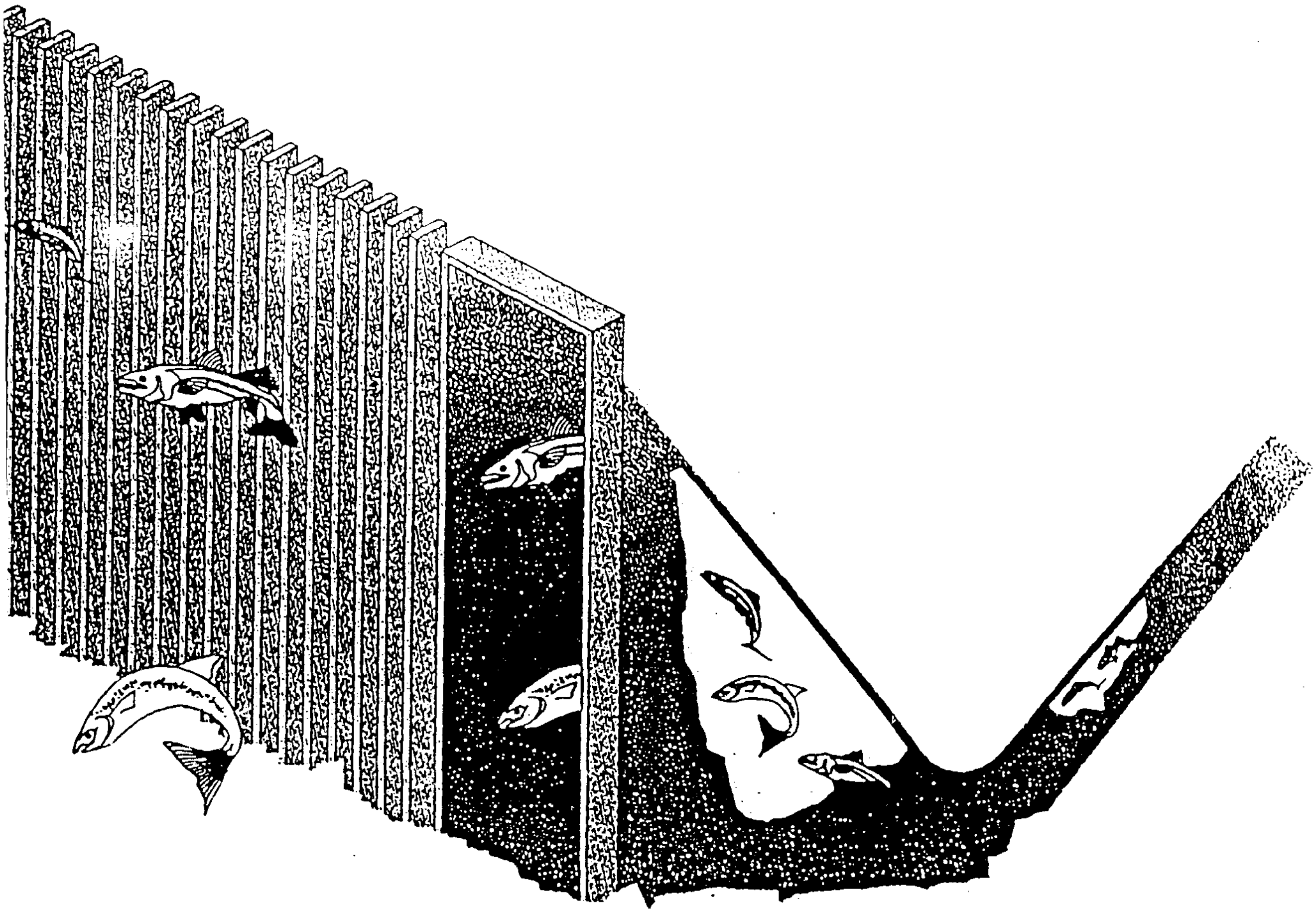

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Fish Collections and Secondary Louver Efficiency at the Tracy Fish Collection Facility: October 1993 to September 1995

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Fish Collections and Secondary Louver Efficiency at the Tracy Fish Collection Facility: October 1993 to September 1995

BY

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Fish Collections and Secondary Louver Efficiency at the Tracy Fish Collection Facility: October 1993 to September 1995

ABSTRACT

The objectives of this study were to (1) describe the fish population passing through the secondary louvers and into the holding tanks at the Tracy Fish Collection Facility (TFCF) and (2) analyze secondary louver efficiency with respect to environmental and operational parameters. We deployed a sieve net in the secondary channel behind the second louver array and collected 254 simultaneous sieve net and holding tank samples between October 1993 and September 1995. To achieve our first goal, we characterized the species composition and size of fish passing through the secondary louvers. Splittail was the numeric dominant in the sieve net and holding tank collections. Most observations (79 percent) were made in 1995, a wet year. Therefore, we hypothesized splittail dominance was the result of a strong spawn, and entrainment of many young-of-year fish [Mean TL = 31 mm (1.2 in)] to the TFCF. Our second goal was to analyze secondary louver efficiency. We defined secondary louver efficiency as the percentage of fish directed into the holding tanks compared to the number of fish entering the secondary channel. We concentrated our analysis of secondary louver efficiency on three independent variables, secondary approach velocity index, debris load, and time of day. Neither secondary approach velocity index nor debris load appeared to have any statistically significant influence on secondary louver efficiency. However, the time of day had a statistically significant impact on secondary louver efficiency in two cases. First, for all species combined, logistic regression showed the time of day was positively correlated with efficiency (Daylight Mean Efficiency = 81 percent, Night = 67 percent). Second, for American shad, the time of day was negatively correlated with efficiency (Daylight Mean = 39 percent, Night = 83 percent). We concluded that future research should continue to focus on time of day as a factor influencing secondary louver efficiency. In addition, we identified opportunities to improve fisheries protection at the TFCF. For example, in the high water year of 1995, we obtained 99.9 percent of 18,371 splittail between May 11 and July 13. Given this contracted period of vulnerability, approach velocity could be manipulated in the secondary louver channel to improve splittail louver efficiency while we continue to meet all water and fish agreement obligations.

BACKGROUND AND FACILITY DESCRIPTION

Since 1873, the U.S. Government has assisted the State of California in water development in the Central Valley (U.S. Congress, 1874). Subsequently, Bennett's (1906) report for the U.S. Reclamation Service [now U.S. Bureau of Reclamation (Reclamation)] described a number of possible sites for water development of the Sacramento River basin. Cooperative investigations by Reclamation and the State Engineer's Office resulted in a comprehensive plan for water development in the Central Valley (Anonymous, 1931). This plan evolved into the Central Valley Project (CVP); a key component was the transfer of water from the Sacramento River basin to the San Joaquin watershed. In 1933, the CVP was approved by State referendum. In 1935, the U.S. Congress authorized the CVP (Rivers and Harbors Act), and Reclamation began construction.

The Central Valley of California receives water from the Sacramento River drainage system from the north and the San Joaquin drainage system from the south. These systems converge in the central portion of the state forming a huge natural estuary and Delta (Figure 1). The hydraulics of the San Francisco Bay-Delta are influenced by many factors including tides, precipitation, freshwater outflows, export pumping, and irrigation practices. Export pumping and irrigation have influenced the Delta ecosystem for decades.

Two important components of the CVP are a pumping plant in the southern portion of the Delta [Tracy Pumping Plant (TPP)] and a canal to move the water to the southern end of the Central Valley [Delta Mendota Canal (DMC)]. These two components are central to the export of water for irrigation, domestic, and industrial needs. Now, the TPP is one of two large pumping plants in the south Delta (the other is the State-operated Harvey O. Banks Delta Pumping Plant). The TPP draws water from the Old River channel of the lower San Joaquin River into the intake channel of the DMC. Before the Old River water enters the DMC, the water passes through the TFCF (Figure 2). The TFCF is a large fish diversion and salvage facility that operates to prevent fish from being drawn into the Delta Mendota Canal intake channel by the TPP. These facilities are located about 14.4 km (9 mi) northwest of Tracy, California. The TPP, intake channel, and a pilot fish-screening structure (site of the present TFCF) were completed in 1951. In 1952, Reclamation and the U.S. Fish and Wildlife Service, with assistance from the California Department of Fish and Game and the California Department of Water Resources, began testing various types of fish-screening devices (U.S. Department of the Interior, 1957) at the pilot structure to reduce impacts of pumping on striped bass (*Morone saxatilis*) and chinook salmon (*Oncorhynchus tshawytscha*). After 2 years of testing, it was determined that a system of louvers, bypasses, and collection/holding tanks was effective at diverting fish from the debris-laden flow of the south Delta. The final design was completed in 1955, and by 1957, the current fish facility was in operation. In the last decade, primary and secondary louvers, louver guides, trashrack, valves, other supporting infrastructure, and velocity control (VC) pumps were replaced at the Tracy Fish Collection Facility.

The fish diversion system at the TFCF uses a louver-bypass-collection system to divert fish from exported flow (Figure 2). The louver sections are a framework of evenly spaced [23.4-mm (0.92-in) openings] vertical slats that traverse the channel and allow water to pass to the pumps while creating turbulence which the fish can detect. Design of the louver system was based on observations that fish orient upstream, into the flow, but when they encounter an obstruction, move laterally to be swept downstream (Bates and Visonhaler, 1956). Thus, the fish guide along the louver face and eventually are carried into a bypass opening. The probability that a fish will be louvered (or guided into a bypass opening) is strongly influenced by its swimming ability, size, and the approach velocity (EPRI, 1986). We define approach velocity as the average velocity parallel to the rectangular channel upstream of the louver array. Other independent factors than approach velocity may influence louvering; these include the amount of debris blocking the louver spaces, bypass velocities, predator load, and time of day among other variables.

Two louver systems screen fish at the TFCF. The first or primary louver system is 97.5 m (320 ft) in length and is angled 15° to a 25.6-m (84-ft) wide channel. Four bypass openings each 15.2 cm (6 in) in width [one occurring about every 22.9 m (75 ft)] lead into 91.4-cm (36-in) diameter pipes that convey water and fish to the secondary louver system. The second louver system includes two parallel lines of louvers [each 9.3 m (30.2 ft) long] that span the 2.4-m (8.0-ft) wide secondary channel also at a 15° angle. Fish and material diverted by this system enter a common bypass opening which feeds into four large circular holding tanks (flows are directed into only one tank at any one time). The second louver system was added to concentrate the collected fish and reduce the volume of water entering the holding tanks. Fish, and debris, are regularly removed from the holding tanks and returned to the Delta. The louver structures are protected by a surface trash deflector (Figure 2) which concentrates and directs floating debris to a conveyor belt for disposal, and by a trashrack with bars spaced at 53.9-mm (2.1-in) intervals. The trashrack is located between the surface trash deflector and the primary louver array. Together, the deflector and trash rack function to keep large debris from entering and damaging the primary louver system. The trashrack also prevents large fish from entering the facility. The trashrack and louvers become heavily clogged with river debris (primarily macrophytes) at various times throughout the year. Consequently, the trashrack and louvers are cleaned frequently, often daily, because debris accumulation may negatively affect fish salvage efficiency.

The louver system at the TFCF was designed to divert and collect young [> 25-mm (1-in) total length (TL)] striped bass and downstream migrating chinook salmon smolts from the exported flow (Bates and Visonhaler, 1956). During the first few years of operation, pumping was mostly restricted to the summer months, a time when young salmon were less vulnerable to entrainment by the pumps. This period of peak pumping coincided with the presence of large numbers of larval and post-larval striped bass. However, Bates and Visonhaler postulated that the louver-bypass system diverted most of these fish.

The current practice of year-round pumping at high rates (and consequently higher velocities) was instituted in the late 1960's with construction of San Luis Reservoir. One consequence of year-round pumping at relatively high rates is that the louver system may be operating less efficiently than originally designed. Under current operating procedures, discharges (Q) through the facility range from 0 to 141.5 m^3/s (0 to 4,500 ft^3/s) in the primary channel and from 0 to 3.5 m^3/s

(0 to 175 ft^3/s) in the secondary channel depending primarily on the number of pumps operated. In addition to the pumps, flow hydraulics and fish entrainment to the TFCF are influenced by the effects of the many water diversions and tides.

The objectives of this investigation were to describe the populations of fish observed in the holding tanks and passing through the secondary louvers and to initiate a re-evaluation of secondary louver efficiency (defined as the success of the secondaries at diverting fish into the holding tanks) under current operating conditions. The current conditions include higher discharges, greater channel approach velocities, and higher debris accumulations than in previous decades. This evaluation focuses on fish species of special concern or economic importance including green (*Acipenser medirostris*) and white (*Acipenser transmontanus*) sturgeon, American shad (*Alosa sapidissima*), splittail (*Pogonichthys macrolepidotus*), white catfish (*Ictalurus catus*), delta smelt (*Hypomesus transpacificus*), chinook salmon, and striped bass.

THE SECONDARY LOUVER SIEVE NET PROGRAM

In the 1950's, the TFCF secondary louver efficiency was 92 to 100 percent for chinook salmon and 86 to 95 percent for striped bass (Bates et al., 1960). In 1966-67, efficiency in the primary louvers was 75 to 100 percent for striped bass of comparable size (Hallock, 1967). From 1991 to 1992, the range of louver efficiencies for chinook salmon was 72 to 100 percent in the secondaries. And, louver efficiencies for striped bass were 40 to 96 percent in the primaries and 44 to 90 percent in the secondaries (Karp et al., 1995.

We hypothesized that louver efficiencies have deteriorated at the TFCF. We investigated this hypothesis in the secondary louvers by deploying a sieve net behind the second of the two secondary louver arrays. We had two principal objectives. First, we studied the fish population passing through the secondary louvers at the TFCF. Second, we analyzed secondary louver efficiency with respect to environmental and operational parameters.

In this report, we evaluate the fish passing through the secondary louvers, determine critical experiments that are needed, and estimate sample sizes required for these future trials. These experiments would further elucidate our understanding of the major influences on salvage efficiency.

METHODS

Data Collection

We collected 254 paired samples between October 27, 1993, and September 20, 1995. Each paired sample consisted of a sieve net sample and a holding tank sample obtained simultaneously. The sieve net is deployed 12.8 m (42 ft) downstream of the final secondary louver array and completely spans the secondary channel. The sieve net [mouth: 244 cm (96 in) by 269 cm (106 in); length: 7.6 m (25 ft); mesh: 6.3 mm (1/4 in)] is deployed for the same length of time fish are directed into a holding tank [effective mesh size: 3.2 mm (1/8 in)]. From both the sieve net and holding tank samples, all fish are identified to species and the number recorded. When possible, we measured individuals to the nearest mm in fork length (FL).

We found the secondary louvers/holding tank system and the sieve net capture chinook salmon in the same size range (Figure 3). However, we felt it possible that other species and life stages might be collected with different effectiveness because the louvers and sieve net are fundamentally different types of gear. Both of these methodologies capture individuals as small as 20 mm (0.8 in) FL. We believe both gears to be most effective for fish greater than 30 mm (1.2 in) FL; therefore, we limited comparisons between the two methods to fish greater than 30 mm (1.2 in) FL.

Environmental and operational data were recorded in association with each paired (sieve net/holding tank) sample: water temperature; depth in front of the trashrack and in the primary and secondary channels; wet weight of debris in the sieve net and holding tank; ambient light conditions (day, dusk, night, and dawn); secondary bypass opening (0 to 60°); and discharge through the holding tank. Occasionally, we recorded whether screen water was on or off and the number and combination of VC pumps in operation.

We used primary channel and secondary channel water depth and facility parameters to calculate primary discharge and secondary discharge. In addition, we used primary and secondary depths, and the number of operating VC pumps to provide the secondary approach velocity index (SAVI).

Statistical Methods

We defined salvage efficiency as [holding tank fish catch/(holding tank fish catch + sieve net fish catch)]. We analyzed the dependent variable salvage efficiency through a four-step process.

First, we coded three independent variables for the analysis. Debris load was coded "1" when less than 150 grams (0.33 lb) of debris was obtained in the holding tank, "2" when the amount of debris was 150 to 350 grams (0.33 to 0.77 lb) grams, and "3" when more than 350 grams (0.77 lb) were observed. Time of day was coded "0" for night, "1" for crepuscular (dawn and dusk) periods, and "2" for day. SAVI was coded "1" for low and intermediate velocity indices and intermediate and "2" for high. Category limits for debris and SAVI were selected by expert opinion. These categories are arbitrary, yet no information concerning the TFCF exists with which to improve them.

Second, we conducted a 3-Way Analysis of Variance (ANOVA) with these three coded independent variables and raw efficiency. If all assumptions of ANOVA were met (normality, homogeneity of variance, and independence of observations), we analyzed and reported the ANOVA table.

Third, if an assumption was violated, we performed two transformations on the efficiency data: $\log_{10}$ and arcsin. We transformed the data so that we might meet the assumption of normality. Then, we could still use the robust ANOVA technique. We then conducted a 3-Way ANOVA with each transformed data set. If all assumptions of

ANOVA were met, we analyzed and reported the ANOVA table.

Fourth, if an assumption was violated with the transformed data, we coded the raw efficiency as "0" when salvage efficiency was less than 0.75 and as "1" when efficiency was greater than 0.75. We then conducted a logistic regression. All statistical analyses were performed with Statistical Analysis Software, Version 6.11 (SAS Institute Inc., Çary, NC).

RESULTS

Sieve Net and Holding Tank Collections

In 254 paired samples, we collected a total of 11,065 fish representing 28 species in the sieve net and a total of 21,408 fish representing 33 species in the holding tanks. In both, the sieve net and holding tanks, the numeric dominant was splittail (Table 1). For all species combined, sieve net and holding tank catch rates (fish/minute) were greater during light hours than during dark hours (Table 2). However, 201 of 254 paired samples were obtained during daytime or crepuscular periods. Furthermore, during the period when catch rates tend to increase at the TFCF (March through June), we collected 94 daytime and crepuscular samples and only 20 samples at night. Thus, the large daytime catch rate we observed in this study could have been inflated because of intensive daytime and crepuscular sampling. In addition to catch rate, louver efficiency was also statistically lower at night for all species combined (Table 3). We also examined the paired sample collections for relationships regarding the target species such as chinook salmon.

The fall run of chinook salmon is the most abundant of the four runs. Therefore, we expected the number of smolts observed at the TFCF to peak in May each year (see Table 4 and Appendix A). During May, the sieve net and holding tank retained chinook salmon smolts at 1.75 to 6 times the rate of other months of the year. For example in the sieve net, chinook salmon smolts were obtained at 0.161 fish/minute in all months except May, when the catch rate was 0.282 fish/minute. In sieve net and holding tank samples, we observed catch rate for chinook salmon taken during light hours was slightly higher than during dark hours (Table 2). However, like the daytime catch rate for all species combined, daytime chinook salmon catch rates could have been inflated due to when we did our most intensive sampling. The inflation of catch rate as an artifact of our sampling regime, could explain why our results differ from that of Puckett et al. (1996). They found catch rates peaked at 2200 h and were generally higher at night. In this study with regard to chinook salmon, the catch rate at the TFCF peaked in May and was slightly higher during light hours; the mean louver efficiency was 83 percent (Table 3). For chinook salmon we obtained sufficient samples (110 paired samples) to analyze seasonal and diel trends and secondary louver efficiency. But, this was not the case for delta smelt.

We caught only two delta smelt during this study. Both were within the period we expected adult delta smelt to be most vulnerable to entrainment. An adult delta smelt was caught on February 2, 1995, and another on April 12, 1995. These dates are within the period we expected adults to be seeking spawning habitat (see Appendix A).

In contrast to Delta smelt, splittail were routinely observed in the sieve net and holding tank paired samples. Splittail abundance may have been high, compared to other years, for two reasons. First, we collected 200 of 254 paired samples in 1995. Second, 1995 was a wet year and a substantial splittail spawn occurred. Of the 18,371 splittail collected in this study, 99.9 percent of these fish were obtained between May 11 and July 13 suggesting that splittail are highly susceptible to entrainment to the TFCF when the young-of-the-year appear in the Delta. However, the nighttime catch rate is unknown because of limited sample size (Table 2). Another interesting result was the mean catch rate in the sieve net was 10.9 splittail per minute while, the catch rate for all other species combined was 1.6 fish per minute. Mean splittail catch rate was higher than that for all species combined because we discarded 0:0 paired samples from this analysis, i.e., if we caught no fish in the sieve net and the holding tank, we did not use this paired sample in the calculation of catch rate because this observation provided no information regarding catch rate. In this study with regard to splittail, the catch rate was six times greater than that for all other species from May 11 to July 13. For splittail, the mean louver efficiency was 63 percent (Table 3).

Unlike splittail, striped bass were taken year-round, the slowest catch rate (0.369 fish/minute) occurred April 6 to June 20, compared to the rest of the year (1.657 fish/minute). This period includes the typical spawning period (Moyle, 1976). We theorize that striped bass eggs and larvae are too small for our gear during this period, April 6 to June 20, and the previous year's progeny has grown increasingly less susceptible to entrainment. In holding tank samples, striped bass exhibited a slightly higher catch rate during light periods than during dark periods. Yet, in the sieve net, the catch rates during light and dark periods were nearly indistinguishable (Table 2). The mean louver efficiency for striped bass was 86 percent (Table 3).

Like striped bass, American shad show seasonal periodicity in their entrainment susceptibility. From May to December, American shad young are moving downstream to the ocean and are most susceptible to entrainment. In the sieve net and holding tank combined, we found the catch rate, between May 1 to December 31, to be 0.533 fish/minute in contrast to the remainder of the year: 0.007 fish/minute. American shad also showed a significant diel trend; they are two or more times as likely to pass through the louvers and into the sieve net during the light hours than during dark hours (Table 2). Mean salvage efficiency was 52 percent. And, the salvage efficiency at night was significantly higher than during the day (Table 4).

White catfish showed little seasonality in the sieve net and holding tank collections. This species was detected year-round. White catfish catch rate in the holding tanks and sieve net was higher during the day than at night (Table 2). Overall, white catfish mean louver efficiency was 89 percent.

In contrast to the white catfish's ubiquity, no sturgeon were taken during this study. Our paired samples spanned approximately 79.4 hours of the 16,632 hours that transpired during the course of this study. Because of sturgeons' rareness in the salvage at the TFCF, their capture was an extremely unlikely event in the study's brief sampling period.

Length Frequencies

We found 96 percent of chinook salmon measured in this study were between 70 and 130 mm (2.8 and 5.2 in) FL (Figure 3a). As expected, chinook salmon at this size were vulnerable to entrainment to the TFCF. Few salmon 30 to 70 mm (1.2 to 2.8 in) FL were collected. Both the holding tank and sieve net mesh sizes are small enough to capture these smaller fish. Possibly, few smolts in this smaller size range have traveled down river a sufficient distance to be subject to entrainment.

Length frequencies of chinook salmon collected in the holding tank and the sieve net are similar (Figure 3b). However, smaller smolts tend to be collected at night (Figure 3c).

A few splittail lengths were recorded during this study (n=74). Of these 74 observations, young of the year [Mean FL = 31 mm (1.2 in)] dominated the catch (Figure 4).

The average FL of striped bass obtained in this study was 116 mm (4.6 in). The largest individual collected was 366 mm (14.4 in) FL (Figure 5).

The distribution of American shad lengths is bell-shaped (Figure 6a) and centered at a mean of 96 mm (3.8 in) FL. When these data were partitioned by gear type, we observed slightly larger fish in the holding tank than in the sieve net (Figure 6b). When partitioned by time of day, these data indicated slightly larger fish were collected during dark hours compared to light hours (Figure 6c).

The distribution of white catfish lengths was bimodal suggesting we often collect the first two year classes (Figure 7). In this study, we collected fish from 33 to 355 mm (1.3 to 14.0 in) FL. This result suggests white catfish may be vulnerable to entrainment into the TFCF their entire lives.

Sieve Net and Holding Tank Statistical Comparisons

When an individual representing a fish species was caught in the sieve net but not in the paired holding tank sample, we defined this as an efficiency of zero for that species. Conversely, when we obtained a species in the holding tank but not in the paired sieve net sample, we defined this as a salvage efficiency of one. These two outcomes regularly occurred. Therefore, we found the secondary efficiency data were distributed bimodally. No transformation produced a normal distribution. Therefore, we relied upon logistic regression, a non-parametric technique (Hosmer and Lemeshow, 1989).

We observed only two weakly significant effects for louver efficiency (Table 3). Interestingly, they both involved time of day:

a positive relationship for all species combined and a negative relationship for American shad. We analyzed efficiency graphically to determine if diel differences exist that were not statistically significant (Figures 8-9). However, it appeared variation in the data would mask any real differences that might exist.

For the Secondary Approach Velocity Index (SAVI) and debris load, no significant relationships to salvage efficiency emerged. The large variability in secondary louver efficiency, with regard to the SAVI, reflects our inability to account for many sources of error in operational parameter measurement (Figures 10-11). Louver efficiency also exhibits a great deal of variability with regard to debris load (Figure 12-13). Our measure of debris load was less susceptible to unmeasured operational parameters than was the secondary approach velocity index. However, the variation in efficiency with regard to debris was considerable.

Three factors interact to make this analysis less robust than desired. First, the required non-parametric analysis, logistic regression, may not be as effective at determining real differences as a parametric technique would be. Second, there is a great deal of variability in our estimates of secondary louver efficiency. Third, operating conditions were not always reported with these samples, e.g., screen water. Thus, additional sources of variation may be masking statistically and biologically significant effects. We concluded that the most conservative interpretation of these data is they do not represent a sample of sufficient size to demonstrate statistically that time of day, debris load, or secondary approach velocity are influencing secondary louver efficiency.

DISCUSSION

In the first assessment of the TFCF, Bates et al. (1960) reported chinook salmon secondary salvage efficiency was 92 to 100 percent. Karp et al. (1995) reported efficiency was 72 to 100 percent. We found the mean secondary louver efficiency was 83 percent for chinook salmon. Overall facility salvage efficiency may be lower for chinook salmon now than when the facility was constructed.

For striped bass. Bates et al. (1960) reported the secondary salvage efficiency was 88 to 97 percent. Hallock (1967) reported striped bass louver efficiencies in the primaries were 75 to 100 percent. Karp et al. (1995) reported louver efficiency for striped bass was 40 to 96 percent in the primaries and 44 to 90 percent in the secondaries. We found secondary louver efficiency was 86 percent. Conservatively, overall facility efficiency for striped bass could be 82 percent (.96 x .857). Like chinook salmon, overall TFCF salvage efficiency for striped bass may now be lower than at the time of construction.

Examination of the sieve net and holding tank collections suggested that time of day was related to catch rate for all species combined, chinook salmon, splittail, American shad, and white catfish. For every species for which sufficient data were collected, except striped bass, time of day appeared related to catch rate. In addition, time of day was a statistically significant influence on salvage efficiency for all species combined and American shad. Furthermore, compared to daytime, larger chinook salmon were taken at night and smaller American shad were collected at night. Thus, subsequent experiments could focus on the relationship between time of day and fish salvage. For example, an experimental approach to the relationship between time of day and salvage would require a new set of salvage efficiency observations. For such an experiment we estimated the required sample size.

To estimate sample size, we used our observations of variation in salvage efficiency to determine the replicates required for a 3-Way ANOVA analysis with the three independent variables we evaluated. The extensive variation (see Table 3, column 3) observed in the salvage efficiency data suggested a large number of samples would be required to determine if the independent variables of interest truly influence salvage efficiency. We calculated the sample size required to discriminate the influence of time of day, debris, and approach velocity on secondary louver efficiency. We wanted to detect a true difference of 10 percent between means. We accepted a 20 percent chance that we could incorrectly accept a false null hypothesis and a 5 percent chance that we might reject a true null hypothesis. We determined, for chinook salmon, 210 observations would be required for each unique combination of the three independent variables (Sokal and Rohlf, 1981). The estimated sample size (n) of 210 for each combination should be conservative if we conducted a 1-Way ANOVA with two or three levels of time of day. In contrast, in this study, we had 110 chinook salmon samples for three levels of light.

We suggested that our sample size was not sufficient to distinguish a statistically significant influence of debris on secondary louver efficiency. Yet, debris causes extensive logistical problems at the TFCF. Each year, floating water-hyacinth, *Eichhornia crassipes*, and Egeria (or Brazilian elodea), *Egeria densa*, require hundreds of hours for removal. These two species were not in the Delta when the TFCF was constructed. These plants were introduced subsequently, and cleaning of the louvers has become more difficult in recent years. In addition to debris, we also investigated the influence of approach velocity on secondary louver efficiency.

Because secondary velocity was not measured, we developed an index of channel velocity, SAVI. However, we were unable to effectively evaluate the influence of channel velocity on secondary salvage efficiency. Any additional data would be improved by including a measurement of channel velocity. While back-calculating the average channel velocity may be helpful, direct measurements of secondary channel velocity may be more important because a complex flow field exists in the secondary channel.

In this study, we found time of day was related to secondary louver efficiency but the influence of debris load and secondary approach velocity was not detected. However, many other factors besides these three independent variables could potentially influence louver efficiency. For example, anything affecting the amount of light in the channel could influence what fish sense and therefore, louver efficiency. Cloudy weather, wind, and water turbidity could all influence the amount of light in the channel and louver efficiency. And, the cumulative effect of factors unaccounted for by us could have obscured the influences of any of the factors we studied. For example, debris load and approach velocity might have a significant influence on louver efficiency and we did not detect it because of unaccounted sources of variation.

The life history of some species is tightly coupled to entrainment to the TFCF. For example, in the high water year of 1995, 99.9 percent of the 18,371 splittail observed in this study was obtained between May 11 and July 13. Chinook salmon provide another example. In May of each year, we captured chinook salmon smolts at 2.5 to 3 times the rate of that during the remainder of the year. In addition, Puckett et al. (1996) found the number of chinook salmon in the TFCF holding tanks was correlated with time of day and tides. We postulate that operations of the TFCF could be better tailored to life history traits of target species. An operations study could determine feasibility of protecting more fish through four steps. First, we would consider a new approach to operating the Tracy system by using real-time monitoring and adaptive management. Second, we would make predictions of fish entrainment to the TFCF and test these predictions. Third, we could experimentally alter operations to decrease impacts on fish while still meeting water and fish agreement obligations. Fourth, we would monitor the results of such experimental operation alterations to determine if we can improve salvage and still meet our obligations to farmers and other agencies.

RECOMMENDATIONS

Long Term

Salvage efficiency at the TFCF may have declined over the last 4 decades. Many changes have occurred in the Delta ecosystem over this period that could also be responsible for this decline. The decline in efficiency could be due to the facility itself having aged; the superior maintenance schedule met at the TFCF cannot forever thwart long-term exposure to brackish water and the weather. Furthermore, new technology has become available in the last 4 decades. Future plans for the Tracy Fish Facility Improvement Program (TFFIP) should include experimental facilities with tests of new technologies and operational flexibility (Liston, 1997). Experimental designs should test louver and screen sequences in lab and field settings. The screen sequence could have an extremely "leaky louver" as the first barrier encountered. Predominantly, large fish would be louvered by this first screen. The second and subsequent screens could be less leaky louvers or positive barriers directing smaller fish to holding tanks.

Short Term

We recommend the collection of a new salvage efficiency data set. The variation in efficiency obtained in this study was used to calculate sample sizes required for a more robust analysis of the influences on secondary salvage efficiency. For each unique combination of independent variables, 210 observations of efficiency should be collected. We suggest that a 1-Way ANOVA be undertaken for each independent variable of interest beginning with time of day. In addition, this new data set could be used to investigate species-specific differences in louvering efficiency between day, crepuscular periods, and night. Furthermore, new data could contribute to our understanding of how different life stages and sizes of fish are louvered.

Whenever possible, direct observations of current velocity should be obtained in the secondary channel. These data should be obtained simultaneously with paired sieve net and holding tank samples.

Further supplementary salvage methods should be investigated. For example, if the velocity control pumps at the TFCF were replaced, perhaps "fish friendly" pumps such as those being tested at Red Bluff (Liston et al., 1997) could be employed to improve fish survival.

SUMMARY AND CONCLUSIONS

We evaluated the influence of time of day, debris load, and secondary approach velocity index on secondary salvage efficiency. Time of day appears to be the variable most commonly associated with changes in efficiency. We recommend additional study of time of day and its influence on efficiency. This study may require a large number of efficiency observations to be collected. Approach velocity has long been recognized as an important parameter affecting fish protection. Channel velocity at the TFCF should be directly measured at the TFCF. With quality velocity data, we could evaluate the importance of channel velocity on fish salvage and possibly make stronger recommendations for improving fish salvage.

Previous studies and this research indicate that salvage efficiency may have declined over the last 40 years. We could optimize the current facility's performance and we may not be able to attain the salvage efficiencies required to maintain critical fish species in perpetuity. We recommend a study of real-time monitoring and adaptive management at the TFCF. A salvage scheme could conceivably be developed that could reduce take of endangered and economically important fishes while water and fish agreement obligations are met at the TFCF.

Analysis of new sieve net and holding tank data taken after September 1995, and proposed lab and field experiments should further refine our understanding of factors affecting louver efficiency. An onsite experimental facility has been recommended (Liston, 1997). An important new concept to test would be a sequence of barriers and screens rather than a single type of barrier. We postulate that screen criteria for Delta smelt and chinook salmon might be met with a sequence of screens operated at one facility. Results from the experimental facility would be used to either significantly retrofit the present facility, or for eventual facility replacement.

ACKNOWLEDGMENTS

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Table 1. Species composition of the sieve net and holding tank samples. The total number of fish collected in the sieve net was 11,065 while 21,408 were collected in the holding tanks. Two species of specific interest in this study were not collected: green sturgeon and white sturgeon. Species list follows order and accepted common names of AFS (1991).

Species	Sieve Net Percent Composition	Holding Tank Percent Composition
Pacific Lamprey	0.036	0.023
American Shad	14.062	4.760
Threadfin Shad	14.062	8.263
Goldfish	0.000	0.014
Common Carp	1.618	1.527
Red Shiner	0.009	0.000
Golden Shiner	0.181	0.504
Sacramento Blackfish	2.485	1.896
Splittail	56.193	56.702
Sacramento Squawfish	0.018	0.037
White Catfish	4.582	8.212
Black Bullhead	0.000	0.005
Brown Bullhead	0.000	0.084
Channel Catfish	0.425	1.116
Wakasagi	0.000	0.005
Delta Smelt	0.009	0.005
Chinook Salmon	1.265	3.760
Mosquitofish	0.090	0.089
Inland Silverside	0.714	0.757

Table 1 cont. Species composition of the sieve net and holding tank samples. The total number of fish collected in the sieve net was 11,065 while 21,408 were collected in the holding tanks.

Species	Sieve Net Percent Composition	Holding Tank Percent Composition
Three-spine Stickleback	0.000	0.009
Prickly Sculpin	0.112	0.027
Pacific Staghorn Sculpin	0.009	0.009
Striped Bass	1.283	5.218
Green Sunfish	0.009	0.005
Warmouth	0.009	0.037
Bluegill	0.913	2.653
Redear Sunfish	0.009	0.182
Smallmouth Bass	0.009	0.009
Largemouth Bass	0.262	0.705
White Crappie	0.000	0.005
Black Crappie	0.877	2.083
Bigscale Logperch	0.018	0.051
Yellowfin Goby	0.271	0.617
Chameleon Goby	0.470	0.631

Table 2. Catch per minute at the Tracy Fish Collection Facility. Dawn, day, and dusk samples combined into "Light" and night samples only in "Dark." "NED" = "Not Enough Data." Sample size (n) refers to the number of samples that contained target fish. Delta smelt were not collected in sufficient detail to make any estimates of catch rate. Two species of specific interest were not collected: green sturgeon and white sturgeon. Species list follows order and accepted common names of AFS (1991).

Species	Sieve Net, Light (Fish/Minute)	Sieve Net, Light (n)	Sieve Net, Dark (Fish/Minute)	Sieve Net, Dark (n)	Holding Tank, Light (Fish/Minute)	Holding Tank, Light (n)	Holding Tank, Dark (Fish/Minute)	Holding Tank, Dark (n)
All Species	7.280	176	0.904	50	13.272	194	3.585	52
American Shad	2.035	48	0.811	15	0.629	41	1.242	24
Splittail	11.158	83	NED	2	9.215	86	NED	4
White Catfish	0.577	50	0.103	16	1.112	151	0.513	46
Chinook Salmon	0.205	30	0.105	10	0.322	80	0.270	17
Striped Bass	0.249	51	0.214	14	0.854	125	0.467	37

Table 3. Secondary louver efficiency (see p. 5 for efficiency calculation) at the Tracy Fish Collection Facility. Delta smelt were not collected in sufficient detail to make any estimate of efficiency. Two species of specific interest were not collected: green sturgeon and white sturgeon. Species list follows order and accepted common names of AFS (1991).

Species	Mean Efficiency	Standard Deviation	Total Number of Observations	Raw Efficiency	Log_{10} of Efficiency	Arcsin of Efficiency	Logistic Regression
All Species	71.1	26.0	254				Day = 80.9^{a} ‡Crepuscular = 79.4^{a} Night = 67.3^{b}
American Shad	51.5	45.5	92				Day = 38.9^{c} Crepuscular = 65.3^{d} Night = 83.3^{e}
Splittail	62.6	30.1	96				
White Catfish	88.7	24.5	208				
Chinook Salmon	83.2	31.1	111				
Striped Bass	85.7	27.8	174				

Note: Independent variables included in these analyses were time of day, debris load on the louvers, and secondary approach velocity index. Columns 5 through 8 represent statistical analyses: an empty cell indicates test assumptions were not met or no variable was significant. If group means are reported, this indicates statistical significance. Statistically similar groups are indicated by a common lower case character.

‡Crepuscular = Dawn and dusk samples.

Table 4. Characteristics of Sacramento River chinook salmon (*Oncorhynchus tshawytscha*) runs observed at Red Bluff Diversion Dam (Compiled from Moyle, 1976; Vogel and Marine, 1991).

Run	First Spawners Reach Red Bluff (Month)	Peak of Spawning (Month)	Downstream Migration (Range)	Downstream Migration Peak (Month)
Spring	Mar	Sep	Nov-May	Feb
Fall	Jul	Nov	Jan-Jun	May
Late-Fall	Oct	Feb	Apr-Dec	Aug
Winter	Jan	Jun	Jul-Mar	Oct

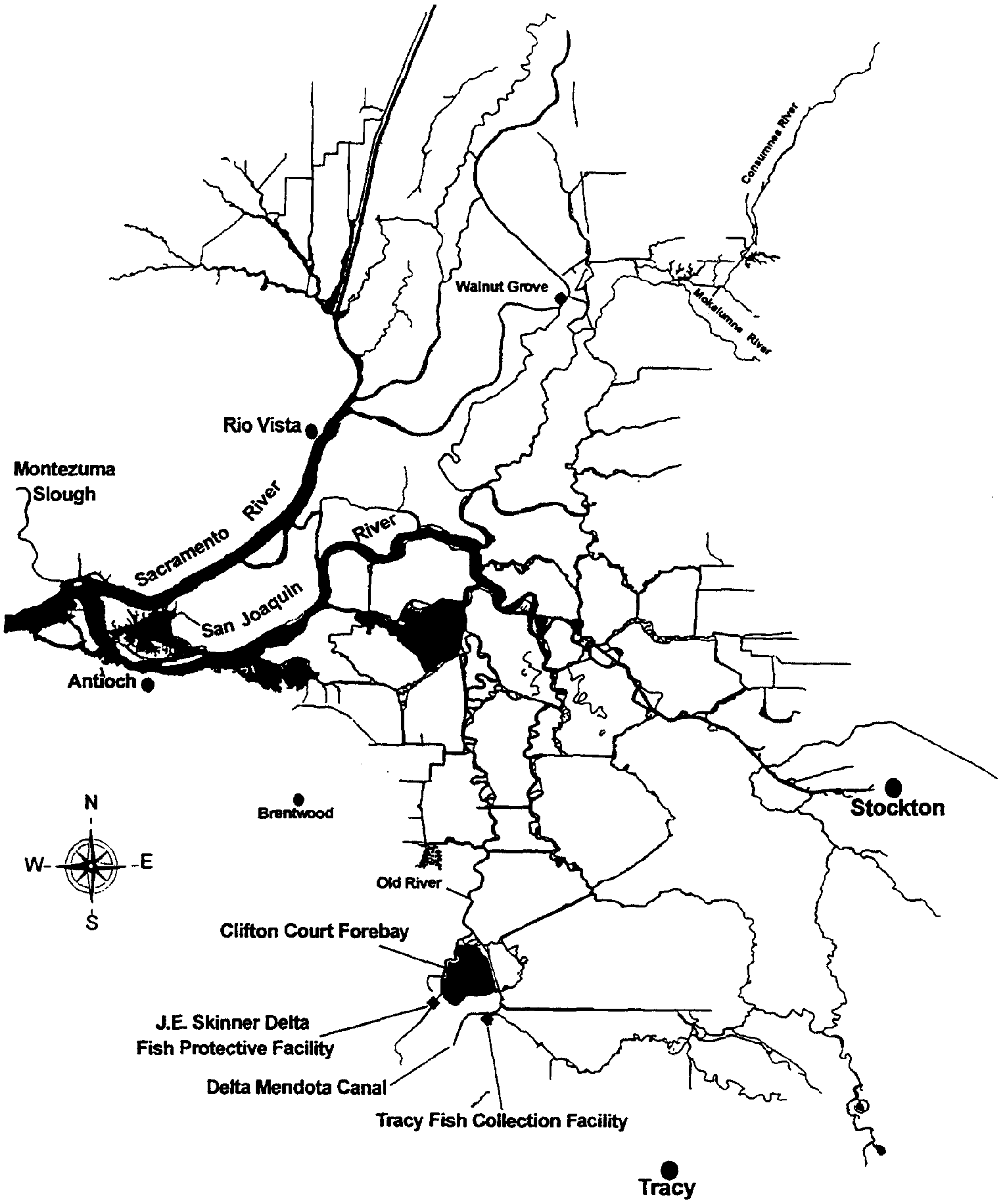

Figure 1. Map of the Sacramento - San Joaquin Delta indicating the location of the Tracy Fish Collection Facility.

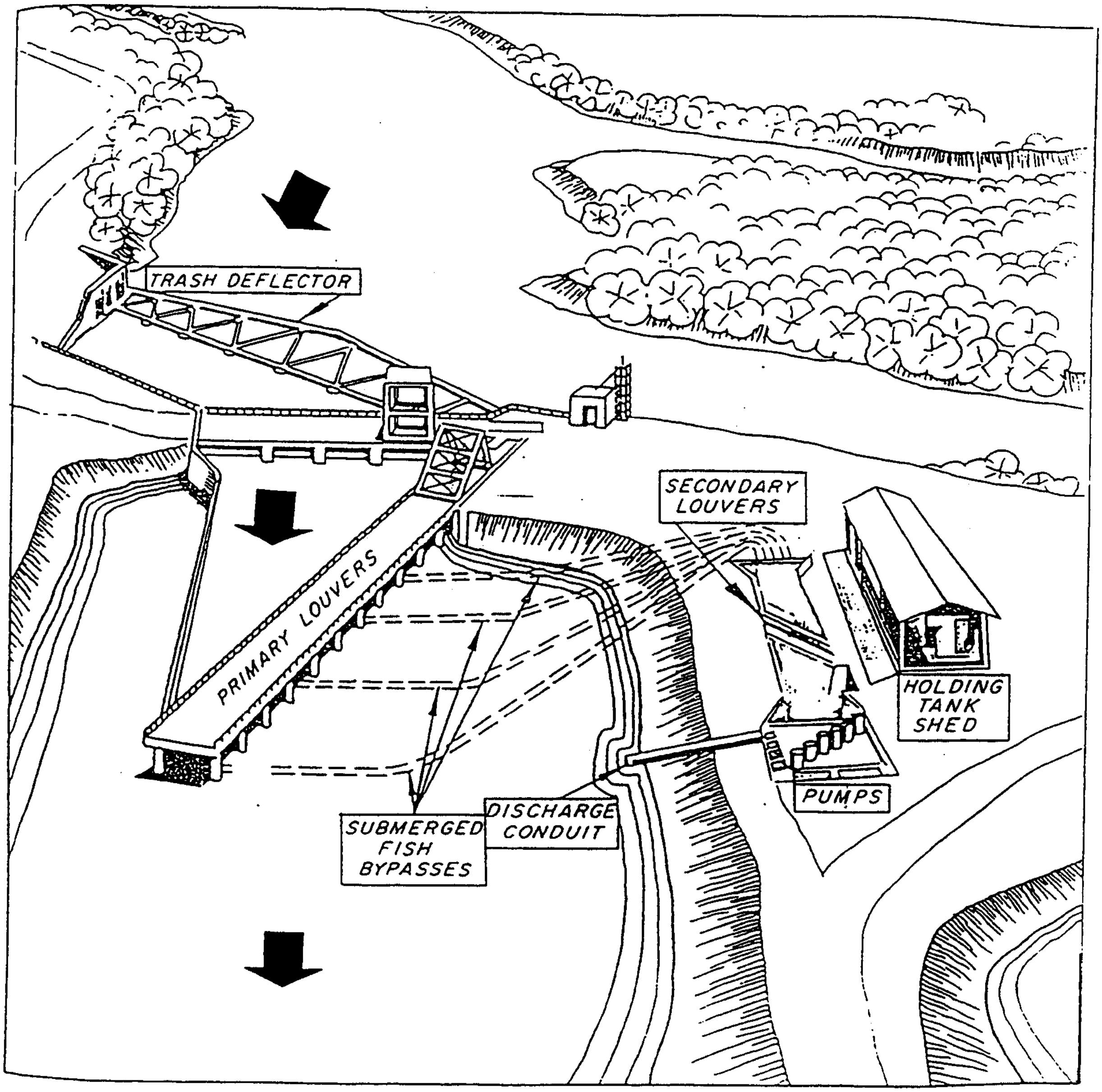

Figure 2. Schematic of the Tracy Fish Collection Facility. Arrows indicate direction of the majority of water's flow.

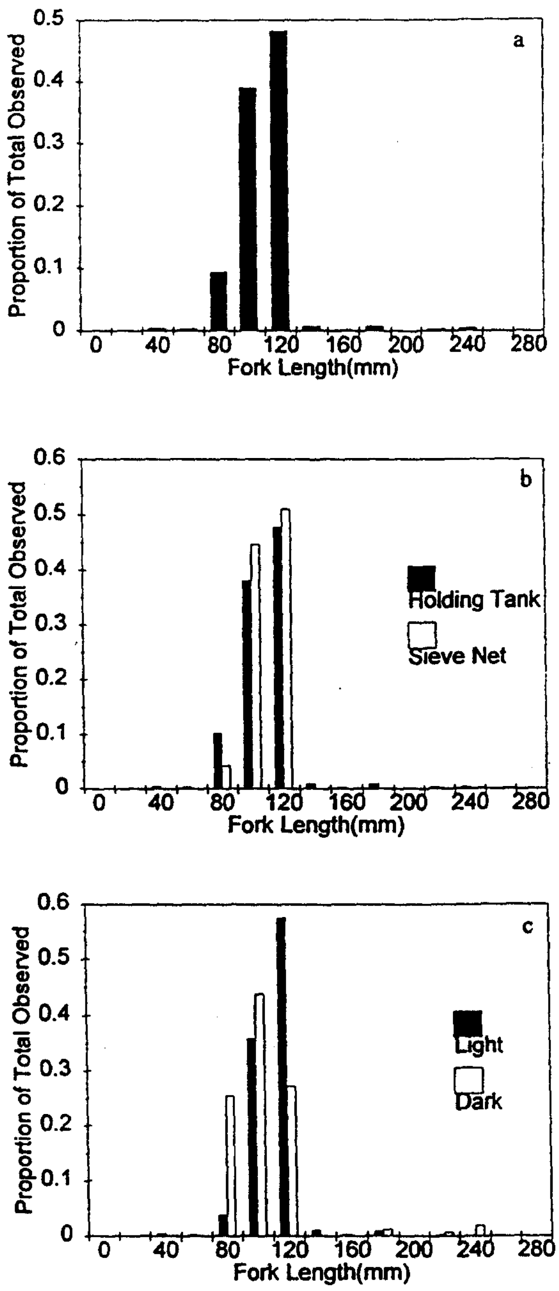

Figure 3. Length frequency histograms at the Tracy Fish Collection Facility for (a) all chinook salmon (n=689), (b) chinook salmon taken in the holding tank (n=595) and sieve net (n=94), and (c) chinook salmon taken during the day (n=482) and at night (n=169). Crepuscular observations (n=38) of chinook salmon were not included in (c).

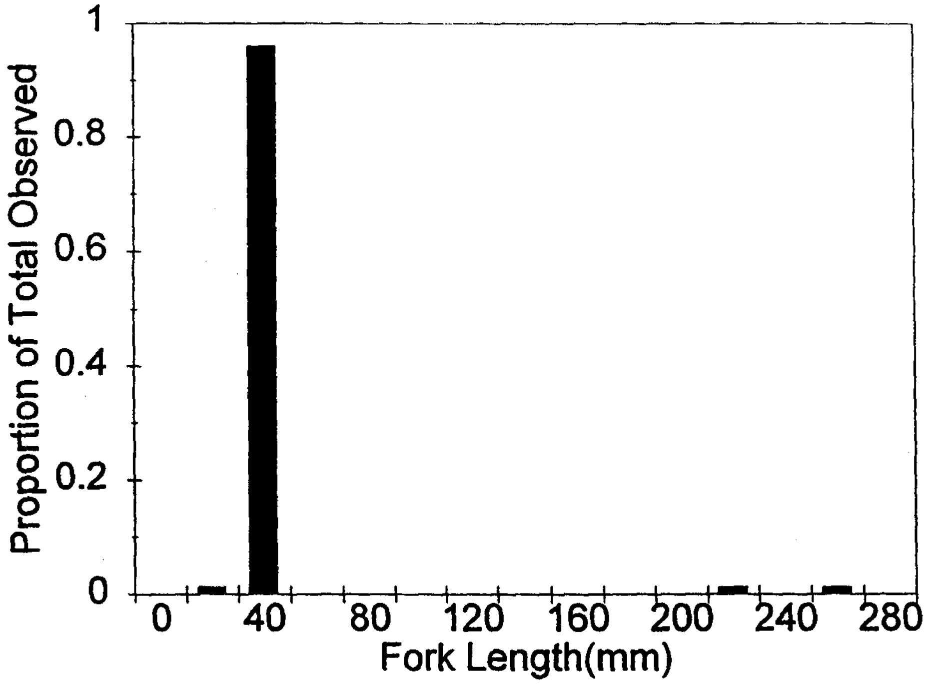

Figure 4. Length frequency histogram at the Tracy Fish Collection Facility for all splittail (n=74).

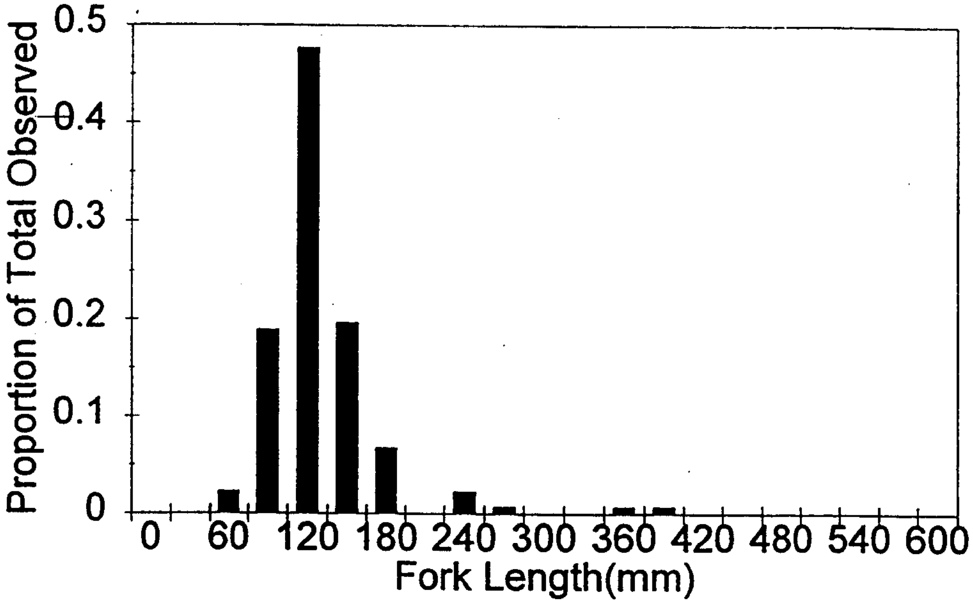

Figure 5. Length frequency histogram at the Tracy fish Collection Facility for all striped bass (n=132).

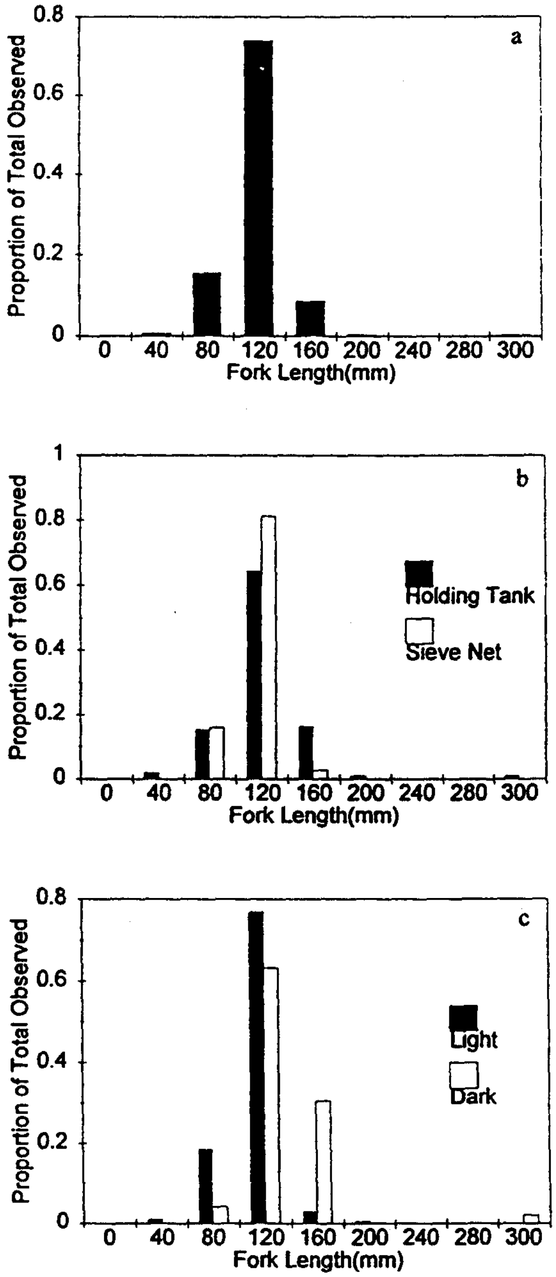

Figure 6. Length frequency histograms at the Tracy Fish Collection Facility for (a) all American shad (n=248), (b) American shad taken in the holding tank (n=104) and sieve net (144), and (c) American shad taken during the day (n=199) and at night (n=49).

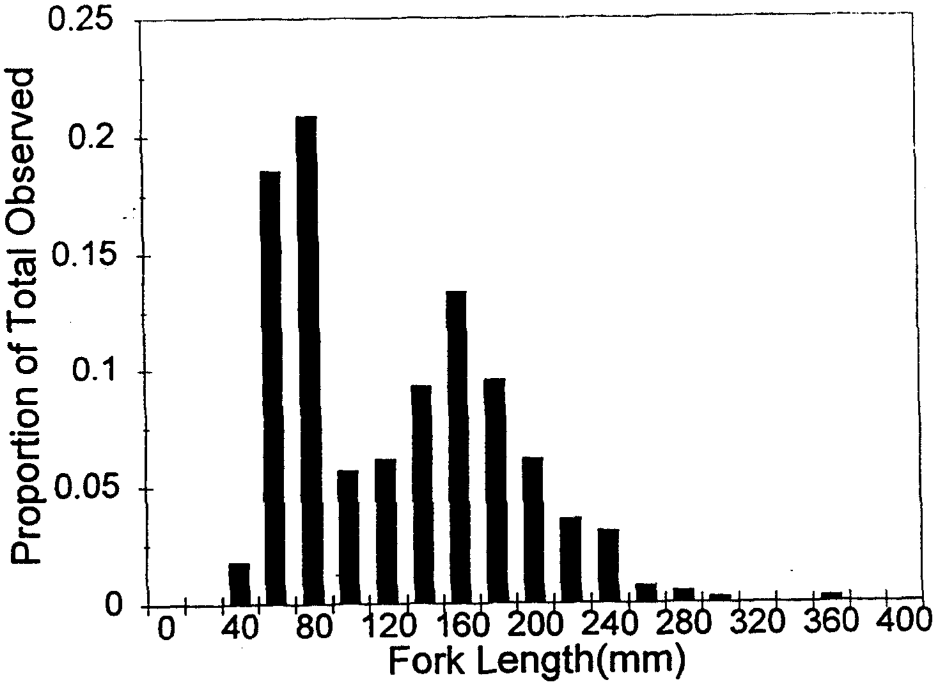

Figure 7. Length frequency histogram at the Tracy Fish Collection Facility for all white catfish (n=388).

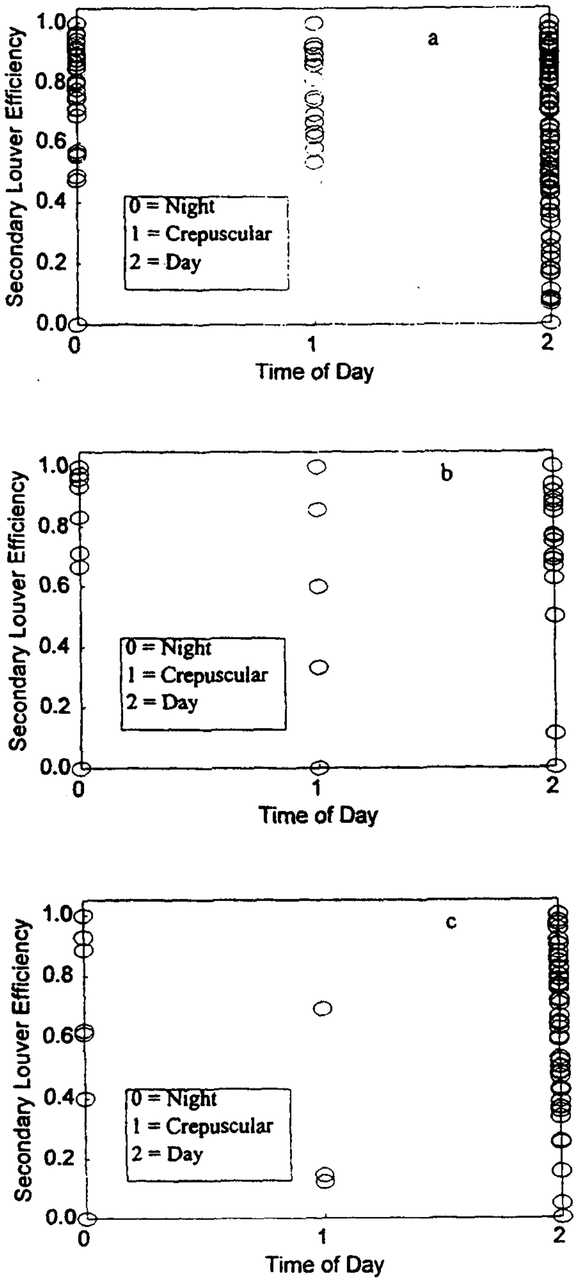

Figure 8. Secondary louver efficiency at the Tracy Fish Collection Facility at three times of day for (a) all species combined, (b) chinook salmon, and (c) splittail.

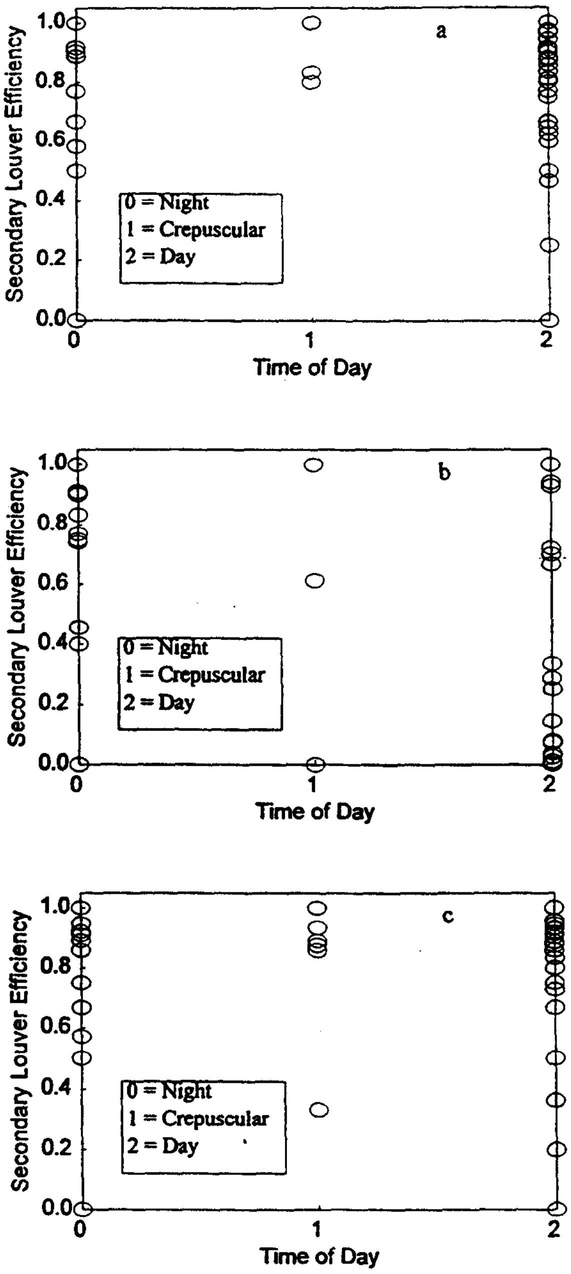

Figure 9. Secondary louver efficiency at the Tracy Fish Collection Facility at three times of day for (a) striped bass, (b) American shad, and (c) white catfish.

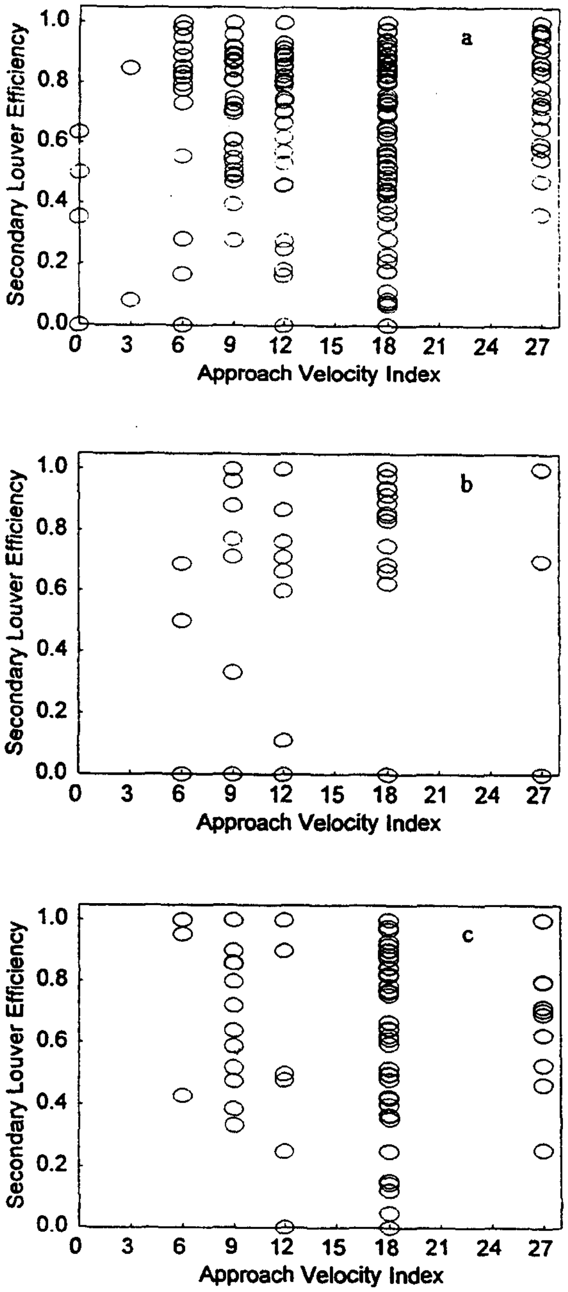

Figure 10. Secondary louver efficiency versus Secondary Approach Velocity Index (see p. 5 for description) at the Tracy Fish Collection Facility for (a) all species combined, (b) chinook salmon, and (c) splittail.

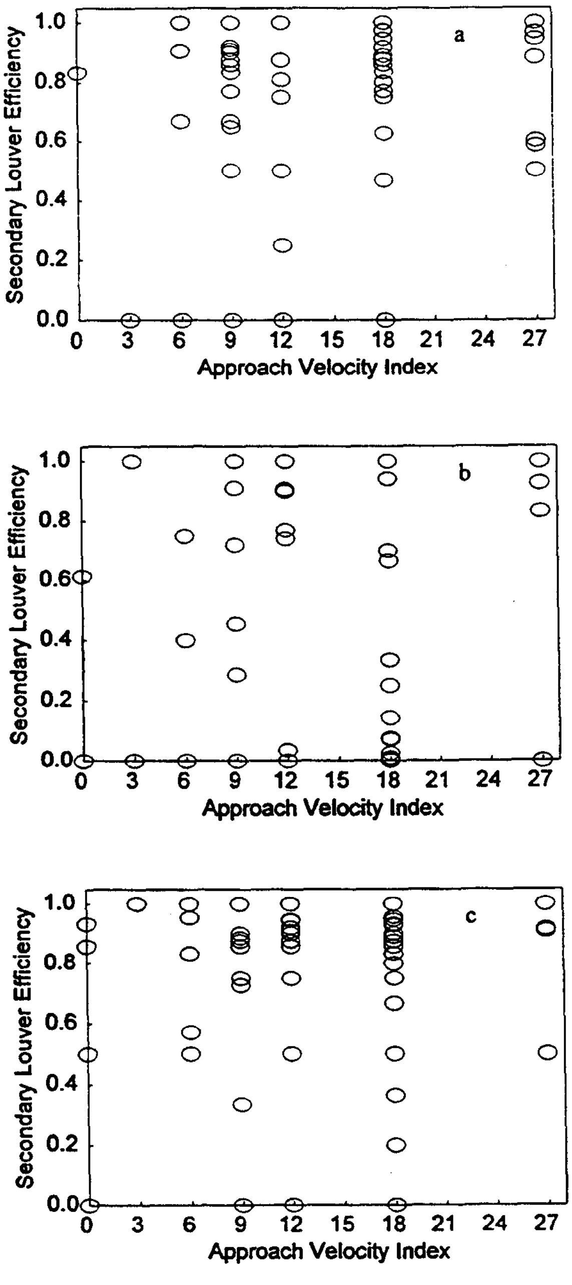

Figure 11. Secondary louver efficiency versus Secondary Approach Velocity Index (see p. 5 for description) at the Tracy Fish Collection Facility for (a) striped bass, (b) American shad, and (c) white catfish.

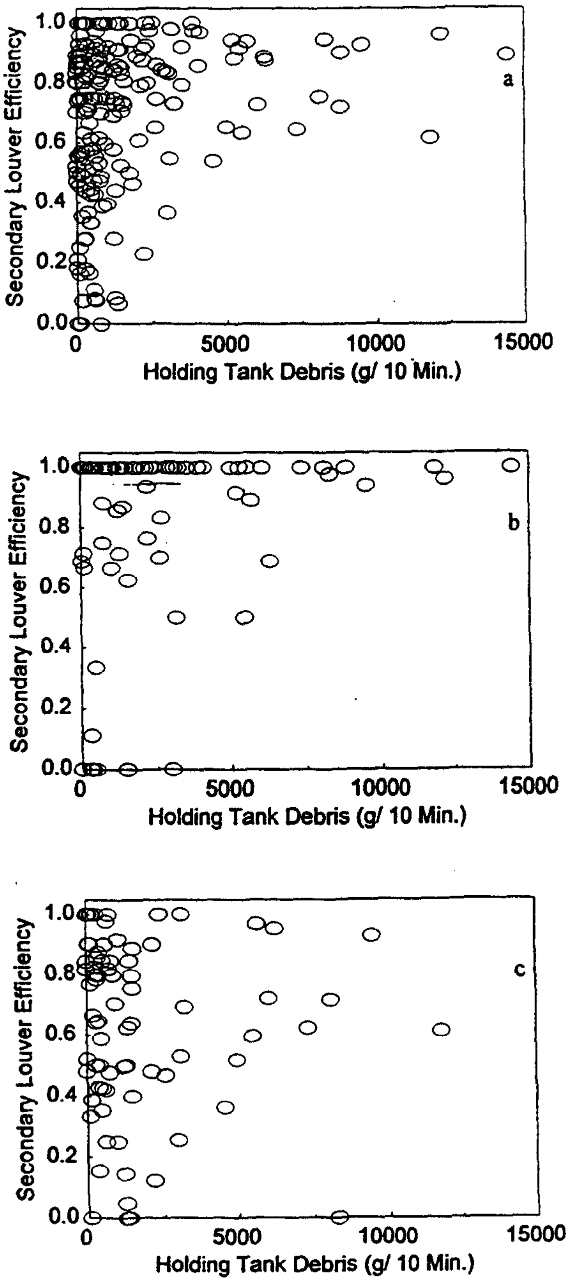

Figure 12. Secondary louver efficiency versus debris load at the Tracy Fish Collection Facility for (a) all species combined, (b) chinook salmon, and (c) splittail.

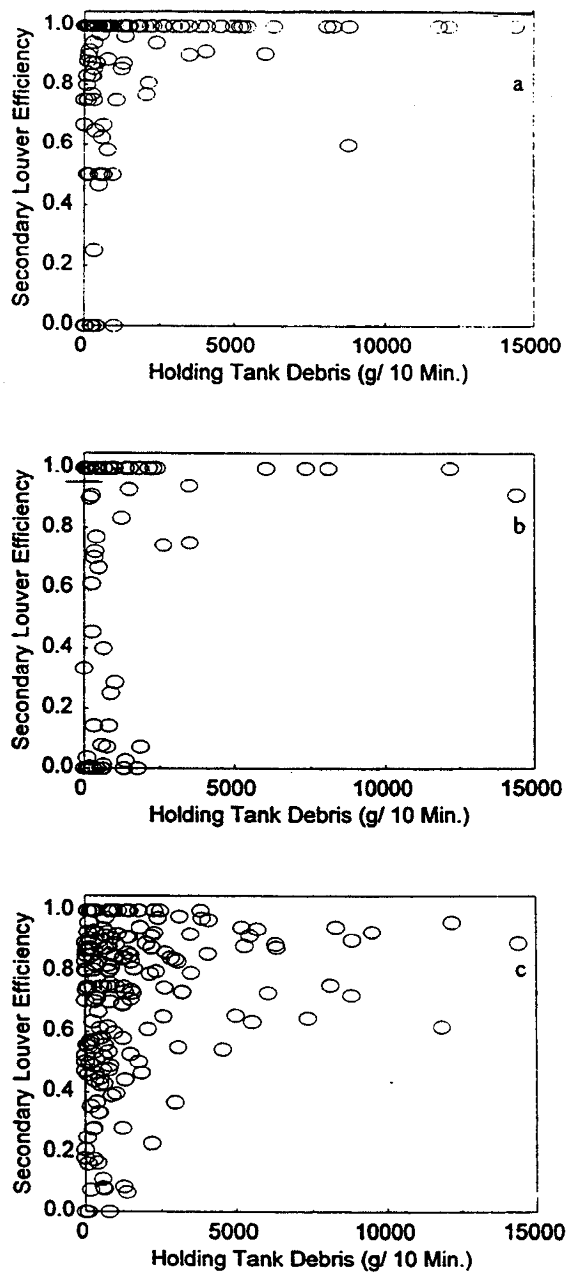

Figure 13. Secondary louver efficiency versus debris load at the Tracy Fish Collection Facility for (a) striped bass, (b) American shad, and (c) white catfish.

APPENDIX A

MAJOR SPECIES OF INTEREST AND LIFE HISTORY INFORMATION

Chinook Salmon

The San Joaquin and Sacramento Rivers support the world's southernmost (38 °N) native spawning populations of chinook salmon. Four runs of chinook occur in these Central Valley rivers: spring, fall, late-fall, and winter. While all of these runs are important to managers, two stand out. First, the winter run is listed as endangered by the State and Federal governments. Therefore, by law, managers must consider actions that might influence the number of these fish. Second, the run comprising the most individuals, and thus of most economic importance, occurs in the fall.

The runs are identified by the time of year they begin their upstream spawning migrations (Table 4). The adults swim up the Sacramento and San Joaquin Rivers to spawn. Some individuals hold in the rivers several months before spawning. For example, in most years fall-run adults begin arriving in the upper Sacramento River in July. Yet, spawning does not begin until October. Eggs hatch in 40 to 60 days, and the alevins continue development in the redds for 2 to 3 weeks (Scott and Crossman, 1973; Moyle, 1976), depending on water temperatures. The fry then swim up and smoltification may occur before out-migration begins. Fall-run emigrants begin their migration in January with a peak in May (Vogel and Marine, 1991). The timing of spawning, duration of incubation and rearing, and timing of migration vary with run, type of water year, discharge regime, temperature, turbidity, and other factors. Therefore, the timing is difficult to predict and can change significantly between years.

Salmon smolts migrating to the sea are the most susceptible life stage to entrainment to the southern Delta pumping facilities. The probability of entrainment increases when the Delta-Cross Channel Gates are open and Sacramento River water can travel to the south Delta pumping facilities via the Mokelumne River. Since the fall run produces the most progeny, chinook salmon smolts observed at the TFCF usually peak in May each year. From November 1 to May 14, the TFCF is operated to minimize take of chinook salmon smolts. To minimize take, Reclamation uses preferred operational criteria suggested by Mecum (1977) and agreed upon with the California Department of Fish and Game (Reclamation, 1992). There are four criteria. First, the primary channel approach velocity shall be maintained between 0.91 to 1.07 m/s (3.0 to 3.5 ft/s). Second, primary bypass ratio shall be maintained between 1.2 and 1.6. Third, secondary approach velocity shall be maintained between 0.9 and 1.07 m/s (3.0 and 3.5 ft/s). Fourth, secondary bypass ratio shall be maintained between 1.2 and 1.6.

Delta Smelt

Delta smelt is a threatened, euryhaline osmerid endemic to the Delta that lives only

1 year. Delta smelt have demonstrated extremely volatile population sizes (U.S. Fish and Wildlife Service, 1995) and experienced severe decreases in numbers that coincide with high Delta outflows (Moyle et al., 1992; but see California Department of Water Resources and U.S. Bureau of Reclamation, 1994). However, Delta smelt have also exhibited resiliency. The species rebounded strongly after the 1986 to 1992 drought, for a short time reaching pre-drought numbers and recolonizing Suisun Bay where they had been extirpated.

Delta smelt are most likely to be entrained to the TFCF during two periods of their life history: spawning migration and larval downstream migration. Adults spawn from January to July and appear capable of spawning at temperatures from 7 to 22 °C (45 to 72 °F). In years with low outflow, spawning usually occurs from late March through mid-May (U.S. Fish and Wildlife Service, 1995). Shallow edgewaters and sloughs are the areas where most spawning occurs. Therefore, adults may be entrained to the TFCF when these fish move out of open water habitat in the Delta and Suisun Bay to seek these shallower spawning habitats. The larvae are positively buoyant and could become entrained to the TFCF when they are moving toward open-water adult habitat.

Splittail

Splittail is a large cyprinid endemic to the Central Valley and is the sole extant species of the genus *Pogonichthys*. Splittail have experienced significant reductions in population size due to reductions in Delta outflow. In addition in recent years, the relationship between large net export years and large splittail year classes appears to be less strong than it once was (Meng, 1993; U.S. Fish and Wildlife Service, 1995).

Splittail live approximately 7 years. Males may begin to spawn at 180 to 200 mm (7.1 to 7.9 in) standard length (SL) (Daniels and Moyle, 1983; Wang, J., personal communication). Female splittail do not spawn until the second year of life (Caywood, 1973); usually a female is at least 20 cm (7.9 in) SL by this time. Splittail spawning greatly depends on water year but may begin in January (Wang, 1986; Meng and Moyle, 1995), continues through July, and usually peaks between February and May (U.S. Fish and Wildlife Service, 1995). Splittail are most susceptible to entrainment to the TFCF at two times. First, when adults migrate toward spawning sites, they may become entrained. Second, young of the year most commonly appear at the south Delta pumping facilities in May through July (Meng and Moyle, 1995).

Striped Bass

Striped bass is a large-bodied, piscivorous percichthyid, exotic to the Delta, but considered an important game fish in the estuary. The striped bass population size is smaller now than in the early 1960's (Moyle, 1976).

Three habitat requirements that provide for a highly productive striped bass fishery are a large body of water with sufficient forage for adult populations, a river in which to spawn, and an estuary with large invertebrate production for juvenile growth. Moyle (1976) suggested most adults spend much of their lives in San Pablo and San Francisco Bays. In the fall, striped bass begin a mass migration east to the Delta. By April, adults move to spawning grounds. Spawning begins when the water temperature exceeds 14.4 °C (58 °F) and therefore usually peaks in May and early June. The eggs are slightly negatively buoyant and require some current to keep them off the substrate. In the Sacramento River, eggs and newly hatched larvae are transported to the Delta and Suisun Bay. In the San Joaquin, eggs and larvae remain near spawning areas because outflow and tidal currents are balanced. If the eggs and larvae never reach the productive waters of the estuary, they may not survive. Thus, striped bass abundance may be correlated with the proportion of summer outflow that is diverted to water projects (Moyle, 1976). And in low water years, young striped bass survival may be lower than in years with higher net outflow.

Striped bass eggs, larvae, and small juveniles are highly susceptible to entrainment during and following the spawning season. Therefore, from May 15 to October 31, TFCF operations attempt to minimize take of striped bass. To improve striped bass salvage efficiency, Reclamation uses preferred operational criteria agreed upon with the California Department of Fish and Game (Reclamation, 1992). These criteria are primary channel approach velocity shall be 0.30 m/s (1.0 ft/s) and shall not exceed 0.76 m/s (2.5 ft/s). Primary bypass ratios shall be maintained between 1.2 and 1.5. Secondary approach velocity shall be 0.30 m/s (1.0 ft/s) and shall not exceed 0.76 m/s (2.5 ft/s). Secondary bypass ratio shall be 1.2.

American Shad

American shad is a large-bodied anadromous clupeid introduced into the Sacramento River between 1871 and 1881 (Skinner, 1962). A commercial fishery existed for this fish from 1879 to 1957 (Moyle, 1976, p. 106). The commercial fishery was then banned in favor of a sport fishery which still exists.

Adults return from their 3- to 5-year marine existence to the estuary in the fall. In late March or early April, the adults migrate to spawning grounds in the Sacramento River and its major tributaries such as the American and Feather Rivers. Peak of the spawning season depends on temperature; the optimum temperature range of 15 to 20 °C (59 to 68 °F) can typically be found in the spawning waters from May to June. Many similarities exist between the American shad life cycle and that of striped bass. Like striped bass, American shad eggs are slightly negatively buoyant and require some current for suspension. The drifting eggs hatch while being transported to the estuary.

Like striped bass, American shad adults are good swimmers (Bell, 1990) and thus adults migrating upstream are not easily entrained to the TFCF. Like striped bass eggs, American shad eggs are susceptible to entrainment. While moving toward the ocean, young American shad develop. And, by late autumn, most American shad have entered saltwater at sizes from 8 to 18 cm (3.2 to 7.1 in) total length (TL) (Moyle, 1976). American shad are decreasingly less vulnerable to entrainment as they grow and travel toward the ocean. At the TFCF, young American shad [98 percent between 80 and 120 mm (3.2 and 4.7 in FL)] are salvaged in significant numbers from May to December with the peak in the last portion of this period.

White Catfish

White catfish is a carnivorous bottom-feeder introduced into the estuary in 1874 (Skinner, 1962; Miller, 1966; Moyle, 1976). Before 1953, white catfish supported a commercial fishery in the Delta but this was discontinued due to overfishing (Pelgen, 1952). Although the white catfish is smaller as an adult [≤ 40 cm (15.7 in) FL in California] than channel catfish [≤ 53 cm (20.9 in) TL in California] and slower growing, the white catfish is more commonly sought by Delta anglers because of its abundance and wide distribution (Moyle, 1976).

White catfish live up to 11 years. Adults begin to spawn when they reach 20 to 21 cm (7.9 to 8.3 in) FL; in the Delta, white catfish of this size are typically 3 to 4 years old. White catfish spawning takes place at water temperatures greater than 21 °C (70 °F) (Borgeson and McCammon, 1967). Thus, in the Delta, the spawning season is usually June to July (Moyle, 1976). Either or both parents guard the adhesive eggs deposited in a nest. At water temperatures in the range of 24 to 29 °C (75 to 84 °F), the eggs hatch in 6 to 7 days. Individuals from 7 to 20 mm (0.3 to 0.8 in) have been taken at the TFCF with plankton nets (L. Hess, personal observation) suggesting white catfish spawn near the TFCF. However, the smallest size of fish routinely counted at the TFCF is greater than 20 mm TL (0.8 in) (C. Liston, personal observation). The largest white catfish salvaged seldom exceed 0.41 m (16 in) FL. This size is usually attained in the Delta at an age of 5 years. Thus, most white catfish may be vulnerable to entrainment for all their lives.

White and Green Sturgeon

White sturgeon adults are capable of attaining the largest body size [4 m (13.1 ft) FL, 590 kg (1,300 lb)] of any species of freshwater fish in North America. This endemic species was once commercially fished from the late 1860's to 1901. Due to overfishing, the commercial fishery was closed 1901 to 1908, 1909 to 1915, and was ended permanently in 1917. A sport fishery was initiated in 1954.

White sturgeon may live to be over 100 years of age (Moyle, 1976). Adults spend most of their lives in the estuary, and some adults move upstream to spawn each year. In the Sacramento-San Joaquin estuary, an individual spawns about every 5 years. Females mature at 11 to 12 years of age and at sizes ranging from 1.1 to 1.5 m (3.6 to 4.9 ft) FL. Males mature at smaller sizes. When ready to spawn, some adults may move into lower portions of rivers in the winter. Moyle (1976) reports spawning "seems to take place between mid-March and early June." The eggs are adhesive and larvae hatch within 2 weeks. The larvae are about 11 mm (0.4 in) at hatching.

Miller (1972) reported yolk-sac larvae may be susceptible to entrainment from March to June. Juveniles are more likely to utilize the upper estuary than adults (Moyle, 1976). Therefore, the juveniles may remain susceptible to entrainment to the TFCF for some time, but the length at which they cease to be susceptible is unknown. However, no white sturgeons longer than 45 cm (17.7 in) FL have been salvaged at the TFCF. Occasionally, juveniles and sub-adults are found impinged on the trash rack at the Tracy Fish Collection Facility.

The green sturgeon is native to the estuary and may spend more time in saltwater than the white sturgeon. Fewer green sturgeon inhabit the estuary than white sturgeon (Miller, 1972), and green sturgeon do not attain as great an adult size [1.3 m (51 in) FL, 45 kg (99 lb)] as white sturgeon in the Delta. Miller also reported green sturgeon may be more likely to undertake large marine migrations compared to white sturgeon.

APPENDIX B

REVIEW OF TRACY FISH COLLECTION FACILITY STUDIES: Volumes 1-4

Since 1989, the Tracy Area Office (Reclamation - Mid-Pacific Region) and the Ecological Research and Investigations Group (Reclamation - Denver) have actively studied the TFCF with the cooperation of the U.S. Fish and Wildlife Service, National Marine Fisheries Service, California Department of Fish and Game, and the California Department of Water Resources. These studies have been aimed at improving fish salvage efficiency for a suite of economically and ecologically important species. Here, we review the first four major studies that have been completed, peer-reviewed, and published in the Tracy Fish Collection Facility Studies. The first study described predator removal from the secondary channel (Liston et al., 1994).

In volume 1, Liston et al. (1994) described the development and implementation of the predator removal program in the secondary channel forebay. Large predatory individuals, primarily striped bass and white catfish, were routinely removed from the secondary channel. Stomach analysis confirmed these predators were feeding on diverted fish. In addition, Liston et al. analyzed the use of angling for predator removal. They showed that the catch per unit effort (CPUE) for angling was far smaller than CPUE for netting. Liston et al. also evaluated striped bass movement within the TFCF by mark/recapture experiments. These authors found that 29 percent of 267 striped bass released in the primary louver forebay were recaptured in the secondary louver forebay within 1 week of release. Liston et al. concluded that predator loads within the TFCF tend to accrue over time. Subsequent to the completion of volume 1, weekly predator removals have been implemented as standard operating procedure at the TFCF.

In volume 2, Hiebert (1994) designed, patented, and installed a continuous ichthyoplankton pump sampler (CIPS). He refined the CIPS unit until it retained approximately 98 percent of eggs entrained by the unit's pump. The CIPS unit was not as successful with larvae, recovering 44 percent of larvae entrained by the unit's pump. Hiebert compared estimates of total entrainment of striped bass eggs and larvae into the TFCF between the CIPS unit and traditional ichthyoplankton netting techniques. In 1991, the CIPS unit estimate of total entrainment into the TFCF was 24.0 million striped bass eggs while the ichthyoplankton netting estimate was 9.7 million eggs. Similarly, the CIPS unit estimate for striped bass larvae entrained was 2.3 million while the ichthyoplankton netting estimate was that 0.2 million striped bass larvae were entrained into the TFCF in 1991. The vast differences in egg and larval entrainment estimates suggest a high degree of ichthyoplankton patchiness at the TFCF. Hiebert also described strong diel trends in the entrainment of several species' eggs and larvae into the TFCF. The strongest diel trend was noted for striped bass; 71 percent of an estimated 3.2 million striped bass eggs were collected between 0000 and 0600 h.

In volume 3, Karp et al. (1995) describe the louver efficiency experiments they conducted. All experiments were with chinook salmon juveniles and striped bass juveniles. They found that debris load and discharge strongly influenced louver efficiency for chinook salmon or striped bass. Furthermore, chinook salmon appeared to be louvered more efficiently at night. Karp et al. measured channel velocities during each experiment and noted that the recommended (Reclamation, 1992) channel velocities for target species were not being met under all conditions. Karp et al.'s findings suggested the three independent variables that we evaluated in this report: debris load, channel velocity, and time of day.

In volume 4, Puckett et al. (1996) evaluated trends in fish salvage data. These data were acquired from 5- or 10-minute counts of fish louvered into the holding tanks. Fish salvage for all species of fish combined was higher in a wet year (1993) than a critical dry year (1994). Similarly, numbers of chinook salmon, striped bass, and splittail were higher in 1993 than 1994. For all three of these species and delta and longfin smelt, the number of individuals salvaged was correlated with season. Puckett et al. related these seasonal correlations to aspects of species' life histories that make them more susceptible to entrainment in some seasons. Specific factors appeared to coincide with salvage for different species. For example, time of day and tide appeared correlated with chinook salmon, splittail, and delta smelt salvage. Puckett et al. also presented data that suggest pumping rate (m^3/s) is directly related to the number of fish salvaged for some species (e.g., splittail); however, pumping rate also appears to interact with a species' life history to influence salvage rates. For example, when young striped bass are in the vicinity of the TFCF and pumping rates are high, salvage rate for striped bass is higher than if pumping rate is constrained.

With the completion of volumes 3 and 4, Karp et al. and Puckett et al. had identified several important trends. One of these trends was that, among other factors, the independent variables debris load, channel velocity, and time of day related to salvage.