparison was valid since fish of all sizes were captured at these two locations.

Overall, 61 Striped Bass were collected in all predator removals but only 56 were present while test fish passed through the facility since 5 Striped Bass were removed from the secondary channel prior to the release of test fish (Appendix H). Out of the 61 Striped Bass collected, only 3 were small enough to pass through the trash rack.

Wild Fish Salvaged

Similar to the Delta Smelt experiment, few wild fish (105) were salvaged during Chinook Salmon trials over the three days of testing. The expanded daily fish salvage for the three days (1734) was greater than the total number of test fish released in all (1200), but not all salvaged wild fish were potential prey (Table 3). Unlike the Delta Smelt experiment, wild Chinook Salmon from the Delta entered the fish facility during the experiment (Figure 7). Test fish likely passed through the primary channel in higher densities than the wild prey items because groups

of 100 were released during the daytime and most of the wild fish entered the facility at night. Wild and test fish in the primary channel provided an average prey/predator ratio of 11:1 [i.e., (600 Test Fish + 26 Wild Fish)/56 Striped Bass] for all species combined during the initial monitoring period (Table 4).

Striped Bass Diet

All Striped Bass caught in the gillnets had empty stomachs even though wild and domestic Chinook Salmon passed through the primary channel the day before. No test fish were released the morning of the gillnetting and overall few prey items were salvaged during these three days of testing (Table 4). It is not known if the empty stomachs were a result of regurgitation or lack of eating.

Table 3.—Species and quantity of fish salvaged during the three days of Chinook Salmon testing in the Tracy Fish Collection Facility primary channel to measure large Striped Bass impact on entrained fish.

	Apr 21–23, 2009 Expanded Salvage
Delta Smelt (*Hypomesus transpacificus*)	0
Chinook Salmon (*Oncorhynchus tshawytscha*)	375
Steelhead Trout (*Oncorhynchus mykiss*)	4
Striped Bass (*Morone saxatilis*)	9
White Catfish (*Ameiurus catus*)	882
Channel Catfish (*Ictalurus punctatus*)	76
American Shad (*Alosa sapidissima*)	0
Threadfin Shad (*Dorosoma petenense*)	20
Bluegill (*Lepomis macrochirus*)	24
Splittail (*Pogonichthys macrolepidotus*)	4
Prickly Sculpin (*Cottus asper*)	332
Yellowfin Goby (*Acanthogobius flavimanus*)	0
Inland Silverside (*Menidia beryllina*)	8
Total	**1734**

Table 4.—Striped Bass estimated abundance, number of test fish released and number of wild fish recovered during the three days of Chinook Salmon testing in the Tracy Fish Collection Facility primary channel. The ratio of prey/predator was approximately 11:1 before the predators were removed.

	Before	**After**
Striped Bass Assumed Present	56	0
Chinook Salmon Released	600	600
Wild Fish Salvaged During Test	26	79
Prey/Predator Ratio	11.2	–

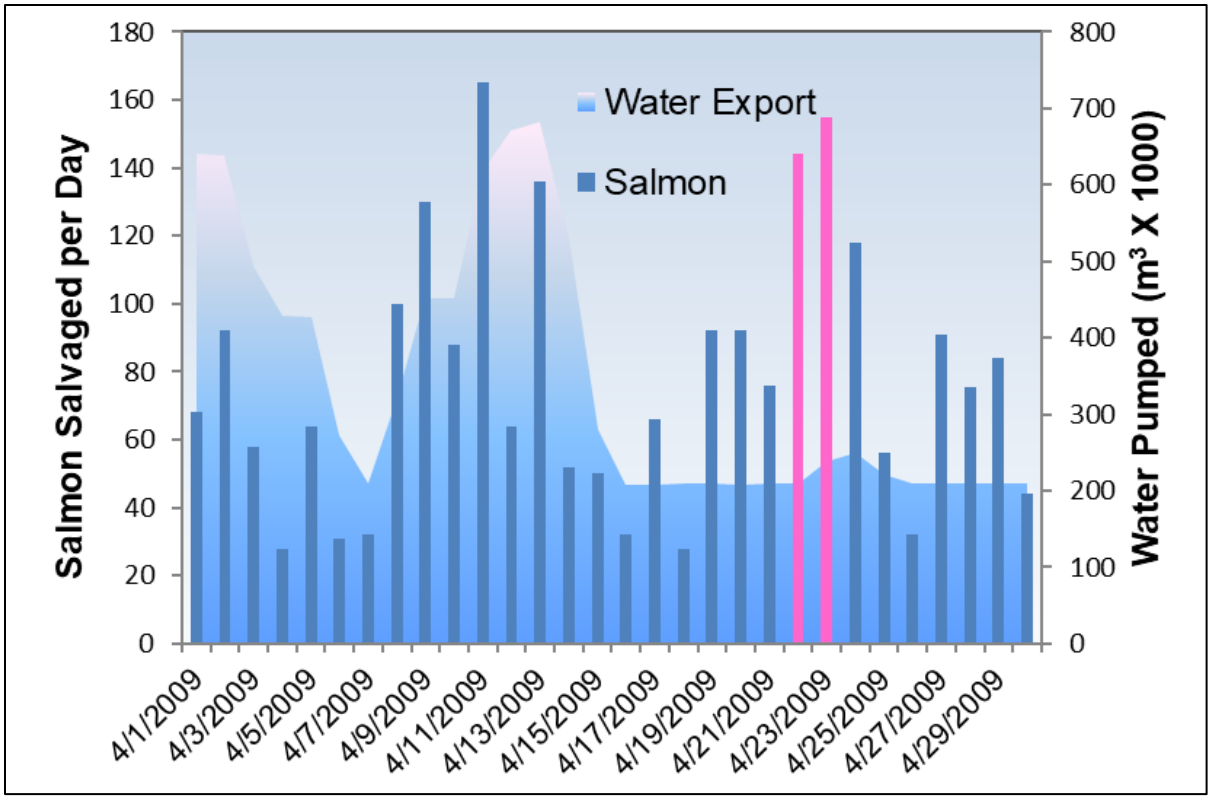

Figure 7.—Wild salmon salvaged per day and water exported through the Tracy Fish Collection Facility. Pink bars denote salvage after the gillnets removed Striped Bass from the primary channel (TFCF expanded salvage data).

Change in Salvage and Predation Rate on Chinook Salmon

Juvenile Chinook Salmon used in the test averaged 72 mm FL (1.7 mm SD), which was 16 mm smaller than the historical monthly average (88 mm FL; Figure 2 and Appendix I). A small difference in Chinook Salmon body length was detected across release groups (Kruskal-Wallis, n = 50, H = 32.45, $P < 0.001$); however, the range of sizes were generally equitably distributed across pre and post releases. When comparing all pre vs post Chinook Salmon lengths there was a small measurable difference in size (Mann-Whitney, W = 82176, $P < 0.001$). While a length difference was detected between the pre and post fish releases, it was not likely this small difference (ca., 1 mm FL) was biologically significant and would greatly influence the salvage results.

More fish were salvaged following the removal of predators. The difference (±95% CI) in Chinook Salmon WFE was 35.2 ± 9.6% and was attributed to the 56 Striped Bass removed (Appendix J). This is equivalent to each Striped Bass reducing WFE by 0.6% (i.e., 35.2% / 56 predators). Hydraulic and environmental conditions were uniform during the three day experiment (Appendix K), which helped ensure prey and predator behaviors were similar when measuring facility efficiency.

Chinook Salmon SLE was analyzed using a two-factor ANOVA comparing the impact of release location and timing of release in comparison to gillnetting. There was no significant main effect based on relation to gillnetting (pre or post, $F(1, 20) = 0.52$, $P = 0.40$) or for fish release location (primary or secondary, $F(1, 20) = 0.87$, $P = 0.36$). In addition, there was no significant

interaction effect ($F(1, 20) = 0.23$, $P = 1.51$). Mean (± 95% CI) SLE for all Chinook Salmon trials was 93.4 ± 2.3% (5.9% SD, n = 24; Appendix J). Chinook Salmon secondary channel participation averaged 94% for all trials, indicating that if predation was occurring in the secondary channel it was only impacting a small percent of fish released.

Striped Bass Morphometrics and Water Velocity

A majority of Striped Bass collected in these experiments were too large to pass through the trash rack. Striped Bass body size measurements indicated that fish approximately ≥400 mm FL should have a difficult time passing through the trash rack (57-mm clear opening) and the gillnet mesh (13.3-cm stretch mesh) should prevent Striped Bass ≥436 mm FL from swimming through the net (Figure 8). Weight data were added to Figure 8 to give the reader a reference for how large these fish were in comparison to their width.

Water velocity within the TFCF changed depending on location within the facility (Figure 9). Generally, water velocity was slowest near the trash rack and peaked entering the holding tank. The JPP pumping and tide together influenced the water flow rate in the primary channel. However, water export had the largest influence on flow rate. The influence of tides on water velocity in the primary channel decreases as JPP pumping increases. Operators at the TFCF have no control of the primary channel velocity; therefore, they have little influence on the primary louver efficiency. Operators control water flow in the secondary channel and holding tanks to achieve appropriate regulatory criteria. While water velocity generally increased with downstream progression through the TFCF, two slow-water refuges were identified within the facility at the beginning of the primary and secondary channels where channel widths are largest.

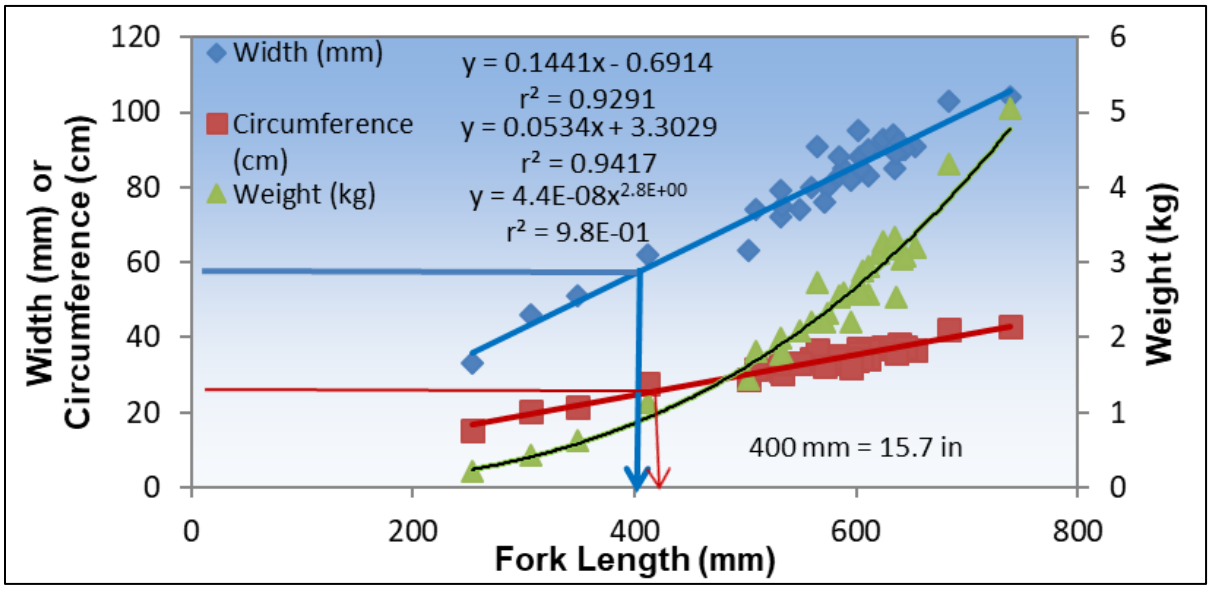

Figure 8.—Striped Bass morphometric data from fish removed in the primary and secondary channels. The wide blue arrow indicates that fish approximately 400 mm FL and above cannot swim through the trash rack and the small red arrow indicates that fish approximately 436 mm FL and above are expected to be caught by the gillnet (13.3-cm stretch mesh).

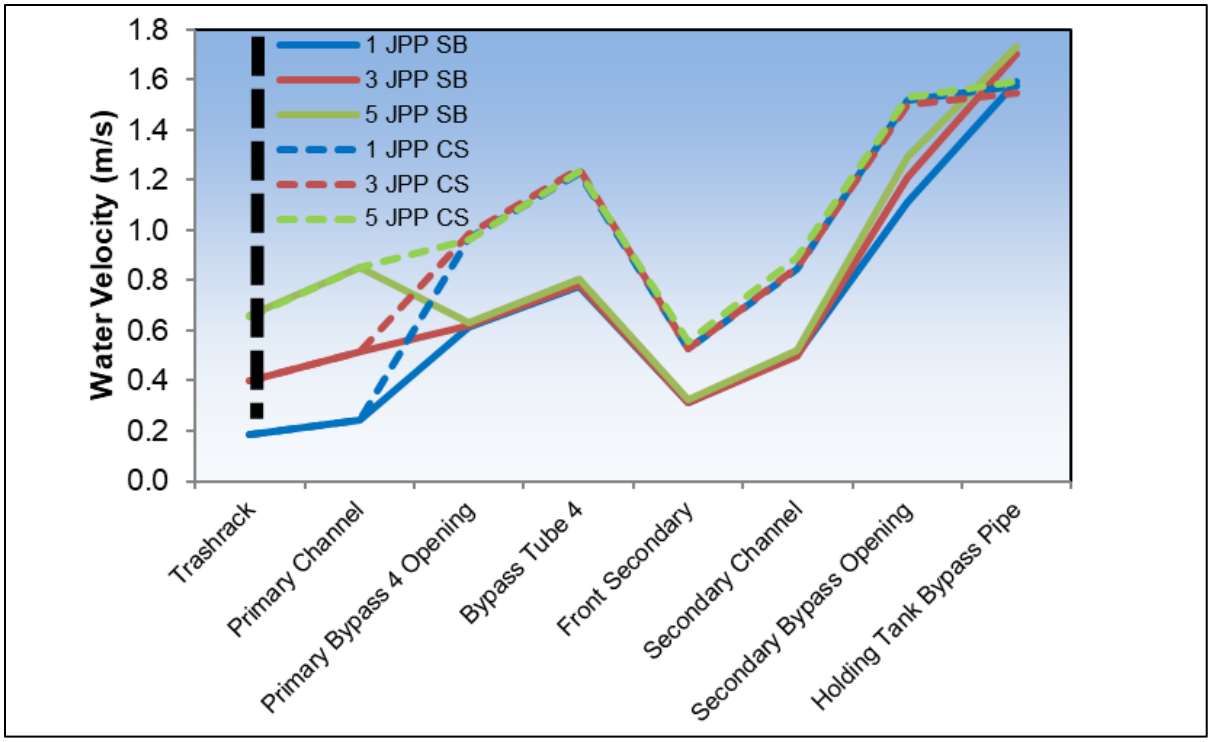

Figure 9.—Water velocities at specific locations within the Tracy Fish Collection Facility (TFCF) are graphed in relation to the number of units in operation at the Jones Pumping Plant (JPP) and operating criteria (Striped Bass [0.5 m/s] or Chinook Salmon [0.9 m/s] secondary velocity). Data were collected from the TFCF daily hydraulic database. To standardize the graph all hydraulic data were taken when water depth in the primary was at 5.5 m. The bold, vertical line represents the location of the trash rack. The graph shows slow water refuges behind the trash rack and at the front of the secondary channel.

Discussion

Results are reported as percent change; however, this format is highly influenced by the number of predators and prey within the facility at the time of testing. Since predatory fish consume a finite amount of prey, results are also expressed in terms of percent of daily salvage consumed per predator. While test results make it possible to evaluate the goal of the study, the information will be difficult to use to predict future predation loss with any certainty because the experiment was completed under a limited range of environmental and hydraulic conditions. In addition, wild fish do not necessarily enter the TFCF exclusively during daylight hours and in groups of 100 fish. However, the data does demonstrate that the Striped Bass predators in the primary channel have the ability to influence the amount of salvaged fish reported daily. Morphometric information on Striped Bass collected during the two predation studies is provided in Appendix L to aid future researchers.

Salvage Impacts

Test results were similar for both prey species (Table 5). Delta Smelt tested in December 2008 when Delta water temperature was near 8 ºC exhibited a 34.0% mean increase in WFE with the removal of 74 Striped Bass. Chinook Salmon tested in April 2009 when Delta water temperature was 21 ºC exhibited a 35.2% mean increase in WFE with the removal of 56 Striped Bass. These values were based on the 80 and 150 min monitoring periods for Delta Smelt and Chinook Salmon, respectively. When the recovery time for capturing test fish was extended, it was evident that the salvage and loss estimates were slightly impacted by delayed passage of fish through the facility until after the experiment had finished. Average WFE for Chinook Salmon when predators were present ranged from 11 to 28% depending on recovery time, and was similar to that found by other agencies at the TFCF (15%; SJRGA 2013). However, even with extended recovery times, WFE only slightly improved. This demonstrates that even if facility louvers are 100% efficient, the National Marine Fisheries Service's TFCF efficiency goal of 75% (NMFS 2009) will never be achieved without controlling the abundance of large resident Striped Bass in the primary channel. When most predators were removed in these experiments, the average WFE increased to 46–56% depending on recovery time. While it is not known how many predators still resided in the primary channel, this low salvage value leads us to believe that a large amount of non-participation is likely occurring from test fish swimming out to the Delta through the trash rack.

Table 5.—Summary table of results from adult Delta Smelt and juvenile Chinook Salmon whole facility efficiency (WFE) experiments investigating the impact of Striped Bass in the primary channel on salvage at the Tracy Fish Collection Facility.

	Delta Smelt	Chinook Salmon
Number Released/Replicate	100	100
Number of Replicates/Trial	3	6
Release Frequency (min)	20	30
Time Trial Monitored (min)	80	150
Predators Removed (P, #)	74	56
Predators Removed (kg)	123	161
Predators >400 mm FL (#)	45	53
Change in WFE due to removal of Predators (L)	34.0%	35.2%
Predation Loss Rate (L/P)	0.5%	0.6%
Primary Channel Vel (m/s)	0.23	0.62
Secondary Channel Vel (m/s)	0.72	0.91
Fish Salvaged/ Day (Avg.)	242	575
Prey/Predator Ratio During Testing	4–73	11
Temp (oC)	8.1	20.8

Predicting a predator's (i.e., Striped Bass) impact on prey (i.e., entrained fish) has traditionally been evaluated by measuring consumption rate (Peckarsky et al. 2008). This study demonstrates that each Striped Bass in the primary channel reduces WFE by approximately 0.5-0.6% (0.5-0.6 prey items per Striped Bass per 100 released; Table 5).

While the number of Striped Bass removed in these two experiments may seem like a large number of fish, greater numbers of Striped Bass are typically removed in the predator removals at higher JPP export rates. An extreme case was the predator removal on April 1, 2010 while the trash rack had been temporarily removed. Striped Bass length frequencies are graphed in relation to those removed in this study to demonstrate that an order of magnitude more fish can be present (Figure 10).

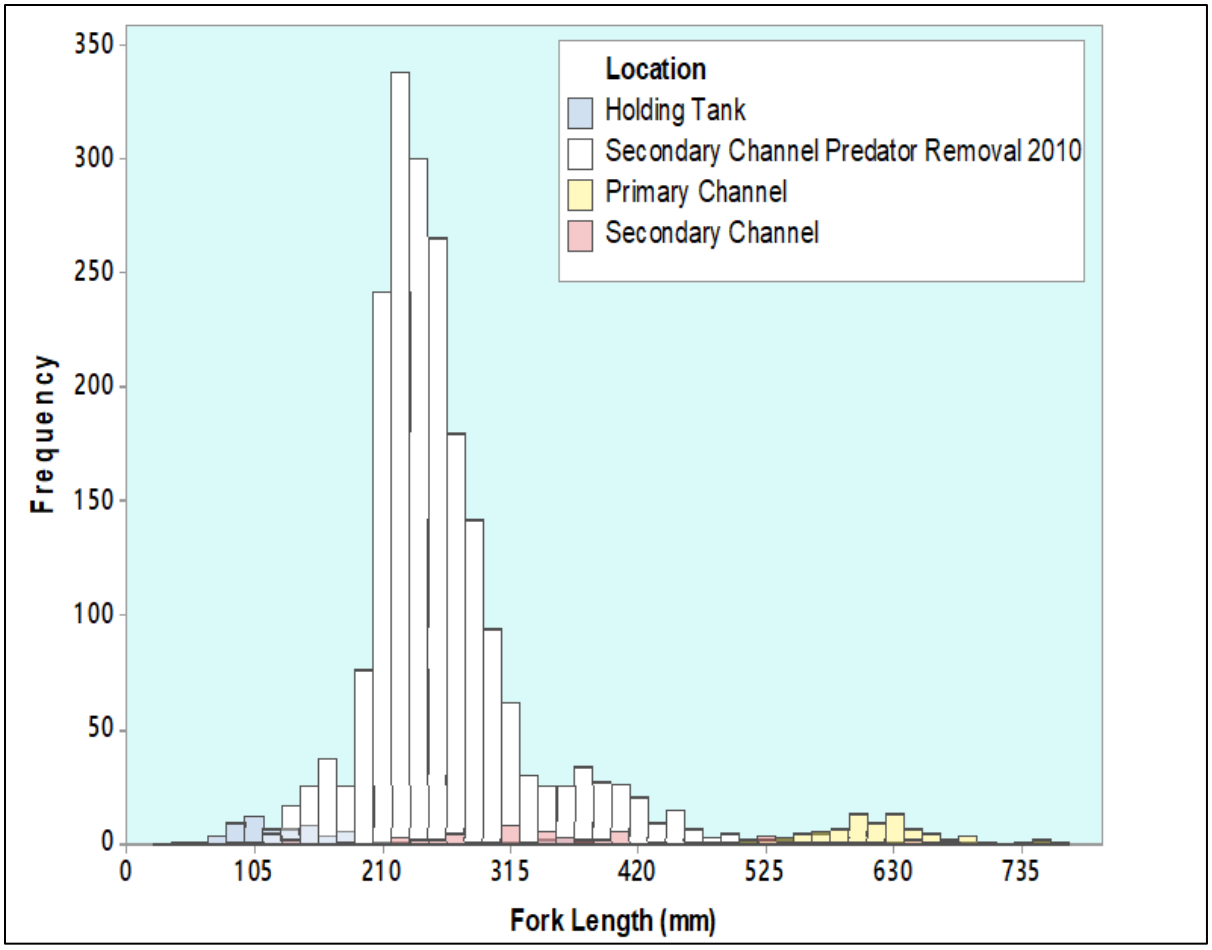

Figure 10.—Striped Bass length frequencies collected in the primary channel, secondary channel, and holding tank during this study graphed in relation to the length frequency of Striped Bass from only one secondary channel predator removal (April 1, 2010), while the trash rack was removed. Striped Bass abundance below 500 mm FL increased in both the salvage and predator removals while the trash rack was temporarily out at the Tracy Fish Collection Facility.

Two different methods were used to evaluate the impact large resident Striped Bass have on the salvage process, and both demonstrated a large decrease in salvage due to their presence. However, the only time of the year this impact could be measured using gillnets was during lowest pumping at the JPP (1 JPP pump in operation). Testing under this condition is theoretically the worst-case scenario for measuring a predator's influence due to the lack of prey in the area and increased interaction time with prey. The prey-to-predator ratio during the Delta Smelt and Chinook Salmon experiments were approximately 4:1–73:1 and 11:1, respectively. Impacts would not likely be as severe with the same number of predators but many times more prey. For example, in Sutphin (2014) the prey to predator ratio was approximately 100–200:1, but no significant difference was detected in salvage rate after predators (35) were removed from the primary channel. A predator to prey ratio could be used to index overall Striped Bass impact and this could be used for adjusting daily loss if predator numbers were known with some reliability. Under most conditions this technique will not work well as predator abundance is not known. In addition, at higher JPP export rates additional variables should influence a predator's impact on the salvage process by changing the number of small (ca., <400 mm FL) predators in

the primary channel, total prey entrained, prey passage rate, success rate of predator capture, and encounter rate. All these items should influence the predator-prey relationship and quickly complicate the process of predicting predation impacts (Krebs 1985).

Whole facility efficiency in both experiments was likely more heavily influenced by large resident predators (98 fish ≥400 mm FL) that could not swim through the trash rack because they were three times more abundant than the smaller fish (32). While many small Striped Bass (<400 mm FL) could have held in the primary channel undetected by the gillnets, this situation was unlikely as previous gillnetting in this area with finer mesh (7.5-cm stretch mesh) during low pumping did not collect many small fish (TFCF unpublished data). Typically, with minimal pumping at the JPP (ca., 1 unit, 26 m^3/s), few prey and predators are salvaged in the holding tanks, as was also seen in this experiment (see Tables 1 and 3). Slower water velocity in the TFCF likely allows a greater size range of fish to freely navigate within the facility and potentially return to the Delta. In addition, reduced pumping likely encourages smaller Striped Bass holding within the facility to leave the facility in search of food because of limited food resources. This mechanism helps explain why past hook and line sampling efforts collected small Striped Bass in the primary channel at high levels of pumping (ca., 5 units, 130 m^3/s) but not at low pumping.

Adult Striped Bass decrease the potential number of fish that can be salvaged directly through consumption and indirectly by chasing prey through the louvers. Non-consumptive effects often play a large role in fish communities (Peckarsky et al. 2008). Both types of loss likely occur, but differentiating between these two types of loss are generally not needed to estimate WFE. Despite this, if loss occurs exclusively by predation, then the impact on salvage should theoretically follow a type II or III functional response (Krebs 1985). Predation impact theoretically decreases with increasing prey abundance up to a threshold where Striped Bass stop feeding (Juanes et al. 2002). Since Striped Bass consume a finite amount of food daily, the amount of loss caused by non-consumptive behavior could be much higher per individual Striped Bass than from ingestion at the TFCF (Juanes et al. 2002).

Striped Bass Accumulation Pattern

While the abundance and seasonal habits of Striped Bass living within the TFCF have not been fully evaluated, a large amount of information is known that can be utilized to discuss Striped Bass accumulation patterns. Striped Bass salvage occurs year round and abundance is inversely related to mean fish length (see Figure 2). Striped Bass captured within the facility (i.e., primary channel, secondary channel, and holding tank), are generally segregated based on size with the largest fish captured in the primary channel (see Figure 4). Adult Striped Bass have the ability to maintain themselves for extended periods inside the primary and secondary channels (Liston et al. 1994, Wu et al. 2015). Adult Striped Bass are entrained in high enough abundance at certain times of the year that they can quickly colonize the secondary channel shortly after a secondary channel predator removal (Sutphin et al. 2014). Once adult Striped Bass reach the secondary channel they have the ability to swim back out to the primary channel (Wu et al. 2015), but data collected on acoustic tagged fish shows this behavior was seldom found (Karp et al. 2017).

In addition to predation, food availability, intraspecies competition, and water velocity are likely the main drivers responsible for partitioning Striped Bass into size classes within the TFCF (see Figure 4). Striped Bass holding behind the trash rack have first access to food entering the TFCF, and this helps explain why larger fish would be more abundant at this location, especially if food is limited. Proximity to resource and not prey density is likely the important driver, as prey density is actually higher in the secondary channel and holding tanks where few of the large Striped Bass were collected. Large fish are known to compete with smaller individuals of the same species for optimal feeding habitat (Matthews 1998). This mechanism is likely contributing to the distribution pattern seen in the facility. In addition to direct competition, water velocity partitions Striped Bass by size class because swimming ability depends on body length (Bainbridge 1957, Haro et al. 2004). Water velocity is not constant throughout the facility. Velocity gradually increases from the head of the channel towards the bypass (see Figure 9). By having two channels connected in series, slow water refuges are available at the front and midway through the salvage process. Predator fish removal efforts have largely focused on removing Striped Bass from the midway refuge, which is located in the secondary channel (Liston et al. 1994, Wu and Bridges 2014, Sutphin et al. 2014). This unique design feature of the TFCF provides separation of fish based on swimming ability, with the strongest staying in the primary channel and weakest forced into the holding tanks.

While this facility design does not effectively remove both prey and predators, we can still use the current design to our advantage if salvage efficiency improvements are requested. Since the facility already segregates the prey from predators, facility improvements should focus on ways to force predators holding in the primary and secondary channels into an empty holding tank periodically. By incorporating an electrical crowder (Svoboda and Horn 2013) or the use of carbon dioxide (CO_2) in the primary channel, as well as a CO_2 treatment in the secondary channel (Wu and Bridges 2014), the TFCF operators could quickly remove all Striped Bass residing within the facility and place them into an empty holding tank.

This study demonstrates that large Striped Bass residing in the TFCF primary channel have the potential to impact salvage operations. These large predators negatively bias the daily salvage and entrainment estimates by removing fish that should be counted in the salvage sampling program. However, predicting Striped Bass daily impact on the salvage process will be difficult to estimate unless their abundance is known or controlled to low levels. Developing techniques for removing the Striped Bass is dependent on knowing that these fish currently reside inside the facility due to confinement, favorable velocity habitat, and food availability.

Conclusions and Recommendations

Long-term, cost-effective strategies for operating the TFCF within criteria (i.e., regular predator removals) are needed. Removing Striped Bass by gillnet is time consuming, expensive, disrupts the normal salvage process, and cannot be completed when the JPP operates with more than one unit. Engineering removal equipment will reduce labor and cost. Over the last several years, two technologies have been developed for removing large fish within the facility (i.e., electric crowder [Svoboda and Horn 2013] and CO_2 [Wu and Bridges 2014]). These new techniques work by interfering with swimming performance and rely on the force of moving water to push Striped Bass downstream. Either technology could be incorporated into the primary or secondary channel operations. Future structural modifications at the facility that prevent large fish from holding in the primary channel or secondary channel for any extended time will cause them to end up in the holding tanks with the juvenile fish. For this reason, methods for separating the adult Striped Bass from the juvenile fish must be considered before installing new devices in the primary and secondary channels to move Striped Bass into the holding tanks.

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Appendix A.—Striped Bass Collected in Gillnets From the Primary Channel Predator Removal Effort During the Delta Smelt Experiment

Table A-1.—Striped Bass (SB) collected in gillnets from the primary channel predator removal effort during the Delta Smelt experiment at the Tracy Fish Collection Facility.

Gillnet Set	SB Caught	Fish < 400 mm FL*	Mean Fork Length (mm)	Std Dev (mm)	Weight Total (kg)	Mean Diameter (mm)	Std Dev (mm)	% with Fish in Stomach	% with Test Fish in Stomach
1	15	0	602	43	41.6	88	7		
2	7	0	611	59	21.0	88	9		
3	6	0	574	62	14.4	79	10		
4	3	0	615	26	7.9	86	4		
5	1	0	636	NA	2.5	89	NA		
All	**32**	**0**	**601**	**48.8**	**87.4**	**86**	**8.4**	**39**	**23**

* = Fish < 400 mm FL can potentially swim through the trash rack.

Table A-2.—Number of Striped Bass (SB) caught at each gillnet location during the Delta Smelt experiment at the Tracy Fish Collection Facility (TFCF). Depletion fishing provided a population estimate (34) and 95% confidence interval (29-39) for the number of Striped Bass in the TFCF primary channel.

Gillnet Location	SB Caught								
1	11								
2	8								
3	13								

Note: There was no significant difference in the number of fish caught at the three gillnet locations ($X^2(2,32) = 1.19$, $P = 0.55$).

Appendix B.—Chronology of Striped Bass Collected and Test Fish Released in the Delta Smelt Experiment

Table B-1.—Striped Bass (SB) abundance and size from the primary and secondary channel predator removals during Delta Smelt predator impact testing at the Tracy Fish Collection Facility. Timing of Delta Smelt releases in relation to the predator removals are provided in the first column. Predators removed from the secondary channel on December 16, 2008 did not influence the results of the Delta Smelt test.

Chronology	SB Caught	Total Weight (kg)	Mean FL (mm)	Std Dev (mm)	Min FL (mm)	Max FL (mm)	Fish < 400 mm FL*	# Male	# Female
Secondary Channel									
Dec 16 AM*** Smelt Released	13	11**	351	149	130	596	9	NA	NA
Dec 17 AM Smelt Released	26	19.9**	352	112	218	648	20	NA	NA
Primary Channel (gillnet)									
Dec 17 Noon	32****	87.4	601	49	503	739	0	15	16
Secondary Channel									
Dec 17 PM Smelt Released	5	4.1**	370	108	253	532	3	NA	NA
Dec 18 AM Smelt Released	4	2.3**	315	132	180	460	3	NA	NA
Dec 19 AM Smelt Released	7	9.7**	447	126	313	678	3	NA	NA
Total Fish	**74**	**123.4**					**29**		

* Fish < 400 mm FL can potentially swim through the trash rack.
** Estimated weight based on fork length.
*** Predators removed on this day did not influence test results and are not included in the row labeled Total Fish.
**** One fish not sexed.

Appendix C.—Delta Smelt Fork Length of Individual Tagged Groups

Table C-1.—Delta Smelt fork length (mm) of individual tagged groups.

	Blue Dorsal	Blue Anal	Yellow Dorsal	Yellow Anal	White Dorsal	White Anal	Violet Dorsal	Violet Anal	Green Dorsal	Green Anal	Pink Dorsal	Pink Anal
N	39	39	39	39	39	39	39	39	39	39	39	39
Median	61	62	59	62	59	57	60	64	63	62	63	62
Average	60	62	60	62	60	60	60	64	63	62	62	63
Std Dev	11.3	9.9	10.8	8.5	9.3	8.3	8.2	9.2	7.1	8.5	9.0	9.2
95% CI	3.5	3.1	3.4	2.7	2.9	2.6	2.6	2.9	2.2	2.7	2.8	2.9
Min	40	40	40	48	41	45	41	45	52	43	41	46
Max	78	84	80	79	81	79	73	82	84	81	80	81

Note: No significant differences were found between group median lengths (Kruskal-Wallace H = 11.04, P = 0.44).

Appendix D.—Delta Smelt Primary and Secondary Channel Louver Efficiency Data

Table D-1.—Delta Smelt whole facility efficiency (WFE), Primary Louver Efficiency (PLE), Secondary Louver Efficiency (SLE), and Secondary Louver Participation (SLP) data pre and post predator removal in the primary channel. The difference between the post and pre predator removal means for WFE and PLE are provided to demonstrate how different the results are from the regression analysis because Striped Bass predators were removed incrementally over time.

	WFE	WFE after Flush	PLE	PLE after Flush	SLE from Primary Release	SLE from Secondary Release	SLP of Secondary Release	SLP of Secondary Release after Flush
Pre-Predator Removal								
12/16/2008	5	5	8	8	63	56	108	108
12/16/2008	3	3	5	5	60	84	95	95
12/16/2008	4	4	7	7	57	61	103	103
12/17/2008	18	18	22	22	82	64	98	98
12/17/2008	10	10	20	20	50	78	103	103
12/17/2008	16	16	26	26	62	76	105	105
Mean	**9.3%**	**9.3%**	**14.7%**	**14.7%**	**62.2%**	**69.9%**	**101.7%**	**101.7%**
Std Dev	**6.4%**	**6.4%**	**9.0%**	**9.0%**	**10.6%**	**11.2%**	**4.7%**	**4.7%**
95% CI	**5.2%**	**5.2%**	**7.2%**	**7.2%**	**8.5%**	**8.9%**	**3.7%**	**3.7%**
Post- Predator Removal								
12/17/2008	9	24	17	38	53	44	100	100
12/17/2008	22	27	37	42	60	55	95	95
12/17/2008	43	43	46	46	94	75	100	100
12/18/2008	21	21	30	30	70	69	98	98
12/18/2008	7	7	14	14	50	88	100	100
12/18/2008	18	18	20	20	90	67	98	98
12/19/2008	36	36	49	49	74	83	100	100
12/19/2008	48	48	56	56	86	93	100	100
12/19/2008	30	30	39	39	77	68	103	103
Mean	**26.0%**	**28.2%**	**34.2%**	**37.1%**	**72.4%**	**71.2%**	**99.2%**	**99.2%**
Std Dev	**14.3%**	**12.7%**	**14.9%**	**13.6%**	**15.8%**	**15.5%**	**2.2%**	**2.2%**
95% CI	**9.4%**	**8.3%**	**9.8%**	**8.9%**	**10.3%**	**10.1%**	**1.4%**	**1.4%**
Difference Between Means	**16.7%**	**18.9%**	**19.6%**	**22.4%**	**10.3%**	**1.3%**	**-2.5%**	**-2.5%**
95% CI Difference Between Means	**13.6%**	**12.3%**	**14.8%**	**13.7%**	**14.8%**	**13.7%**		

Appendix E.—Hydraulic and Environmental Data Collected During the Delta Smelt Efficiency Experiment

Table E-1.—Hydraulic and environmental data collected during the Delta Smelt efficiency test. BR is defined as the bypass ratio (ratio of velocity in the bypass entrance to the velocity in the channel).

	Primary Channel Depth (m)	Primary Channel Velocity (m/s)	Primary Channel BR	Secondary Channel Depth (m)	Secondary Channel Velocity (m/s)	Secondary Channel BR	Bypass 4 Entrance Vel (m/s)	Light (µmol/s m^2)	Turbidity (NTU)	Water Temperature (C)
Pre-Predator Removal										
12/16/2008	5.73	0.26	4.0	6.39	0.76	1.2	0.97	101.3	7.40	8.8
12/16/2008	5.79	0.25	4.3	6.39	0.79	1.1	0.98	136.1	7.40	8.8
12/16/2008	5.83	0.25	4.3	6.61	0.77	1.2	0.97	226.0	7.40	8.8
12/17/2008	5.53	0.28	3.6	5.83	0.77	1.3	0.91	309.6	9.17	8.0
12/17/2008	5.58	0.28	3.7	5.96	0.79	1.2	0.92	355.7	9.17	8.0
12/17/2008	5.64	0.27	3.7	6.16	0.75	1.3	0.90	355.7	9.17	8.0
Post-Predator Removal										
12/17/2008	5.56	0.12	8.3	5.91	0.77	1.3	0.91	168.1	5.09	8.6
12/17/2008	5.52	0.12	8.0	5.77	0.78	1.3	0.92	103.2	5.09	8.6
12/17/2008	5.49	0.15	6.7	5.67	0.79	1.4	0.93	50.6	5.09	8.6
12/18/2008	5.47	0.22	4.4	5.78	0.77	1.4	0.89	400.4	6.97	7.5
12/18/2008	5.52	0.25	3.9	5.96	0.73	1.3	0.87	409.8	6.97	7.5
12/18/2008	5.59	0.25	3.9	6.07	0.73	1.3	0.89	585.1	6.97	7.5
12/19/2008	5.33	0.26	3.6	5.44	0.75	1.4	0.88	94.5	6.86	7.4
12/19/2008	5.39	0.27	3.7	5.54	0.78	1.4	0.89	60.2	6.86	7.4
12/19/2008	5.45	0.25	3.7	5.74	0.73	1.3	0.88	161.1	6.86	7.4

Appendix F.—Regression Analysis on the Delta Smelt Data

Table F-1.—Multiple regression model from the Delta Smelt predation study using the number of predators present as the only independent variable predicting Whole Facility Efficiency (WFE).

WFE Predictors	Coefficient	SE Coef.	T	P
Constant	28.56	3.945	7.24	0.000
Predators	-0.329	0.0989	-3.33	0.005
Source	Df	SS	MS	F P
Regression	1	1312.8	1312.8	11.09 0.005
Resid Error	13	1538.5	118.3	
Total	**14**	**2851.3**		

S = 10.88 r^2 = 46.0% $r^2_{(adj)}$ = 41.9%

Table F-2.—Multiple regression model from the Delta Smelt predation study using the number of predators present, water turbidity, and light level as independent variables predicting Whole Facility Efficiency (WFE).

WFE Predictors	Coefficient	Coefficient ±95% CI	SE Coef.	T	P
Constant	10.32	29.49	13.40	0.77	0.458
Predators	-0.4597	0.209	0.0948	-4.85	0.001
Turbidity	4.951	5.091	2.313	2.14	0.056
Light	-0.0565	0.0365	0.0166	-3.41	0.006
Source	Df		SS	MS	F P
Regression	3		2106.8	702.27	10.38 0.002
Resid Error	11		744.5	67.68	
Total	14		2851.3		

S = 8.23 r^2 = 73.9% $r^2_{(adj)}$ = 66.8%

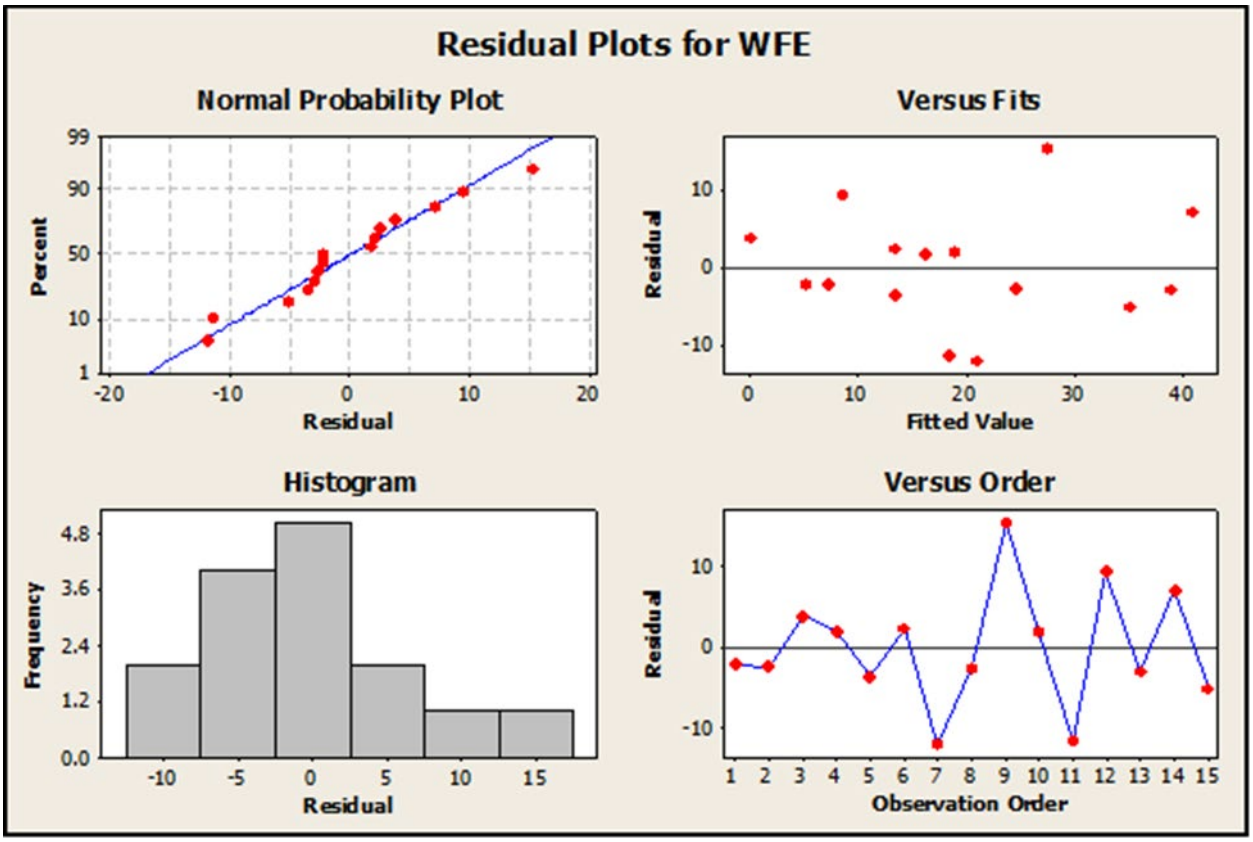

Figure F-1.—Residual plots from the multiple regression equation using predators, light, and turbidity to predict Whole Facility Efficiency (WFE).

Appendix G.—Striped Bass Collected in the Primary Channel Gillnets During the Chinook Salmon Experiment

Table G-1.—Striped Bass (SB) collected in gillnets from the primary channel predator removals completed during the Chinook Salmon experiment at the Tracy Fish Collection Facility.

Gillnet Set	SB Caught	Fish < 400 mm FL*	Mean Fork Length (mm)	Std Dev (mm)	Weight Total (kg)	Mean Diameter (mm)	Std Dev (mm)	% with Fish in Stomach	% with Test Fish in Stomach**
1	31	1	615	65	91.3	87	11	0	0
2	3	0	572	32	6.3	85	2	0	0
3	3	0	593	39	7.7	77	6	0	0
4	3	0	689	65	13.5	100	8	0	0
5	7	0	633	74	22.0	88	10	0	0
6	5	0	641	34	15.5	89	3	0	0
All	**52**	**1**	**620**	**63.2**	**156.3**	**87**	**10.4**	**0**	**0**

* = Fish < 400 mm FL can potentially swim through the trash rack
** No test fish were released the day of gillnetting.

Table G-2.—Number of Striped Bass (SB) caught at each gillnet location during the Chinook Salmon experiment at the Tracy Fish Collection Facility. No population estimate could be provided since gillnet catch did not decline linearly over time.

Gillnet Location	SB Caught								
1	20								
2	19								
3	13								

Appendix H.—Chronology of Striped Bass Collected and Test Fish Released in the Chinook Salmon Experiment

Table H-1.—Striped Bass (SB) abundance and size from the primary and secondary channel predator removals during Chinook Salmon testing. Timing of Chinook Salmon releases in relation to the predator removals are provided in the first column. Predators removed from the secondary channel on April 21, 2009 did not influence the results of the test.

Chronology	SB Caught	Total Weight (kg)	Mean FL (mm)	Std Dev (mm)	Min FL (mm)	Max FL (mm)	Fish < 400 mm FL*	# Male	# Female
Secondary Channel April 21*** Salmon Released	5	15.0**	620	64.5	550	706	0		
Primary Channel (gillnet) April 22	52****	156.3	620	63	380	768	1	39	12
Secondary Channel April 23 Salmon Released	4	4.7**	428	109.3	310	545	2		
Total Fish	**56**	**161.0**					**3**		

* Fish < 400 mm FL can potentially swim through the trash rack.
** Estimated weight based on fork length.
*** Predators removed on this day did not influence test results and are not included in the row labeled Total Fish.
**** One fish not sexed.

Appendix I.—Chinook Salmon Individual Tag Group Sizes

Table I-1.—Chinook Salmon fork length (mm) of individual tagged groups.

	Blue Dorsal	Yellow Anal	Blue Anal	Blue Caudal	Pink Caudal	Yellow Dorsal	Green Caudal	Pink Dorsal	Green Dorsal	Yellow Caudal	Green Anal	Pink Anal
Count	50	50	50	50	50	50	50	50	50	50	50	50
Median	69	71.5	72	72	72	72	72	72.5	74	74	74.5	75
	a	ab	ab	ab	abc	abc	abc	bc	bc	bc	bc	c
Average	69.2	70.0	71.2	71.3	71.8	72.1	72.8	73.6	72.3	72.6	73.3	75.6
Std Dev	6.6	8.4	5.9	6.1	5.7	7.4	5.6	6.8	6.1	6.7	6.9	7.1
95% CI	1.8	2.3	1.6	1.7	1.6	2.1	1.6	1.9	1.7	1.9	1.9	2.0
Min	57	49	55	57	53	56	62	57	59	56	55	55
Max	85	88	89	90	87	94	93	92	85	85	90	93

Note: Significant differences were found between group lengths (Kruskal-Wallace H = 32.45, P = 0.001). Medians that do not share a letter are significantly different (Dunn's test, $P < 0.05$).

Appendix J.—Chinook Salmon Primary and Secondary Channel Louver Efficiency Data

Table J-1.—Chinook Salmon whole facility efficiency (WFE), Primary Louver Efficiency (PLE), Secondary Louver Efficiency (SLE), and Secondary Louver Participation (SLP) data pre and post predator removal in the primary channel.

	WFE	WFE after Overnight Collection	PLE	PLE after Overnight Collection	SLE from Primary Release	SLE from Secondary Release	SLP of Secondary Release	SLP of Secondary Release after Overnight Collection
Pre-Predator Removal								
4/21/2009	31	40	31	41	100	92	95	100
4/21/2009	11	23	13	26	85	97	95	98
4/21/2009	7	20	8	26	88	100	93	98
4/21/2009	7	32	8	36	88	93	103	103
4/21/2009	4	20	5	31	80	97	88	90
4/21/2009	6	31	6	35	100	91	88	98
Mean	**11.0%**	**27.7%**	**11.8%**	**32.5%**	**89.9%**	**95.1%**	**93.3%**	**97.5%**
Std Dev	**10.1%**	**8.0%**	**9.8%**	**6.0%**	**8.3%**	**3.5%**	**5.6%**	**4.2%**
95% CI	**8.0%**	**6.4%**	**7.8%**	**4.8%**	**6.6%**	**2.8%**	**4.5%**	**3.3%**
Post-Predator Removal								
4/23/2009	43	54	44	55	98	98	103	103
4/23/2009	46	57	48	60	96	88	83	90
4/23/2009	50	62	51	63	98	97	93	98
4/23/2009	43	53	46	56	94	100	105	108
4/23/2009	45	55	51	61	88	97	95	98
4/23/2009	50	54	53	58	94	83	90	95
Mean	**46.2%**	**55.8%**	**48.8%**	**58.8%**	**94.6%**	**93.9%**	**94.6%**	**98.3%**
Std Dev	**3.2%**	**3.3%**	**3.4%**	**3.1%**	**3.6%**	**6.7%**	**8.3%**	**6.1%**
95% CI	**2.6%**	**2.6%**	**2.7%**	**2.4%**	**2.9%**	**5.3%**	**6.6%**	**4.8%**
Difference Between Means	**35.2%**	**28.2%**	**37.0%**	**26.3%**	**4.7%**	**-1.2%**	**1.3%**	**0.8%**
95% CI Difference Between Means	**9.6%**	**7.9%**	**9.4%**	**5.9%**				

Appendix K.—Hydraulic and Environmental Data Collected During the Chinook Salmon Efficiency Experiment

Table K-1.—Hydraulic and environmental data collected during the Chinook Salmon efficiency test. BR is defined as the bypass ratio (ratio of velocity in the bypass entrance to the velocity in the channel).

	Primary Channel Depth (m)	Primary Channel Velocity (m/s)	Primary Channel BR	Secondary Channel Depth (m)	Secondary Channel Velocity (m/s)	Secondary Channel BR	Bypass 4 Entrance Vel (m/s)	Light (µmol/s m^2)	Turbidity (NTU)	Water Temperature (C)
Pre-Predator Removal										
4/21/2009	5.30	0.20	5.24	1.55	0.92	1.45	0.99	1038.2	18.1	20.2
4/21/2009	5.39	0.18	6.32	1.60	0.94	1.38	1.03	1685.5	14.2	20.2
4/21/2009	5.47	0.15	7.40	1.63	0.94	1.33	1.05	1313.2	19.5	20.1
4/21/2009	5.52	0.17	6.40	1.69	0.91	1.31	1.02	1194.3	14.9	20.1
4/21/2009	5.59	0.18	6.06	1.75	0.88	1.32	1.02	1297.2	15.9	20.6
4/21/2009	5.67	0.17	6.75	1.80	0.89	1.33	1.05	1069.6	14.9	20.4
Post-Predator Removal										
4/23/2009	5.30	0.17	6.33	1.53	0.92	1.45	0.98	1681.5	25.5	20.9
4/23/2009	5.29	0.15	6.92	1.51	0.92	1.47	0.98	1673	21.9	21.1
4/23/2009	5.30	0.20	5.41	1.53	0.93	1.44	1.00	1171.4	25.3	21.1
4/23/2009	5.41	0.23	4.80	1.62	0.92	1.33	1.01	948.1	20.9	21.2
4/23/2009	5.49	0.23	4.84	1.67	0.91	1.36	1.04	1498	20.2	21.2
4/23/2009	5.57	0.23	4.84	1.74	0.89	1.37	1.03	1653	24.7	21.4

Appendix L.—Striped Bass Morphometric Data Collected During the Chinook Salmon and Delta Smelt Experiments

Table L-1.—Striped Bass morphometric data.

Date	Activity	Total Length (mm)	Fork Length (mm)	Width (mm)	Circumference (cm)	Weight (kg)	Gender
12/17/2008	Secondary Predator Removal	272	253	33	15.1	0.21	
12/17/2008	Secondary Predator Removal	561	532	72	31.1	1.77	
12/17/2008	Secondary Predator Removal	441	412	62	27.7	1.13	
12/17/2008	Secondary Predator Removal	331	306	46	20.4	0.42	
12/17/2008	Secondary Predator Removal	377	349	51	21.6	0.62	
12/17/2008	Primary Predator Removal	572	533	75	30.5	1.8	M
12/17/2008	Primary Predator Removal	627	588	85	35	2.59	F
12/17/2008	Primary Predator Removal	735	684	103	42	4.31	M
12/17/2008	Primary Predator Removal	567	532	79	33	1.98	M
12/17/2008	Primary Predator Removal	642	602	95	37	2.74	M
12/17/2008	Primary Predator Removal	613	574	80	33	2.32	F
12/17/2008	Primary Predator Removal	601	559	80	34.5	2.2	M
12/17/2008	Primary Predator Removal	685	641	90	37	3.04	M
12/17/2008	Primary Predator Removal	645	603	88	34.5	2.67	M
12/17/2008	Primary Predator Removal	626	585	88	35	2.55	F
12/17/2008	Primary Predator Removal	641	600	84	34	2.58	F
12/17/2008	Primary Predator Removal	665	620	91	37	3.12	F
12/17/2008	Primary Predator Removal	663	624	93	37.5	3.27	M
12/17/2008	Primary Predator Removal	704	653	91	36.5	3.2	F
12/17/2008	Primary Predator Removal	680	634	94	37	3.21	F
12/17/2008	Primary Predator Removal	630	584	83	34.5	2.54	M
12/17/2008	Primary Predator Removal	652	606	88	36	2.88	F
12/17/2008	Primary Predator Removal	787	739	104	43	5.05	M
12/17/2008	Primary Predator Removal	604	565	91	36.5	2.73	F
12/17/2008	Primary Predator Removal	655	611	90	36.5	2.95	M
12/17/2008	Primary Predator Removal	644	602	84	36	2.63	F
12/17/2008	Primary Predator Removal	615	571	76	32.5	2.2	M
12/17/2008	Primary Predator Removal	536	503	63	29	1.44	F
12/17/2008	Primary Predator Removal	536	509	74	31.6	1.82	M
12/17/2008	Primary Predator Removal	660	611	83	34.4	2.58	M
12/17/2008	Primary Predator Removal	587	549	74	33.2	2.08	F
12/17/2008	Primary Predator Removal	682	639	92	38.3	3.17	M

Date	Activity	Total Length (mm)	Fork Length (mm)	Width (mm)	Circumference (cm)	Weight (kg)	Gender
12/17/2008	Primary Predator Removal	675	635	85	37.1	3.33	F
12/17/2008	Primary Predator Removal	682	644	90	37.3	3.08	F
12/17/2008	Primary Predator Removal	642	605	85	34.4	2.59	F
12/17/2008	Primary Predator Removal	634	595	82	31.9	2.21	F
12/17/2008	Primary Predator Removal	672	636	89	35.8	2.54	NA
4/22/2009	Primary Predator Removal	410	380	48	21.5	0.63	M
4/22/2009	Primary Predator Removal	625	585	82	32.9	2.54	M
4/22/2009	Primary Predator Removal	703	660	97	39.8	3.99	M
4/22/2009	Primary Predator Removal	640	600	77	33.8	2.54	M
4/22/2009	Primary Predator Removal	737	689	92	39.9	4.05	F
4/22/2009	Primary Predator Removal	673	636	87	37.1	3.22	M
4/22/2009	Primary Predator Removal	632	595	76	33.1	2.41	M
4/22/2009	Primary Predator Removal	574	532	71	31.3	1.94	M
4/22/2009	Primary Predator Removal	804	753	113	46	5.64	M
4/22/2009	Primary Predator Removal	711	665	100	40.5	4.09	NA
4/22/2009	Primary Predator Removal	672	630	90	36	3.21	M
4/22/2009	Primary Predator Removal	680	637	98	36	2.99	F
4/22/2009	Primary Predator Removal	755	705	103	39	3.9	F
4/22/2009	Primary Predator Removal	674	640	92	37.5	3.37	M
4/22/2009	Primary Predator Removal	628	582	78	31.4	2.21	M
4/22/2009	Primary Predator Removal	615	572	78	34.5	2.4	F
4/22/2009	Primary Predator Removal	630	593	84	34.2	2.65	M
4/22/2009	Primary Predator Removal	699	664	86	37.4	3.35	M
4/22/2009	Primary Predator Removal	736	685	90	39	3.97	M
4/22/2009	Primary Predator Removal	692	649	90	35.4	2.99	F
4/22/2009	Primary Predator Removal	660	619	92	36.4	2.84	M
4/22/2009	Primary Predator Removal	638	608	87	35	2.55	M
4/22/2009	Primary Predator Removal	571	535	74	31.5	2.1	M
4/22/2009	Primary Predator Removal	658	610	87	35.8	2.83	F
4/22/2009	Primary Predator Removal	667	623	92	36.8	2.98	F
4/22/2009	Primary Predator Removal	677	636	90	37.5	3.15	M
4/22/2009	Primary Predator Removal	660	618	87	36	2.85	M
4/22/2009	Primary Predator Removal	606	564	82	33	2.18	M
4/22/2009	Primary Predator Removal	630	589	90	34.8	2.51	M
4/22/2009	Primary Predator Removal	634	595	84	33.2	2.45	M
4/22/2009	Primary Predator Removal	654	613	89	35.4	2.76	M
4/22/2009	Primary Predator Removal	585	550	83	31	2	M
4/22/2009	Primary Predator Removal	595	557	85	33.2	2.18	M
4/22/2009	Primary Predator Removal	651	609	87	30.7	2.15	M
4/22/2009	Primary Predator Removal	640	595	81	34.2	2.69	M

Date	Activity	Total Length (mm)	Fork Length (mm)	Width (mm)	Circumference (cm)	Weight (kg)	Gender
4/22/2009	Primary Predator Removal	597	553	70	30.3	2.05	M
4/22/2009	Primary Predator Removal	686	630	80	35	2.95	F
4/22/2009	Primary Predator Removal	670	626	90	36.2	3.03	M
4/22/2009	Primary Predator Removal	812	755	104	45	6.09	M
4/22/2009	Primary Predator Removal	735	686	105	40.4	4.35	M
4/22/2009	Primary Predator Removal	660	633	88	33.7	2.81	F
4/22/2009	Primary Predator Removal	581	547	76	31.5	2.12	M
4/22/2009	Primary Predator Removal	724	674	94	38.3	3.57	F
4/22/2009	Primary Predator Removal	641	595	85	35.9	2.87	F
4/22/2009	Primary Predator Removal	518	768	107	44.3	5.68	M
4/22/2009	Primary Predator Removal	606	567	86	32.1	2.11	M
4/22/2009	Primary Predator Removal	686	645	83	33.1	2.85	M
4/22/2009	Primary Predator Removal	689	641	92	38	3.26	M
4/22/2009	Primary Predator Removal	710	678	91	37	3.43	M
4/22/2009	Primary Predator Removal	635	589	87	34.8	2.65	F
4/22/2009	Primary Predator Removal	681	635	84	35	2.91	M
4/22/2009	Primary Predator Removal	704	661	90	35.6	3.28	M

Table L-2.—Primary channel Striped Bass morphometric data based on gender.

Gender	N	Total Length (mm)	Fork Length (mm)	Width (mm)	Circumference (cm)	Weight (kg)
Female (Mean)	28	656	613	87	35.5	2.8
Std Dev		46	43	8	2	1
Male (Mean)	54	648	612	86	35.3	2.9
Std Dev		69	66	11	4	1

Note: Length distributions are not significantly different ($K\text{-}S_{Test}$ =0.152, $K\text{-}S_{Crit}$ = 0.316).