RECLAMATION

Managing Water in the West

Tracy Series Volume 53

Larval Fish Distribution through the Primary Channel at the Tracy Fish Collection Facility: Spatial and Temporal Patterns of Distribution and Abundance

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

September 2015

Mission Statements

The mission of the Department of the Interior is to protect and provide access to our Nation's natural and cultural heritage and honor our trust responsibilities to Indian Tribes and our commitments to island communities.

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

1. REPORT DATE *(DD-MM-YYYY)*
September 2015

2. REPORT TYPE
Final

3. DATES COVERED *(From - To)*

4. TITLE AND SUBTITLE
Larval Fish Distribution through the Primary Channel of the Tracy Fish Collection Facility: Spatial and Temporal Patterns of Distribution and Abundance

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Jarod D. Hutcherson, Michael J. Horn, and René C. Reyes

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Bureau of Reclamation, Technical Service Center
Fisheries and Wildlife Resources Group, 86-68290
PO Box 25007, Denver, CO 80225-0007

8. PERFORMING ORGANIZATION REPORT NUMBER
Tracy Series Volume 53

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
Historical fish salvage operations at the Tracy Fish Collection Facility have not typically emphasized larval fish entrainment. From April–July 2010, larval fish entrainment through the primary channel of the Tracy Fish Collection Facility was examined to determine spatial and temporal patterns of larval fish entering the channel, and to quantify larval fish entrainment into the Delta Mendota Canal during this period. Entrainment nets, placed in a 3×3 array (vertical × horizontal positions) in the primary channel, were used to capture incoming larval fish. Sampling occurred over ten 24-hour periods over the study. Sampling position, vertically and horizontally had a significant effect on larval fish catch per unit effort. Catch per unit effort was also significantly higher during night, compared to day collection periods. Using four representative species, spatial and temporal analyses suggest species-specific dependencies. No significant effect was determined for river stage or tidal fluctuations across fish species. Total estimated entrainment at the facility exhibited a logarithmic increase over the study. However, collinearity among variables precluded determining which (date, temperature, or discharge) were the primary contributors to this trend. Daily entrainment mid-May was estimated ~40,000 larval fish daily and increased to ~4.7 million larval fish on July 1, 2010.

15. SUBJECT TERMS
larval fish, entrainment, Tracy Fish Collection Facility, spatial patterns, temporal patterns

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	a. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
				47	Zachary A. Sutphin Connie D. Svoboda

19b. TELEPHONE NUMBER *(Include area code)*
303-445-2141
303-445-2152

This page intentionally left blank

Tracy Fish Facility Studies
California

Larval Fish Distribution through the Primary Channel of the Tracy Fish Collection Facility: Spatial and Temporal Patterns of Distribution and Abundance

Tracy Series Volume 53

by

Jarod D. Hutcherson[1], Michael J. Horn[1], and René C. Reyes[2]

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

[2] U.S. Department of the Interior
Bureau of Reclamation
Tracy Fish Collection Facility; TO-417
16650 Kelso Road
Byron, CA 94514-1909

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

September 2015

Tracy Fish Facility Improvement Program

J. Carl Dealy, Manager

Tracy Series Editors

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

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

Cover

Fish photography by René Reyes, Tracy Fish Collection Facility, Tracy, California. Design by Doug Craft.

Disclaimer

Table of Contents

Figures

Figures - Continued

Figure *Page*

Appendices

Appendix

Executive Summary

Operations at the Tracy Fish Collection Facility (TFCF) have not traditionally emphasized larval fish. While larval fish are, to some degree, removed from inflow waters at the facility, species and numbers of fish < 25 mm in length were not historically identified, counted, or measured during operations. With increasing interest being placed on the continuing declines of many fish species in the Sacramento-San Joaquin River Delta, it is increasingly important to determine how operations of pumping facilities might be impacting these species.

The objective of this study was to provide information on tidal, seasonal, diel and spatial dependency, and if operations (*i.e.*, pumping) impact the rate of larval fish entrainment. Daily entrainment, corresponding to the study dates was also estimated. Larval fish were captured from incoming flows in the primary channel using a 3×3 sampling array (three horizontal × three vertical locations, fishing three 500µm-mesh nets at a time). A total of ten 24-h sampling sets were completed May 11–July 1, 2010. During each 24-h sample set, all quadrants of the 3×3 array were sampled every 3–4 h (sample period). Catch per unit effort (CPUE) was calculated for each net, during each sample period, based on total fish captured/m^3 water. Additionally, species-specific CPUE was calculated for four representative species present at the facility. Incorporating additional environmental and hydraulic information, data were analyzed to determine whether significant relationships between CPUE and time-of-day, tidal fluctuations, river stage, temperature, and discharge existed.

Significant differences in horizontal and vertical distribution of larval fish across the primary channel were detected. Catch per unit effort was significantly higher during nighttime hours when compared to daytime hours. These trends were not universal among the four representative species, suggesting that distribution in the primary channel is species-specific. No significant differences in CPUE, across species, were detected based on tidal fluctuation or river stage. Over the study period, with respect to increasing date, temperature, and discharge, there was a logarithmic increase in daily estimated entrainment at the TFCF. Entrainment estimates during the study period increased from ~40,000 larval fish/day in mid-May to ~4.7 million larval fish/day by July 1, 2010.

Larval fish distribution is spatially and temporally dependent. These differences in distribution suggest that a single sample site in the primary channel may not accurately represent overall entrainment through the primary channel of the TFCF. However, the overriding factors contributing to entrainment appear to be discharge and seasonality. Future studies should attempt to estimate salvage efficiency compared to overall entrainment rates.

This page intentionally left blank

Introduction

Operations at the Tracy Fish Collection Facility (TFCF) have not traditionally emphasized larval fish salvage (Hiebert *et al.* 1995). While larval fish are, to some degree, removed from inflow waters at the facility, species and numbers of fish < 20 mm in length were not historically identified, counted, or measured during operations. With increasing interest being placed on the continuing decline of many fish species in the Sacramento-San Joaquin River Delta (Delta; Sommer *et al.* 2007), it is increasingly important to determine how pumping facilities (*i.e.*, the California State Water Project and the Central Valley Project; Figure 1) in the Delta might be impacting these species.

The TFCF, located in Byron, California, is a fish salvage facility designed to capture fish entrained by the export of water by the C.W. "Bill" Jones Pumping Plant (JPP), located 4 km (2.5 miles) downstream of the TFCF. Flow in the Delta-Mendota Canal (DMC) is controlled by the JPP. At the TFCF, fish are diverted into cylindrical holding tanks before they are transported to a release site, downstream from the influence of pumping operations. Adults, and larger juvenile fish, salvaged at the TFCF are quantified using a 30-min fish count every 2 h. Since 2008, larval fish were also collected from fish counts every 6 h, dependent upon one or more of several "triggers" (*e.g.*, presence of Delta Smelt, *Hypomesus transpacificus*, in Delta trawls/surveys, water temperature at Rio Vista, Antioch, or Mossdale; BOR 2008). Though there has been some effort to quantify larval fish entrainment from pumping operations (Hiebert *et al*. 1995), fish salvage is more often the focus (Grimaldo *et al*. 2009). Much is still unknown regarding larval entrainment patterns, or how tidal, seasonal, diel, and spatial differences in larval abundance are reflected in entrainment patterns at the facility. Entrainment through the primary channel often relies on single point evaluation (Siegfried *et al*. 2000; Hiebert *et al*.1995) and may not adequately describe patterns of distribution for entrained larval fish.

The objective of this study was to provide information on tidal, seasonal (with respect to the primary larval fish sampling season; BOR 2008), diel and spatial dependency, and how operations (*i.e.*, export pumping) impact larval fish entrainment. Understanding the nature of the entrained larval fish community in terms of species, and spatial and temporal differences in abundance, will provide valuable information for managers looking to avoid adverse impacts to operations associated with entrainment of larval fish. We also estimated total larval fish entrainment through the primary channel of the TFCF during the study period. Such data will be useful in the future as an aid to determining operational impacts on larval fish entrainment, and to possibly refine adjustments to operations as larval fish populations receive further scrutiny.

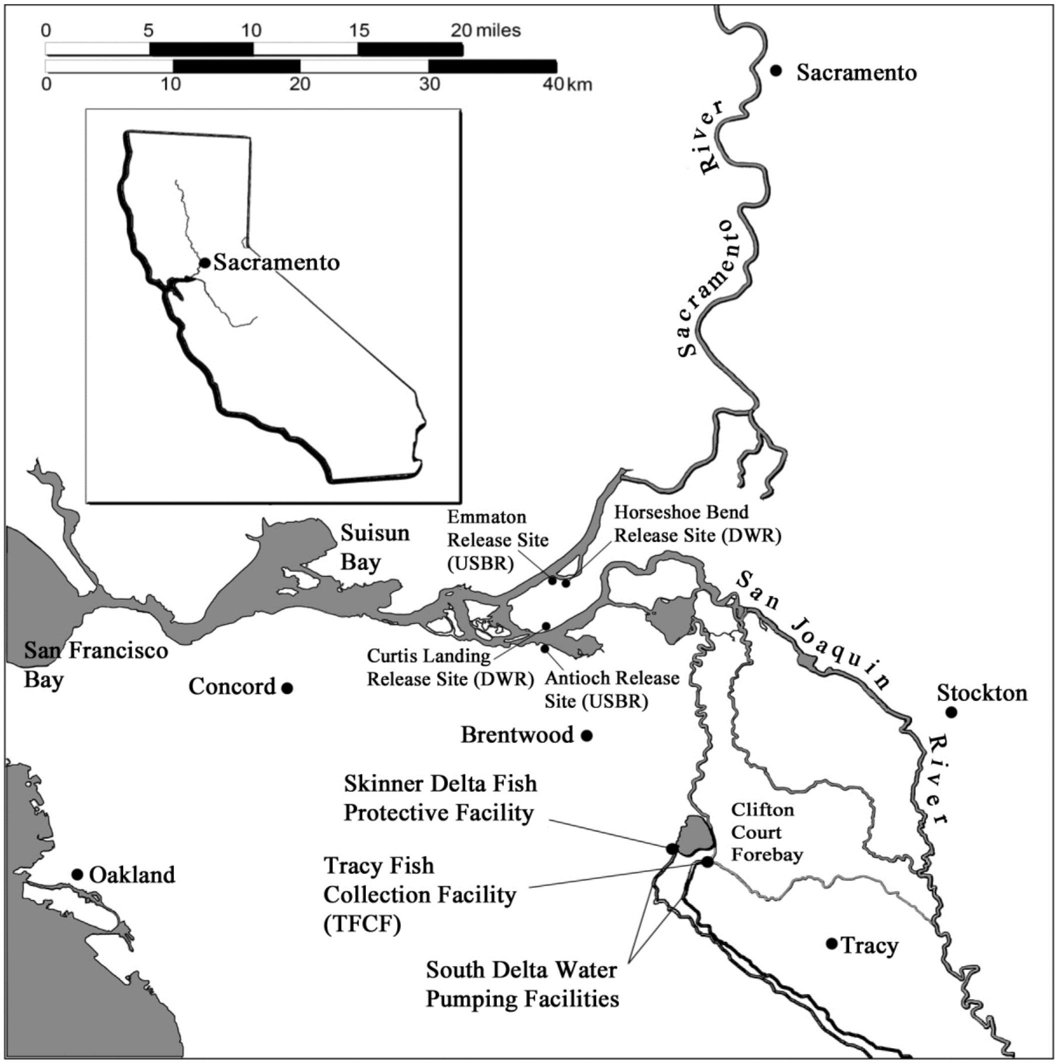

Figure 1. Map of California's Sacramento-San Joaquin Delta (SSJD) and the location of the Central Valley Project pumping facilities and the United States Bureau of Reclamation (USBR) owned Tracy Fish Collection Facility and the California State Water Project and the California Department of Water Resources (DWR) owned Skinner Delta Fish Protective Facility.

Methodology

Sampling

A study design, based on previous entrainment studies (Borthwick and Weber 2001; Siegfried *et al.* 2000; Hiebert *et al.* 1995), was used at the TFCF to quantify entrainment of larval fish. Sampling took place April 22–July 1, 2010. The survey timing was selected to encompass the seasonal periods when larval fish are most abundant at the TFCF (Siegfried *et al.* 2000). Entrainment nets were used to determine patterns and densities of incoming larval fish in the primary channel. Nets (500 µm) were 0.75 m × 0.75 m square (0.56 m^2), 2.5 m long, with a removable, cylindrical PVC collection container attached to the terminal end of each net. In a study comparing the effects of mesh size, smaller mesh size (330µm) did not necessarily increase the catch rate for fish larvae in the 4–6 mm range and smaller mesh size was more prone to clogging (Fujimura 1989). Therefore, 500 µm mesh was considered sufficient for larvae encountered in the primary channel at the TFCF. Mechanical flow meters (General Oceanics Inc., Miami, Florida), centered and suspended across the net opening with steel cable were used to measure the volume of water passing through the nets during each sample period (Figure 2). Nets were attached to ropes, via carabiners, on the downstream side of the trash rack bridge. These ropes were tied to the trash rack bridge and held vertical with steel weights to keep nets perpendicular to incoming flows.

The purpose of the study design was to provide representative sampling of larval fish entering the primary channel, accounting for potential differences in spatial distribution. To accomplish this, a 3×3 sampling array (three vertical locations × three horizontal locations, effectively dividing the cross-sectional area of the primary channel into nine quadrants) was used for this study. In this array, three nets were placed at respective locations across the primary channel at a single horizontal band for a specified duration. After removing the contents of the nets, they were then raised or lowered to the next corresponding depth in the water column (non-random order). The three vertical locations were spaced, approximately the same distance apart, across the primary channel. These locations are referred to hereafter as “A,” “B,” and “C,” indicating their location across the primary channel (Figure 3). The three horizontal bands were 0.5 m below the water surface, 2.5 m below the surface, and directly on the bottom of the canal (which varied under different hydraulic conditions from 5.0–6.4 m, though not recorded). These locations are respectively referred to as “Top,” “Middle,” and “Bottom.” The three depths of the water column were sampled consecutively, not simultaneously, due to the physical limitations of trying to sample all nine quadrants at once.

Pilot sampling was completed April 21–22, 2010, in order to more effectively plan full-scale sampling efforts. Full-scale 24-h sampling was completed May 11–July 1, 2010. A total of ten 24-h intervals occurred in 2010. Sampling consisted of two 24-h sampling intervals within a week. For the second 24-h sampling interval in the week, netting periods were typically staggered 1h later to the previous 24-h interval, to account for the tidal cycle being greater than 24h (50 min later each day). During each 24-h interval, all nine quadrants of the 3×3 array were sampled every 3–4 h (defined as the *sample period*; so, 6 sample periods over 24 h). Each sample period consisted of the three nets (A, B, and C) collecting for a specific duration at each of the three horizontal bands (top, middle, and bottom of the water column). Nets were typically collecting for 30 min, though in high flows sampling time was sometimes reduced because of debris loads (largely *Egeria densa*).

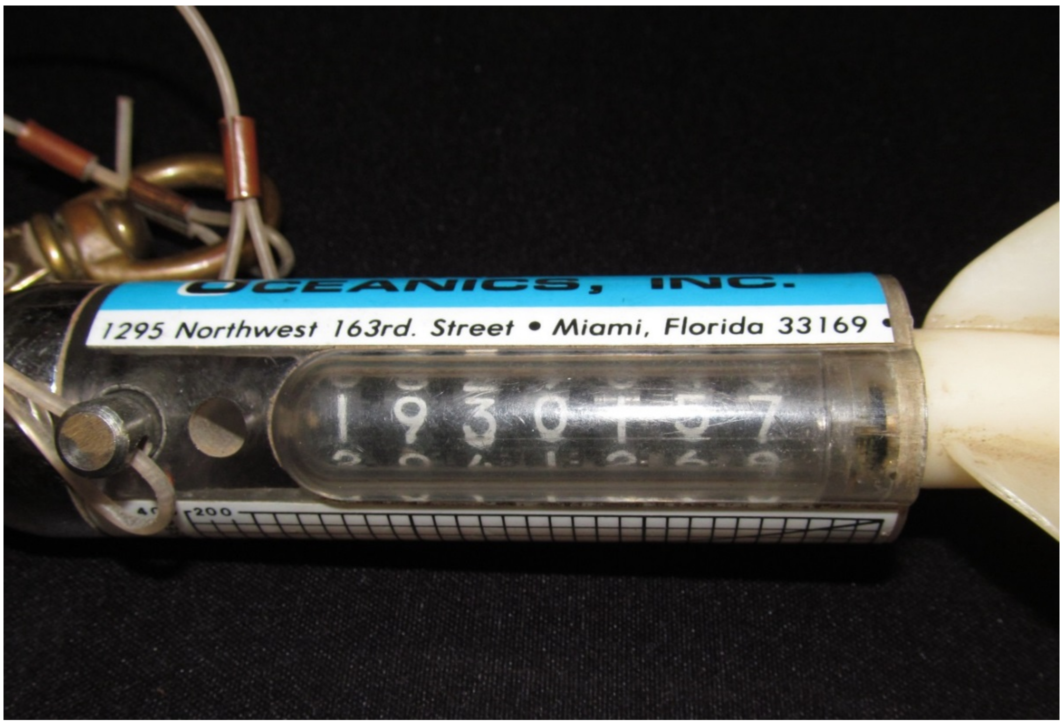

Figure 2. General Oceanics© mechanical flowmeter used for determining flow through entrainment nets. Flow is determined from a manufacturer-provided formula, the area of the net opening (0.56 m^2), and the difference between rotational counts on the meter before and after each sample period.

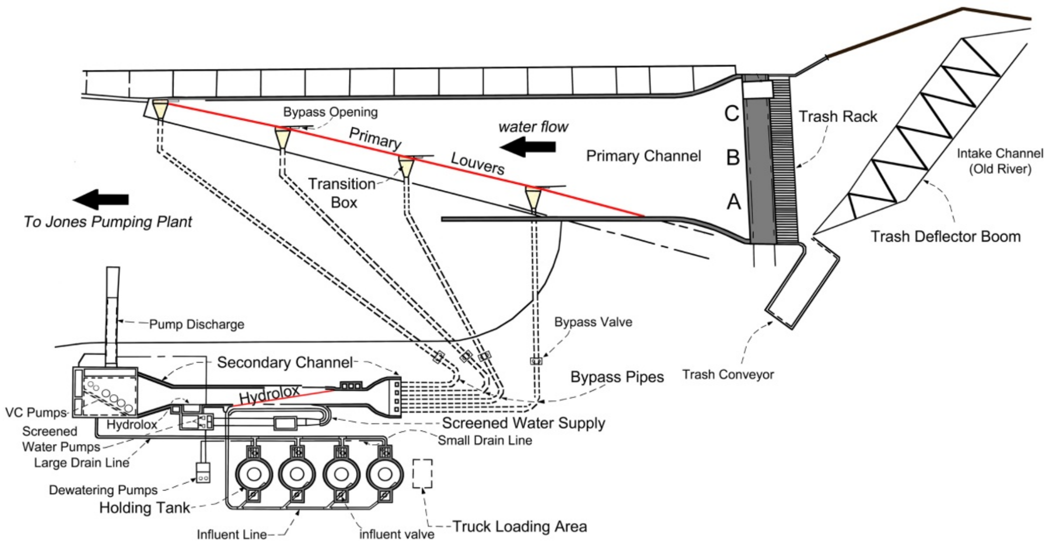

Figure 3. Overhead schematic depicting approximate locations of the lateral placement (“A,” “B,” and “C”) of larval fish entrainment nets in the primary channel (downstream of the trash rack) at the Tracy Fish Collection Facility.

Larval Identification

Following each sample set at the respective vertical placement, net contents were removed and preserved in individual containers, nets cleaned of any debris, and re-set at the next corresponding depth (*e.g.*, top, middle, or bottom). Fish captured in nets were sorted by removing the contents of the individual net’s collection container and placing materials into Nalgene containers with 10 percent buffered formalin solution. Rose Bengal (4,5,6,7-Tetrachloro-2′, 4′, 5′, 7′-tetraiodofluorescein disodium salt) was added to the solution, staining fish a red-pink hue. This aided in post-processing, making the fish easier to visually distinguish from detritus (Mitterer and Pearson 1977). During processing, samples were transferred to rectangular, clear glass dishes, and illuminated from below to aid in the separation of fish from debris. Fish were then transferred to vials with 10 percent buffered formalin solution for later identification. Biologists at the TFCF, trained in Delta larval fish identification, classified fish with the aid of a Leica™ MZ7_5 stereomicroscope (Leica Microsystems Inc., Buffalo Grove, Illinois). Fish were enumerated, measured (mm, total length), and identified to species, when possible, or to the lowest practical classification when fish were too damaged to be reliably identified.

Data Analyses

Environmental and Hydraulic Data

Environmental and hydraulic data were obtained for other parameters that may have impacted entrainment rates. This data included discharge at the JPP, water temperature, river stage (height), tidal influences, and sunrise/sunset times. Discharge at the JPP was used in lieu of primary channel velocity at the TFCF, with the assumption that discharge through the DMC from the TFCF to the JPP was the same (flowmeters at the TFCF were not functioning properly April–May of the study period). Discharge at the JPP, temperature, river stage, and tidal changes near the TFCF were queried on the California Data Exchange Center (CDEC) website. Discharge data was collected from the California Department of Water Resources-maintained JPP sensor (TRP). River stage and temperature were collected from the CDEC sensor, nearest to the TFCF—the USGS-maintained Grantline Canal sensor (GLC), located ~950 m straight-line distance from the TFCF. River stage and the resultant tidal change, as well as temperature values, were provided at 15-min intervals. Tidal fluctuations were calculated as a function of change between river stage readings. Discharge data at the JPP was reported as a singular daily value. Daily sunrise/sunset times were queried from the U.S. Naval Observatory website.

Flow Calculations/Corrections

Flow through each net was determined with a General Oceanics© mechanical flowmeter (General Oceanics Inc., Miami, Florida), centered across the opening of each entrainment net. Volume was calculated using the difference between rotational counts recorded from each flowmeter, the total fishing time of the nets, and from a formula provided by the manufacturer. Total volume filtered was proportional to these counts and the area of the net opening (0.56 m^2). However, during early sampling efforts, discharge in the DMC was relatively low, and flows in the primary channel were often insufficient to effectively turn flowmeters. Flowmeters were re-fit with larger-blade propellers, more suited to low flows. Often, though, even these were insufficient to accurately measure flows during some collection periods. On the other hand, at higher flows, aquatic vegetation occasionally became entangled on the flowmeters preventing accurate readings. In either instance, count data from flowmeters could not be reliably used to calculate flow. Because these were not limited to only a few instances, we did not want to omit the data from fish collected during this time.

To account for these inaccurate readings, flow was estimated from other available hydraulic data: JPP discharge, river stage, tidal fluctuation, in conjunction with flowmeter readings that were considered accurate. To do this, a database of all the flow values from each quadrant was constructed and paired with the corresponding hydraulic variables (JPP discharge, river stage, and tidal change). Known counts where it was observed that the flowmeters were not turning (typically only observable at the top location or as nets were brought to the surface for content collection), or where debris was bound to the flowmeter blades, were not included in the analysis. Furthermore, there may have been instances where inaccurate flowmeter counts occurred but were not observed (*e.g.*, flowmeter was not turning, debris may have temporarily tangled on flowmeter—but the issue not identified,). To account for this, data were evaluated for outliers (Samuels and Witmer 2003), and these flow values were also removed from analysis.

For each quadrant of the 3×3 sampling array (vertical and horizontal spatial distribution), a regression equation was developed in SigmaPlot™ using multiple linear regression (SigmaPlot 13, Systat Software, Inc., San Jose, California; see Appendix 1, Table A1-1 for regression equations and associated r^2 values). These regression equations were used to calculate values in the data set in lieu of inaccurate readings or outliers.

Catch per Unit Effort

Catch per unit effort (CPUE) was initially calculated for each net location at each time interval. Units for CPUE in this study are reported as fish captured/m^3 water filtered. CPUE was calculated to standardize for fluctuations in total soak time between net sets (*i.e.*, variations from the nominal soak time of 30 min) in addition to spatial and temporal velocity fluctuations in the primary channel. The total number of fish captured was divided by the total volume of water filtered through each net to calculate the CPUE value. CPUE values were used as the basis for analyzing differences in spatial and temporal fish distribution through the primary channel (see *Statistical Analyses*). In addition to CPUE, as a measure of total fish captured across all species, four species-specific CPUE values were also calculated. Prickly Sculpin (*Cottus asper*) and Sacramento Splittail (*Pogonichthys macrolepidotus*) were selected because they are native California species. Striped Bass and Threadfin Shad (*Dorosoma petenense*) were selected because they frequently occur at TFCF (CDFW 2015a) and are generally cited as a declining pelagic species in the Delta (Sommer *et al.* 2007) and a species of interest at the TFCF (Sutphin and Hueth 2015). This evaluation was completed in order to determine whether species-specific distributions were present that would have not otherwise been evident from examining distributions across all species.

Statistical Analyses

Catch per unit effort was compared within the 3×3 array using two-way ANOVA. Quadrant values were first standardized as a proportion of total CPUE within each sampling period (*i.e.*, the CPUE of the evaluated quadrant divided by the sum of CPUE from all nine quadrants). This allowed for a comparison within sampling day and across sampling season, since CPUE could be influenced by other temporal variables. The two categories for analysis were horizontal location and depth. Next, CPUE values were evaluated for diel variation (day/night), within each 24-h period. In a similar manner to CPUE analysis for spatial variation, CPUE values were first standardized—in this instance, within quadrant of the 3×3 array, across each 24-h period (*i.e.*, the CPUE from the evaluated quadrant divided by the sum of the CPUE from that same quadrant over each 24-h sample set). When data did not meet the assumptions for parametric statistics, standard transformations were attempted to normalize the data (Fletcher *et al.* 2005; Bartlett 1936). If those attempts were unsuccessful, data was rank-transformed and the statistical analysis performed. When significant differences were found, the Holm-Sidak pairwise comparison method was used to determine where significant differences existed.

Following this analysis, CPUE values were compared to the collected variables (see *Environmental and Hydraulic Data*). To avoid including multiple variables that might be inter-related (*e.g.*, date and temperature), violating the assumption of parametric statistics, a Pearson's product-moment correlation was used to test for multi-collinearity between variables. Variables that had a close association ($r \geq 0.60$; Connor *et al.* 2003) were not directly included in the analysis. For all subsequent tests, regression analyses were used to determine whether correlations between CPUE and the tested variable existed. Post hoc analysis of CPUE over the sampling season was performed with polynomial regression. Statistical comparisons were completed with SigmaPlot™. For all statistical analyses, p-values, $\alpha \leq 0.05$, were considered significant.

Daily Entrainment Estimates

Daily entrainment estimates were calculated using species-specific CPUE values for all sample periods from the 3×3 sampling array, in relation to the total discharge through the DMC. The following assumptions were made to estimate daily entrainment during the sampling periods:

Since cross-sectional flow was not uniform, measured or calculated discharge in each of the nine net locations was assumed to represent respective discharge in that quadrant of the canal. Velocity profiles of the primary channel indicate that flows are not horizontally or vertically uniform, and flow dynamics can be quite different when measured at different times (Frizell and Bark 2006; pers. comm. Svoboda). Measured or calculated flows (mean ± SD) from this study are presented in Appendix 1, Figure A1-1. Similar to the aforementioned research, we observed varying flows across the primary channel. While we did not observe any indications of net clogging from fine particulate matter, this parameter was not analyzed. Though we could not completely preclude the influence of this factor, we assume (for the calculations of discharge relating to entrainment [see above description]) that it would have influenced all nets equally across the primary channel. As a result, and given the collected data, it was presumed that this was still the best approach for estimating representative discharge, and resultantly, entrainment across the primary channel.

The sum of discharge in the nine quadrants of the primary channel was assumed to be equal to the total discharge at the JPP. Total discharge through an individual quadrant was calculated by dividing the total discharge at the JPP during each sampling period by the proportional volume through the net, in that same quadrant, in relation to the other quadrants of the 3×3 sampling array—for example, if the total volume in all nine nets of a sampling period was 10 m^3, and the volume from one net was 0.5 m^3, then 5 percent of the water (0.5 m^3/10 m^3), was assumed to have passed through that quadrant. If the discharge at JPP was 100 m^3/s (3,531 cfs), and the sampling interval was 4 h, then the total volume of water assumed to have passed through that respective quadrant was $5\% \times (100\ m^3/s \times 60\ s/min \times 60\ min/h \times 4\ h/\text{sampling interval}) = 7.2 \times 10^4\ m^3$.

Entrainment was estimated using species-specific CPUE values calculated for each net set. Catch per unit effort was multiplied by the total volume of water estimated to have passed through a quadrant for each time interval (see previous paragraph), resulting in an estimate of total fish passing through that quadrant. The sum of fish from all nine quadrants represented the number of fish entering the primary channel within that time interval. Lastly, the sum of fish from all sampling periods (six 4-h intervals) over a 24-h period was the total daily entrainment estimate.

All ten 24-h intervals, from May 12 to July 1, 2010 were used for daily entrainment estimates. The first collection period, April 22, 2010 was not used for calculating daily entrainment since only two sample periods, spanning 8 h, were completed. CPUE estimates, compiled from each sampling period, for each net, were applied to the multiplication factor from the above calculations to extrapolate total daily entrainment.

This page intentionally left blank

Results

Distribution

In the following analyses, CPUE values did not meet the assumptions of parametric statistics and standard transformations were unsuccessful for normalizing data. Therefore, values were rank-transformed and analyzed using two-way ANOVA. Significant differences in CPUE existed in both horizontal ($P = 0.007$) and vertical distribution in the primary channel ($P < 0.001$; Figure 4). However, the horizontal × vertical interaction was not significant ($P = 0.906$). The outside netting positions ("A" and "C") had significantly higher proportional CPUE from the middle position ("B") but not significantly different from each other. The top, middle, and bottom positions were all significantly different from each other, with CPUE decreasing from top to bottom.

Additionally, spatial distribution appears to be species-specific. For the four representative species, Prickly Sculpin CPUE was significantly different in both vertical and horizontal distribution ($P < 0.001$ and $P = 0.049$, respectively). No significant differences were detected for Sacramento Splittail ($P = 0.392$ and $P = 0.510$, vertical and horizontal distribution). Striped Bass appeared to have significantly different distribution vertically ($P < 0.001$) but not horizontally ($P = 0.288$). Lastly, Threadfin Shad had significantly different vertical and horizontal distribution ($P < 0.001$ and $P = 0.015$, respectively). Additional species-specific CPUE information, regarding the four representative species, is available in Appendix 3.

Since significant spatial distribution differences existed, further analyses were also evaluated by quadrant. Sampling intervals were categorized as day or night, according to sunset/sunrise times (http://www.usno.navy.mil/USNO/). Two-way ANOVA, and subsequent pairwise comparison, indicated that CPUE was significantly lower during daytime intervals (0.147 ± 0.016, mean ± 2SE) when compared to nighttime sampling ($P < 0.001$; 0.198 ± 0.025, mean ± 2SE), but was not significantly different across quadrants ($P = 0.111$; Figure 5). In regards to species-specific diel distribution, no significant differences across diel period were detected for Prickly Sculpin or Threadfin Shad (Appendix 3, Figure A3-2 and Table A3-2). However, Sacramento Splittail and Striped Bass CPUE was significantly higher at night when compared to daily sampling periods. Additionally, Striped Bass CPUE had a significant location × diel interaction, where CPUE decreased top to bottom at night but had an inverse effect during daytime hours.

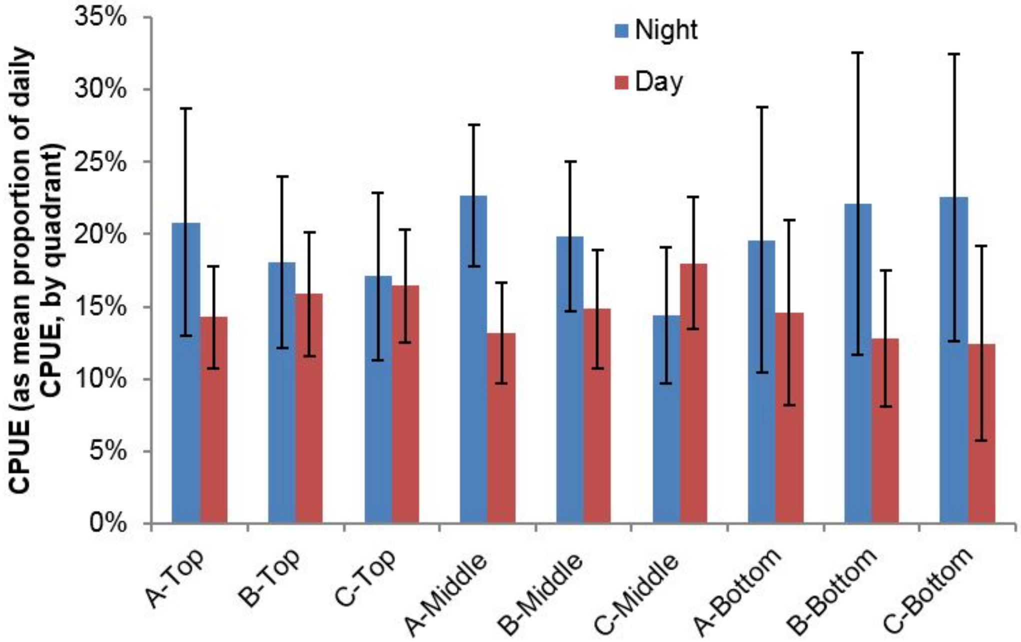

Figure 4. Catch per unit effort (CPUE; mean ± 2SE), standardized for each sampling period, for larval fish entering the primary channel of the Tracy Fish Collection Facility.

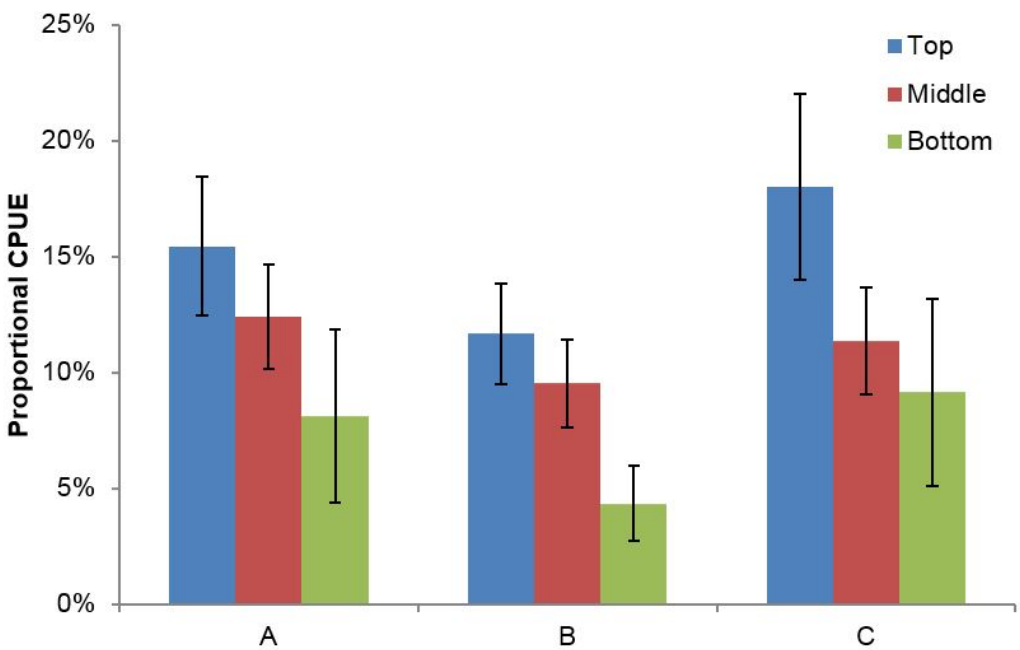

Figure 5. Catch per unit effort (CPUE; mean ± 2SE), standardized by quadrant, for diel differences of larval fish distribution across the primary channel of the Tracy Fish Collection Facility.

In a similar manner as the diel analysis, CPUE was standardized across a 24-h cycle to evaluate effects of tidal fluctuation and river stage on CPUE. However, r^2-values were generally below 0.1 (Appendix 4). As a result of the lack of fit, no further analysis was conducted.

Moving from daily CPUE-variable relationships, larger spatial-temporal relationships became more difficult to separate. A Pearson product-moment correlation indicated multicollinearity between date, mean daily temperature, and discharge ($r > 0.8$ in all instances, $P < 0.01$). This precluded teasing apart relationships between these variables and CPUE. However, these variables, in particular date and discharge, indicated a logarithmic increase in estimated daily entrainment occurring over the study period (Figure 6). While we were unable to discern differences between seasonality and discharge, post hoc analysis of CPUE × date indicated a significant correlation, though only robust ($r^2_{adj} > 0.6$) for the middle-tier nets (Figure 7).

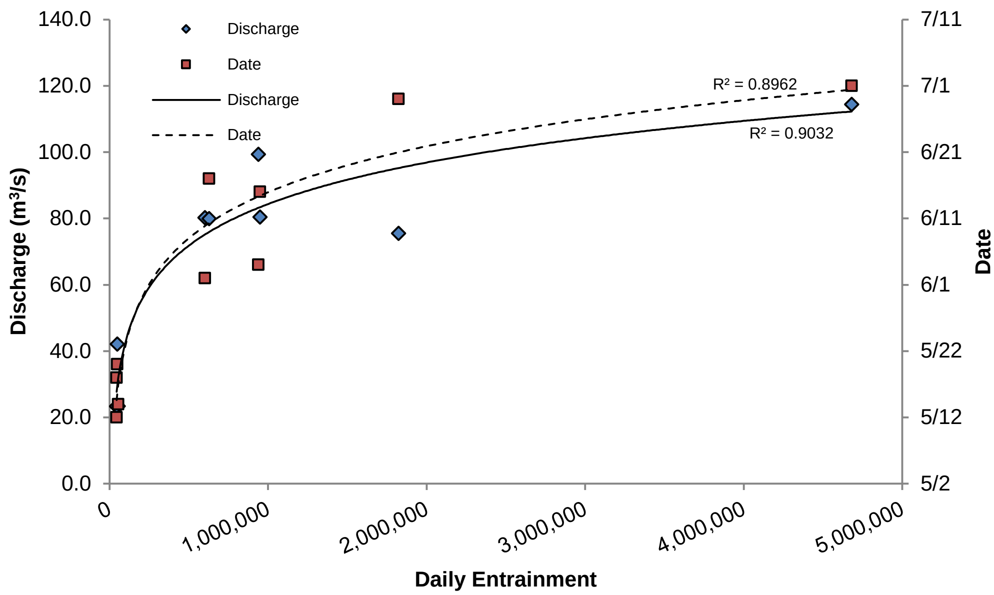

Figure 6. Daily larval fish entrainment estimates through the primary channel of the Tracy Fish Collection Facility into the Delta Mendota Canal. Estimates in relation to discharge at the C.W. “Bill” Jones Pumping Plant and collection dates during the 2010 study period. Logarithmic trendlines and associated r^2-values shown.

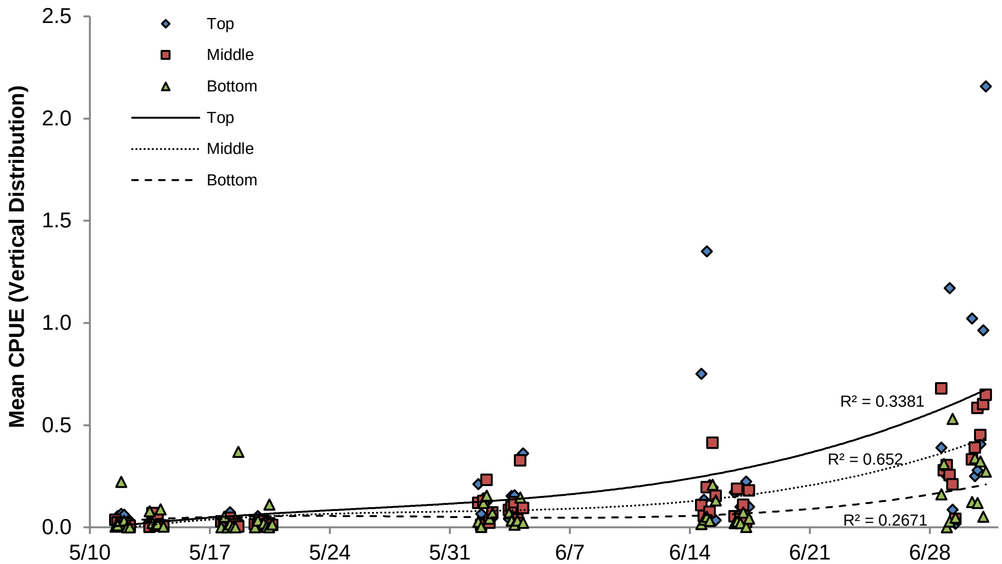

Figure 7. Third-order polynomial relationship between catch per unit effort (CPUE) and time, over the 2010 larval fish entrainment study at the Tracy Fish Collection Facility.

Entrainment Estimates

Daily entrainment estimates for the survey dates are shown in Figure 8. Species composition, by sampling date, is shown in Figure 9. Prickly Sculpin were most common through the May 20 sample period. However, Striped Bass and Common Carp were most abundant in early June. Thereafter, Common Carp, sunfish (*Lepomis* spp.) and Threadfin Shad became the most abundant species. Numerical values for species-specific estimates of larval fish entrainment (including fish in "Other" category) through the primary channel, by date, are available in Appendix 5.

Discussion

Larval fish distribution, in terms of CPUE, in the primary channel of the TFCF was spatially and temporally dependent. In addition, species-specific distribution trends did not always correspond to overall species distribution. This suggests a single sampling location in the primary channel may be insufficient to describe entrainment through the primary channel (Siegfried *et al.* 2000; Hiebert *et al.* 1995). Nonnative species made up the majority of fish entering the primary channel and only a few native species were present in the collected samples (*i.e.*, Prickly Sculpin, Sacramento Splittail, Sacramento Blackfish, *Orthodon microlepidotus*, Sacramento Sucker, *Catostomus occidentalis*)—with Sacramento Splittail being the only species of special concern (CDFW 2015b). Since distribution of larval fish in the primary channel appears to be species-specific, and because of the lack of threatened and endangered (T&E) species collected during the study, this prevents assumptions pertaining to T&E larval entrainment.

Entrainment rates are likely a combination of fish spawning seasons, which themselves are a combination of environmental factors (Harvey *et al.* 2002; Gerlach and Kahnle 1981), in addition to pumping rates at downstream facilities (Grimaldo *et al.* 2009; Siegfried *et al.* 2000). Our results indicate a similar trend. Over the study period, there was a logarithmic increase in the density of larval fish commensurate with JPP pumping, date, and temperature. Siegfried *et al.* (2000) also noted a non-linear increase in larval fish with increased JPP pumping. In addition, we found diel period to have a significant effect on CPUE of larval fish, with higher CPUE during nighttime sampling intervals. No significant effects from tidal fluctuation or river stage were detected. It is likely that diel effects and JPP discharge override these factors (Siegfried *et al.* 2000; Hiebert *et al.* 1995).

It is possible that our results underestimate larval fish in the primary channel. Net avoidance by larval fish was not factored for entrainment estimates. Other research has suggested net avoidance by larval fish, particularly as total length increases (Gartz *et al.* 1999). The opportunity for net avoidance increases as flows decrease since the amount of time for larval fish to potentially detect collection nets is extended. This could have been one reason for the logarithmic increase in estimated entrainment—a result of underestimating entrainment earlier in the sampling season, when there was lower JPP discharge. On the other hand, net fouling during high flows could have resulted in an underestimate of larval fish entrainment later in the study. Future efforts could factor in these influences. Electronic flowmeters, in lieu of mechanical ones, could be used to better estimate flows through nets, as well as directly measure flows across the primary channel. Net fouling could be estimated prior to collecting periods. For example, multiple nets could be placed in close proximity to each other, fishing simultaneously. Each of the three nets could be removed at increasing intervals. The difference in flows detected could help to give an estimate of net fouling, as a function of time, during collection periods. Net avoidance by larval fish has been estimated by

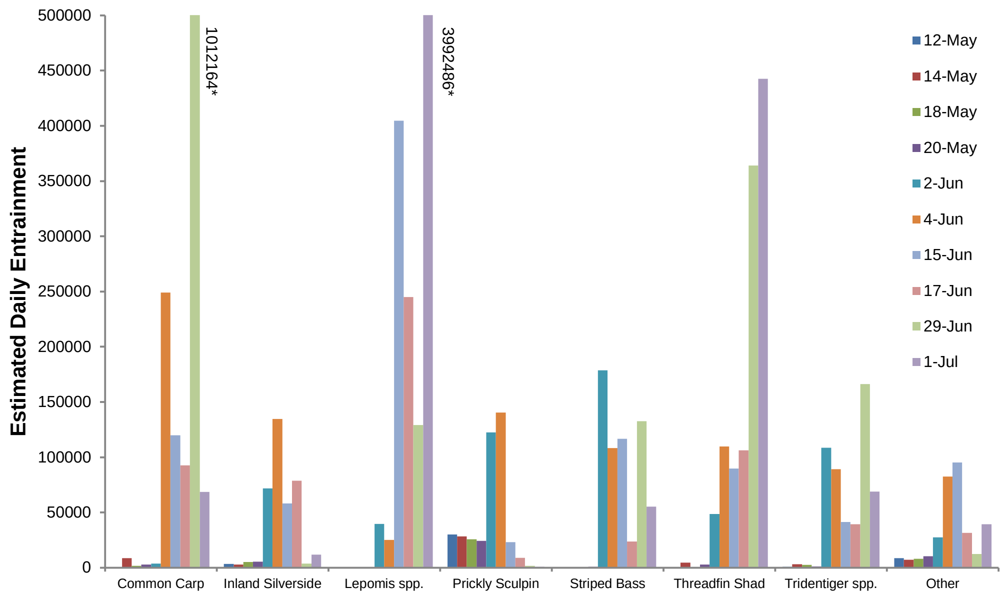

Figure 8. Daily entrainment estimates of larval fish species during the 2010 larval entrainment study. Note the two values (under Common Carp and *Lepomis* spp.) that exceed the vertical axis; in this case, the estimated values are described at the top of the respective bar.

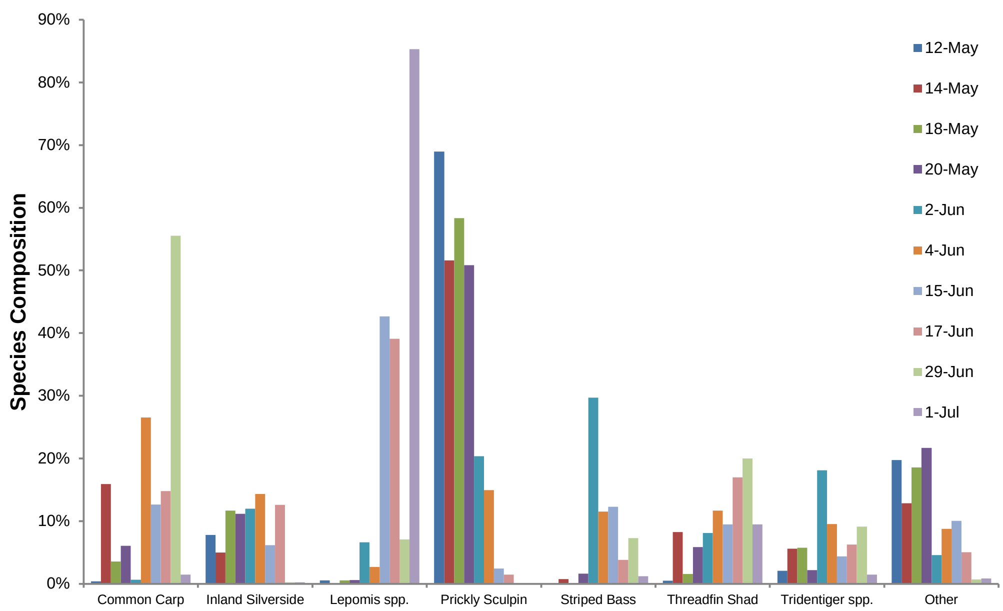

Figure 9. Larval fish species composition through the primary channel of the Tracy Fish Collection Facility, based on daily entrainment estimates during the 2010 study period.

using different sized nets, fishing concurrently, and observing the difference in density of captured fish (Gartz *et al.* 1999).

Because the louver system at the TFCF was originally designed to salvage fish > 25 mm (Bates and Vinsonhaler 1957), there is likely significant loss of larval fish through the primary and secondary channels, as well as the screens within the holding tanks (Reyes *et al.* 2012). Future efforts should focus on comparing entrainment rates to salvage efficiency. Sampling across these locations (primary channel, secondary channel, and holding tanks) could allow for loss estimates. While originally part of this study design, water conditions in 2011 precluded accurate sampling within the holding tanks at the TFCF.

Population-level effects relating to water exports are poorly understood (Grimaldo *et al.* 2009). However, given the decline in native fish over time, facility operations should focus on ways to reduce entrainment losses, when possible (Grimaldo *et al.* 2009; Brown *et al.* 2009; Brown and Michniuk 2007). Results indicate that larval fish entrainment into the DMC are likely tied to pumping and seasonality; because of this, it may be difficult to alter facility operations during California's irrigation/agriculture season in order to reduce entrainment. Some differences were found in diel densities of fish, though. Altering pumping (*i.e.*, reducing pumping during nighttime hours) could potentially reduce overall entrainment. The magnitude of this reduction would correspond to seasonal abundances of larval fish as well as the capacity to reduce pumping during this time. Spatial factors influencing entrainment through the primary channel would be more difficult to account for and may not be controllable under current operations.

This page intentionally left blank

Acknowledgements

Project funding was provided by the Bureau of Reclamation, Tracy Fish Collection Facilities Research Program. We would like to thank Brent Bridges and Carl Dealy, and other members of the Tracy Technical Advisory Team for providing project oversight and support. We would also like to thank Brandon Wu for his assistance with the study logistics, and also the operational staff for their support while performing surveys.

This page intentionally left blank

References

Bartlett, M.S. 1936. *The square root transformation in analysis of variance*. Supplement to the Journal of the Royal Statistical Society 3:68–78.

Bates, D.W. and R. Vinsonhaler. 1957. *Use of louvers for guiding fish.* Transactions of the American Fisheries Society 86:38–57.

Brown, L.R. and D. Michniuk. 2007. *Littoral fish assemblages of the alien-dominated Sacramento-San Joaquin Delta, California, 1980–1983 and 2001–2003.* Estuaries and Coasts 30:186–200.

Brown, L.R., W. Kimmerer, and R. Brown. 2009. *Managing water to protect fish: a review of California's environmental water account, 2001–2005.* Environmental Management 43:357–368.

Bureau of Reclamation (BOR). 2008. *SOP #32: Larval Delta Smelt and Longfin Smelt sampling at the TFCF fish count station*. Tracy Fish Collection Facility Sampling Protocol, Updated June 2012. Bureau of Reclamation, Byron, California.

(California Department of Fish and Wildlife (CDFW). 2015a. *Annual salvage report.* <ftp://ftp.dfg.ca.gov/salvage/Annual%20Salvage%20Reports/>. Accessed 25 Aug 2015.

_____. 2015b. *California Fish Species of Special Concern, 3rd Edition*. <https://www.wildlife.ca.gov/Conservation/Fishes/Special-Concern>. Assessed 9 September 2015.

Connor, W.P., H.L. Burge, J.R. Yearsley, and T.C. Bjornn. 2003. *Influence of flow and temperature on survival of wild subyearling fall Chinook salmon in the Snake River.* North American Journal of Fisheries Management 23:362–375.

Fletcher, D., D. Mackenzie, and E. Villouta. 2005. *Modelling skewed data with many zeros: a simple approach combining ordinary and logistic regression*. Environmental and Ecological Statistics 12:45–54.

Frizell, K. and R. Bark. 2006. *Determining hydraulic conditions for holding areas of large predatory fish with the Tracy Fish Collection Facility*. World Environmental and Water Resource Congress 2006:1–9.

Fujimura, R.W. 1989. *Tests on the effect of mesh size on the capture of striped bass larvae in the Sacramento-San Joaquin estuary.* Interagency ecological study program for the Sacramento-San Joaquin estuary. Technical Report 21.

Gartz, R.G., L.W. Miller, R.W. Fujimura, and P.E. Smith. 1999. *Measurement of larval striped bass (Morone saxatilis) net avoidance using evasion radius estimation to improve estimates of abundance and mortality*. Journal of Plankton Research 21:561–580.

Gerlach, J.M. and A.W. Kahnle. 1981. *Larval fish drift in a warmwater stream.* American Fisheries Society Warmwater Streams Symposium, pp. 154–162.

Grimaldo, L.F., T. Sommer, N.V. Ark, G. Jones, E. Holland, P.B. Moyle, B. Herbold, and P. Smith. 2009. *Factors affecting fish entrainment into massive diversions in a tidal freshwater estuary: can fish losses be managed?* North American Journal of Fisheries Management 29:1253–1270.

Harvey, B.C., J.L. White, and R.J. Nakamoto. 2002. Habitat relationships and larval drift of native and nonindigenous fishes in neighboring tributaries of a coastal California river. Transactions of the American Fisheries Society 131:159–170.

Hiebert, S., C. Liston, P. Johnson, C. Karp, and L. Hess. 1995. *Continuous monitoring of fish eggs and larvae, 1991–1992*. Tracy Fish Collection Facility Studies, Volume 2, U.S. Bureau of Reclamation, Mid-Pacific Region and Denver Technical Service Center.

Mitterer, L.G. and W.D. Pearson. 1977. Rose Bengal stain as an aid in sorting larval fish samples. The Progressive Fish-Culturist 39:119–121.

Reyes, R.C., Z.A. Sutphin, and B.B. Bridges. 2012. Effectiveness of fine mesh screening a holding tank in retaining larval and juvenile fish at the Tracy Fish Collection Facility. Tracy Fish Collection Facility Studies, Technical Bulletin 2012-1. U.S. Bureau of Reclamation, Mid-Pacific Region and Denver Technical Service Center.

Samuels, M.L. and J.A. Witmer. 2003. Statistics for the Life Sciences, Third edition. Prentice Hall, Upper Saddle River, New Jersey.

Siegfried, S., D. Craft, S. Hiebert, and M. Bowen. 2000. Continuous monitoring of fish eggs and larvae at the Tracy Fish Collection Facility, Tracy, California, February–June 1994. Tracy Fish Collection Facility Studies, Volume 6, U.S. Bureau of Reclamation, Mid-Pacific Region, and Denver Technical Service Center.

Sommer, T., C. Armor, R. Baxter, R. Breuer, L. Brown, M. Chotkowski, S. Culberson, F. Feyrer, M. Gingras, B. Herbold, W. Kimmerer, A. Mueller-Solger, M. Nobriga, and K. Souza. 2007. The collapse of pelagic fishes in the upper San Francisco estuary: El colapso de los peces pelagicos en la caecera del estuario San Francisco. Fisheries 32:270–277.

Sutphin, Z.A. and C.D. Hueth. 2015. Effects of loading density during transport on physiological stress and survival of Sacramento-San Joaquin Delta fishes. California Fish and Game 101:108–130.

Svoboda, C. 2015. March 2009 velocity profile in the primary channel of the Tracy Fish Collection Facility. Denver, Colorado, personal communication.

This page intentionally left blank

Appendix 1 - Formulas Used to Calculate Flow Through Nets when Accurate Readings from Mechanical Flowmeters were not Available

This page intentionally left blank

Table A1-1. Formulas were developed using multiple linear regression (SigmaPlot 13, Systat Software, Inc., San Jose, CA). Reported values ($r_{2adj.}$) indicate fit of hydraulic data to mechanical flowmeter readings along with associated significance (p-values) for hydraulic variables.

Table orientation represents cross-sectional area of primary channel, with the south-north orientation reading left to right and vertical placement in the water column corresponding top to bottom; since sensor data is reported in standard units, that is also how these equations are formulated. F = flow, D = discharge (cfs at C.W. “Bill” Jones Pumping Plant), RS=river stage (ft. at Grantline Canal Sensor), TC = tidal change (percent change from previous reading, at 15-min. intervals, at Grantline Canal Sensor).

A-Top: $r^2_{adj.}$ = 0.370 D: P = 0.099 RS: P = 0.300 TC: P < 0.001 F = 2.681 + (0.00120 × D) + (0.500 × RS) + (68.093 × TC)	**B-Top:** $r^2_{adj.}$ = 0.333 D: P = 0.156 RS: P = 0.629 TC: P < 0.001 F = 7.598 + (0.000871 × D) - (0.191 × RS) + (51.999 × TC)	**C-Top:** $r^2_{adj.}$ = 0.141 D: P = 0.109 RS: P = 0.207 TC: P = 0.042 F = 13.425 - (0.00153 × D) - (0.724 × RS) + (40.012 × TC)
A-Middle: $r^2_{adj.}$ = 0.443 D: P = 0.017 RS: P = 0.031 TC: P < 0.001 F = 9.230 + (0.00172 × D) - (0.956 × RS) + (68.128 × TC)	**B-Middle:** $r^2_{adj.}$ = 0.608 D: P = 0.005 RS: P < 0.001 TC: P = 0.035 F = 15.013 + (0.00140 × D) - (1.742 × RS) + (23.442 × TC)	**C-Middle:** $r^2_{adj.}$ = 0.463 D: P = 0.004 RS: P < 0.001 TC: P = 0.555 F = 11.238 + (0.00153 × D) - (1.371 × RS) + (6.427 × TC)
A-Bottom: $r^2_{adj.}$ = 0.601 D: P < 0.001 RS: P = 0.157 TC: P < 0.001 F = 0.368 + (0.00384 × D) - (0.555 × RS) + (55.685 × TC)	**B-Bottom:** $r^2_{adj.}$ = 0.487 D: P = 0.007 RS: P < 0.001 TC: P = 0.010 F = 10.261 + (0.00177 × D) - (1.376 × RS) + (30.863 × TC)	**C-Bottom:** $r^2_{adj.}$ = 0.445 D: P = 0.001 RS: P < 0.001 TC: P = 0.761 F = 8.102 + (0.00292 × D) - (2.144 × RS) - (5.771 × TC)

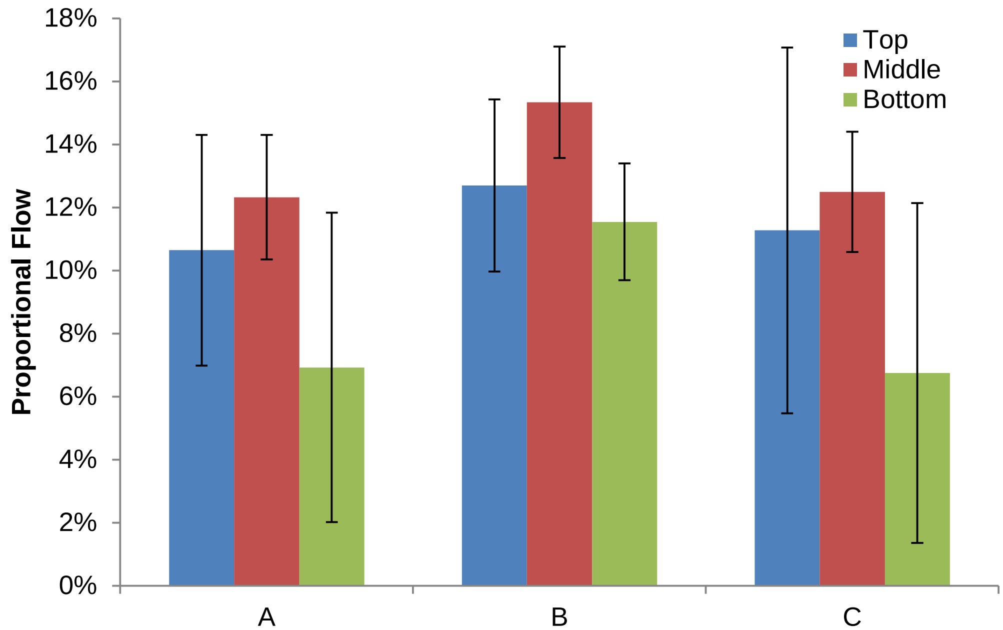

Figure A1-1. Proportional flows (mean ± SD), in relation to other quadrants April–July 2010 during larval fish entrainment study at the Tracy Fish Collection Facility. Values based on measurements recorded from flow meters attached to entrainment nets.

Appendix 2 - Mean Fish Sizes Captured May–July, 2010 in the Primary Channel at the Tracy Fish Collection Facility

This page intentionally left blank

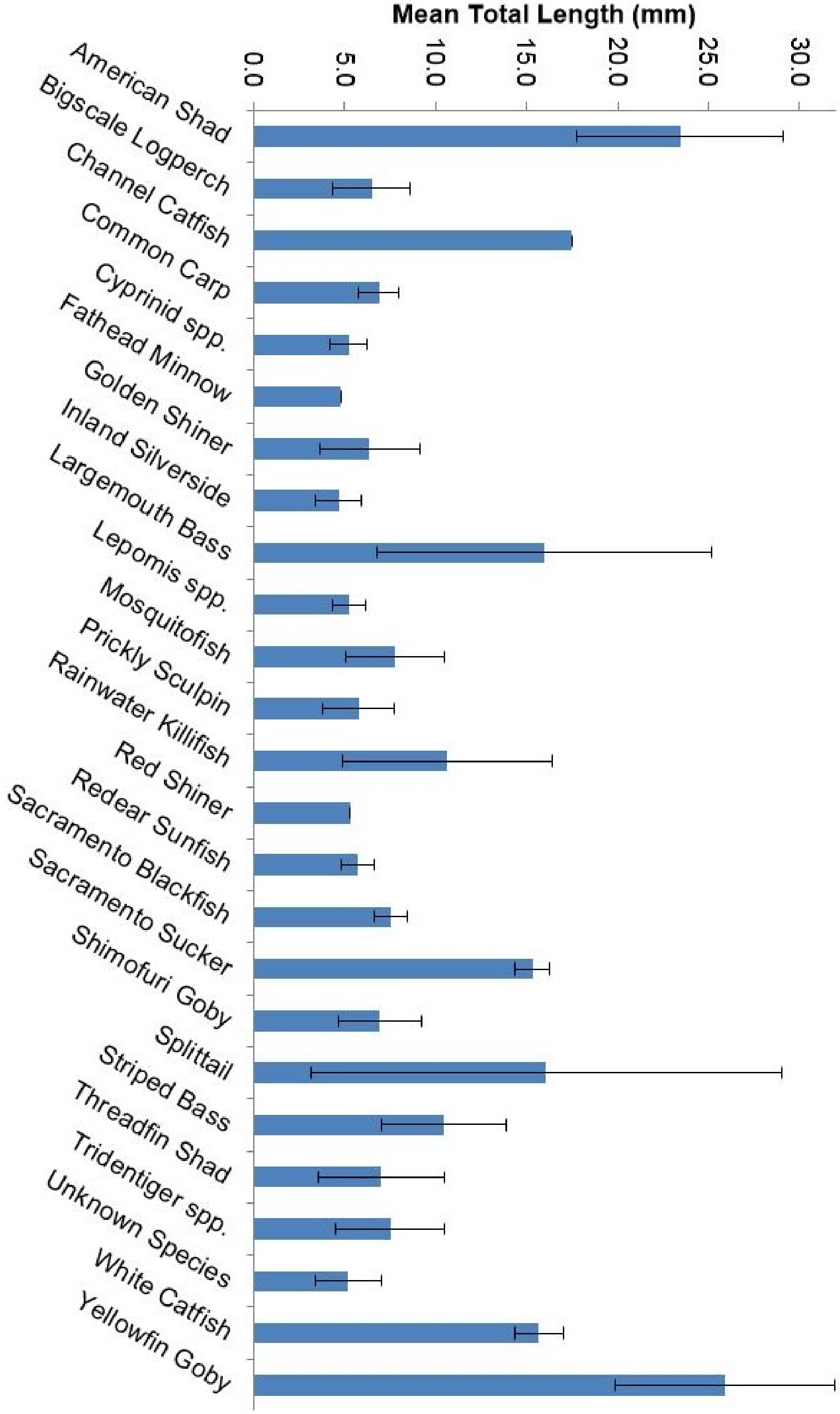

Figure A2-1. Total length (mm; mean ± SD) of larval fish collected in the primary channel of the Tracy Fish Collection Facility during study period, April 22–July 1, 2010.

This page intentionally left blank

Appendix 3 - Species-Specific Spatial and Diel Distribution in the Primary Channel at the Tracy Fish Collection Facility

This page intentionally left blank

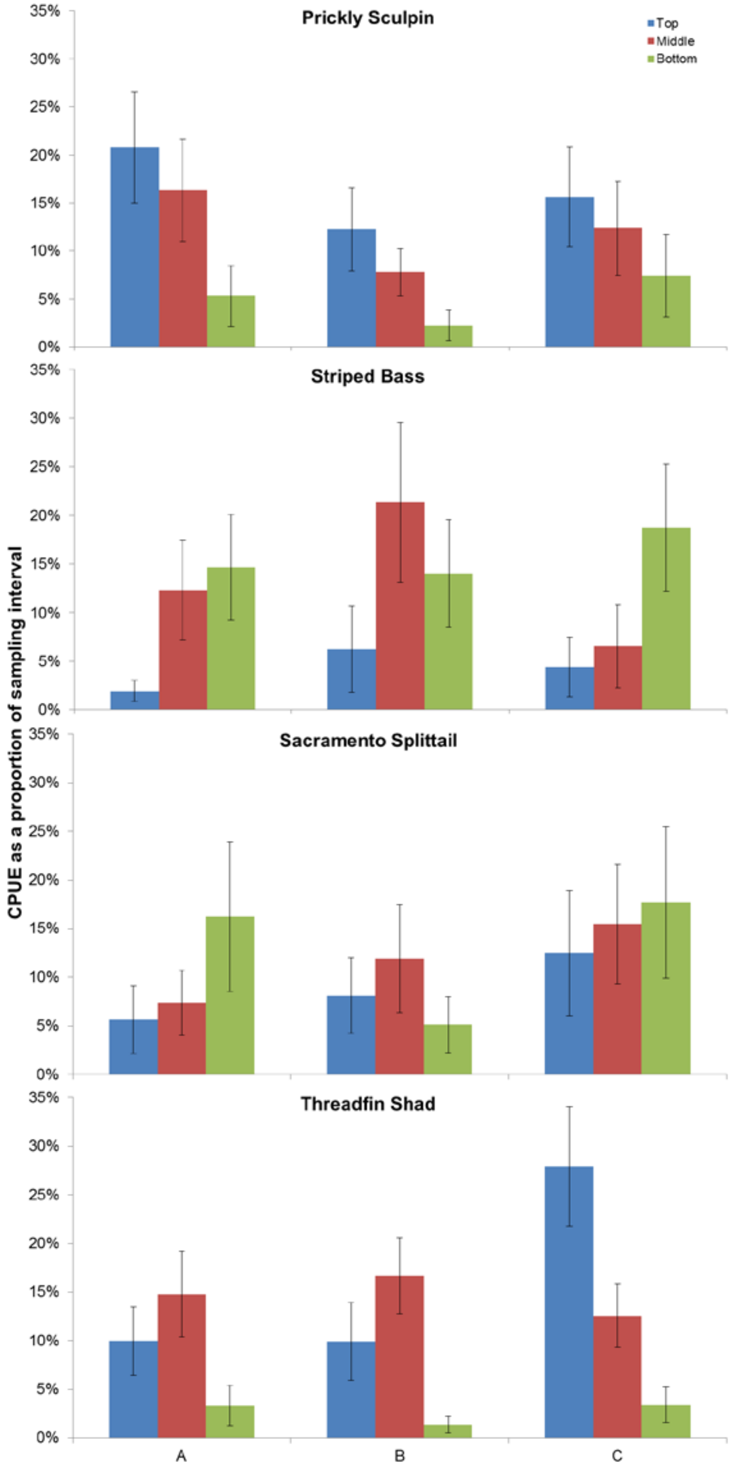

Figure A3-1. Catch per unit effort (CPUE; mean ± 2SE, standardized across quadrants), by spatial distribution, for four representative species of larval fish in the primary channel at the Tracy Fish Collection Facility. The vertical positions indicated, A–C, are from left to right across the primary channel, looking downstream.

Table A3-1. P-values for spatial distribution of four representative species of larval fish (Figure A3-1) in the primary channel of the Tracy Fish Collection Facility

	Prickly Sculpin	Sacramento Splittail	Striped Bass	Threadfin Shad
Depth	<0.001	0.392	<0.001	<0.001
Horizontal	0.049	0.510	0.288	0.015
Depth×Horizontal	0.923	0.828	0.212	<0.001
Within Depth:				
Top×Middle	0.029	—	<0.001	—
Top×Bottom	<0.001	—	<0.001	—
Middle×Bottom	<0.001	—	0.359	—
Within Horizontal:				
A×B	0.046	—	—	—
A×C	0.401	—	—	—
B×C	0.214	—	—	—
Within Top:				
A×B	—	—	—	0.660
A×C	—	—	—	<0.001
B×C	—	—	—	<0.001
Within Middle:				
A×B	—	—	—	0.913
A×C	—	—	—	0.739
B×C	—	—	—	0.857
Within Bottom:				
A×B	—	—	—	0.749
A×C	—	—	—	0.948
B×C	—	—	—	0.646
Within A:				
Top×Middle	—	—	—	0.031
Top×Bottom	—	—	—	0.004
Middle×Bottom	—	—	—	<0.001
Within B:				
Top×Middle	—	—	—	0.037
Top×Bottom	—	—	—	<0.001
Middle×Bottom	—	—	—	<0.001
Within C:				
Top×Middle	—	—	—	0.004
Top×Bottom	—	—	—	<0.001
Middle×Bottom	—	—	—	<0.001

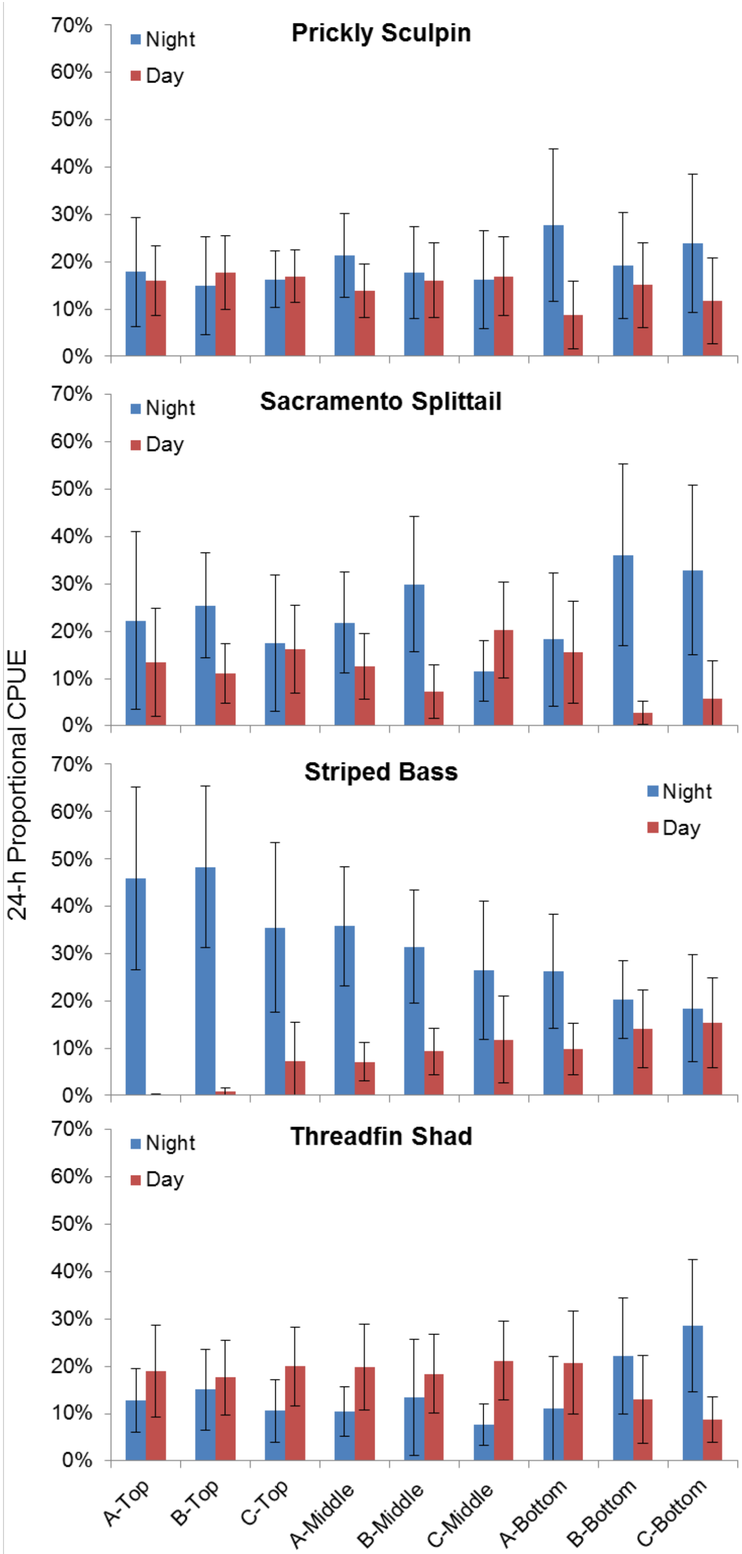

Figure A3-2. Spatial distribution in catch per unit effort (CPUE; mean ± 2SE), standardized by quadrant over 24-h period, for four representative species entering the primary channel of the Tracy Fish Collection Facility.

Table A3-2. P-values for spatial and diel distribution of four representative species of larval fish (Figure A3-2) in the primary channel of the Tracy Fish Collection Facility

	Prickly Sculpin	Sacramento Splittail	Striped Bass	Threadfin Shad
Diel Period	0.079	0.002	<0.001	0.568
Location	0.209	0.867	0.537	0.800
Diel Period×Location	0.811	0.533	0.014	0.239

Appendix 4 - Catch Per Unit Effort (CPUE; as a Proportion of 24h CPUE for Each Quadrant), in Relation to Tidal Fluctuation and River Stage

This page intentionally left blank

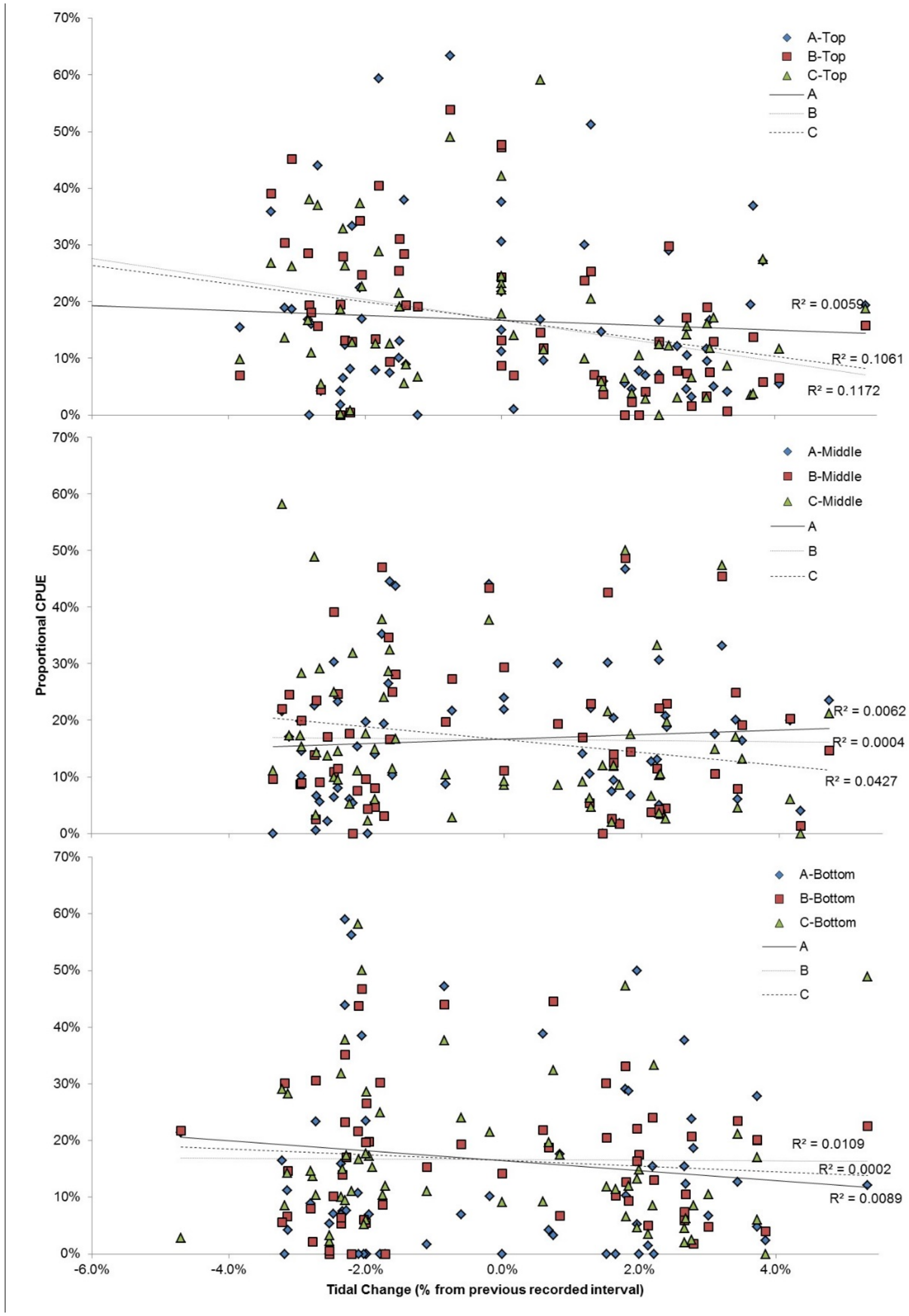

Figure A4-1. Tidal fluctuation and catch per unit effort (CPUE; as a proportion of 24h CPUE for each quadrant). Linear trendline and associated r^2-value indicated.

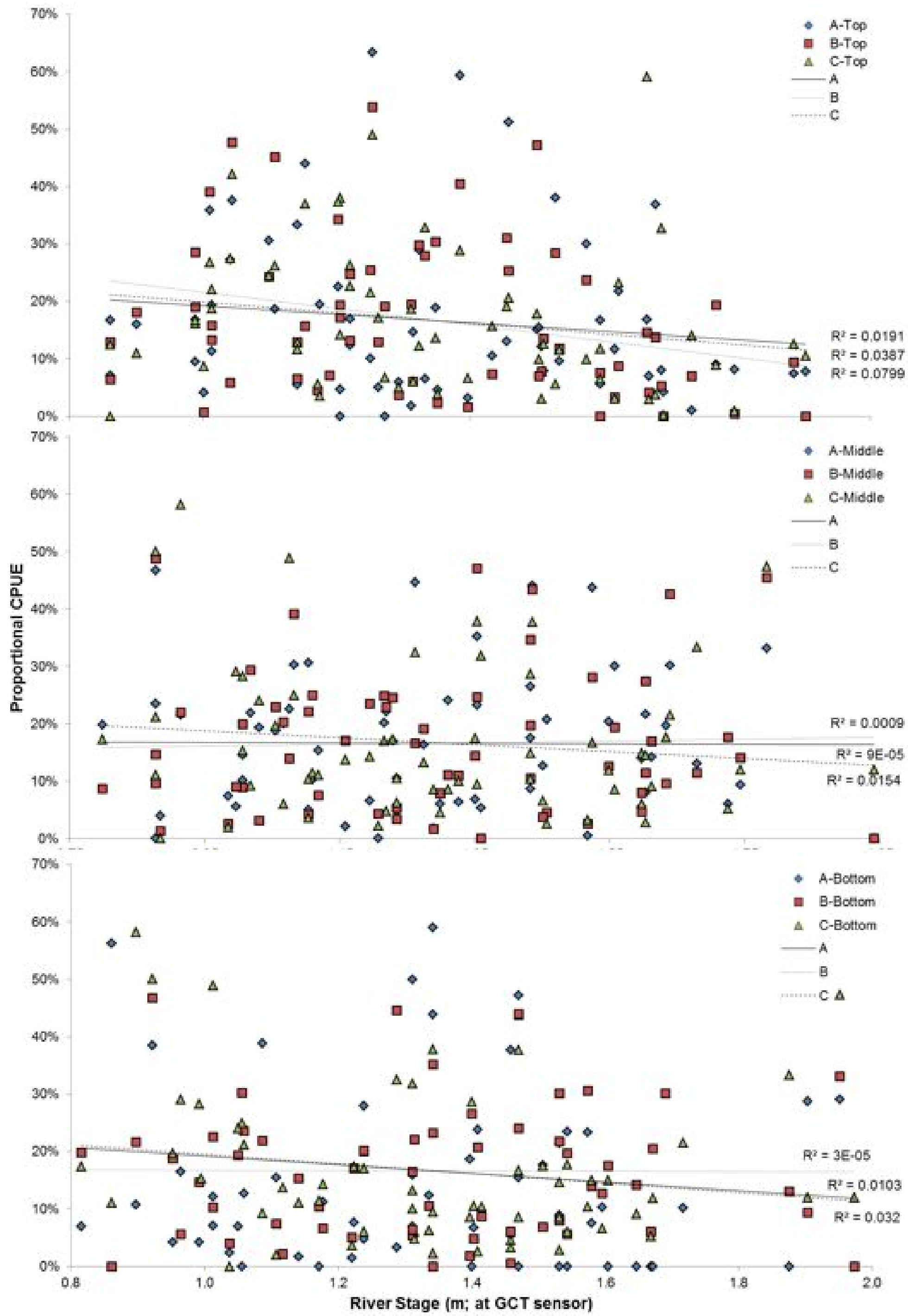

Figure A4-2. Catch per unit effort (CPUE; as a proportion of 24h CPUE for each quadrant). Linear trendline and associated r^2-value indicated.

This page intentionally left blank

Appendix 5 - Total Estimated Larval Fish Entering the Primary Channel During 2010 Study Period

This page intentionally left blank

Table A5-1. Total estimated larval fish, by species and sampling date, entering the primary channel during 2010 study period.

Species	5/12/10	5/14/10	5/18/10	5/20/10	6/2/10	6/4/10	6/15/10	6/17/10	6/29/10	7/1/10
American Shad, Alosa sapidissima	0	0	0	0	0	0	0	633	1086	0
Bigscale Logperch, Percina macrolepida	436	221	410	1843	17700	71399	8676	10250	1065	2463
Channel Catfish, Ictalurus punctatus	0	0	0	0	0	0	0	0	533	0
Common Carp, Cyprinus carpio	167	8750	1582	2894	3702	249128	119746	92780	1012164	68552
Inland Silverside, Menidia beryllina	3400	2752	5167	5349	71914	134519	58228	78803	3839	11863
Largemouth Bass, Micropterus salmoides	332	2567	0	0	4700	3177	5774	0	1920	5825
Lepomis spp.	229	43	234	286	39643	25278	404731	245082	129266	3992486
Mosquitofish, Gambusia affinis	0	0	0	0	643	0	505	0	466	0
Prickly Sculpin, Cottus asper	30062	28413	25801	24331	122528	140527	23087	8976	1649	950
Rainwater Killifish, Lucania parva	0	0	0	254	0	691	5442	7088	1618	4727
Sacramento Blackfish, Orthodon microlepidotus	229	0	0	286	0	0	2233	628	0	0
Sacramento Splittail, Pogonichthys macrolepidotus	7065	2767	6721	7740	1549	566	0	1782	0	0
Sacramento Sucker, Catostomus occidentalis	208	740	0	0	0	0	739	0	0	0
Small cyprinid spp.	326	548	131	254	642	2245	5018	3374	2097	4680
Striped Bass, Morone saxatilis	0	419	0	770	178729	108384	116578	23846	132559	55301
Threadfin Shad, Dorosoma petenense	218	4529	683	2798	48626	109778	89800	106392	364018	442697
Tridentiger spp.	911	3075	2551	1046	108734	89306	41404	39315	166269	68918
Unknown spp. (too damaged to identify)	0	239	355	0	662	3023	25439	7918	1545	514
White Catfish, Ameiurus catus	0	0	0	0	0	0	0	0	2205	21231
Estimated Entrainment:	**43581**	**55064**	**43634**	**47852**	**599773**	**938023**	**907400**	**626867**	**1822299**	**4680208**