RECLAMATION
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Tracy Series Volume 51

Predatory Fishes in the Tracy Fish Collection Facility Secondary System: An Analysis of Density, Distribution, Re-colonization, and Impact on Salvageable Fishes

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

June 2014

1. REPORT DATE *(DD-MM-YYYY)*
June 2014

2. REPORT TYPE
Final

3. DATES COVERED *(From - To)*

4. TITLE AND SUBTITLE
Predatory Fishes in the Tracy Fish Collection Facility Secondary System: An Analysis of Density, Distribution, Re-colonization Rates, and Impact on Salvageable Fishes

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

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Bureau of Reclamation, Technical Service Center
Fisheries and Wildlife Resources Group, 85-829000
PO Box 25007, Denver, CO 80225-0007

8. PERFORMING ORGANIZATION REPORT NUMBER
Volume 51

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

10. SPONSOR/MONITOR'S ACRONYM(S)

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

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

13. SUPPLEMENTARY NOTE

14. ABSTRACT
A multi-year study was completed to quantify monthly species-specific biomass of predatory fishes in the Tracy Fish Collection Facility (TFCF) secondary channel, as well as bypass tubes that lead from the TFCF primary channel to secondary channel. This data was used, along with TFCF fish salvage data, to develop a bioenergetics model to predict the effects of predators on salvageable fish. Additional data was collected to supplement information collected on the effects of multiple consecutive predator removals in a single day and re-colonization rates of predators in the secondary channel. Results suggest predators are typically distributed evenly amongst all secondary channel components, and their biomass in the secondary channel is above what is typically observed in natural settings. Predators re-colonized the secondary channel within seven days, and, typically, more than one removal effort was necessary to assure the majority of predators were removed. The bioenergetics model indicates predators may have consumed nearly 14,000 fish over the modeled year. However, predator consumption would have been < 0.2 percent of total salvageable fish at the TFCF.

15. SUBJECT TERMS
Predation, Bioenergetics, Tracy Fish Collection Facility, Striped Bass, Catfish, Salvage

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
					Donald E. Portz, Ph.D.
a. REPORT	b. ABSTRACT	a. THIS PAGE		69	19b. TELEPHONE NUMBER *(Include area code)* 303-445-2220

Standard Form 298 (Rev. 8/98)
Prescribed by ANSI Std. Z39.18

Tracy Fish Facility Studies
California

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by

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

June 2014

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EXECUTIVE SUMMARY

The Bureau of Reclamation's (Reclamation) Tracy Fish Collection Facility (TFCF), located in California's Sacramento-San Joaquin Delta, is a fish salvage facility intended to reduce fish entrainment at the Bill Jones Pumping Plant. To comply with the most recent regional Biological Opinion, Reclamation is required to reduce impacts of predatory fish present at the TFCF in order to achieve the highest fish salvage efficiency possible within present day operations and original design limitations. In order to reduce predator impacts and optimize means to remove predators from the TFCF, it is important to understand the baseline levels and effects of predators at the facility. However, the majority of information on the abundance and baseline effects of predators at the facility is anecdotal. Therefore, we completed a multiyear (2004–2006) study to monitor monthly species-specific biomass of predators in the secondary channel, as well as bypass tubes that lead from the primary channel to secondary channel. These data were used, along with TFCF fish salvage data, to develop a simple bioenergetics model to predict the effects of predators on salvageable fish. Additional data were collected in 2011 to supplement information we collected on the effects of multiple consecutive predator removals in a single day and re-colonization (predator removals on multiple consecutive days) rates of predators in the secondary channel.

Predator removal was generally 2 hours to fully complete, which equals about 4 to 10 staff-hours. Though a single effort removed the majority of predator biomass from the secondary, with removal methods employed, a second and third effort is likely required to assure that nearly all of the predators have been captured. Our results indicate predatory fish are generally equally distributed in all bypasses and within the secondary channel and at densities much greater than generally reported in natural settings. Also, following removal, predators generally tended to re-colonize the secondary system within a week. Our results suggest larger (> 100 mm fork length [FL]) striped bass (*Morone saxatilis*) and catfish (white catfish *Ameiurus catus* and channel catfish *Ictalurus punctatus*) contributed to the majority of biomass removed and likely had the largest impact on salvageable fish. The bioenergetics model indicates predators in the secondary could have consumed nearly 14,000 fish over the modeled year, which would have been equivalent to < 0.2 percent of total salvageable fish at the TFCF. Given the effort and safety concerns associated with each predator removal, we recommend focusing predator removal efforts during times when threatened or endangered species are present at the facility. We also recommend the continued development of new predator removal techniques that will reduce the need for personnel to access the secondary channel and minimize the time salvage operations are shut down.

INTRODUCTION

The Bureau of Reclamation's (Reclamation) Tracy Fish Collection Facility (TFCF), located in California's Sacramento-San Joaquin Delta (SSJD; Figure 1), functions to divert and salvage fish, preventing them from entering the Delta-Mendota Canal, thereby minimizing entrainment and pump induced mortality at Bill Jones Pumping Plant (see South Delta Water Pumping Facilities, Figure 1). Hydraulic conditions, standard operating procedures (*e.g.*, predator removal activities, SOP# TFF-13) and research efforts are aimed at maximizing TFCF fish salvage efficiency, which includes survival of fishes from when they enter the facility (downstream of trashrack, Figure 2) until they are truck-transported and released in the western SSJD (TFCF Fish Release Site; Figure 1).

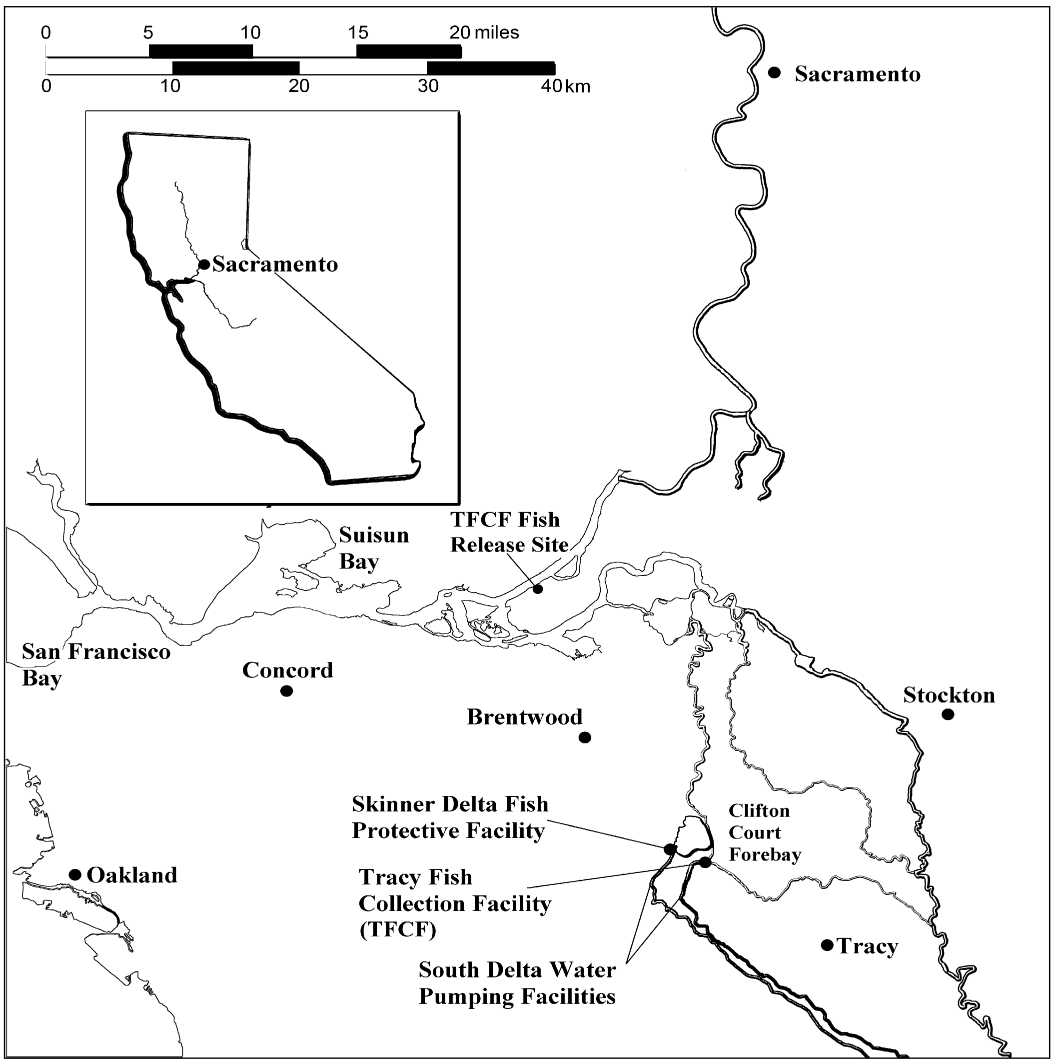

Figure 1.—Map of California's Sacramento-San Joaquin Delta and the location of the United States Bureau of Reclamation-owned Tracy Fish Collection Facility and fish release site, and the California Department of Water Resources-owned Skinner Delta Fish Protective Facility. Inset: study location in relation to Sacramento, CA and the Pacific Ocean.

There are a number of factors (*e.g.*, water velocity, diel period, bypass ratio) that affect fish salvage efficiency at the TFCF (Bowen *et al.* 1998, Sutphin and Bridges 2008). However, predation is assumed to be significant, and has long been assumed to contribute to significant losses of salvageable fish at the TFCF (Orsi 1967, Liston *et al.* 1994, Fausch 2000). Anecdotal evidence suggests large predatory fish accumulate and reside throughout all major components of the facility, including in front of the trash boom and trash rack, the primary channel, and bypass tubes. Predatory fishes are often observed in the secondary channel, holding tank, count bucket, haul bucket, and in the haul trucks (Liston *et al.* 1994; Figure 2).

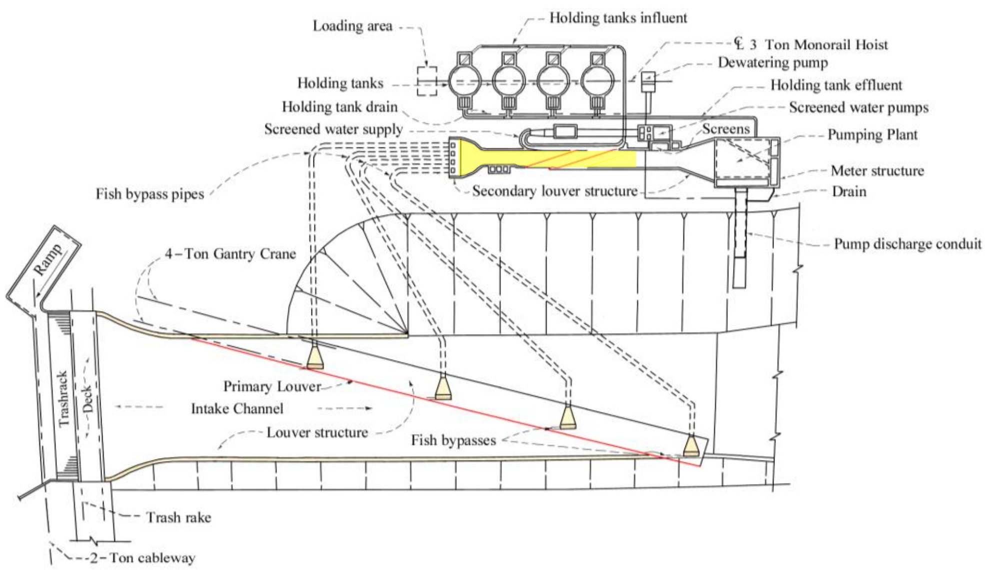

Figure 2.—Schematic of Reclamation's Tracy Fish Collection Facility (TFCF; Byron, CA) depicting the major facility components. Research and predator removal activities were conducted in the TFCF secondary channel (highlighted in yellow) and bypass tubes (entrance from primary channel highlighted in yellow).

Large anthropogenic structures (*i.e.*, TFCF) can provide favorable conditions for predators as a result of increased ambush sites and disorientation of prey fish as they pass through unfamiliar structures (Tucker *et al.* 1998). These conditions can result in unnatural predator-prey relationships and predator carrying capacities. Therefore, predation loss at the TFCF is a major concern, and Reclamation biologists have focused significant research efforts in this area and continue to conduct research to improve predator removal efficiency and personnel safety during such operations. The primary means by which TFCF employees attempt to improve fish salvage efficiency and minimize fish loss due to predation is by conducting periodic predator removals in the secondary channel (TFCF SOP# TFF-13). Predator removals involve lowering the secondary channel water level by closing bypass tubes (see Figure 2), seining and netting the secondary channel, and flushing each bypass tube with short duration bursts of high velocity water while simultaneously capturing fish using a modified fyke net.

To comply with the most recent regional Biological Opinion, Reclamation is required to reduce impacts of predatory fish present at the TFCF in order to achieve the highest fish salvage efficiency possible within present day operations and original design limitations (National Marine Fisheries Service [NMFS] Biological Opinion 2009). However, there is only minimal data (see Liston *et al.* 1994) that provide a baseline estimate of the overall effects of predatory fish on salvageable fish in the secondary channel. Therefore, the primary objective of this research was to estimate the seasonal abundance and total weight (biomass) of predatory fish in the secondary channel between the entrance to the bypass tubes and the posterior louver array located in the secondary channel. To estimate predation in the secondary channel and overall impacts on salvageable fish, a bioenergetics model [a mass balance equation where energy consumption by a predator is balanced by major physiological processes (Tytler and Calow 1985)] was used to estimate energy consumption and, ultimately, total predation during the study period.

The secondary objectives of this research were to estimate the effort (staff-hours) and effectiveness of the current predator removal process, as well as estimate the re-colonization rates of predators in the secondary channel. Reclamation is currently investigating alternative (safer and possibly more efficient) means to remove predators from different components of the TFCF (Wu and Bridges 2014), and an estimate of the effort and effectiveness of the current predator removal method will provide a baseline for comparison. Current predator removal efforts require shutting down salvage at the TFCF and involve a significant number of personnel. Therefore, Reclamation's best interest is to maximize effort by conducting predator removals only when necessary (*e.g.*, when there is high biomass of predators in the secondary channel). The re-colonization rates of predatory fishes can provide TFCF personnel guidance for the frequency at which predator removals should be conducted.

METHODS

Predator Abundance and Distribution

Predator removals were conducted in the TFCF secondary channel and bypass tubes (Figure 2) between July 2, 2004 and July 5, 2006 (Appendix 1, Table A1-1) as a means to summarize predator abundance (species specific biomass) and distribution (*i.e.*, removal location), and to provide data to estimate effects of predators in the secondary channel system on fish salvage. Predator removals consisted of lowering water levels in the secondary channel to wadeable depths 0.3–0.6 m (1–2 ft) and removing fish from six secondary channel locations: pre-louver, post louver, bypass tube 1, bypass tube 2, bypass tube 3, and bypass tube 4 (Figure 3).

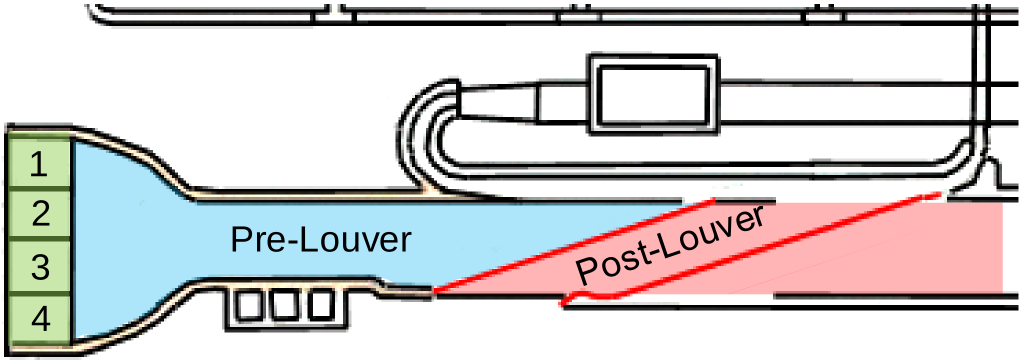

Figure 3.—Drawing (overhead view) of the Tracy Fish Collection Facility secondary channel and the six predator removal locations (bypasses 1, 2, 3, and 4 in green, pre-louver in blue, and post-louver in red) within the channel. Water flows through the bypasses (1-4) into the pre-louver location, where fish are directed into pipes leading to holding tanks and remaining water moves through the post-louver location.

Fish were removed from the pre-louver and post-louver locations using a combination of long-handled nets [33 cm x 45.7 cm (13 in × 18 in) opening, 6.4 mm (1/4 in) mesh; Figure 4] and a 7.6 m (25 ft) beach seine [7.6 m x 2.1 m (25 ft × 7 ft), 6.4 mm (1/4 in) mesh; Figure 4]. After all fish were removed from the pre- and post-louver locations, a modified fyke net [1 m x 1 m (41 in × 41 in) opening, 3.7 m (12 ft) long] was used to remove fish from each bypass tube (Figure 5). Fish were removed from bypass tubes by situating the fyke net at the confluence of the bypass tube and the secondary channel at low water depths and opening the bypass, allowing water to flow from the primary channel through the bypass while flushing fish into the fyke net. The bypass tubes were flushed in random order. Seining and dip-netting in the pre- and post-louver locations always occurred prior to the flushing of all bypasses.

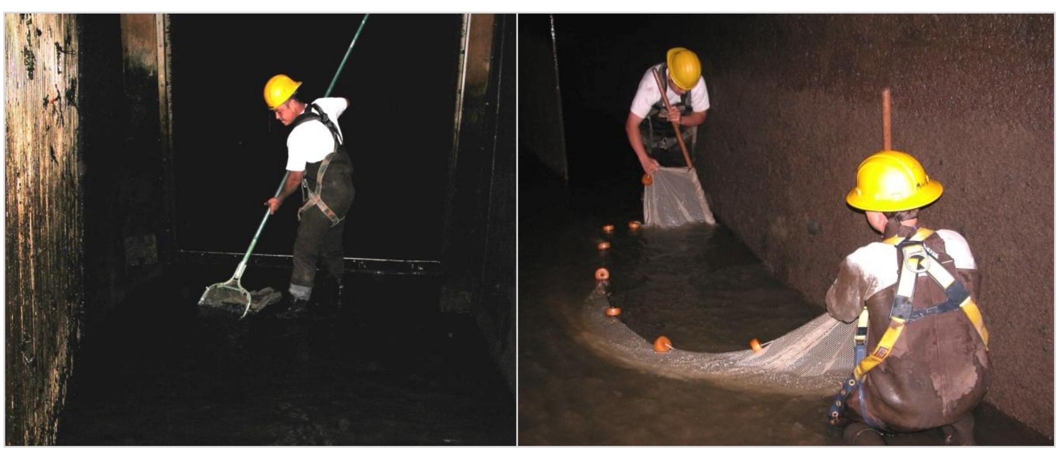

Figure 4.—Long-handled dip net (left image) and beach seine (right image) being used to remove predators from pre- and post-louver locations in the Tracy Fish Collection Facility secondary channel.

Figure 5.—Modified fyke net being used to remove predators from bypass 2 in the Tracy Fish Collection Facility secondary channel. Fish were removed from randomly selected bypass tubes by increasing water velocities in the tube to flush out fish. Inset: Fish were emptied into a plastic basket and lifted out of the secondary channel.

Fish were lifted out of the secondary channel using a plastic basket; when a high amount of fish were removed, a reinforced steel support structure was used (Figure 6). After removal from the secondary channel, group weights (g) and all predator lengths (fork length [FL] and total length [TL]; mm), as a function of removal location, were obtained using a Sartorius Element ELT 6001 scale (Sartorius AG; Goettingen, Germany) and fish measuring boards, respectively. Individual fish weights were calculated, post hoc, using length versus weight (LW) relationships developed from fish captured either at the TFCF or in the SSJD (Appendix 2, Table A2-1). For this research, predators were defined as fish that were assumed to be, at a minimum, moderately piscivorous, and would therefore have greatest impact on salvageable fish at the TFCF (Stevens 1966, Turner 1966, Thomas 1967). Predators included striped bass (*Morone saxatilis*), white catfish (*Ameiurus catus*), channel catfish (*Ictalurus punctatus*), bluegill (*Lepomis macrochirus*), largemouth bass (*Micropterus salmoides*), and redear sunfish (*Lepomis microlophus*). All other species removed were not processed, but put immediately into a TFCF holding tank.

Figure 6.—Plastic bucket (left image) and reinforced steel support structure (right image) used to remove fish from the Tracy Fish Collection Facility secondary channel during predator removal efforts.

Prior to each predator removal, a HydroRanger 200 depth meter (Siemens Corp; Berlin, Germany) was used to measure TFCF primary and secondary channel water depth (ft) , while a multiple-path compound transit-time flowmeter (Model 7510, Accusonic Technologies, Inc., West Wareham, Massachussetts) was used to measure flow (cfs) in the primary and secondary channels. Secondary water velocity was calculated using Equation 1.

$$\text{Secondary Water Velocity} = \text{Flow (cfs)} \div \text{Depth (ft)} \div \text{Width (8 ft)} \quad (1)$$

A YSI 6500 Environmental Monitoring System (YSI Inc., Yellow Springs, OH) was used to record water temperature (°C) before the start of each predator removal. Start time and total time required to complete each predator removal were also recorded.

Tracy Fish Collection Facility 10-minute-count (see Sutphin *et al.* 2007) data collected 2 days before and 2 days after each predator removal were used to estimate the species, size, and abundance of fish passing through the secondary channel. Ten-minute-count data were also used to see if there was a correlation between the amount of available prey, classified as either benthic/littoral, pelagic, or as total prey (Appendix 2, Table A2-1), and the total weight of predators in the secondary channel. The 10-minute-count procedure (currently a 30-minute procedure) is a fish salvage subsampling effort conducted multiple times daily at the TFCF that estimates TFCF fish salvage (Karp *et al.* 1997, Sutphin *et al.* 2007), and therefore should permit adequate comparisons as well as an acceptable bioenergetics model (see Methods: Effects of Predators on Salvageable Fish: A Bioenergetics Approach). Because the 10-minute-count data only provides salvaged fish lengths, these data were coupled with LW relationships (Appendix 2, Table A2-1) to calculate total weight of salvaged fish in order to quantify effects of available prey (*i.e.*, salvageable fish) on abundance and distribution of predators in the secondary channel, as well as provide data for the bioenergetics model.

Multiple Consecutive Predator Removals and Predator Re-colonization Rates

Predator removals, using the same methods as described previously (see Methods: Predator Abundance and Distribution), were conducted for 3 to 5 consecutive days in September 2004, September and February 2005, and January, March, April, June and August 2011. On the first day of each multiday predator removal effort, three to four predator removals were completed consecutively to determine the effectiveness of single and multiple predator removal efforts (predator removal efficiency) at removing fish from the TFCF secondary channel system. By completing multiple predator removals on the first day (day 1), it was assumed the majority of fish were removed from the secondary channel, making our estimates of the re-colonization rates of fish in the channel more accurate. Effects of removal effort (multiple removals in one day) and re-colonization rates assume all predators removed were residents (*i.e.*, closed system) in the secondary channel. However, the secondary system is not closed because fish can move freely between the primary and secondary channels when bypasses are open. Therefore, this should be considered when interpreting data and results. On subsequent days, standard predator removals were completed. Also, during predator removals conducted in 2011, while flushing each bypass, we recorded the length of time required to reach maximum velocity, the maximum velocity reached, the time at maximum velocity, and total time for each flush for each bypass. Bypass velocities were calculated using Equation 2:

Bypass Water Velocity (ft/s) = Bypass Flow (cfs) ÷ Bypass Cross-Sectional Area (3-ft diameter) (2)

Effects of Predators on Salvageable Fish: A Bioenergetics Approach

The Wisconsin Sea Grant Bioenergetics Model *Fish Bioenergetics 3.0* (Hanson *et al.* 1997) was used to estimate food consumption rates (g of prey/g of fish/day) of predators in the secondary channel. Because year had no effect on predator total weight in the secondary, the bioenergetics model was averaged over year and incorporated all available predator removal data. Data applied to the model, as well as estimates of the effects of predators on fish salvage, assumed that predator abundance, as a function of predator removal data, and prey abundance, as a function of 10-minute-count data, remained uniform between predator removal dates.

Predators in the secondary were broken down into the following categories for analysis: small striped bass (< 100 mm FL), medium striped bass (100-200 mm FL), large striped bass (> 200 mm FL), small catfish (< 100 mm FL; white and channel catfish combined), medium catfish (100-200 mm FL), large catfish (> 200 mm FL), and centrarchids (all size classes of bluegill, redear sunfish, and largemouth bass combined). Fish were separated into size classes because we assumed ontogenetic changes in prey preference (*i.e.*, macroinvertebrates versus fish) and changes in gape limits coincide with increasing size (Turner 1966, Wainwright and Richards 1995, Moyle 2002, Overton 2003), and thus different impacts on salvageable fishes. Catfish were combined for analysis because white and channel catfish are generally opportunistic bottom feeders (Turner 1966) and we assumed they would have similar diet preferences across size class. Centrarchids were combined for analysis because we assumed bluegill and redear sunfish were opportunistic and prey primarily on invertebrates (Turner 1966, Wilbur 1969), and there were not enough largemouth bass collected in predator removals (29 total and 12 percent of centarchid total weight) to significantly affect overall centrarchid consumption rates.

Bioenergetic model parameters (*e.g.*, metabolism, wastes, and growth) used for adult striped bass were reported by Hartman and Brandt (1995), centrarchid parameters used were reported by Kitchell *et al.* (1974) for juvenile and adult bluegill, and parameters used for catfish were reported by Blanc and Margraf (2002). Energy density of predator and prey were taken from available scientific literature (Table 1). In an effort to keep analyses pertaining to the bioenergetics model simple, it was assumed that all predators would consume the two most abundant prey species (based on 10-minute-count data) in the secondary channel and bypass tubes (see Appendix 3, Table A3-1). Therefore, the energy density of the two most abundant prey items were averaged for prey energy input into the bioenergetics model.

Table 1.—Source study for energy density values (joules/gram) used for predator and prey species in the Tracy Fish Collection Facility secondary channel predator bioenergetics model

Species	Energy Density (joules/g)	Classification	Source Study
Amphipod	4429	Prey	Cummins and Wuychuck 1971
Shad spp. (herring as surrogate)	5534	Prey	Rudstam 1989
Striped bass (< 100 mm)	5023	Prey/Predator	Hartman and Brandt 1995
Cyprinids (fathead minnow as representative)	4104	Prey	Duffy 1998
Centrarchids (bluegill as representative)	4186	Prey/Predator	Kitchell et al. 1974
Salmonids (Chinook salmon as representative)	5764	Prey	Stewart and Iberra 1991
Striped bass (> 100 mm)	6488	Predator	Hartman and Brandt 1995
Catfish (channel catfish as representative)	3052	Predator	Blanc and Margraf 2002

Specific growth rates of fishes at the TFCF are unavailable. Therefore, based on reported growth data for juvenile (Cox and Coutant 1981, Cech *et al.* 1984, Harmon and Peterson 1994) and adult striped bass (Hasler 1988, Tucker *et al.* 1998, Kimmerer *et al.* 2005), juvenile and adult catfish (Andrews and Stickney 1972, Kilambi *et al.* 1977) and juvenile bluegill (Lemke 1977, Beitinger and Magnuson 1979), we assumed conservative growth rates (mass) of 1 percent/day for small and medium striped bass and catfish, 0.75 percent/day for adult striped bass and centrarchids, and 0.6 percent/day for adult catfish. Water temperature data applied to the model was derived from readings taken during each predator removal (Appendix 1, Table A1-1) and was assumed to be constant between predator removal dates for model application.

Food consumption rates of predators (g of prey/g of fish/day) in the secondary channel, as calculated by the bioenergetics model, were multiplied by the percentage of diet assumed to consist of fish to achieve fish consumption rates (g of fish/g of fish/day). We assumed the percentage of diet comprising fish for small, medium and large striped bass was 4 percent, 56 percent and 80 percent, for small, medium and large catfish was 2 percent, 16 percent, and 55 percent, and for centrarchids was 35 percent. It was assumed that the remaining diet was composed of amphipods. Diet preferences were loosely based on information reported in Turner (1966), Miller (1966), Thomas (1967), and Becker (1983). However, occupying the secondary channel at the TFCF provides fish a unique opportunity to be selective, and their diet preferences may not be the same as in a natural setting. Therefore, future efforts to quantify consumption rates, based on diet data obtained from sampled fish at TFCF could be used in place of the assumed rates to further refine this model. Fish consumption rates were multiplied by the total weight of predators removed (biomass), as a function of category (*i.e.*, species and size class), to obtain the total weight (g) of fish consumed by each size class of predator on each day of the simulated year.

To estimate the effects of predators in the secondary channel on salvageable fish species, and for model simplicity, we assumed all predators would only target and prey on the most abundant species present in the secondary channel as derived from 10-minute-count data two days before and after each predator removal (Appendix 3, Table A3-1). We also assumed all predators were gape limited and, based on their mean size (calculated from predator removal data), would not consume prey items with a mean weight of > 60 percent of their mean weight (Dorner and Wagner 2003). Given the lack of natural habitat and bypassing water funneling prey to them, it was assumed that predators adhered to the optimal foraging theory and, if larger species were available, would not choose to consume prey species with mean weights < 5 percent of their mean weight (Appendix 4, Table A4-1). Based on these assumptions, and to simplify inputs to the model, we selected the two most likely species consumed, and based on their mean weights and percentage of occurrence (assuming they were the only two species consumed) we calculated the amount of prey (species-specific) consumed over our modeled year. It is recognized that, due to the selection of only the two most abundant prey species, estimates of predation loss for certain listed species may not be provided by the model. Despite this, it is likely that the loss of these species is less than that for the more abundant species that will be incorporated into the model.

Statistical Analyses

Predator Abundance and Distribution

The majority of our predator abundance and distribution data did not meet the assumptions (normal distribution or equal variance) to model using parametric statistics. To test if there was a measurable effect of removing predators from the secondary channel and bypass tubes on fish salvage, a Mann-Whitney Rank Sum Test was employed to test for differences in fish salvage total weight (using 10-minute-count data) 2 days prior and 2 days after a removal. A two-way analysis of variance (ANOVA) on ranked predator total weight was used to test for effects of year on total weight of predators, as a function of species and size-class, in the TFCF secondary channel. Since this comparison resulted in no significant year effect (year × species) we averaged over year for all additional analyses. A two-way ANOVA on ranked total weight was employed to test for effects of month and removal location on predator (species group) total weight. Additionally, linear regression models and ANOVA were used to determine if there was a significant correlation between available prey (benthic/littoral, pelagic or total prey as estimated using 10-minute-count data 2 days prior to each predator removal effort) and secondary water velocity (ft/s) on the total weight of striped bass, catfish, and centrarchids.

Multiple Consecutive Predator Removals and Predator Re-colonization Rates

The majority of our predator re-colonization data did not meet the assumptions to model using parametric statistics. Therefore, a two-way ANOVA on rank-transformed data was employed to test for differences in flows (cfs) and total time of flush (s) across bypasses, as well as differences in percent biomass (g) across multiple removal efforts over three consecutive flushes. Because the majority of total fish and biomass removed from the secondary channel and bypass tubes consisted of striped bass, white catfish, and channel catfish (see Results), analyses and interpretation focused on striped bass and catfish (white and channel catfish grouped together) isolated into three size classes: < 100 mm FL, 100–200 mm FL, and > 200 mm FL. As a tool to predict the number of predator removals required to remove all predators from the secondary channel, multiple predator removal data, using total predator biomass, was modeled using power regression.

All statistical analyses were conducted using SigmaStat 3.5 software (Systat Software Inc., Richmond, California); the significance level (α) for all analyses was set at 0.05. For simplicity, descriptive statistics is not included in results, but all differences reported were significant at this defined α level.

RESULTS

Predator Abundance and Distribution

In general, predator removals were completed during the same diel period (07:00 a -12:30 p) and took between 0.8 h and 2 h (Appendix 1, Table A1-1) to complete with a crew of four researchers and typically one TFCF operator. Two researchers removed debris and fish from the secondary channel, one processed removed fish, and one served as a safety monitor. One TFCF operator controlled facility hydraulics. Therefore, for a single predator removal effort, it generally takes between 4 and 10 labor-hours for completion. On average, bypass tubes were flushed during predator removal efforts for 149.9 ± 15.2 s (mean ± standard deviation), and maximum flows and velocities reached between 0.9 and 1.6 m^3/s, and 3.1 and 5.9 m/s (mean velocity ± standard deviation = 4.8 ± 0.5 m/s), respectively, for 42.0 ± 10.3 s (n = 136). As predicted, as primary channel water depth increased, bypass velocity tended to increase (Appendix 5, Figure A5-1). Mean maximum flow in bypass 4 (44.4 ± 3.7 cfs; mean ± standard deviation) was significantly lower compared to bypass 2 (49.6 ± 5.0 cfs), and maximum flow in bypass 1 (46.3 ± 4.5 cfs) and three (46.4 ± 4.0 cfs) were not different compared to the other bypasses. Total time bypasses were flushed was not significantly different across individual bypasses.

In total, 6.8 kg of striped bass (SB) < 100 mm FL (n = 714), 110.7 kg of SB 100–200 mm FL (n = 2009), 563.9 kg of SB > 200 mm FL (n = 1660), 18.4 kg of catfish < 100 mm FL (n = 4639), 60.4 kg of catfish 100–200 mm FL (n = 1641), 99.8 kg of catfish > 200 mm FL (n = 680), and 10.5 kg of centrarchids (n = 261) were removed from the secondary channel and bypass tubes (Figure 7; Appendix 6, Table A6-1). Mean weight (g) of predators from each predator removal effort is reported in Appendix 4, Table A4-1. Though averaged together for analysis, white catfish contributed to 89 percent of catfish total weight, and bluegill contributed to 74 percent of centrarchid total weight. Striped bass and catfish > 200 mm FL contributed to the majority (90 percent) of biomass removed.

Density (g of fish/L) of striped bass, catfish, and all predators combined, assuming the volume of the secondary channel and bypass tubes is 401,448 L (Appendix 7, Table A7-1), ranged from 0.001–0.212 g/L (mean ± standard deviation = 0.05 ± 0.05 g/L), 0.001–0.044 g/L (mean ± standard deviation = 0.01 ± 0.01 g/L), and 0.003–0.235 g/L (mean ± standard deviation = 0.06 ± 0.05), respectively. Biomass (kg of fish/ha) of striped bass, catfish, and all predators combined in the secondary channel, assuming a secondary area of 0.1 hectares, ranged from 3.43–850.25 kg/ha (mean ± standard deviation = 191.08 ± 202.65), 4.85–178.13 kg/ha (mean ± standard deviation = 50.69 ± 51.35), and 13.70–942.35 kg/ha (mean ± standard deviation = 244.68 ± 215.72), respectively. Averaged over year, there was no difference in striped bass (total or SB > 200 mm FL) or centrarchid (total) total weight across month. However, catfish total weight in June and July was significantly different compared to October and April. Total weight differences across species, but within month, are summarized in Figure 7.

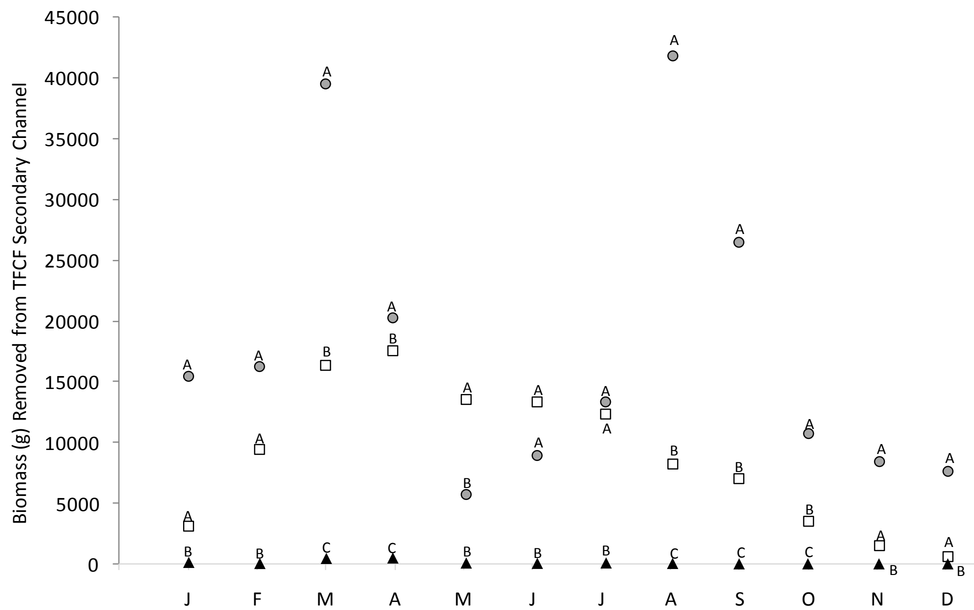

Figure 7.—Mean total weight of predators removed from the Tracy Fish Collection Facility secondary channel as a function of species group (striped bass = grey circle; white and channel catfish = white square; largemouth bass, redear sunfish, and bluegill = black triangle). Different letters above species symbols indicate significant differences in total weight within month ($P < 0.05$; ANOVA). Measures of variance are not displayed because they are large and create a distraction.

Predator removal location, as well as species, had a significant effect on total weight of fish removed from the TFCF secondary channel. However, there was no significant difference in mean lengths of predators as a function of removal location (Figure 8). Total weight of striped bass removed from bypass 1 was significantly greater compared to all other bypasses, but not different than pre- and post-louver removal locations (Figure 9). Striped bass total weight removed from the pre-louver location was significantly greater compared to bypasses 3 and 4. The total weight of catfish removed from bypass 1 was significantly greater than total weight removed from bypass 3, and pre- and post-louver locations. Catfish total weight from all other locations was significantly greater

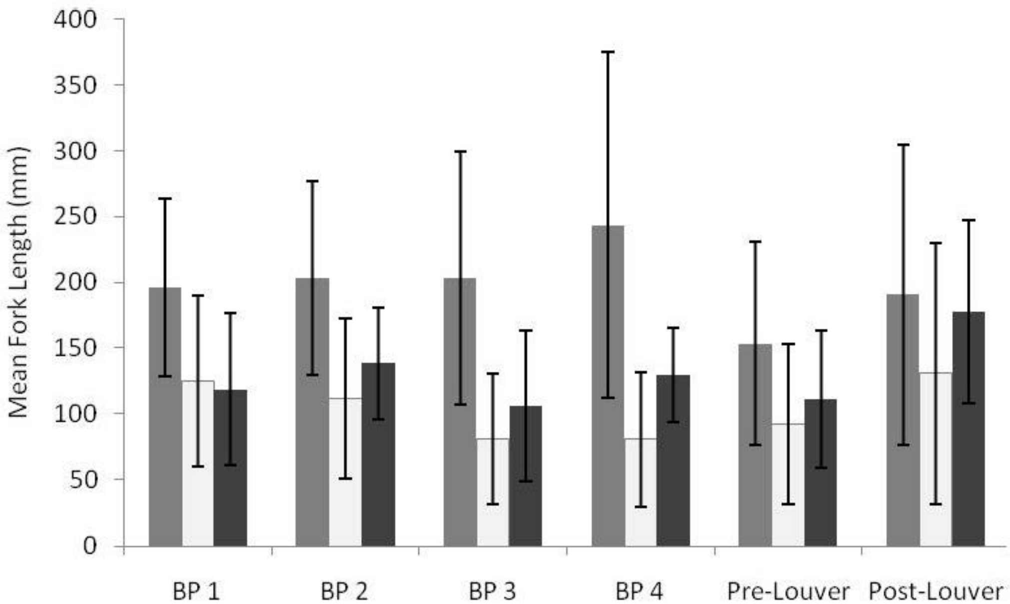

Figure 8.—Mean (± SD) fork lengths (mm) of striped bass (grey), catfish (white), and centrarchids (black), from six predator removal locations within the Tracy Fish Collection Facility Secondary Channel. There were no significant differences in lengths across species (P > 0.05; ANOVA).

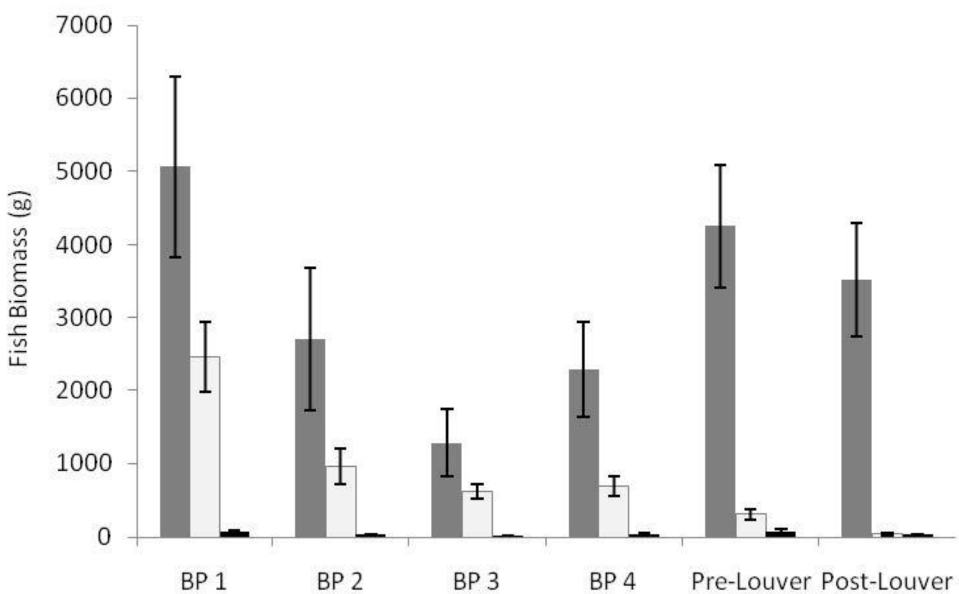

Figure 9.—Mean total weight (± SE) of striped bass (grey), catfish (white), and centrarchids (black) removed from six locations within the Tracy Fish Collection Facility Secondary Channel.

than the total weight removed from the post-louver location. There were no significant differences in centrarchid total weight as a function of removal location. Within all bypasses, the total weights of striped bass and catfish were not significantly different from each other, but greater than the total weight removed for centrarchids. The total weights of all species were significantly different in the pre-louver location, and striped bass total weight from the post-louver location was greater than the total weight of both catfish and centrarchids.

Removal of predators from the secondary channel had no measurable effect on benthic/littoral, pelagic, or total fish salvage ($P > 0.05$; Mann-Whitney Rank Sum Test). There was no correlation between available total weight of pelagic, benthic/littoral, or total prey in the secondary (derived from TFCF fish count data) and total weight of striped bass ($P > 0.05$, $R^2 < 0.05$), catfish ($P > 0.05$, $R^2 < 0.05$), or centrarchids ($P > 0.05$, $R^2 < 0.05$). Velocity in the secondary (Appendix 1, Table A1-1) had no effect on total weight of predators in the TFCF secondary channel ($P > 0.05$, $R^2 = 0.01$).

Multiple Consecutive Predator Removals

The first predator removal efforts resulted in removal of 73 ± 24 percent (mean ± standard deviation; n = 17) of total predator biomass, and only an additional 16 ± 10 percent of biomass was removed in secondary efforts. On average, the majority of striped bass, across all size classes, were removed in initial efforts (Figure 10). However, there was no significant difference in biomass removed as a function of removal effort (flush). Effort did have an effect on biomass of catfish removed, as biomass of all size classes of catfish removed in initial efforts were greater compared to efforts two and three (Figure 10). When assessed across all predators in the secondary channel, and as a function of mean biomass, the regression relationship (power, $y = 0.77x^{-2.22}$, $R^2 = 0.95$) suggests it will require eight predator removals to remove all predators (Figure 11).

Predator Re-colonization Rates

On the fourth day after initial (day 0) predator removal efforts, 86 ± 28 percent (mean ± standard deviation; n = 8) of total biomass (g), for all species combined, had re-colonized the TFCF secondary channel. Aside from striped bass > 200 mm FL, > 80 percent mean biomass of small (≤ 100 mm FL) and medium (101–200 mm FL) striped bass and catfish, and large (> 200 mm FL) catfish, recolonized the TFCF secondary channel (Figure 12). The relationship of predators, as a total of biomass per effort, re-colonizing the secondary channel expressed using a logarithmic relationship is displayed in Figure 13 ($y = 0.36\ln(x) + 0.39$, $R^2 = 0.34$). This relationship was used as it provided the best goodness of fit (R^2) of the models evaluated for predicting the number of days required for full recolonization of predators into the secondary channel.

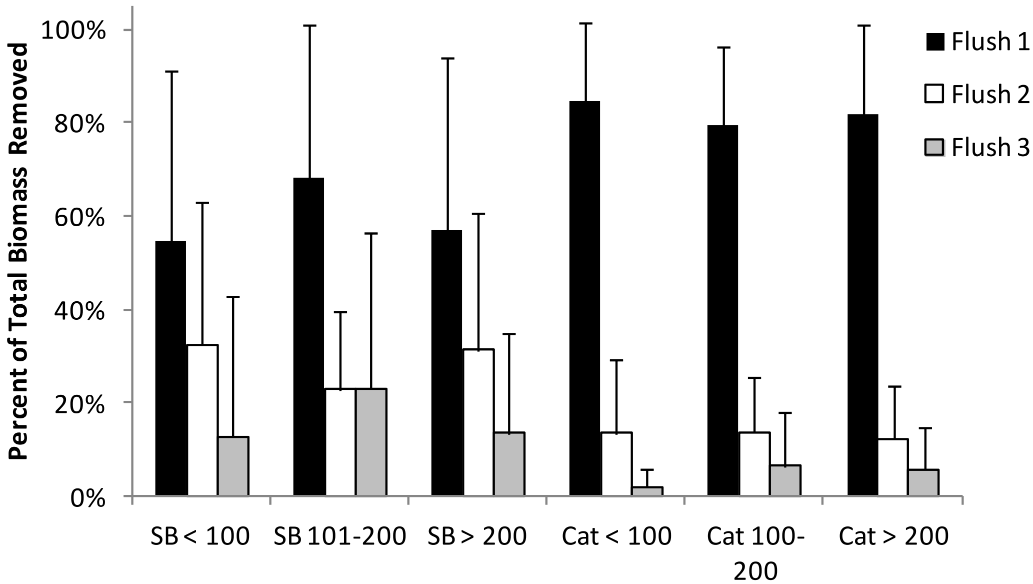

Figure 10.—Mean (± standard deviation) percent biomass (g) of striped bass (SB) and catfish (white and channel catfish; Cat), in three size classes, removed from the Tracy Fish Collection Facility secondary channel on three consecutive removal efforts (flush 1, 2, and 3). Biomasses of all size classes of catfish removed in flush 1 were significantly greater compared to flushes 2 and 3 (ANOVA on ranks; $P < 0.05$); no other differences across treatments were detected. Percent biomass is a function of total biomass removed over all efforts within each day of predator removals.

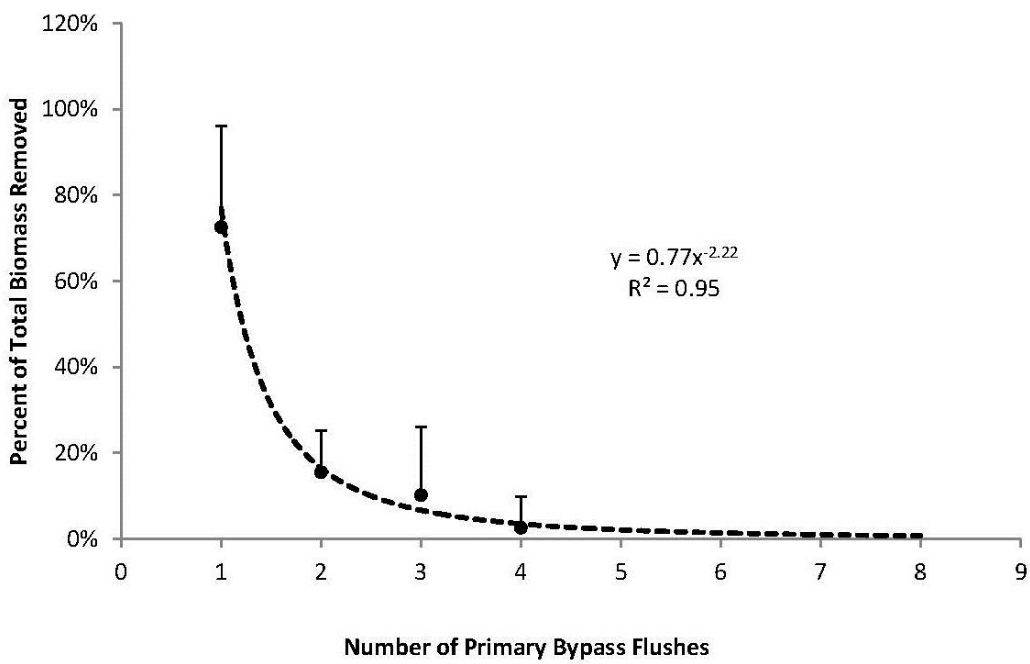

Figure 11.—Percent of total biomass of predators removed, in total (striped bass, catfish, and centrarchids) as a function of Tracy Fish Collection Facility bypasses flushes expressed as a power relationship.

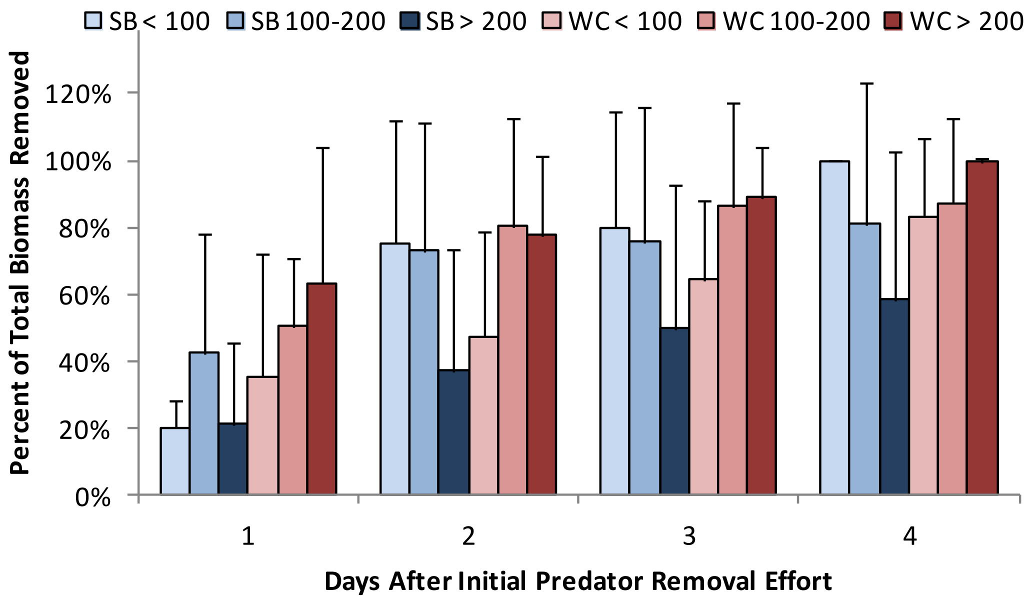

Figure 12.—Mean (± standard deviation) percent biomass (g) of striped bass (SB) and catfish (white and channel catfish; Cat), in three size classes, removed from the Tracy Fish Collection Facility secondary channel 1, 2, 3, and 4 days after an initial (day 0) predator removal effort. Percent biomass is a function of total biomass removed over all efforts within each week of predator removals.

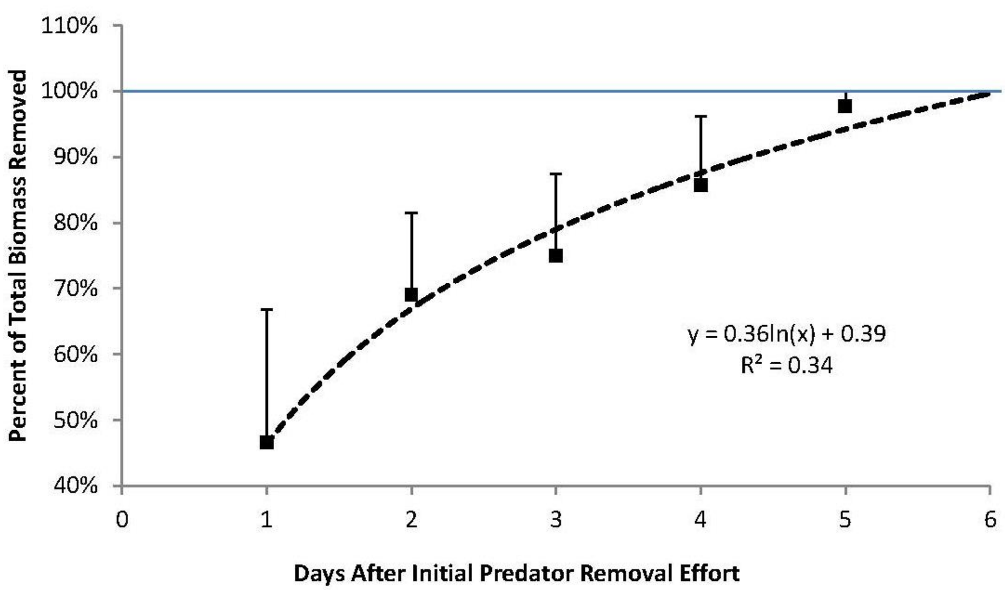

Figure 13.—Mean percent biomass (+ 1 standard error) of all predatory fish in total (striped bass, catfish, centrarchids), removed from the Tracy Fish Collection Facility secondary channel 1, 2, 3, and 4 days after an initial (day 0) predator removal effort expressed with a logarithmic relationship. Percent biomass is a function of total biomass removed over all efforts within each week of predator removals.

Effects of Predators on Salvageable Fishes: A Bioenergetics Approach

Results of the bioenergetics model suggest larger sub-adult and adult (> 100 mm FL) striped bass and catfish have the biggest impact on biomass of salvageable fishes (Table 2). Based on 2005 TFCF fish salvage estimates for threadfin shad (*Dorosoma petenense*; 1,111,293), striped bass (124,537), centrarchids (205,882), Sacramento splittail (*Pogonichthys macrolepidotus*; 342,655), Chinook salmon (*Onchorhynchus tshawytscha;* 25,637), common carp (*Cyprinus carpio;* 6,097), and American shad (*Alosa sapidissima*; 329,047), and considering described model assumptions, the percentage of each species consumed by predators in the secondary were 0.3 percent, 3.0 percent, 0.6 percent, 0.4 percent, 6.0 percent, 7.5 percent, and 0.9 percent, respectively. Since some of the listed species were never one of the 2 most abundant prey species being salvaged, estimated loss for these species was not provided by the model. Despite this, it is likely the loss of listed species is less than the loss estimated for more abundant species.

Table 2.—Results of bioenergetics model detailing the total weight of fishes consumed, as well as the number of fish consumed by species, by predators in the Tracy Fish Collection Facility Secondary Channel (by species and size class) over one calendar year between 2004 and 2006. SB = striped bass, Cat = white and channel catfish, and centrarchids include sunfish and black bass.

Predator Species and Size Class (mm FL)	Percentage of Diet Comprised of Fishes	Total Fish Total Weight Consumed (g)	Total Number of Fish Consumed by Species						
			TFS	SB	Sunfish	ST	CS	Carp	AS
SB < 100	4%	105.8	23.0	0.2	0.0	0.0	0.0	0.3	0.0
SB 101 – 200	56%	19,477.2	1,035.8	489.6	162.8	188.1	2.0	189.2	147.1
SB > 200	80%	100,138.0	1,335.2	2,570.4	712.7	625.3	1,526.9	54.0	2,654.9
Cat < 100	2%	136.3	8.7	6.9	7.0	6.4	0.0	5.8	20.2
Cat 101 – 200	16%	2,093.5	122.7	56.7	47.3	144.2	3.2	67.7	171.2
Cat > 200	55%	8,137.5	114.2	564.7	197.3	360.2	13.3	136.5	8.7
Centrarchids	35%	838.4	63.8	44.0	8.3	3.6	0.2	4.9	0.8
Total		**130,926.7**	**2,703**	**3,733**	**1,135**	**1,328**	**1,546**	**458**	**3,003**

DISCUSSION

Striped bass, particularly those > 100 mm FL, were the dominant predator as a function of biomass, and based on our simplified bioenergetics model and prey biomass, consumed the most salvageable fishes in the TFCF secondary channel. These results are consistent with other reports on predators in the TFCF secondary, as well as within the San Francisco Estuary and SSJD (Liston *et al.* 1994, Moyle 2002). In fact, results reported by Liston *et al.* (1994), who also evaluated the abundance of predators in the TFCF secondary channel, generally support our findings, as they also indicated catfish (primarily white catfish) were the second most abundant predator and centrarchids contributed minimally to the predator biomass in the secondary channel. Interestingly, the TFCF trash rack, the first physical structure fish encounter at the TFCF (see Figure 2), was designed with 5.08 cm (2 in) vertical slot openings and should keep fish $\geq$ 5.08 cm (2") in maximum width from moving from Old River into the primary channel. Striped bass length to maximum width calculation ($y = 0.14x - 0.55$; $R^2 = 0.96$), developed from data collected at the TFCF, suggests the 2" vertical openings restrict passage of striped bass > 375 mm FL. Therefore, multiple samplings of striped bass > 375 mm FL during our research supports unpublished findings by Bark *et al.* (in review) that suggest larger predators not only reside within the TFCF but also are able to move back and forth from the primary and secondary channel, and, findings from Liston et al. (1994) that suggest back and forth movements from the Delta Mendota Canal.

Month had no effect on total weight of striped bass (total or SB > 200 mm FL) or centrarchids, and a minimal effect on catfish, in the TFCF secondary system. Therefore, predation in the TFCF secondary should be a concern year round. Our results also indicate the amount of available prey (based on 10-minute-count data), benthic or pelagic, had no effect on biomass of predators in the secondary system. These results suggest, regardless of season, there was sufficient prey moving through the TFCF between 2004 and 2006 to support a high biomass of predators in the secondary channel and bypass tubes. Fish salvage as a function of month between 2004 and 2006 supports this assumption (Appendix 8, Figure A8 -1). Similarly, sieve net samples (mesh size = 1.59 mm [0.06 in]) collected from the secondary channel 7.0 m (23 ft) behind the secondary louver during unrelated research studies indicate there is an abundance of macroinvertebrates (primarily amphipods) that are either flushed through or reside within the secondary channel that can provide an additional source of food for predators. The abundance of food in, and moving through, the secondary channel supports high biomass (13.70 – 942.35 kg/ha) of large piscivorous fishes that would unlikely be supported by natural conditions or in the absence of the man-made TFCF. Although the carrying capacity or density of large piscivorous fishes a particular system can support depends on system productivity and abundance of available prey, as well as available habitat, water quality, and fish exploitation rates, biomass of piscivorous fishes in lakes generally ranges between 1 and 50 kg/ha and is rarely above 200 kg/ha (Downing and Plante 1993).

Within the secondary channel, the highest biomass of predators tends to reside within bypass 1, with a high biomass of striped bass also residing in the secondary channel before (pre) and after (post) the secondary louver (see Figure 3). Bypass 1 is the shortest of the bypasses (see Figure 2). Interestingly, predators accumulated the most in bypass 1, where the environment is more competitive, as a result of higher density of predators, and less energetically efficient due to elevated energy exertion necessary to maintain higher swimming speeds (Freadman 1981). It is possible a majority of the fish salvaged at the TFCF are moving through bypass 1, resulting in the greatest amount of available prey moving through this bypass, which may cause predators to target this location to increase their predator to prey encounter rates and the opportunity to consume prey. However, this is not supported by Bates and Logan (1960) who suggest the majority of small (< 12.8 cm) striped bass traveled from the primary to the secondary channel at the TFCF via bypass 4. It is possible some striped bass are selecting to reside in the secondary channel before or after the secondary louver, whereas catfish are typically not selecting these areas because this location provides an advantage for visual predators (*e.g.,* striped bass) and less so for tactile predators (*e.g.,* catfish). Striped bass are pelagic predators (Moyle 2002), and as adults are primarily piscivorous and rely heavily on their vision to target prey (Stevens 1966). Catfish have highly developed barbels containing taste receptors around their mouths, which permit them to be specialized bottom feeders in turbid or low-light conditions (Moyle and Cech 1996). The bypass tubes that empty into the TFCF secondary channel run under the Delta Mendota Canal likely permit minimal light penetration. However, the secondary channel, immediately before and after the secondary louver, is not enclosed and allows natural light to penetrate. Increased light levels may be advantageous for visual predators (Diehl 1988, McMahon and Holanov 1995), and may explain why primarily striped bass, and not catfish, tend to reside in the secondary channel before and after the louver. It is important to note, however, that fish sampling location could be an artifact of sampling methodology, because the necessity to dewater the secondary channel prior to sampling provides fish the opportunity to re-distribute into different areas and the secondary channel is not a closed system.

The bioenergetics model provides an estimation of the potential effects of predators in the TFCF secondary facility on salvageable fish. Results from the model suggest in one average calendar year between 2004 and 2006 predators in the secondary channel consumed nearly 131 kg of salvageable fish. Based on the assumption that predators are opportunistic and gape-limited, and using the mean weights of fish at the TFCF, predator consumption in the secondary channel resulted in a loss of 13,906 fish over a typical year. Based on the mean annual total salvage of fish between 2004 and 2006, predators in the secondary channel consumed less than 0.2 percent of salvageable fish. The historical TFCF fish salvage data suggests the abundance, size, and species of fish salvaged at the TFCF changes temporally (ftp://ftp.delta.dfg.ca.gov/salvage/). Therefore, one should be mindful when trying to apply our results outside of the temporal period of our data collection. Also, the results of our bioenergetics model rely heavily on a number of assumptions. Because we assumed that predators only consumed the most abundant species being salvaged at the TFCF, it is likely that we overestimated the loss of these species and underestimated (we assumed no loss) the loss of less abundant species (*i.e.,* ESA listed species). Despite this, the loss of less abundant species, including listed species, is likely less than that reported for more abundant species. The bioenergetics model was averaged across sampling years (2004–2006) to develop results for an average year within our sampling period and assumed predator abundance in the secondary channel did not change between sample periods. Unpublished data (Bark *et al.*) on the movements of large striped bass in the TFCF, along with data on the re-colonization rates of predators in the secondary channel, suggests that it is unlikely predator abundance remained constant between sample periods. However, since there is no data to determine whether abundances increased or decreased between sample periods, the assumption that abundance remains constant is most appropriate for the bioenergetics model.

In conclusion, the location, function, and design of the TFCF apparently supports an unnatural predator-prey relationship. Though our bioenergetics model suggests predators likely do not consume a significant amount of overall salvageable fish, abundance of predators suggests predation of salvageable fishes at the TFCF potentially contributes to declines in abundances of native, threatened or endangered species, including, but not limited to, delta smelt (*Hypomesus transpacificus*), Chinook salmon, steelhead (*O. mykiss*), and Sacramento splittail that would not occur in the absence of man-made infrastructure. The combination of high volumes of water, which carries an abundance of fish moving to the southern SSJD and through the Delta Mendota Canal, and subsequent lack of a bypassing flow, results in a high density of fish and an abundance of prey moving through the TFCF. The abundance of anthropogenic structures in the TFCF provides favorable habitat conditions for large predators (*e.g.,* striped bass and catfish) to ambush prey. Unnatural flow conditions (when water and fish move from the primary channel to the bypasses they encounter an approximate 2.1 m [7 ft] drop in elevation, for example), channels and bypasses that continually concentrate fish into smaller volumes of water, as well as rapidly changing light levels (when fish move from the primary channel, which is open, and enter a bypass, which is closed to light penetration) at the TFCF likely disorient fish, which in turn affects their ability to swim and respond to predators, making them easy prey (Rieman *et al.* 1991, Larinier 2001).

RECOMMENDATIONS

Results of our bioenergetics model suggest that predators in the secondary channel and bypass tubes at the TFCF have a minimal impact on total salvageable fishes. Also, our research indicates, at worst, it likely takes 2 total-hours and 10 staff-hours to complete a single predator removal. Due to the effort required for predator removals, we recommend removal efforts are concentrated at times when species of special concern are present at the TFCF or when predator levels are noticeably high. Results of our multiple consecutive predator removal efforts suggest a majority (73 percent, on average) of predators are likely removed after a single removal effort, but three removal efforts are necessary to be satisfied that almost all (> 95 percent) predators have been removed from the secondary channel. Re-colonization data suggests, on average, the majority of catfish and striped bass re-colonized in the secondary channel within 4 days after a predator removal. Therefore, as mandated by the most recent NMFS Biological Opinion, we recommend that, at a minimum, single effort predator removals be completed on a weekly basis when species of concern are present at the TFCF to minimize effects of predators on salvageable fish. Due to elevated velocities through bypasses, it may also be advantageous to conduct predator removals using the current method at high tides (high primary channel water depth). Our results also suggest a significant proportion of predators can reside or take refuge within the bypass tubes; therefore, future predator removals should continue to include flushing of bypass tubes or should incorporate methods to remove fish from this component of the secondary system. Given the amount of time required to complete predator removals, and the safety concerns associated, we recommend continued investigations to develop predator removal techniques that do not require shutting down salvage operations or personnel entering the TFCF secondary channel for extended periods of time. Since larger (> 100 mm FL) striped bass were found to be the dominant predator, they likely have a greater impact on fish moving through the secondary channel and bypass tubes. Due to this, future predator removal techniques should focus on their removal. Similarly, efforts should be undertaken to determine the extent of, and reduce, if necessary, the movement of predators from the Delta Mendota Canal into the TFCF primary channel.

ACKNOWLEDGMENTS

Funding for this research was provided by the Bureau of Reclamation's Mid-Pacific Region. We would like to thank Charles D. Hueth, Andrew A. Schultz, Brent B. Bridges, Jarod Hutcherson, and Michael R. Trask for aiding in data collection. A special thanks to Joel A. Imai and the Tracy Fish Facility Diversion Workers for aiding in all predator removal efforts. We would also like to recognize Ron G. Silva and Brent B. Bridges for providing general study oversight. Finally, we would like to thank Donald E. Portz, and three additional peer reviewers, for their thorough review of this volume.

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APPENDICES

1 Dates, Start Times, and Other Water Quality and Operational Conditions During Predator Removals Conducted at Reclamation's Tracy Fish Collection Facility

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APPENDIX 1

Dates, Start Times, and Other Water Quality and Operational Conditions During Predator Removals Conducted at Reclamation's Tracy Fish Collection Facility

Table A1-1.—Dates, start times, and other water quality and operational conditions during predator removals conducted at Reclamation's Tracy Fish Collection Facility

Date	Start Time	Water Temperature (°C)	Length of Removal (h:min)	Primary Depth (ft)	Secondary Depth (ft)	Secondary Velocity (ft/s)
2-Jul-04	7:00 AM	22.8	2:00	17.2	5.3	2.4
18-Aug-04	11:00 AM	25.0	1:00	17.4	6.3	2.1
2-Sep-04	7:00 AM	23.9	2:00	17.1	5.6	2.3
10-Sep-04	8:30 AM	23.9	2:00	18.1	5.8	2.3
15-Oct-04	7:15 AM	19.4	1:20	17.5	5.8	2.3
1-Nov-04	12:30 PM	15.0	2:00	17.6	5.6	3.1
12-Nov-04	10:00 AM	14.4	2:00	17.2	5.6	3.1
6-Dec-04	12:00 PM	8.9	1:30	16.1	4.9	3.3
20-Dec-04	7:00 AM	10.0	1:30	14.8	3.9	3.8
14-Jan-05	9:00 AM	10.0	1:30	15.2	3.7	4.1
31-Jan-05	9:30 AM	9.4	1:30	17.2	5.2	3.3
8-Feb-05	8:00 AM	10.6	1:30	17.8	5.7	3.1
25-Feb-05	8:00 AM	13.3	2:00	18.4	6.3	2.9
11-Mar-05	8:00 AM	16.7	2:00	19.1	6.7	2.9
29-Mar-05	8:30 AM	13.9	1:00	20.2	8.7	0.9
18-Apr-05	8:20 AM	15.6	1:20	19.1	7.6	1.0
29-Apr-05	8:00 AM	16.1	1:00	19.8	8.5	0.9
9-May-05	8:30 AM	15.6	1:00	21.6	7.7	0.6
27-May-05	8:30 AM	18.9	1:00	21	8	0.5
10-Jun-05	8:00 AM	18.3	1:00	19.5	7.2	2.0
20-Jun-05	8:30 AM	21.1	1:30	19.3	6.6	2.2
19-Jul-05	8:30 AM	25.6	2:00	18.3	6.4	2.1
12-Aug-05	8:00 AM	25.6	1:00	16.9	5.7	2.3
26-Aug-05	8:30 AM	23.3	1:00	16.3	4.2	2.9
16-Sep-05	8:30 AM	21.1	1:00	18.5	6.1	2.3
26-Sep-05	8:00 AM	20.6	1:00	15.8	3.8	3.1
14-Oct-05	9:30 AM	19.4	1:00	15.8	4.3	2.8
25-Oct-05	7:00 AM	17.8	1:00	16.1	4	3.0
10-Mar-06	8:35 AM	15.6	1:00	18.9	5.9	3.0
20-Mar-06	9:15 AM	12.2	1:00	19.4	6	3.2
3-Apr-06	8:30 AM	12.8	1:00	22.3	9.8	0.4
21-Apr-06	9:00 AM	15.0	0:48	20.7	7.4	0.6
12-May-06	9:30 AM	18.9	1:00	21.1	7.9	0.5
26-May-06	8:30 AM	17.2	1:00	22.1	8.1	1.2
9-Jun-06	9:00 AM	20.8	1:00	19.9	7.4	1.6
5-Jul-06	12:30 PM	21.9	1:00	16.8	5.3	2.4

APPENDIX 2

Length to Weight Calculations Used to Estimate Weights of Fish for Predator Removal Biomass Comparisons, as well as a Bioenergetics Model to Compare Effects (Consumption) of Predators on Salvageable Fish at the Tracy Fish Collection Facility

Table A2-1.—Length to weight calculations used to estimate weights of fish for predator removal biomass comparisons, as well as a bioenergetics model to compare effects (consumption) of predators on salvageable fish at the Tracy Fish Collection Facility. Data reported as being from the TFCF is from unpublished data.

Species	LW Relationship	Source Study	Habitat Zone
Striped bass, *Morone saxatilis*	$0.002\,L^{2.93}$	TFCF (R^2 = 0.94)	Pelagic
White catfish, *Ameiurus catus*	$0.001\,L^{2.98}$	TFCF (R^2 = 0.99)	Benthic / Littoral
Channel catfish, *Ictalurus punctatus*	$0.002\,L^{2.87}$	TFCF (R^2 = 0.99)	Benthic / Littoral
Centrarchidae, Bluegill, *Lepomis macrochirus*	$0.0009\,L^{3.18}$	TFCF (R^2 = 0.99)	Pelagic
Salmonidae, Chinook salmon, *Oncorhynchus tshawytscha*	$0.006\,L^{3.19}$	TFCF (R^2 = 0.99)	Pelagic
Threadfin shad, *Dorosoma petenense*	$0.004\,L^{3.27}$	TFCF (R^2 = 0.88)	Pelagic
American shad, *Alosa sapidissima*	$0.003\,L^{2.93}$	TFCF (R^2 = 0.98)	Pelagic
Common carp, *Cyprinus carpio*	$0.0009\,L^{3.19}$	TFCF (R^2 = 0.99)	Pelagic
Sacramento splittail, *Pogonichthys macrolepidotus*	$0.005\,L^{3.19}$	TFCF (R^2 = 0.99)	Pelagic
Sacramento sucker, *Catostomus occidentalis*	$0.0146\,L^{3.01}$	Kimmerer et al. 2005	Benthic / Littoral
Inland silverside, *Menidia beryllina*	$0.0097\,L^{2.87}$	Kimmerer et al. 2005	Pelagic
Delta smelt, *Hypomesus transpacificus*	$0.0018\,L^{3.38}$	Kimmerer et al. 2005	Pelagic
Western mosquitofish, *Gambusia affinis*	$0.0066\,L^{3.15}$	Kimmerer et al. 2005	Pelagic
Rainwater killifish, *Lucania parva*	$0.0061\,L^{3.18}$	Kimmerer et al. 2005	Pelagic
Threespine stickleback, *Gasterosteus aculeatus*	$0.0086\,L^{3.04}$	Kimmerer et al. 2005	Pelagic
Yellowfin goby, *Acanthogobius flavimanus*	$0.0087\,L^{2.98}$	Kimmerer et al. 2005	Benthic / Littoral
Shimofuri goby, *Tridentiger bifasciatus*	$0.0017\,L^{3.47}$	Kimmerer et al. 2005	Benthic / Littoral
Prickly sculpin, *Cottus asper*	$0.0037\,L^{3.3}$	Kimmerer et al. 2005	Benthic / Littoral

APPENDIX 3

Dominant Prey Items and Mean Weights (G) of Fishes Salvaged at the Tracy Fish Collection Facility

Table A3-1.—Dominant prey items and mean weights (g) of fish salvaged at the Tracy Fish Collection Facility 2 days before and 2 days after predator removal efforts. The following abbreviations are employed: TFS = threadfin shad, AS = American shad, SB = striped bass, BG = bluegill, ST = splittail, Carp = common carp, CS = Chinook salmon, YF = yellowfin goby.

Date	Spp 1	Weight (g)	Spp 2	Weight (g)	Spp 3	Weight (g)	Spp 4	Weight (g)
14-Jan-05	TFS	11.8	AS	163.8	SB	31.7	BG	4.9
31-Jan-05	TFS	10.3	AS	259.0	SB	24.4	BG	6.7
8-Feb-05	TFS	7.8	SB	27.6	BG	9.1	AS	329.7
25-Feb-05	AS	329.7	SB	49.1	BG	9.8	TFS	11.1
10-Mar-06	SB	29.6	CS	52.6	BG	1.1	N/A	N/A
11-Mar-05	BG	33.8	SB	39.6	TFS	11.2	YF	16.5
20-Mar-06	SB	42.1	CS	76.3	TFS	15.2	BG	0.9
29-Mar-05	BG	3.9	SB	42.7	TFS	5.8	N/A	N/A
3-Apr-06	BG	1.2	SB	25.5	N/A	N/A	N/A	N/A
18-Apr-05	SB	20.5	CS	7.8	BG	3.1	N/A	N/A
29-Apr-05	TFS	21.0	CS	9.9	ST	0.8	BG	1.3
9-May-05	ST	0.4	CS	8.4	BG	2.4	N/A	N/A
12-May-06	BG	1.6	CS	16.1	Carp	48.8	N/A	N/A
26-May-06	SB	322.6	CS	13.8	ST	0.7	TFS	15.1
27-May-05	BG	14.6	CS	11.4	ST	0.8	TFS	4.1
9-Jun-06	Carp	1.0	ST	0.8	CS	11.2	TFS	14.2
10-Jun-05	BG	4.8	ST	1.6	SB	0.4	CS	11.8
20-Jun-05	SB	2.6	ST	2.5	TFS	2.3	BG	1.4
2-Jul-04	TFS	1.7	SB	1.2	AS	125.5	BG	4.7
5-Jul-06	TFS	2.0	SB	5.3	ST	1.4	N/A	N/A
19-Jul-05	TFS	0.9	SB	5.1	AS	1.1	N/A	N/A
12-Aug-05	TFS	1.9	SB	37.8	AS	4.4	N/A	N/A
18-Aug-04	TFS	6.0	SB	7.5	BG	6.2	N/A	N/A
26-Aug-05	AS	23.0	SB	113.9	TFS	2.3	N/A	N/A
2-Sep-04	TFS	15.9	BG	44.4	SB	5.4	TFS	3.3
10-Sep-04	TFS	4.7	SB	14.8	AS	74.5	BG	5.6
16-Sep-05	TFS	5.4	SB	67.1	AS	4.8	N/A	N/A
26-Sep-05	TFS	4.9	SB	33.2	AS	105.5	BG	16.2
14-Oct-05	AS	27.3	SB	24.4	TFS	5.3	BG	1.7
15-Oct-04	AS	25.1	SB	85.8	TFS	2.7	BG	1.3
25-Oct-05	TFS	16.8	AS	19.2	SB	36.8	BG	1.9
1-Nov-04	TFS	11.2	AS	74.4	SB	6.6	N/A	N/A
12-Nov-04	TFS	8.0	AS	60.4	SB	36.2	BG	1.8
6-Dec-04	TFS	9.0	AS	136.8	YF	28.5	BG	4.3
20-Dec-04	TFS	9.4	AS	77.3	YF	30.6	BG	2.1

APPENDIX 4

Mean Weights (G) of Predators from the Tracy Fish Collection Facility Secondary Channel

Table A4-1.—Mean weights (g) of predators (striped bass = SB, white and channel catfish = Cat, redear sunfish, bluefill, and largemouth bass = centrarchids) from the Tracy Fish Collection Facility Secondary Channel

Date	SB < 100	SB 101 – 200	SB > 200	SB Total	Cat < 100	Cat 101 – 200	Cat > 200	Cat Total	Centrarchids
1/14/2005		60.7	510.0	570.7		53.3	216.8	270.1	22.2
1/31/2005	12.3	44.2	315.5	372.0		41.1	240.8	281.8	
2/8/2005	13.3	38.3	255.3	306.8		28.3	176.7	205.0	
2/25/2005	10.4	82.1	421.8	514.4		41.1	217.6	258.7	31.7
3/10/2006		82.6	414.1	496.8		40.3	153.2	193.5	
3/11/2005	10.3	50.6	241.5	302.4	1.2	46.2	158.9	206.3	
3/20/2006		123.2	50.1	173.3		73.7	111.6	185.4	
3/29/2005	10.0	40.0	1146.5	1196.4	3.5	44.6	200.7	248.7	
4/3/2006		68.1	2666.4	2734.5	23.9	33.5	116.0	173.4	17.2
4/18/2005		32.1	1144.0	1176.1	3.7	27.1	102.6	133.4	0.9
4/21/2006			2461.1	2461.1	3.4	33.2	155.0	191.5	13.4
4/29/2005		9.6	323.6	333.2	3.1	26.6	122.9	152.6	
5/9/2005			2498.8	2498.8	4.3	44.2	110.7	159.1	
5/12/2006			2354.1	2354.1	5.0	50.9	213.3	269.1	525.3
5/26/2006			2008.0	2008.0	3.3	46.0	116.2	165.6	504.0
5/27/2005			2972.4	2972.4	3.5	49.5	199.3	252.2	
6/9/2006		39.7	2597.0	2636.7	3.7	38.0	140.8	182.4	22.1
6/10/2005		49.3	823.4	872.7	8.5	49.6	119.6	177.7	
6/20/2005	4.1	56.0	412.5	472.7	13.0	42.2	102.4	157.6	40.6
7/2/2004		72.4		72.4	11.0	30.6	163.8	205.3	60.6
7/5/2006		70.3	379.0	449.2	15.9	28.4	121.3	165.6	13.6
7/19/2005	3.8	79.0	281.4	364.3	22.1	18.0	127.3	167.4	105.7
8/12/2005	9.6	75.8	346.3	431.7	4.4	31.3	156.9	192.6	113.7
8/18/2004	9.3	25.0	177.4	211.7	2.0	26.8	166.5	195.3	52.5
8/26/2005	10.7	79.0	242.4	332.1	8.6	23.1	124.0	155.7	60.3
9/2/2004	8.8	32.6	214.9	256.3	2.2	21.7		23.9	69.4
9/10/2004	8.9	36.2	192.5	237.6	2.6	23.7	444.6	471.0	46.5
9/16/2005	4.8	84.3	209.0	298.1	3.7	27.0	143.4	174.0	91.7
9/26/2005		81.0	258.2	339.2	14.1	28.7	106.1	148.9	70.6
10/14/2005	8.2	84.5	312.5	405.2	9.6	37.7	122.3	169.5	1.5
10/15/2004		62.8	219.3	282.1	3.4	29.6		33.1	
10/25/2005		90.0	196.0	286.0	2.9	32.2	110.7	145.9	
11/1/2004	14.1	57.0	172.5	243.6	5.7	42.2	120.9	168.8	15.4
11/12/2004	12.4	46.3	291.2	349.9	4.2	40.0	157.7	201.9	20.6
12/6/2004	12.8	49.6	336.6	399.0	5.3	46.2	121.0	172.5	
12/20/2004	9.7	46.3	186.4	242.5	5.6	52.0	153.4	211.0	40.1

APPENDIX 5

Relationship Between Tracy Fish Collection Facility Primary Channel Depth and Bypass Water Velocity During Predator Removals

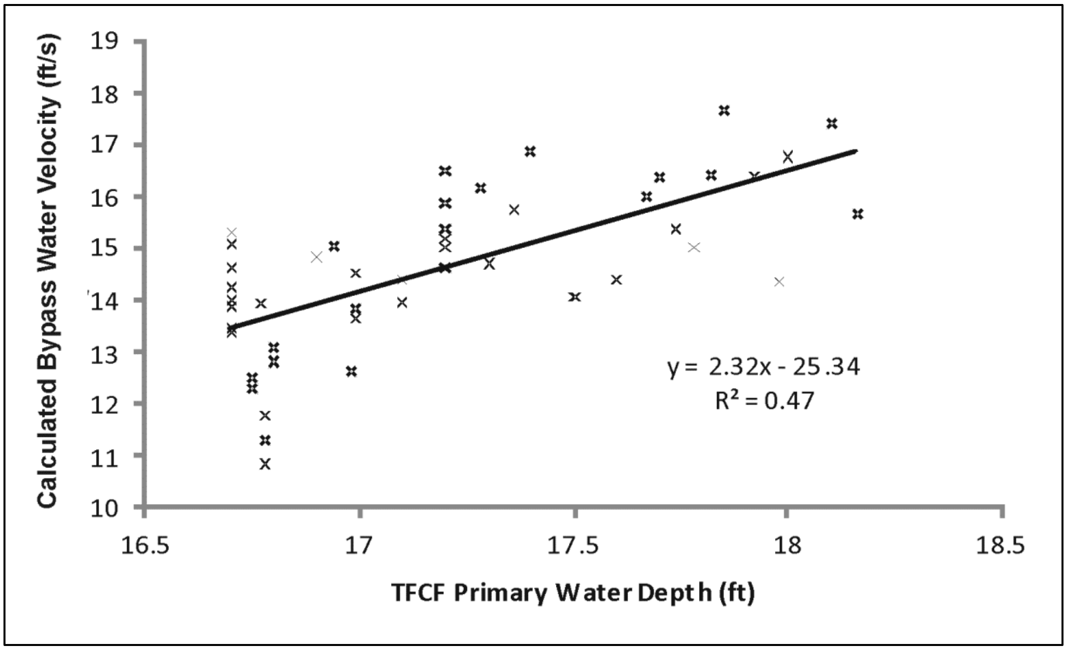

Figure A5-1.—Relationship between Tracy Fish Collection Facility primary channel depth (tide influenced) and bypass water velocity during predator removals.

APPENDIX 6

Total Weight (Biomass; G) of Predators Removed from the Tracy Fish Collection Facility Secondary Channel

Table A6-1.—Total weight (biomass; g) of predators, by species (SB = striped bass, Cat = white and channel catfish, Centrarchids = largemouth bass, redear sunfish, and bluegill) and size class (mm), removed from the Tracy Fish Collection Facility Secondary Channel during predator removal efforts

Date	SB < 100	SB 100 – 200	SB > 200	Cats < 100	Cats 100 – 200	Cats > 200	Centrarchids
2-Jul-04	0.0	3400.8	6029.6	1022.0	5502.5	9988.9	60.6
18-Aug-04	3777.9	4192.7	3547.4	1289.4	1419.7	499.4	2413.1
2-Sep-04	1470.8	6331.4	7950.8	905.1	456.1	0.0	971.0
10-Sep-04	623.4	6187.5	7121.5	920.3	1281.8	496.7	232.7
15-Oct-04	0.0	1507.0	8553.7	192.3	414.7	0.0	0.0
1-Nov-04	14.1	1766.7	8452.2	17.0	1855.4	1451.0	30.8
12-Nov-04	273.3	2267.7	4077.2	104.0	2478.7	6624.5	2085.2
6-Dec-04	38.3	5552.6	4376.3	10.6	3880.6	3751.3	0.0
20-Dec-04	29.2	3335.8	1864.2	5.6	935.5	920.4	441.0
14-Jan-05	0.0	364.1	27031.2	0.0	746.8	2168.1	244.6
31-Jan-05	24.7	662.3	2839.4	0.0	369.5	2889.4	0.0
8-Feb-05	39.9	956.6	3063.2	0.0	626.9	883.5	0.0
25-Feb-05	20.9	1067.7	27415.9	0.0	452.6	3263.8	126.8
11-Mar-05	72.0	19737.4	65216.0	1.2	2216.0	6992.7	0.0
29-Mar-05	10.0	759.2	20636.5	13.9	2987.1	1806.1	0.0
18-Apr-05	0.0	128.4	8008.0	925.9	622.3	102.6	0.9
29-Apr-05	0.0	19.2	323.6	268.7	266.3	491.6	0.0
9-May-05	0.0	0.0	12494.0	17.3	309.1	221.3	0.0
27-May-05	0.0	0.0	5944.8	7.0	197.8	1992.6	0.0
10-Jun-05	0.0	592.2	4940.2	117.5	2527.3	6577.3	0.0
20-Jun-05	4.1	1737.2	5775.1	1272.1	7132.0	7989.3	81.1
19-Jul-05	7.7	4188.4	13789.9	3216.2	4093.1	9933.1	845.4
12-Aug-05	182.9	10308.0	38788.0	271.5	3037.2	5804.8	568.6
26-Aug-05	32.0	14221.0	50415.3	379.1	1662.7	1736.0	301.7
16-Sep-05	28.7	12139.5	45564.9	1334.4	3236.4	4875.6	641.6
26-Sep-05	0.0	2429.3	16266.7	668.6	1089.7	530.4	141.1
14-Oct-05	107.2	844.9	9061.2	165.2	75.3	244.5	3.0
25-Oct-05	0.0	900.1	11170.6	64.0	1256.0	221.5	0.0
10-Mar-06	0.0	495.8	43068.6	0.0	80.7	2144.4	0.0
20-Mar-06	0.0	369.6	1302.3	0.0	147.5	558.1	0.0
3-Apr-06	0.0	136.2	13331.9	1035.6	401.8	348.0	86.0
21-Apr-06	0.0	0.0	59067.4	53.6	132.6	2789.8	26.8
12-May-06	0.0	0.0	2354.1	15.0	101.8	1066.3	525.3
26-May-06	0.0	0.0	2008.0	102.4	598.6	813.7	504.0
9-Jun-06	0.0	715.4	12984.9	757.8	1671.8	4786.0	66.2
5-Jul-06	0.0	3373.7	9095.1	3272.9	6126.4	4853.0	136.1

APPENDIX 7

Dimensions and Calculated Volume of the Tracy Fish Collection Facility Bypass Tubes and Secondary Channel

Table A7-1.—Dimensions and calculated volume of the Tracy Fish Collection Facility bypass tubes and secondary channel

	Length (ft)	Radius (ft)	Width (ft)	Surface Area (ft^2)	Surface Area (ha)	Volume (ft^3)	Volume (L)
Bypass 1	184.5	1.5	NA	1,757	0.016	1,300	36,812
Bypass 2	243.5	1.5	NA	2,312	0.022	1,720	48,705
Bypass 3	270.5	1.5	NA	2,567	0.024	1,911	54,113
Bypass 4	335.5	1.5	NA	3,179	0.03	2,370	67,111
Secondary Channel		NA	8	1,109	0.01	6,876	194,707

APPENDIX 8

Total Number of Fishes Salvaged, by Month, at the Tracy Fish Collection Facility Between 2004 and 2006

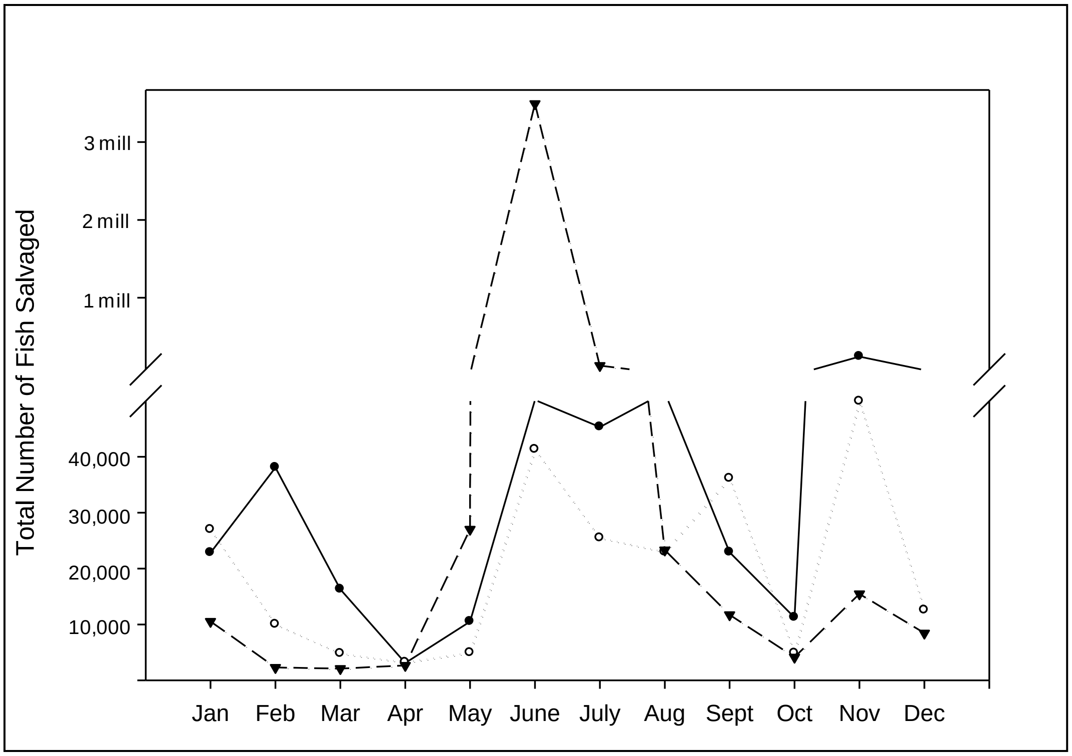

Figure A8-1.—Total number of fishes salvaged, by month, at the Tracy Fish Collection Facility in 2004 (black circle), 2005 (white circle), and 2006 (black triangle).