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Empirical and Experimental Analyses of Secondary Louver Efficiency at the Tracy Fish Collection Facility: March 1996 to November 1997

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Mark D. Bowen, Brent B. Baskerville-Bridges, K.W. Frizell, Lloyd Hess, Catherine A. Karp, Scott M. Siegfried, and Sarah L. Wynn

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Bureau of Reclamation, Technical Service Center
Fisheries Applications Research Group, D-8290
PO Box 25007
Denver CO 80225

Bureau of Reclamation, Mid-Pacific Region
Division of Resources Management, MP-400
2800 Cottage Way
Sacramento CA 95825-1898

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13. ABSTRACT ***(Maximum 200 words)***

The Bureau of Reclamation operates the Tracy Fish Collection Facility (TFCF) to remove fish from San Francisco Bay-Delta water before that water is diverted south. We obtained empirical measurements of secondary louver efficiency at the TFCF for 33 species of fish. We also conducted insertion experiments with splittail, *Pogonichthys macrolepidotus*.

In this study we found mean louver efficiency for chinook (*Oncorhynchus tshawystcha*) juveniles to be 85.1 percent. We found the mean louver efficiency for striped bass (*Morone saxatilis*) juveniles to be 61.5 percent. Both of these efficiencies are lower than historical values (Bates et al., 1960).

For four species of fish, splittail, delta smelt (*Hypomesus transpacificus*), chinook salmon, and striped bass, we analyzed three independent variables and their influence on secondary louver efficiency. None of these independent variables (time of day, debris load, average channel velocity) was statistically significantly related to or a strong predictor of secondary louver efficiency.

Splittail insertion experiments showed secondary louver efficiency was significantly higher during the day, and during the daytime a simulated heavy debris load significantly reduced efficiency. Combined empirical and experimental approaches provide the best approach to evaluation of factors influencing louver efficiency at the TFCF.

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Volume 11

Empirical and Experimental Analyses of Secondary Louver Efficiency at the Tracy Fish Collection Facility: March 1996 to November 1997

by

Mark D. Bowen[1], Brent B. Baskerville-Bridges[2], K.W. Frizell[3], Lloyd Hess[1], Catherine A. Karp[1], Scott M. Siegfried[2], and Sarah L. Wynn[4]

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

[1] U.S. Department of the Interior – Bureau of Reclamation
Technical Service Center – Fisheries Applications Research Group, D-8290
P.O. Box 25007
Denver CO 80225-0007

[2] U.S. Department of the Interior – Bureau of Reclamation
Tracy Field Office
16650 Kelso Road
Byron CA 94514

[3] U.S. Department of the Interior – Bureau of Reclamation
Technical Service Center – Water Resources Research Laboratory, D-8560
P.O. Box 25007
Denver CO 80225-0007

[4] U.S. Department of the Interior – Bureau of Reclamation
Technical Service Center – Ecological Research and Investigations Group, D-8220
P.O. Box 25007
Denver CO 80225-0007

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Doug Craft
U.S. Department of the Interior – Bureau of Reclamation
Technical Service Center – Fisheries Applications Research Group, D-8290
PO Box 25007
Denver CO 80225-0007

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EXECUTIVE SUMMARY

The Tracy Fish Collection Facility (TFCF) was completed in 1954 to salvage primarily chinook salmon and striped bass. An assessment of TFCF secondary louver efficiency in the late 1950s (Bates et al., 1960) showed louver efficiency for chinook salmon was between 92 and 100 percent; louver efficiency for striped bass was between 86 and 95 percent. By the early 1990s (Karp et al., 1995), louver efficiency for both of these species had deteriorated. In this report, the current secondary louver efficiency is evaluated for chinook salmon, striped bass, and 31 other species of fish.

Secondary louver efficiency was determined by simultaneously obtaining louvered fish in the holding tank and catching fish slipping through the louvers with a sieve net deployed behind the secondary louvers. We found the secondary louver efficiency had not improved since the early 1990s: (1) efficiency for chinook salmon averaged 85.1 percent and (2) efficiency for striped bass averaged 61.6 percent. Multivariate statistical analysis found only one significant relationship between any of three independent variables (average channel velocity, time of day, and debris load) studied and secondary louver efficiency. Average channel velocity varied positively with secondary louver efficiency of chinook salmon. However the relationship was not a strong one; average channel velocity cannot predict chinook salmon secondary louver efficiency.

No independent variable influenced delta smelt average channel velocity in a statistically significant manner. However, careful observation indicated one factor that varied inversely with delta smelt louver efficiency. When average channel velocity was less than or equal to 1.09 feet per second (ft/s) delta smelt louver efficiency was 82.5 percent. When average channel velocity was between 1.09 and 3.1 ft/s, delta smelt louver efficiency was 64.0 percent. When average channel velocity was greater than or equal to 3.1 ft/s, delta smelt louver efficiency was 13.0 percent. Because of this result and others detailed in the report, it is recommended that the average velocity in the secondary channel be maintained at 1.09 ft/s year-round except when chinook salmon are present at the TFCF. When chinook salmon are present, it is recommended that average velocity in the secondary channel be maintained at 3.1 ft/s.

Experiments were conducted to evaluate the influence of debris load on splittail secondary louver efficiency. An extremely heavy debris load was

simulated with a special experimental net. With the net in place, splittail were inserted into the secondary channel. Splittail secondary louver efficiency was significantly lower when the net was present during the day, but there was no difference at night. This suggests that louver efficiency is decreased when splittail can see the debris during the day. The experimental approach was found to be effective in determining the influences on louver efficiency. It is suggested that future research at the TFCF use this experimental approach to supplement the classical empirical approach.

INTRODUCTION

California's Central Valley Project moves water from the Sacramento River watershed south to the San Joaquin Valley (figure 1) and more southern localities. At the Federal south-Delta diversion point, the U.S. Department of the Interior (Interior), Bureau of Reclamation (Reclamation) operates the Tracy Fish Collection Facility (TFCF). After tests of various fish screens (U.S. Department of the Interior, 1957), Reclamation selected a system in which fish salvage is performed (figure 2) by a system of louvers and bypasses as water passes through the TFCF and into the Delta-Mendota Intake Canal (DMC). The DMC transports water to the Tracy Pumping Plant (TPP), where the water is lifted and then travels by gravity south for agricultural and domestic uses.

The fish salvage at the TFCF is accomplished in two louver channels. The primary channel has a maximum depth of 6 meters (m) (20 feet [ft]) and is completely traversed by the primary louver array, which is 97.5 m (320 ft) long and 25.6 m (84 ft) wide (figure 2). The louver array is angled 15 degrees to the channel and has four bypasses. Each bypass is 15.3 centimeters (cm) (6 inches [in]) wide and leads to a primary bypass pipe 91.4 cm (36 in) in diameter. These four pipes deliver water to the secondary louver channel.

The secondary louver channel has a maximum depth of 4.9 m (16 ft) and contains two parallel louver arrays that span the channel's entire 2.4 m (8 ft) width. Similar to the primary louvers, both secondary louver arrays are angled 15 degrees to the flow. The anterior louver array in the secondary channel ends in a rectangular opening. This steel "bypass" is 15.3 cm (6 in) wide. However, this is not a bypass to a holding tank (figure 3); the steel ends 1.7 m (5.6 ft) in front of the posterior louver array's true bypass (width = 15.3 cm [6 in]). A fish could be "louvered" by the anterior secondary louver array and potentially swim through the posterior secondary louver array and be transported into the DMC.

Each louver array consists of a series of vertical slats spaced 2.3 cm (0.9 in) apart. The louver slats create a visual and turbulent barrier to fish. Most fish swim against the current but are eventually transported downstream. When a fish encounters the louver array it tends to swim laterally away from the turbulence into the more laminar flow. Thus, fish are "guided" toward the bypass.

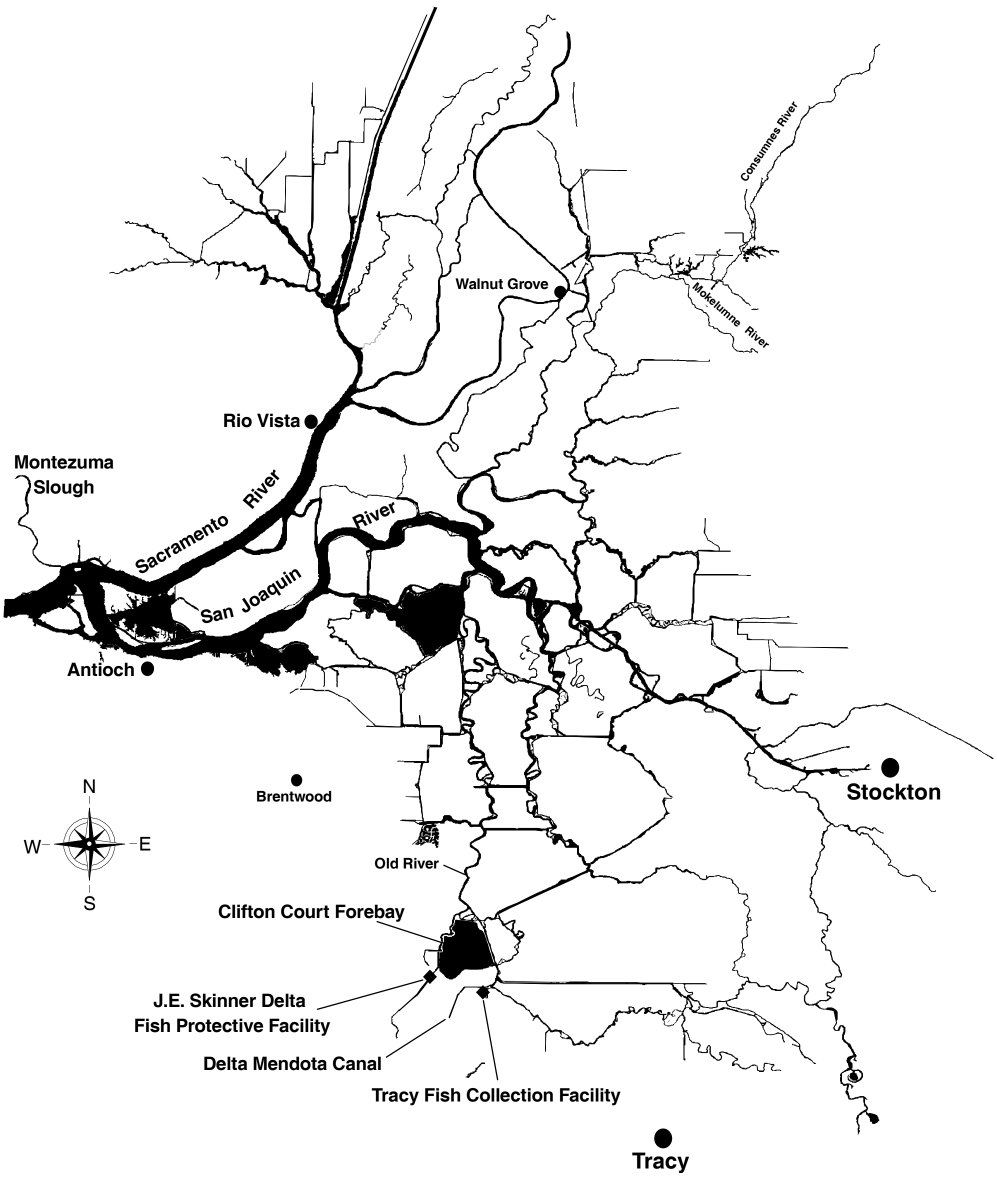


FIGURE 1.—The Sacramento-San Joaquin Delta with the location of the TFCF indicated.

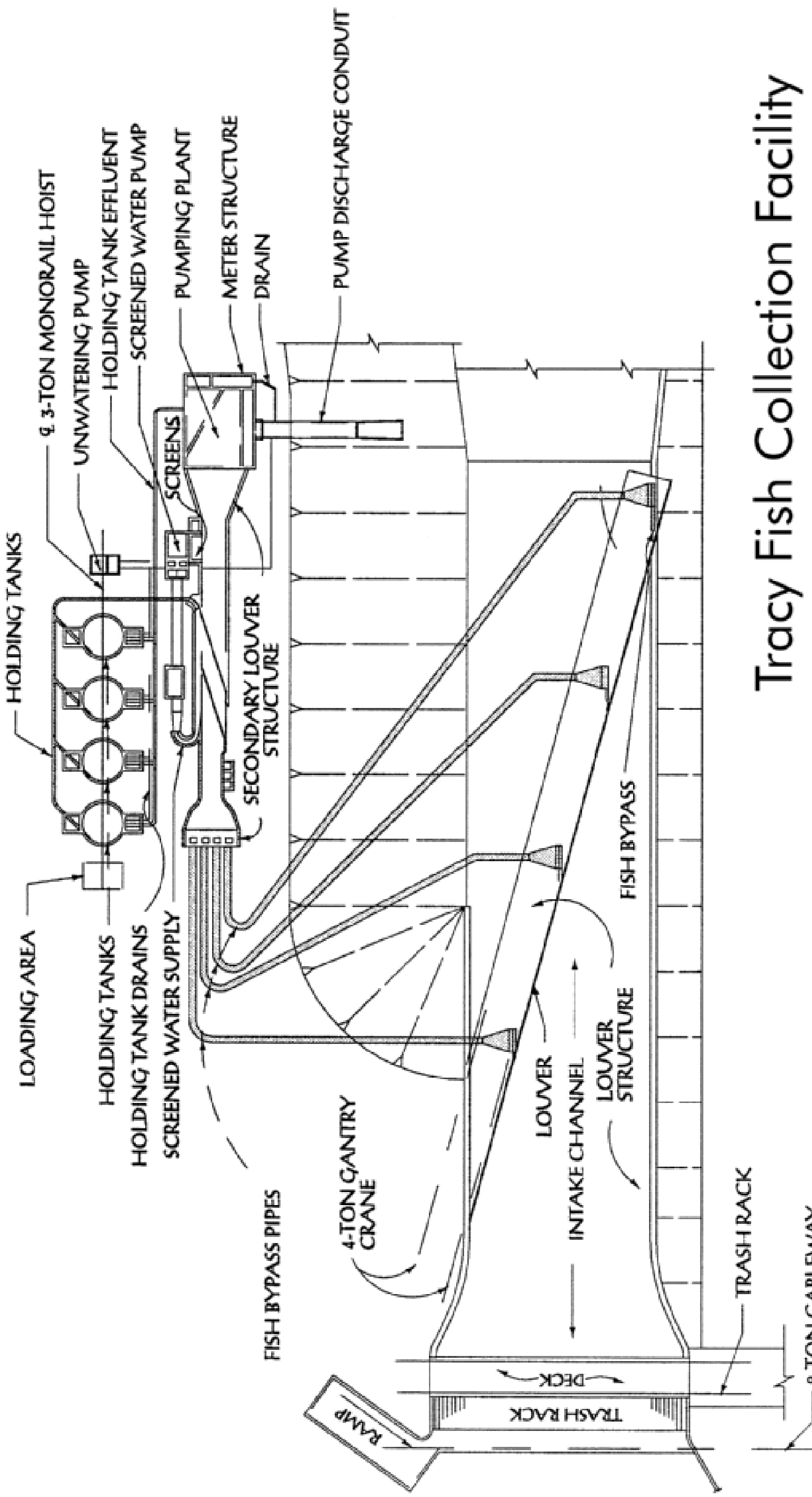


FIGURE 2.—Schematic of the TFCF.

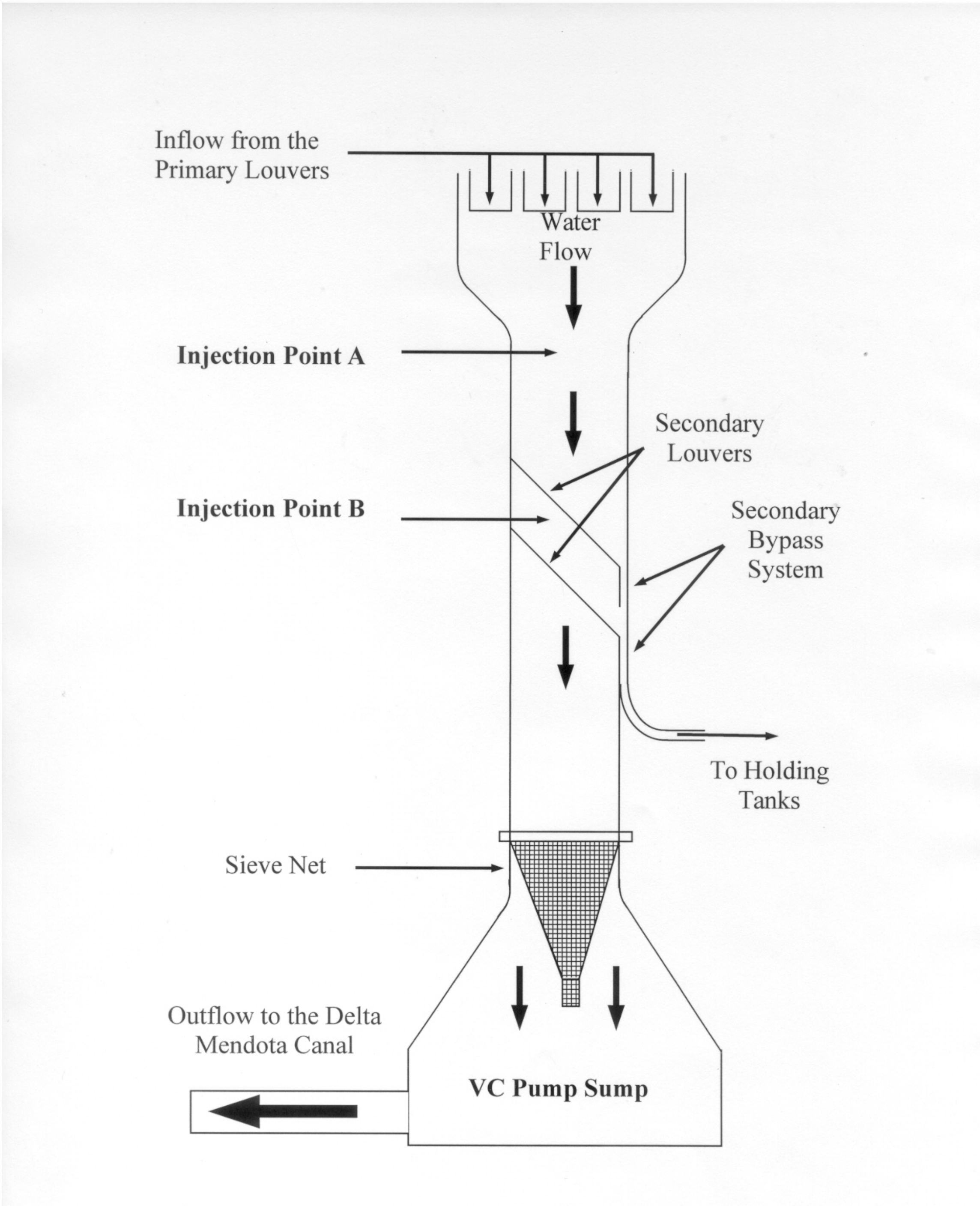


FIGURE 3.—The secondary channel at the TFCF. Sieve net and splittail injection locations are indicated.

Secondary Louver Efficiency

Since the completion of the TFCF, secondary louver efficiency has apparently decreased for the two target species for which the facility was primarily constructed: juvenile chinook salmon, *Oncorhynchus tshawytscha*, and juvenile striped bass, *Morone saxatilis* (table 1). We began this study to determine if this decrease was continuing and to investigate the influence of time of day, channel approach velocity, and louver debris load on secondary louver efficiency. After collecting many empirical observations of efficiency, we conducted experiments to evaluate the influence of time of day and louver debris load on splittail, *Pogonichthys macrolepidotus*, louver efficiency. Thus, we were able to compare empirical and experimental approaches to the study of secondary louver efficiency.

TABLE 1.—Range of secondary louver efficiencies observed at the TFCF, Tracy, California, from 1955 to present

	Chinook Salmon Efficiency, Lower Range Limit	Chinook Salmon Efficiency, Upper Range Limit
Bates et al., 1960	92	100
Karp et al., 1995	72	100
Bowen et al., 1998	83	85
	Striped Bass Efficiency, Lower Range Limit	Striped Bass Efficiency, Upper Range Limit
Bates et al., 1960	86	95
Karp et al., 1995	44	90
Bowen et al., 1998	61	86

METHODOLOGY

Secondary Louver Efficiency

We constructed a sieve net (2 millimeters [mm] [0.08 in] mesh) on a frame posterior to the two secondary louver arrays (figure 3). For 10 minutes (min), we simultaneously deployed the sieve net in the channel and directed flow from the bypass into a holding tank (effective mesh size 6 mm [0.25 in]). At the end of 10 min, we redirected flow into another holding tank and withdrew the sieve net. Fish and debris were removed from the holding tank and sieve net.

The holding tank and sieve netted fish were then identified to species, and fork length (FL) was measured to the nearest mm (0.04 in). Species, lengths, and numbers of fish were recorded with operational and environmental parameters (table 2). For each 10-min observation, instantaneous secondary louver efficiency was calculated as:

$$E_i = H_i \cdot (H_i + S_i)^{-1}$$

where,

E_i	=	Instantaneous secondary louver efficiency
H_i	=	Number of fish in the holding tank
S_i	=	Number of fish in the sieve net

TABLE 2.—Environmental and operational parameters recorded with simultaneous holding tank/sieve net observations at the TFCF

Operational	Environmental
Number of pumps operating at the TPP	Tide: out, in, slack
Primary channel discharge	Primary depth
Secondary channel discharge	Secondary depth
Primary channel velocity	Time of day
Secondary channel velocity	Debris load
Primary bypass ratio	Temperature
Secondary bypass ratio	Conductivity
Holding tank discharge	Salinity
VC pump combination	
Screen water (always off)	

We recognize that this instantaneous efficiency places more weight on fish that enter the secondary louver channel alone (n = 1) than on fish that enter in a group.

To account for this, grand secondary louver efficiency was calculated as:

$$E_g = H_g \cdot (H_g + S_g)^{-1}$$

where,

E_g = Grand secondary louver efficiency

H_g = Number of fish in the holding tank for all 10-min samples combined

S_g = Number of fish in the sieve net for all 10-min samples combined

Splittail Injection Experiments

Two controls and one treatment were conducted. The first control was no net on the secondary louver array. The second control was a cotton net (mesh size of 25.6 mm [1 in]) weighted with rebar, 12.8 mm (0.5 in) in diameter, on the bottom of the net. The treatment was a cotton net, a duplicate of the control net, altered to simulate an extremely heavy debris load on the anterior secondary louver.

The treatment net was prepared with a cotton net, mesh size of 25.6 mm (1 in), on which was assembled plastic simulated vegetation and a plastic sheet. First, rebar 12.8 mm (0.5 in) in diameter was affixed to the bottom of the cotton net with cable ties to weight the bottom of the net. Second, 2,000 simulated vegetation clusters were affixed to the front of the cotton net with binder clips. Third, a plastic sheet was attached to the back of the net. From the plastic sheet, pieces were removed at random in three shapes: square, rectangular, and circular. The shapes were cut in three sizes: 0.09, 0.18, and 0.72 square meter (m^2) (1, 2, and 8 square feet [ft^2]). Pieces were removed until 17 percent of the plastic had been removed.

In a trial, no net, the control net, or the treatment net was affixed to the anterior secondary louver array. In addition, when the treatment net was in place, a perforated plate (3.7 m by 0.9 m (10 ft by 3 ft) with holes 2 mm (0.08 in) in diameter was situated on the last 0.9 m (3 ft) of the anterior secondary louver array. Thus, no fish could pass through the louver array in the 0.9 m (3 ft) closest to the bypass entrance. This perforated plate simulated the debris clogging that occurs near the bypass during heavy debris loading. We conducted a factorial design (table 3) with time of day

TABLE 3.—Factorial design executed in the splittail injection experiments. The number in each cell represents the number of replicates completed for each combination

Treatment	Day	Night
No net	3	3
Control net	4	2
Vegetation net	3	3

and the debris load treatments. All treatments began 1 hour (h) after high tide and each treatment was 3 h in duration. We also conducted three dimensional velocity profiles 91 cm (3 ft) along the front of the anterior louver with no net, the control net, and the experimental net in place.

In the spring of 1998, 1,440 splittail were retained from holding tank collections. For each experimental trial, 80 splittail (mean FL of 7 cm [3 in]) were prepared. Forty splittail were dyed with Bismarck brown for 3 h with 0.45 gram (g) of Bismarck brown in 220 liters (L) (100 gallons [gal]) of water. These 40 splittail then received a clip on the lower lobe of the caudal fin. Forty undyed splittail received a clip on the upper lobe of the caudal fin. One hour after high tide, the 40 dyed, clipped splittail were released by minnow bucket immediately downstream from the anterior secondary louver array. Hence, these fish were released between the two secondary louver arrays. The 40 undyed, clipped splittail were released 10 m (32.6 ft) upstream from the leading edge of the anterior louver array.

One hour after injection, and at the end of each hour during the trial, the sieve net was raised and all fish and debris were removed. Thus, the sieve net was out of the water for an average of 4 min every hour. This produced a slight overestimate of splittail secondary louver efficiency. We corrected for this effect by calculating the catch rate in the sieve net per minute. Then, we added the number of fish that would have been obtained in that 4 min. This discrepancy could not be avoided; when the sieve net was left in place for the entire 3-h duration of a trial, it was ripped by extensive accumulations of materials such as woody debris, plastics, and fish.

Delta Smelt Recommendation

Using logistic regression, we modeled delta smelt secondary louver efficiency as a function of approach velocity. Delta smelt louver efficiency was defined as instantaneous louver efficiency (see equation page 6) and can also be interpreted as the probability of a delta smelt being successfully louvered into a holding tank. Calculations were performed using PROC PROBIT in SAS/STAT Release 8.02 (SAS Institute Inc., 1999-2001). Using the logistic regression model, we estimated the approach velocity that is associated with a given secondary louver efficiency; this problem is one of inverse prediction, i.e., prediction of the independent variable (approach velocity) from the dependent variable (delta smelt secondary louver efficiency). Using the INVERSECL option, we obtained 95 percent inverse confidence limits for a value of velocity that yields a given louver efficiency. The inverse confidence limits indicate the precision in our estimate of that velocity. We graphed the lower inverse confidence limit for several efficiencies (figure 11) because the lower limit is a conservative estimate of the minimum velocity needed to achieve a given efficiency.

RESULTS

Between March 15, 1996, and November 9, 1997, we collected 26,539 fish representing 33 species of fish. These fish were obtained through 456 simultaneous 10-min holding tank/sieve net samples. Grand efficiency was calculated for each species (table 4).

Between March 1996 and November 1997, juvenile chinook salmon secondary louver efficiency was 85.1 percent; juvenile striped bass louver efficiency was 61.5 percent. The apparent reduction from the average 1960 (Bates et al., 1960) levels of louver efficiency noted in earlier studies (table 1) is still in effect for these two species.

Because of the bimodal distribution of empirical efficiency data (Bowen et al., 1998), we relied on logistic regression (Hosmer and Lemeshow, 1989) and Probit Analysis (SAS Institute Inc., 1999-2001) to evaluate the influence of channel approach velocity, time of day, and debris loading. With logistic regression, we found that juvenile chinook secondary salvage efficiency was positively influenced by channel approach velocity in the secondary channel (table 5: Probability of the Logistic Model Fit, $P = 0.7536$; Probability that Approach Velocity Explains No Variation, $P = 0.0009$). However, channel approach velocity was not a good predictor of secondary louver efficiency

TABLE. 4.— Grand secondary louver efficiency (see equation on page 6) of individuals successfully salvaged at the TFCF, Tracy, California, from March 1996 – November 1997. Order of fishes follows AFS (1991)

Common Name	Scientific Name	Percent Successfully Louvered	n
Lamprey Species	*Petromyzontidae*	72.7	11
River lamprey	*Lampetra ayersi*		
Pacific lamprey	*Lampetra tridentata*		
White sturgeon	*Acipenser transmontanus*	80.0	5
American shad	*Alosa sapidissima*	40.4	1,986
Threadfin shad	*Dorosoma petenense*	52.9	6,897
Red shiner	*Cyprinella lutrensis*	64.7	17
Common carp	*Cyprinus carpio*	32.8	58
Golden shiner	*Notemigonus crysoleucas*	75.0	28
Sacramento blackfish	*Orthodon microlepidotus*	88.2	17
Splittail	*Pogonichthys macrolepidotus*	71.2	765
Sacramento sucker	*Catostomus occidentalis*	32.2	839
White catfish	*Ameiurus catus*	86.5	2,516
Black bullhead	*Ameiurus melas*	80.0	5
Brown bullhead	*Ameiurus nebulosus*	92.3	26
Channel catfish	*Ictalurus punctatus*	73.4	576
Wakasagi	*Hypomesus nipponensis*	74.1	27
Delta smelt	*Hypomesus transpacificus*	65.0	1,112
Longfin smelt	*Spirinchus thaleichthys*	60.2	113
Steelhead	*Oncorhynchus mykiss*	100.0	22
Chinook salmon	*Oncorhynchus tshawytscha*	85.1	1,890
Western mosquitofish	*Gambusia affinis*	35.3	17
Inland silverside	*Menidia beryllina*	45.3	190
Prickly sculpin	*Cottus asper*	67.8	2,448
Striped bass	*Morone saxatilis*	61.5	4,017
Warmouth	*Lepomis gulosus*	76.8	56
Bluegill	*Lepomis macrochirus*	73.5	1,277
Redear sunfish	*Lepomis microlophus*	96.2	26
Largemouth bass	*Micropterus salmoides*	70.7	610
Black crappie	*Pomoxis nigromaculatus*	82.3	62
Bigscale logperch	*Percina macrolepida*	54.7	75
Yellowfin goby	*Acanthogobius flavimanus*	58.5	388
Shimofuri goby	*Tridentiger bifasciatus*	26.8	422
Starry flounder	*Platichthys stellatus*	90.5	21

TABLE 5.— Logistic regression analysis of the effects of three independent variables' on secondary louver efficiency at the TFCF, Tracy, California, from March 1996 – November 1997. Number of simultaneous 10-minute holding tank/sieve net samples were: splittail (n = 121), delta smelt (n = 149), chinook salmon (n = 196), and striped bass (n = 253)

Model	Splittail Probability of Model Fit	Splittail Probability of Significance	Delta Smelt Probability of Model Fit	Delta Smelt Probability of Significance	Chinook Salmon Probability of Model Fit	Chinook Salmon Probability of Significance	Striped Bass Probability of Model Fit	Striped Bass Probability of Significance
Approach Velocity	0.5375	0.5375	0.0028	0.0048	0.8639	0.8640	0.0420	0.0457
Time of Day	0.3312	0.3333	0.1414	0.1442	0.5137	0.5141	0.2570	0.2576
Debris	0.0379	0.0402	0.0025	0.0034	0.4523	0.4561	0.0007	0.0009
Ap. Veloc.+ Time of Day	0.5376	0.5856 0.3552	0.0034	0.0043 0.1235	0.7855	0.8127 0.5011	0.0358	0.0358 0.1901
Ap. Veloc.+ Debris	0.0830	0.4147 0.0343	0.0002	0.0061 0.0047	0.7536	0.0009 0.5279	0.0003	0.0380 0.0008
Time of Day+ Debris	0.0776	0.3728 0.0437	0.0081	0.4891 0.0078	0.5259	0.3967 0.3591	0.0024	0.4893 0.0014
Ap. Veloc.+ Time of Day+ Debris	0.1260	0.4351 0.3904 0.0368	0.0004	0.0060 0.4646 0.0118	0.7305	0.9239 0.3941 0.3721	0.0008	0.0326 0.3855 0.0013

(Somer's *D* = 0.065; (= 0.090). For example, chinook salmon louver efficiency appears unrelated to channel approach velocity in some analyses (table 6). These conflicting results leave us without a consistent relationship between approach velocity and chinook salmon secondary louver efficiency.

For three other species of concern—splittail, threatened delta smelt, *Hypomesus transpacificus*, and striped bass—we analyzed statistically the influence of channel approach velocity, time of day, and debris loading on salvage efficiency. Only one (velocity) of these three independent variables influenced salvage efficiency for any species in a statistically significant manner (table 5). Yet, even when these factors were not statistically significant, we noted differences in salvage efficiency. Splittail louver efficiency was lower during crepuscular periods (table 7) and when debris load was light (table 8).

No statistically significant factor was isolated for delta smelt. However, on inspection of the empirical data, channel approach velocity appears inversely related to delta smelt louver efficiency (table 6). When channel approach velocity is less than 0.33 meter per second (m/s) (1.09 feet per second [ft/s]), delta smelt secondary louver efficiency is 82.5 percent. Secondary louver efficiency is 64.0 percent when channel approach velocities are between 0.33 and 0.95 m/s (1.09 and 3.1 f/s). Secondary louver efficiency is 13.0 percent when channel approach velocities exceed 0.95 m/s (3.1 ft/s).

Other factors also showed some relationship to delta smelt louver efficiency through inspections of the data. Delta smelt louver efficiency increased as debris in the 10-min counts increased (table 8). But delta smelt louver efficiency varied inversely with temperature (table 9).

Similarly to delta smelt, juvenile striped bass secondary louver efficiency was statistically not significantly influenced by approach velocity. However, table 6 shows that channel approach velocity appears inversely related to striped bass louver efficiency, and secondary louver efficiency is highest when channel approach velocity is less than 0.33 m/s (1.09 ft/s). Furthermore, striped bass efficiency increased with bypass ratio (table 10). But striped bass louver efficiency was independent of tidal state (table 11).

Secondary louver efficiency was low for some species of interest. Grand efficiency for American shad (*Alosa sapidissima*) was only 40.4 percent; in addition, efficiency was inversely proportional to temperature (table 9).

TABLE 6.—Secondary louver efficiency in three approach-velocity categories for fish collected at the TFCF, Tracy, California, from March 1996 – September 1997

Common Name	<0.33 m/s (<1.09 ft/s) Successfully Louvered (%)	<0.33m/s (1.09 ft/s) n	0.33-0.95 m/s (1.09-3.1 ft/s) Successfully Louvered (%)	0.33-0.95 m/s (1.09-3.1 ft/s) n	$0.95 m/s (>3.1 ft/s) Successfully Louvered (%)	$0.95 m/s ($3.1 ft/s) n
American shad	—	0	39.4	1,614	44.9	372
Bigscale logperch	100.0	3	53.5	71	—	1
Black bullhead	—	0	80.0	5	—	0
Black crappie	100.0	1	81.5	54	85.7	7
Bluegill	47.7	44	74.6	949	73.9	284
Brown bullhead	100.0	1	95.8	24	—	1
Centrarchids	—	0	37.5	8	—	1
Channel catfish	66.7	3	71.1	523	94.0	50
Chinook salmon	85.7	14	84.8	1,686	87.4	190
Common carp	—	0	32.8	58	—	0
Delta smelt	82.5	103	64.0	986	13.0	23
Golder shiner	—	0	74.1	27	100.0	1
Goldfish	—	0	100.0	2	—	0
Green sturgeon	—	0	—	1	—	0
Green sunfish	—	0	100.0	1	—	0
Inland silverside	33.3	3	43.5	168	63.2	19
Lamprey Species	—	0	80.0	10	—	1
Largemouth bass	100.0	7	69.9	582	71.4	21
Longfin smelt	53.8	13	60.6	99	100.0	1
Prickly sculpin	91.2	171	66.8	2,136	53.2	141
Pumpkinseed	—	0	100.0	1	—	0
Red shiner	—	0	68.8	16	—	1
Redear sunfish	100.0	2	94.7	19	100.0	5
Sacramento blackfish	—	0	88.2	17	—	0
Sacramento sucker	—	4	30.7	807	53.6	28
Shimofuri goby	100.0	1	26.7	420	—	1
Splittail	—	0	71.1	751	64.3	14
Starry flounder	—	0	90.0	20	100.0	1
Steelhead	—	0	100.0	20	100.0	2
Striped bass	96.7	120	59.3	3,756	65.2	141
Threadfin shad	58.0	143	50.8	5,632	61.7	1122
Threespine stickleback	—	0	66.7	3	—	0
Tule perch	—	0	100.0	2	—	0
Wakasagi	—	0	73.1	26	100.0	1
Warmouth	100.0	1	81.0	42	61.5	13
Western mosquitofish	—	0	35.7	14	33.3	3
White catfish	98.1	53	86.3	2,155	83.1	308
White crappie	—	0	100.0	1	—	0
White sturgeon	—	0	80.0	5	—	0
Yellowfin goby	100.0	1	57.7	381	100.0	6

TABLE 7.— Secondary louver efficiency at three periods of day for fish collected at the TFCF, Tracy, California, from March 1996 – September 1997. Crepuscular period data combine dawn and dusk samples

Common Name	Day Successfully Louvered (%)	Day n	Crepuscular Successfully Louvered (%)	Crepuscular n	Night Successfully Louvered (%)	Night n
Lamprey Species	100.0	3	100.0	1	57.1	7
River lamprey						
Pacific lamprey						
White sturgeon	50.0	2	100.0	1	100.0	2
American shad	37.4	1,099	35.5	414	51.8	473
Threadfin shad	42.8	2,935	49.9	889	63.4	3,073
Red shiner	83.3	6	0.0	1	60.0	10
Common carp	17.4	23	34.8	23	58.3	12
Golden shiner	63.6	11	100.0	4	76.9	13
Sacramento blackfish	87.5	8	75.0	4	100.0	5
Splittail	74.6	319	59.9	172	74.5	274
Sacramento sucker	37.6	189	23.7	266	35.4	384
White catfish	87.9	495	86.9	444	86.0	1,577
Black bullhead	100.0	1	100.0	1	66.7	3
Brown bullhead	100.0	3	100.0	3	90.0	20
Channel catfish	61.0	182	84.8	66	78.0	328
Wakasagi	81.8	11	75.0	8	62.5	8
Delta smelt	65.7	720	60.6	188	66.7	204
Longfin smelt	62.1	66	52.9	34	69.2	13
Steelhead	100.0	8	100.0	7	100.0	7
Chinook salmon	82.9	346	84.3	408	86.0	1,136
Western mosquitofish	25.0	4	33.3	3	40.0	10
Inland silverside	36.5	96	66.7	9	52.9	85
Prickly sculpin	72.4	1,410	57.1	524	66.0	514
Striped bass	62.2	2,434	60.8	431	60.1	1,152
Warmouth	100.0	2	100.0	4	74.0	50
Bluegill	72.1	308	77.0	183	73.3	786
Redear sunfish	100.0	15	100.0	4	85.7	7
Largemouth bass	74.6	240	63.9	61	68.9	309
Black crappie	87.1	31	81.3	16	73.3	15
Bigscale logperch	56.8	44	42.9	14	58.8	17
Yellowfin goby	83.3	66	57.9	19	53.1	303
Shimofuri goby	21.8	335	41.7	12	46.7	75
Starry flounder	100.0	8	—	0	84.6	13

TABLE 8.— Secondary louver efficiency at three debris levels for fish collected at the TFCF, Tracy, California, from March 1996 – September 1997. Debris mass was obtained in the holding tank during a 10-min simultaneous holding tank/sieve net sample

Common Name	< 350 g (< 12.3 oz) Successfully Louvered (%)	< 350 g (< 12.3 oz) n	350 – 1000 g (12.3 – 35.3 oz) Successfully Louvered (%)	350 – 1000 g (12.3 – 35.3 oz) n	$ 1000 g ($35.3 oz) Successfully Louvered (%)	$ 1000 g ($35.3 oz) n
Lamprey Species	100.0	1	—	0	70.0	10
River lamprey						
Pacific lamprey						
White sturgeon	50.0	2	100.0	1	100.0	1
American shad	37.4	511	28.6	825	57.8	650
Threadfin shad	40.4	2,264	46.9	2,080	69.4	2,421
Red shiner	57.1	7	33.3	3	80.0	5
Common carp	16.3	43	100.0	7	100.0	3
Golden shiner	62.5	8	62.5	8	91.7	12
Sacramento blackfish	100.0	2	75.0	4	90.9	11
Splittail	57.3	248	78.7	235	83.7	257
Sacramento sucker	18.6	601	70.2	141	61.8	89
White catfish	76.0	434	84.8	580	90.4	1,442
Black bullhead	—	0	50.0	2	100.0	3
Brown bullhead	100.0	1	100.0	5	90.0	20
Channel catfish	53.8	221	82.2	107	87.6	242
Wakasagi	68.4	19	66.7	3	100.0	5
Delta smelt	55.2	717	85.2	305	91.5	71
Longfin smelt	51.6	91	92.3	13	100.0	9
Steelhead	100.0	4	100.0	5	100.0	11
Chinook salmon	77.8	334	79.5	347	89.0	1,125
Western mosquitofish	60.0	5	25.0	4	14.3	7
Inland silverside	37.5	56	30.2	53	62.8	78
Prickly sculpin	67.1	1,469	70.7	569	66.8	373
Striped bass	51.4	2,198	72.9	1,089	79.4	683
Warmouth	50.0	8	60.0	5	83.7	43
Bluegill	54.5	112	63.0	238	77.5	874
Redear sunfish	100.0	10	100.0	6	90.0	10
Largemouth bass	55.9	281	77.3	176	92.6	148
Black crappie	53.8	13	73.3	15	96.9	32
Bigscale logperch	47.8	46	66.7	21	62.5	8

TABLE 9.—Secondary louver efficiency at three temperature ranges for fish collected at the TFCF, Tracy, California, from March 1996 – September 1997

Common Name	< 14 °C (< 57.2 °F) Successfully Louvered (%)	< 14 °C (< 57.2 °F) n	14 – 20 °C (57.2 – 68 °F) Successfully Louvered (%)	14 – 20 °C (57.2 – 68 °F) n	$ 20 °C ($68 °F) Successfully Louvered (%)	$ 20 °C ($ 68 °F) n
Lamprey Species	75.0	4	71.4	7	—	0
Pacific lamprey						
River lamprey						
White sturgeon	100.0	1	75.0	4	—	0
American shad	45.5	237	40.7	970	38.5	779
Threadfin shad	59.4	957	59.2	2,832	45.1	3,108
Red shiner	25.0	4	75.0	8	80.0	5
Common carp	12.5	8	30.5	36	50.0	14
Golden shiner	75.0	4	92.8	14	50.0	10
Sacramento blackfish	100.0	2	90.0	10	80.0	5
Splittail	80.0	75	71.6	381	68.8	309
Sacramento sucker	41.3	29	31.1	751	40.6	59
White catfish	86.2	313	86.5	1,655	86.6	548
Black bullhead	100.0	1	66.6	3	100.0	1
Brown bullhead	100.0	6	86.6	15	100.0	5
Channel catfish	—	0	25.0	4	40.0	5
Wakasagi	0.0	1	82.3	17	66.6	9
Delta smelt	78.0	146	65.4	588	59.2	378
Longfin smelt	83.3	12	57.9	88	53.8	13
Steelhead	100.0	3	100.0	17	100.0	2
Chinook salmon	87.7	49	85.5	1,576	81.8	265
Western mosquitofish	66.6	3	20.0	5	33.3	9
Inland silverside	50.0	16	61.5	78	31.2	96
Prickly sculpin	78.9	176	65.7	1,889	72.5	383
Striped bass	63.9	441	67.6	726	59.5	2,850
Warmouth	70.0	30	100.0	18	50.0	8
Bluegill	69.3	323	74.4	806	77.7	148
Redear sunfish	100.0	2	92.3	13	100.0	11
Largemouth bass	72.1	61	80.3	102	68.2	447
Black crappie	100.0	3	86.6	45	64.2	14
Bigscale logperch	83.3	6	51.1	43	53.8	26
Yellowfin goby	55.0	69	64.2	98	57.0	221
Shimofuri goby	39.3	94	57.1	21	20.8	307
Starry flounder	90.0	10	100.0	1	90.0	10

TABLE 10.—Secondary louver efficiency in three bypass ratio categories for fish collected at the TFCF, Tracy, California, from March 1996 – September 1997

Common Name	< 1.2 Successfully Louvered (%)	< 1.2 n	1.2 – 1.6 Successfully Louvered (%)	1.2 – 1.6 n	$ 1.6 Successfully Louvered (%)	$ 1.6 n
Lamprey Species	75.0	800	50.0	200	—	0
River lamprey						
Pacific lamprey						
White sturgeon	50.0	2	100.0	200	—	0
American shad	40.8	867	41.3	673	43.7	183
Threadfin shad	54.1	2,813	52.4	2,342	42.6	514
Red shiner	60.0	5	83.3	6	50.0	2
Common carp	6.7	6	35.7	14	85.7	7
Golden shiner	69.2	13	70.0	10	100.0	3
Sacramento blackfish	100.0	4	100.0	6	50.0	2
Splittail	75.1	133	73.5	310	73.8	88
Sacramento sucker	62.2	45	32.3	229	58.3	48
White catfish	88.2	1,166	82.9	705	85.3	123
Brown bullhead	88.8	18	100.0	3	100.0	3
Channel catfish	83.5	184	65.7	286	60.0	33
Wakasagi	50.0	2	75.0	4	77.7	9
Delta smelt	70.7	263	58.0	205	71.3	381
Longfin smelt	47.0	34	61.1	18	75.0	44
Steelhead	100.0	11	100.0	3	—	0
Chinook salmon	85.2	987	88.5	453	84.6	117
Western mosquitofish	25.0	8	66.6	3	—	0
Inland silverside	45.0	71	55.5	54	25.0	24
Prickly sculpin	65.8	369	70.1	463	77.4	655
Striped bass	58.4	1,046	60.5	1,652	67.6	650
Warmouth	71.0	38	90.0	10	100.0	1
Bluegill	73.4	792	78.7	320	64.4	76
Redear sunfish	85.7	7	100.0	7	100.0	3
Largemouth bass	76.8	138	66.8	326	80.3	61
Black crappie	80.9	21	91.3	23	50.0	8
Bigscale logperch	28.5	7	65.5	29	75.0	12
Yellowfin goby	46.6	60	55.1	234	85.2	34
Shimofuri goby	13.3	127	33.9	206	5.7	52
Starry flounder	83.3	6	90.9	11	100.0	4

TABLE 11.—Secondary louver efficiency at three tidal states for fish collected at the TFCF, Tracy, California, from March 1996 – September 1997. Slack tide is the 6-h period between sequential tidal peaks

Common Name	Out Successfully Louvered (%)	Out n	Slack Successfully Louvered (%)	Slack n	In Successfully Louvered (%)	In n
Lamprey Species	33.3	3	100.0	1	85.7	7
River lamprey						
Pacific lamprey						
White sturgeon	100.0	2	—	0	66.7	3
American shad	41.7	770	37.0	608	42.3	608
Threadfin shad	54.1	2,465	46.2	1,947	57.0	2,485
Red shiner	72.7	11	—	1	60.0	5
Common carp	47.4	19	20.0	15	29.2	24
Golden shiner	80.0	5	71.4	7	75.0	16
Sacramento blackfish	66.7	6	100.0	5	100.0	6
Splittail	70.1	214	70.0	247	73.0	304
Sacramento sucker	34.5	278	33.9	224	29.1	337
White catfish	83.4	945	84.1	473	90.3	1,098
Black bullhead	66.7	3	—	0	100.0	2
Brown bullhead	85.7	7	100.0	7	91.7	12
Channel catfish	69.9	269	63.6	110	83.8	197
Wakasagi	70.0	10	100.0	1	75.0	16
Delta smelt	62.0	368	62.1	240	68.7	504
Longfin smelt	51.1	45	61.3	31	70.3	37
Steelhead	100.0	6	100.0	1	100.0	15
Chinook salmon	85.8	494	76.3	270	86.9	1126
Western mosquitofish	25.0	8	100.0	4	0.0	5
Inland silverside	37.8	74	25.9	27	57.3	89
Prickly sculpin	69.6	1,165	58.0	531	71.8	752
Striped bass	60.6	1,448	62.7	1,008	61.5	1,561
Warmouth	76.9	26	54.5	11	89.5	19
Bluegill	78.2	655	61.5	195	71.9	427
Redear sunfish	92.3	13	100.0	4	100.0	9
Largemouth bass	69.7	188	71.8	216	70.4	206
Black crappie	76.9	26	93.3	15	81.0	21
Bigscale logperch	57.1	28	45.0	20	59.3	27
Yellowfin goby	77.2	57	63.8	105	51.3	226
Shimofuri goby	26.9	186	24.7	93	28.0	143
Starry flounder	92.3	13	100.0	1	85.7	7

Furthermore, the efficiency for American shad is lower during daytime (table 7: 37.4 percent) and crepuscular (dawn and dusk combined) periods (35.5 percent) than at night (51.8 percent). Threadfin shad, *Dorosoma petenense*, showed a similar trend with the highest secondary efficiency observed at night (63.4 percent) and lower efficiencies observed during the day (42.8 percent) and crepuscular periods (49.9 percent).

As expected, for most species, secondary louver efficiency did not consistently vary with tidal state (table 11). The absolute number of fish entrained to the TFCF might vary with an incoming tide, but we did not expect this to vary the efficiency with which the louvers operate.

Similar to tidal state, we did not expect secondary efficiency to vary with the weight of debris obtained in a 10-min holding tank count (table 8). But 25 of the 32 species showed an increase in louver efficiency with an increasing debris load. We do not know if debris load was directly correlated with fouling of the louvers by debris. For example, when we measured extremely high debris loads (greater than 1,000 g in the 10-min holding tank count), the louvers could be dirty or clean depending on the time since they were last cleaned. It is possible that increased debris load in the 10-min sample is associated with higher debris fouling on the louvers; this fouling might reduce the area through which fish might pass from the secondary louvers, allowing an increase in efficiency. Splittail was 1 of 25 species that displayed this trend: higher debris loads provided higher secondary louver efficiency. Because debris load may not be related to fouling, we decided to further investigate the relationship between debris and louver efficiency using splittail as an example.

Secondary louver efficiency data for almost all species were not distributed normally (figures 4-8). Most commonly, these data were bimodal; no known transformation will provide normally distributed data from such distributions. Data for splittail were not distributed normally (figure 4d). We hypothesized this was due to the common occurrence of only one fish coming through the secondary channel at a time. Therefore, we decided to inject a number of splittail (n=40) to produce data distributed normally (figure 9) and allow us to employ parametric statistical techniques to elucidate the relationship between time of day, debris fouling, and splittail secondary louver efficiency.

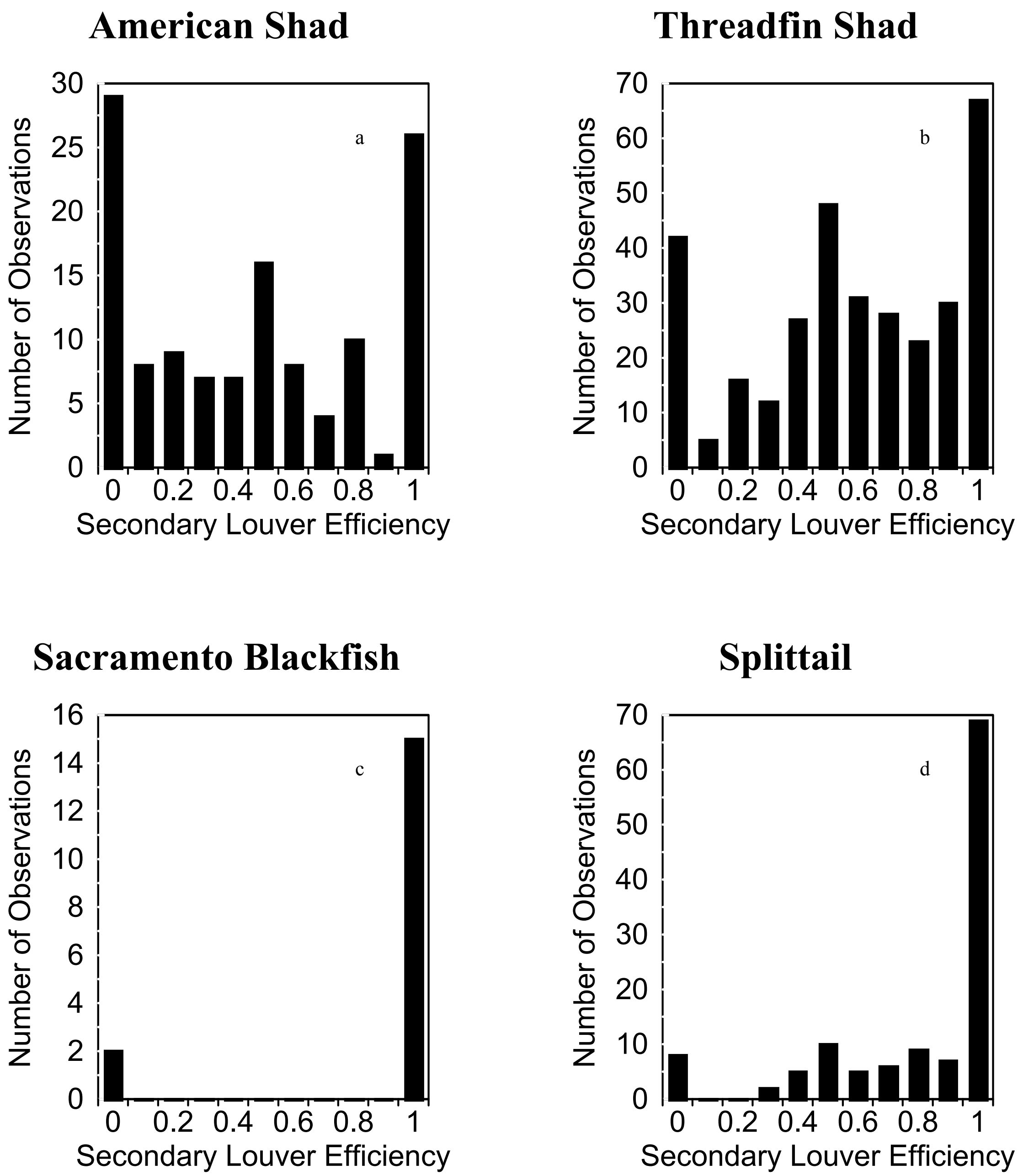


FIGURE 4.— Frequency distribution of secondary louver efficiency observations for (a) American shad, (b) threadfin shad, (c) Sacramento blackfish, and (d) splittail at the TFCF, March 1996 – November 1997.

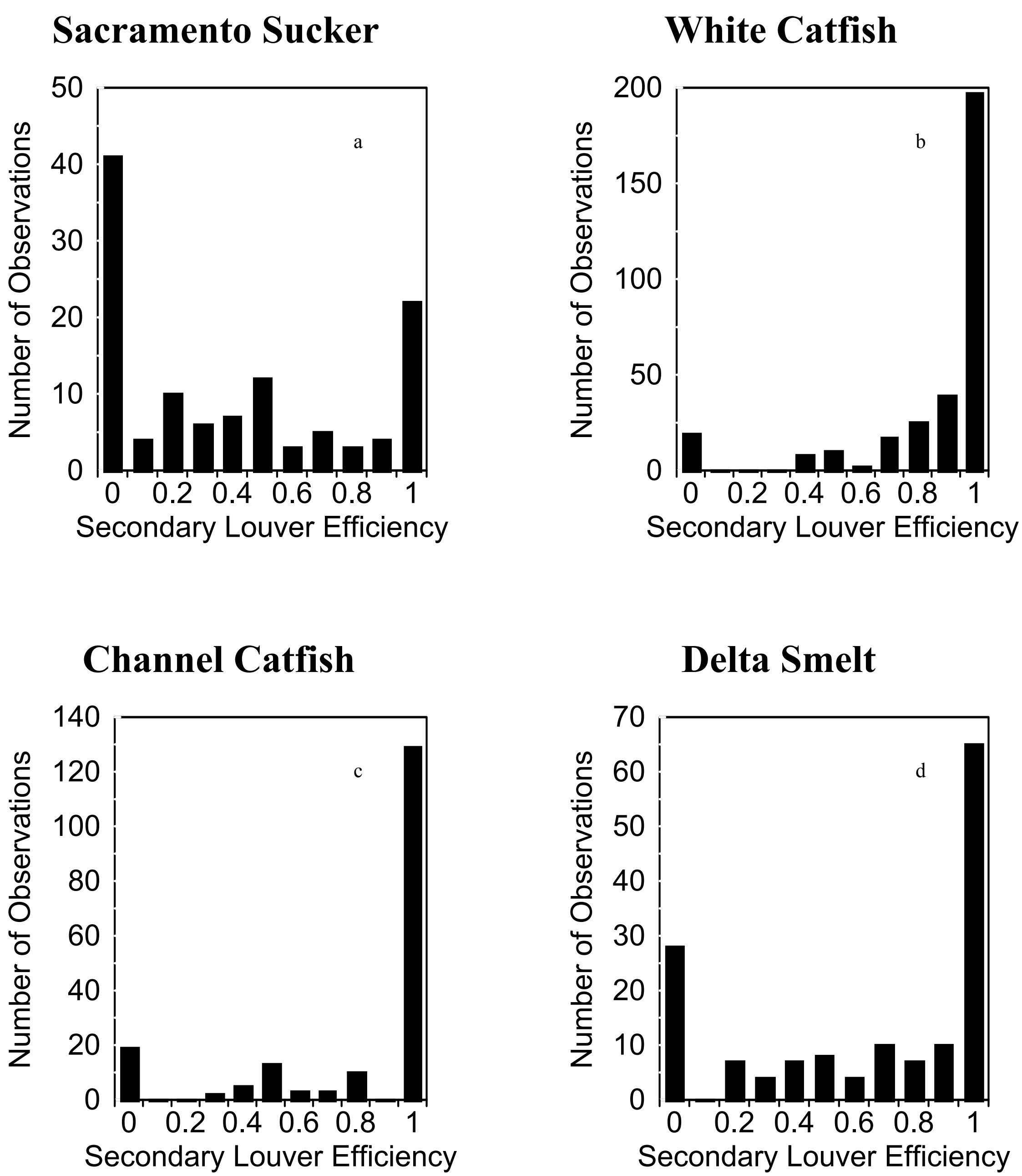


FIGURE 5.— Frequency distribution of secondary louver efficiency observations for (a) Sacramento sucker, (b) white catfish, (c) channel catfish, and (d) delta smelt at the TFCF, March 1996 – November 1997.

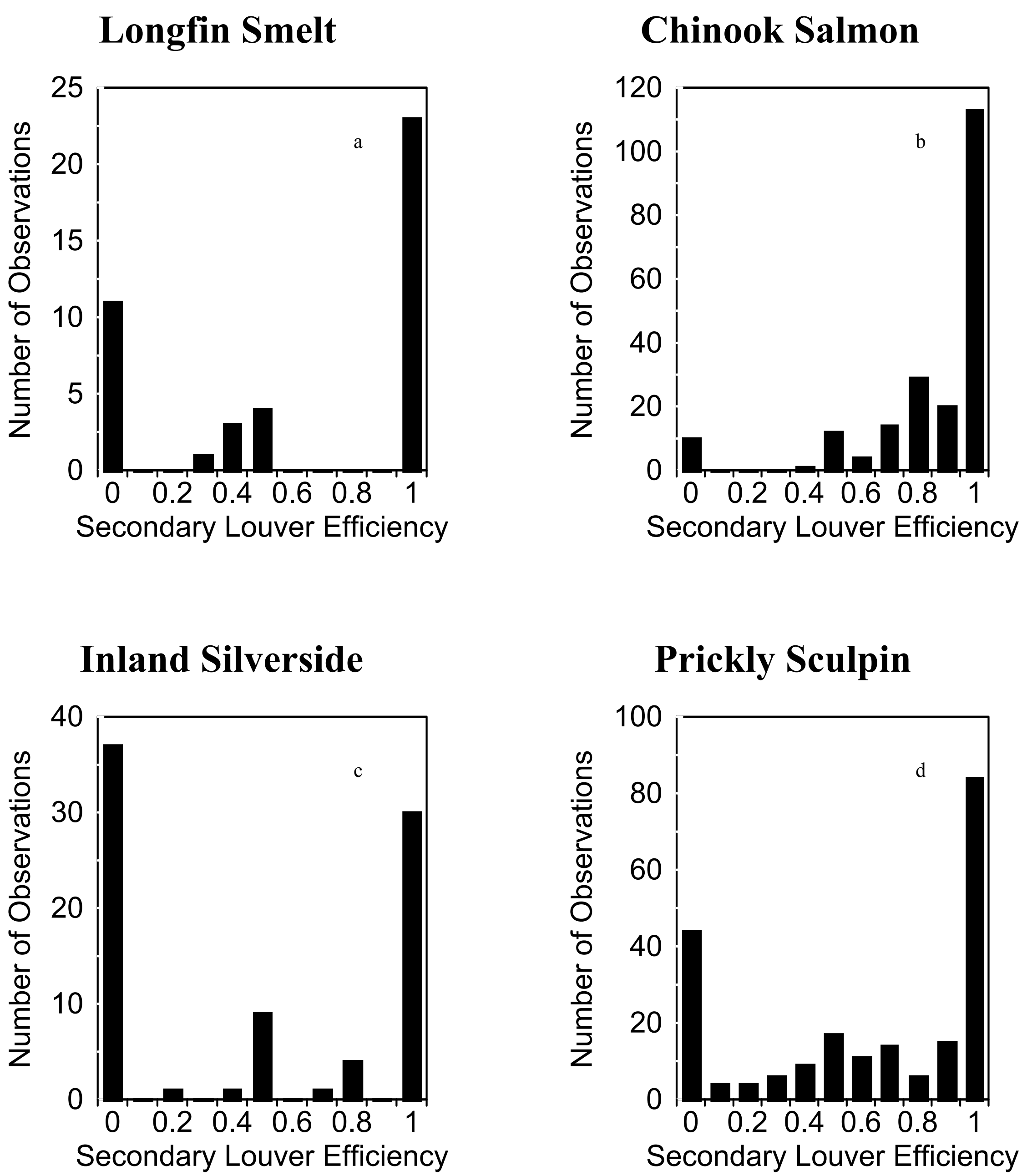


FIGURE 6.— Frequency distribution of secondary louver efficiency observations for (a) longfin smelt, (b) chinook salmon, (c) inland silverside, and (d) prickly sculpin at the TFCF, March 1996 – November 1997.

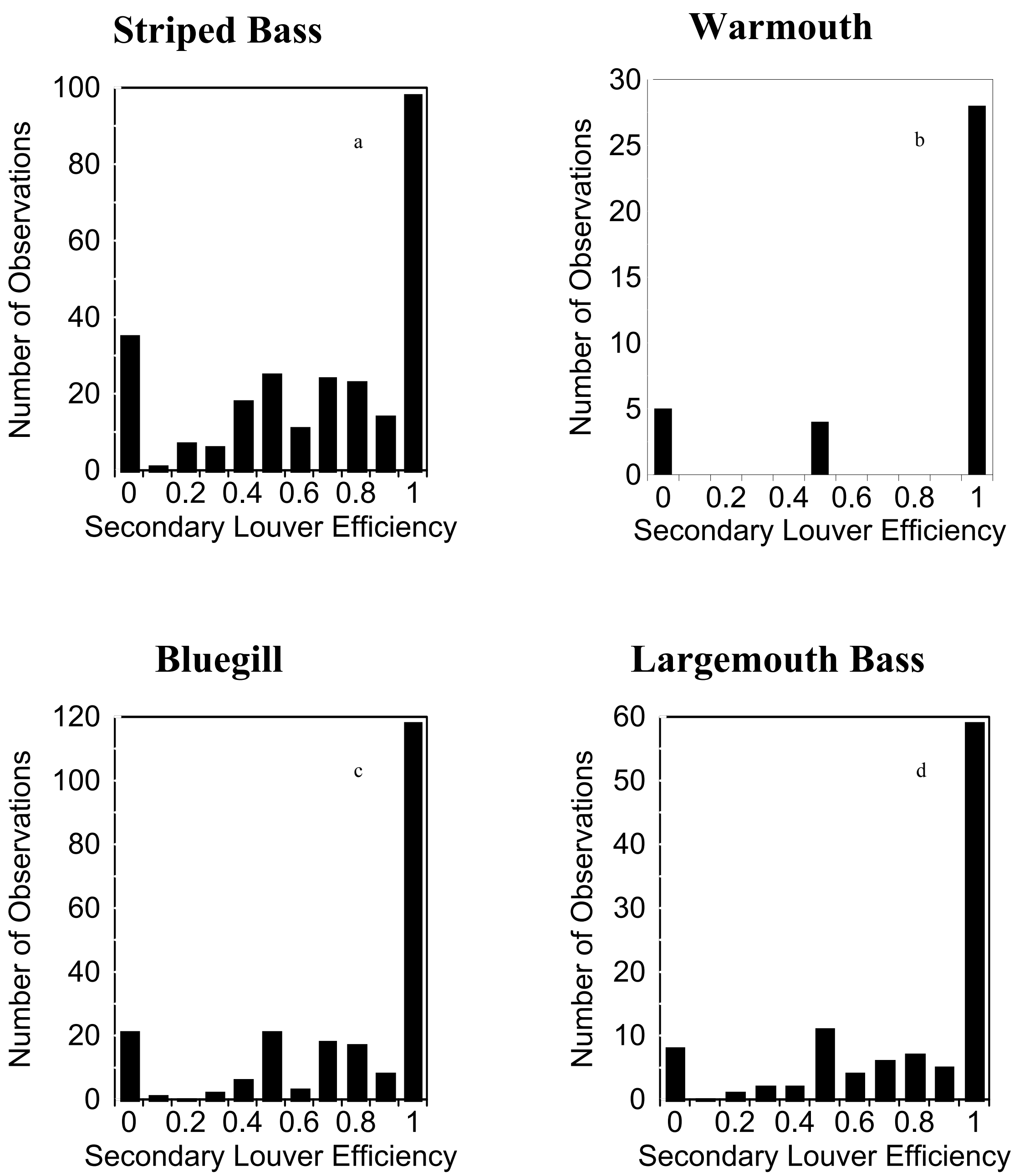


FIGURE 7.— Frequency distribution of secondary louver efficiency observations for (a) striped bass, (b) warmouth, (c) bluegill, and (d) largemouth bass at the TFCF, March 1996 – November 1997.

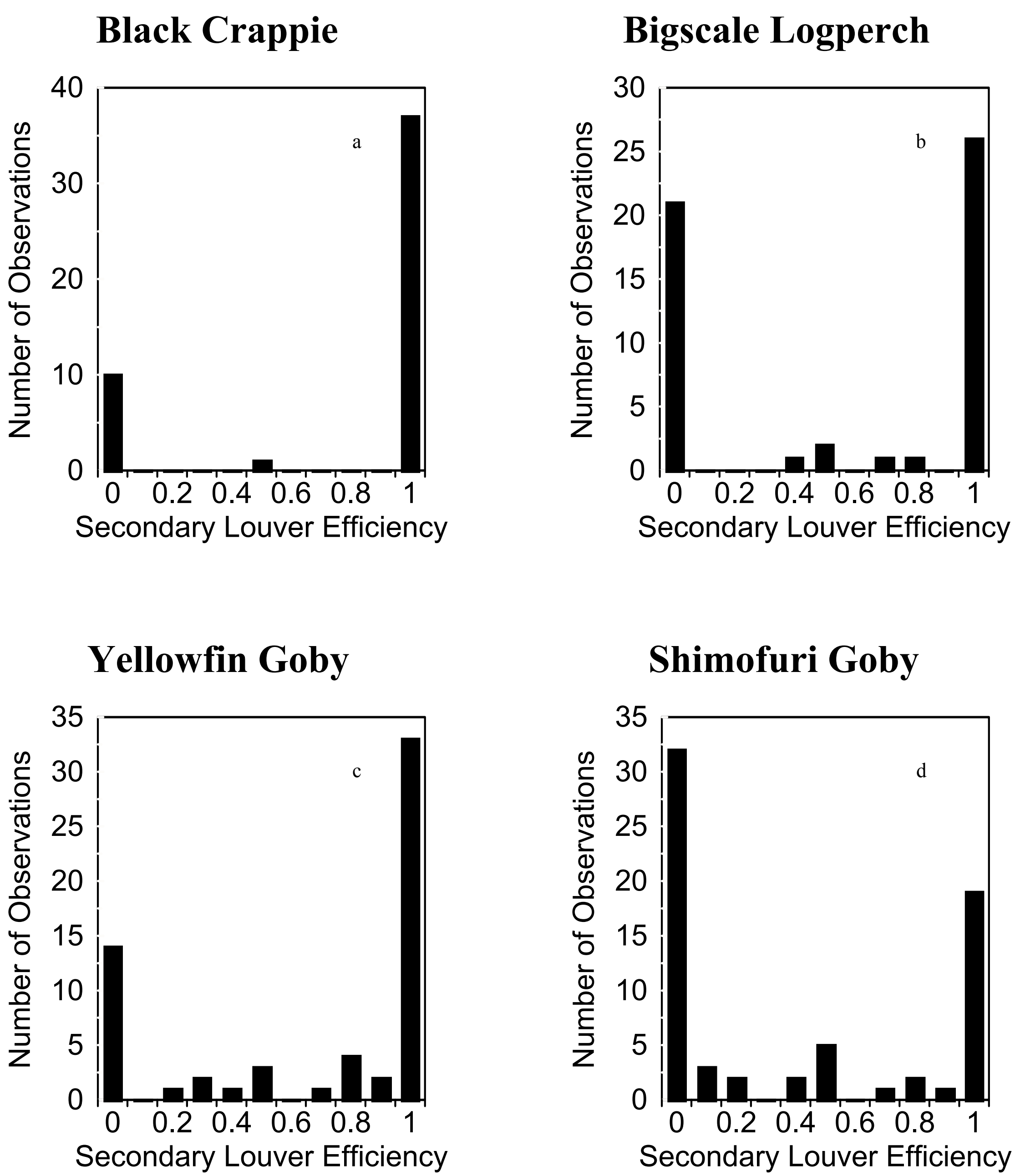


FIGURE 8.— Frequency distribution of secondary louver efficiency observations for (a) black crappie, (b) bigscale logperch, (c) yellowfin goby, and (d) shimofuri goby at the TFCF, March 1996 – November 1997.

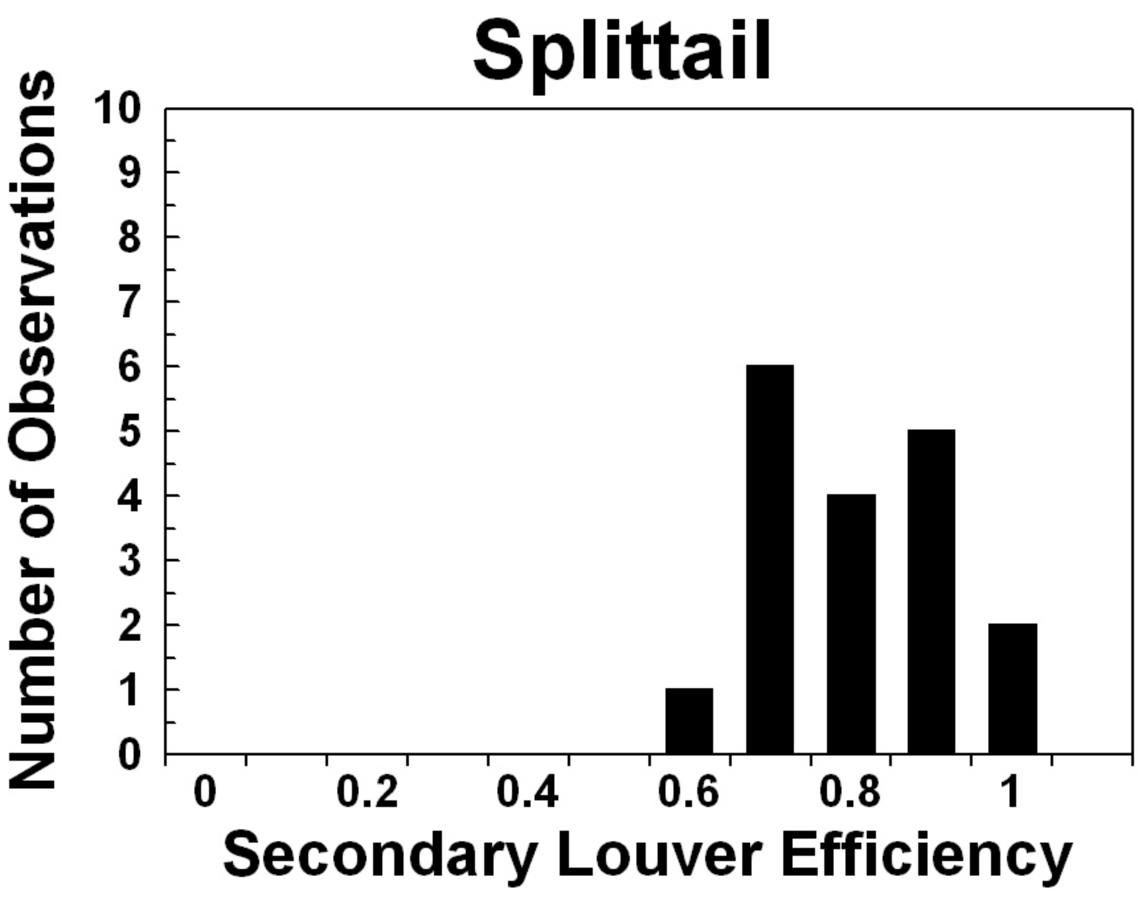


FIGURE 9.—Distribution of splittail secondary louver efficiency during injection experiments.

Splittail louver efficiency was also assessed through an experimental approach (table 12). Velocity profiles conducted without a net (figure 10a), with the control net (figure 10b), and with the experimental vegetation net (figure 10c) showed the experimental net was influencing the velocity profile in the secondary channel.

When isolated through experimentation, time of day exhibits a statistically significant impact on splittail salvage efficiency ($F = 9.92$; $P = 0.00071$). For the specific set of conditions under which the experiments were conducted, mean splittail louver efficiency during the day was 81.2 percent and at night it was 67.9 percent. Debris fouling simulated by the experimental net significantly reduced splittail secondary louver efficiency during the day (table 12).

TABLE 12.— Net experimental louver efficiency for splittail released in the secondary channel at the TFCF, March 1999 – May 1999. Superscripts indicate statistically significant difference via Two-Way, Model I ANOVA and planned comparison of means

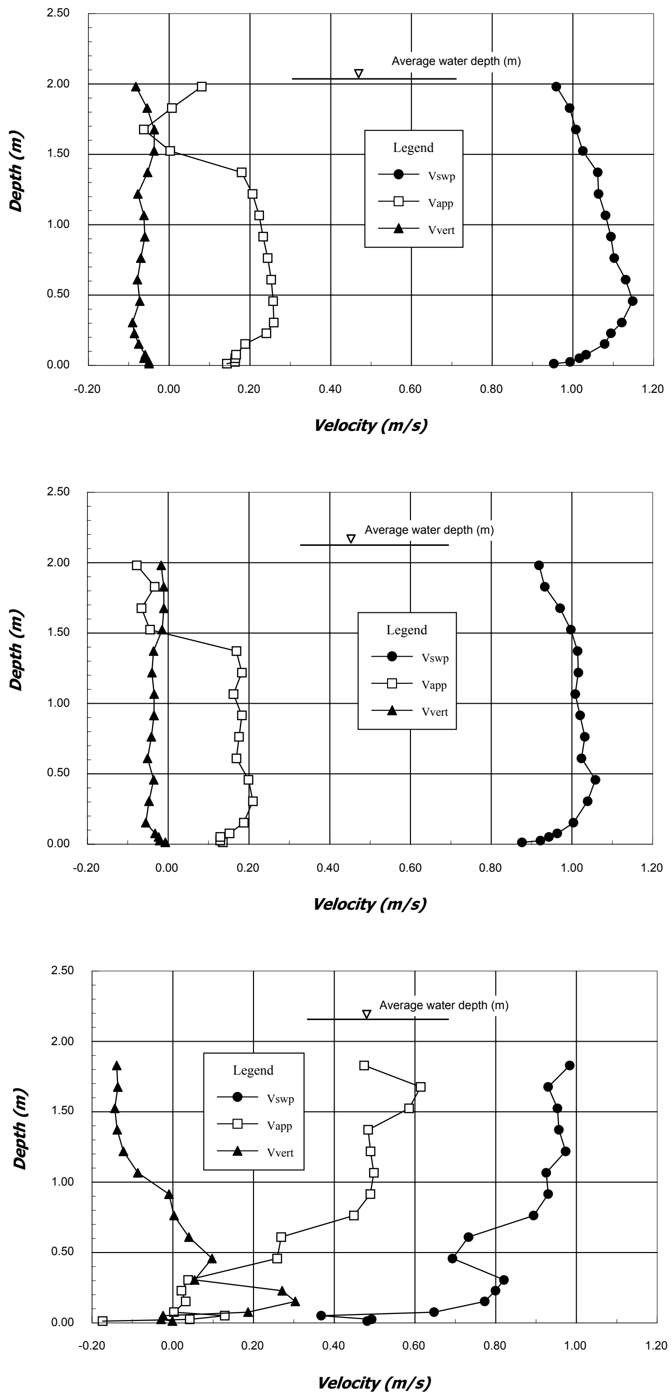
Treatment	Louver Efficiency, Day	sd	Louver Efficiency, Night	sd
Controls	86.5[a]	7.6	68.8[c]	8.4
Vegetation net	73.2[b]	9.2	66.5[c]	6

We estimated the amount of time spent collecting the empirical data to be 1,870 human-hours or 233 days. Next, we calculated the time spent obtaining the experimental observations concerning the influence of time of day and debris loading on splittail louver efficiency: 360 human-hours or 45 days. The empirical approach yielded one statistically significant relationship: channel approach velocity influences chinook salmon louver efficiency. The experimental approach yielded two statistically significant relationships: time of day and debris load influence splittail louver efficiency. Therefore, we suggest the experimental approach may be more efficient at demonstrating statistically significant influences on louver efficiency for particular species. However, the empirical approach allows the assessment of many factors (table 2) and their potential influence on louver efficiency for all fish species caught at the TFCF.

Delta Smelt Recommendation

After conducting the Probit analysis and inspecting the data, it seems possible to achieve better than 75 percent secondary louver efficiency for delta smelt.

We plotted the predicted lower limit vs. louver efficiency (figure 11). With this graph in mind, we recommend using an average channel approach velocity of 0.33 m/s (1.09 ft/s) when the principal objective is to salvage delta smelt. The lower limit figure (figure 11) predicts that we should achieve approximately 80 percent secondary louver efficiency with this value. We would recommend an even lower channel velocity, but it seems unlikely to us that we can keep louver efficiency for other fish if approach velocity is



(a) No net

(b) Control net

(c) Experimental debris net

FIGURE 10.— Three dimensional velocity profile in front of the anterior louver array with (a) no net, (b) the control net, and (c) the experimental debris net in place. The velocity probe was placed 5.1 cm (2 in) from the louver array surface.

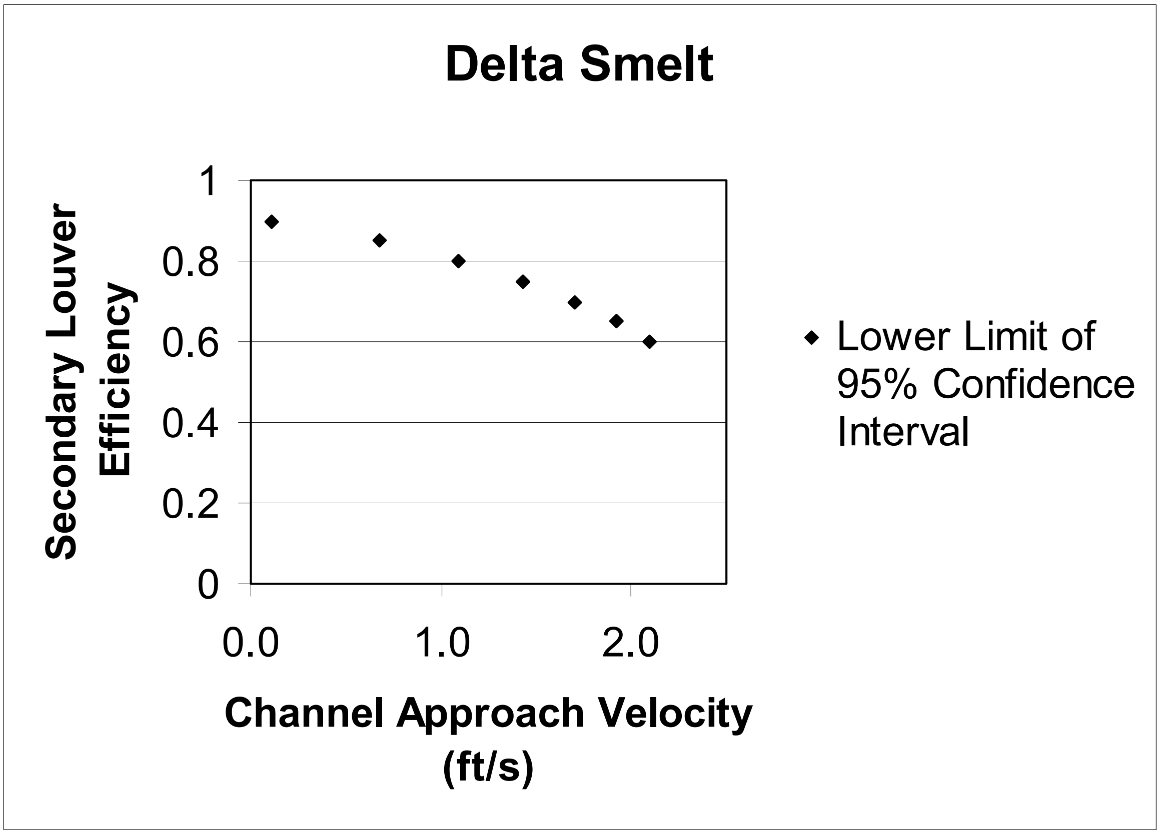


FIGURE 11.— Predicted secondary louver efficiency for delta smelt given channel approach velocity. These predictions were made using Probit analysis to generate the mean and confidence limits predicted at a particular channel velocity. (See page 9.)

lower than 0.33 m/s (1.09 ft/s). Thus, this recommendation may allow us to get above 75 percent for delta smelt and maintain louver efficiency for other species that do not exhibit the inverse relationship between approach velocity and louver efficiency (e.g., chinook salmon and steelhead).

DISCUSSION

Fish entrained to the TFCF often arrive individually and, thus, 0 and 1 are regular observations of the proportion of fish successfully salvaged. This result provides typically bimodal distributions in the secondary louver efficiency data (figures 4-8). In contrast, experimental injection of fish provided a normally distributed louver efficiency distribution (figure 9). Experimental analysis of factors influencing louver efficiency provided an effective approach for establishing statistical significance of factors. However, for exploring a large number of potential influences on louver efficiency for 33 or more species of fish (table 4), the empirical approach is more efficient.

In the first experiments conducted, we found that the two sets of louvers in the secondary channel synergistically produce louver efficiencies up to 30 percent higher than one set of louvers alone (tables 13-1 and 13-2). Splittail released between the louver arrays had less time to orient themselves to the flow than those released in front of the more anterior louver array. Yet, the magnitude of louver efficiency increase with two louver arrays suggests the two sets of louver arrays are important in achieving satisfactory efficiencies. Thus, a series of barriers and screens may be more efficient than any one screen alone.

The size of fish appeared related to secondary louver efficiency for only one of the five target species we studied (table 14). American shad larger than 30-mm (1.2 in) FL were louvered less successfully than those smaller than 30-mm (1.2 in) FL. This relationship between size and louver efficiency lends itself to the experimental analysis of louver efficiency. Therefore, future research might use an experimental approach to determine if the observed variance in louver efficiencies with size are statistically significant.

This research also pointed out an unexpected result with respect to “take” of listed species at the TFCF. Currently, if Reclamation improves delta smelt louver efficiency at the TFCF, the official “take” is higher.

No consistent relationship between secondary channel approach velocity and splittail was evident. However, through inspection of the empirical data, relationships between secondary channel velocity did appear for delta smelt and striped bass. The highest delta smelt louver efficiency occurs at velocities lower than 0.33 m/s (1.09 ft/s).

TABLE 13-1.—Louver efficiency for those splittail released in front of both secondary louver arrays at the TFCF, March 1999 – May 1999

	Day	Night
No net	81.7	66.4
Control net	91.4	72.3
Vegetation net	73.2	66.5

TABLE 13-2.—Louver efficiency for those splittail released between the secondary louver arrays

	Day	Night
No net	51.1	47.8
Control net	57.2	55.0
Vegetation net	47.4	41.2

TABLE 14.—Percentage of two size ranges of target species successfully louvered at the TFCF March 1996 – November 1997

Species	Efficiency < 30 mm FL	n	Efficiency $30 mm FL	n
American shad	55.8	138	39.3	1848
Chinook salmon	—	0	85.0	1890
Delta smelt	64.2	1044	72.1	68
Striped bass	59.3	3184	65.7	833
Splittail	78.1	73	70.2	692

Similarly, striped bass show the highest louver efficiency at velocities below 0.33 m/s (1.09 ft/s), and the louver efficiency was positively related to bypass ratio (table 10). Secondary louver efficiency for chinook salmon was highest when channel velocity exceeded 0.94 m/s (3.1 ft/s). Logistic regression showed approach velocity was positively related to chinook salmon louver efficiency. We summarize these results into a suggested operations table for the secondary channel (table 15) with respect to channel velocity, bypass ratio, and time of year.

TABLE 15.— Proposed changes to operations for secondary louver channel at the TFCF. The recommended secondary channel approach velocity appears on the same line as the species for which the recommendation is intended. Justification for these recommended velocities appears in this section and the Results section

Season	Species Found in Salvage	Approach Velocity Recommended for Secondary Channel	Bypass Ratio Recommended for Secondary Channel
Spring	Delta smelt, Chinook salmon, Striped bass	< 0.33 m/s (1.09 ft/s)	
Summer and fall	Striped bass	< 0.33 m/s (1.09 ft/s)	$ 1.6
Winter	Chinook salmon, Striped bass	> 0.94 m/s (3.1 ft/s)	

CONCLUSIONS

We suggest average approach velocity in the secondary channel be maintained below 0.33 m/s (1.09 ft/s) year-round, except when chinook salmon are present at the TFCF. When salmon are present, average velocity in the secondary channel should, if possible, equal or exceed 0.94 m/s (3.1 ft/s).

To understand louver efficiency at the TFCF, emphasis should be placed on experimental analysis of independent variables such as time of day, debris load, approach velocity, bypass ratio, and temperature. An experimental approach will require the use of the Tracy Aquaculture Facility (TAF); resources to maintain the TAF are an important part of this experimental approach.

When new agreements are prepared for the Tracy Fish Collection Facility, new “take” calculations could include “take” reductions for demonstrated improvements in louver efficiency. In addition, allowance should be made in the agreement for future research to improve “take” calculations.

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REFERENCES

AFS. 1991. *Common and Scientific Names of Fishes from the United States and Canada.* 5th Edition. American Fisheries Society. Bethesda, Maryland.

Bates, D.W., O. Logan, and E.A. Pesonen. 1960. *Efficiency Evaluation*, Tracy Fish Collection Facility, Central Valley Project, California. U.S. Fish and Wildlife Service. Seattle, Washington, 67 pp.

Bowen, M.D., S.M. Siegfried, C.R. Liston, L. Hess, and C.A. Karp. 1998. Tracy Fish Collection Facility Studies, California, Volume 7. *Fish Collections and Secondary Louver Efficiency at the Tracy Fish Collection Facility: October 1993 to September 1995.* Bureau of Reclamation, Technical Services Center, Denver, Colorado.

SAS Institute Inc., 1999-2001. *SAS/STAT User's Guide.* Version 8. Sas Institute Inc. Cary, North Carolina.

Hosmer, D.W., and S. Lemeshow. 1989. *Applied Logistic Regression.* John Wiley and Sons: New York, New York.

Karp, C.A., L. Hess, and C.R. Liston. 1995. Tracy Fish Collection Facility Studies, California, Volume 3. *Re-evaluation of louver efficiencies for juvenile chinook salmon and striped bass at the Tracy Fish Collection Facility, Tracy, California, 1993.* Bureau of Reclamation, Technical Services Center, Denver, Colorado.

U.S. Department of the Interior. 1957. *Fish protection at the Tracy Pumping Plant*. Bureau of Reclamation, Region 2, Sacramento, California.