LARVAL FISH ENTRAINMENT BY ARCHIMEDES LIFTS AND AN INTERNAL HELICAL PUMP AT RED BLUFF RESEARCH PUMPING PLANT, UPPER SACRAMENTO RIVER, CALIFORNIA

Red Bluff Research Pumping Plant
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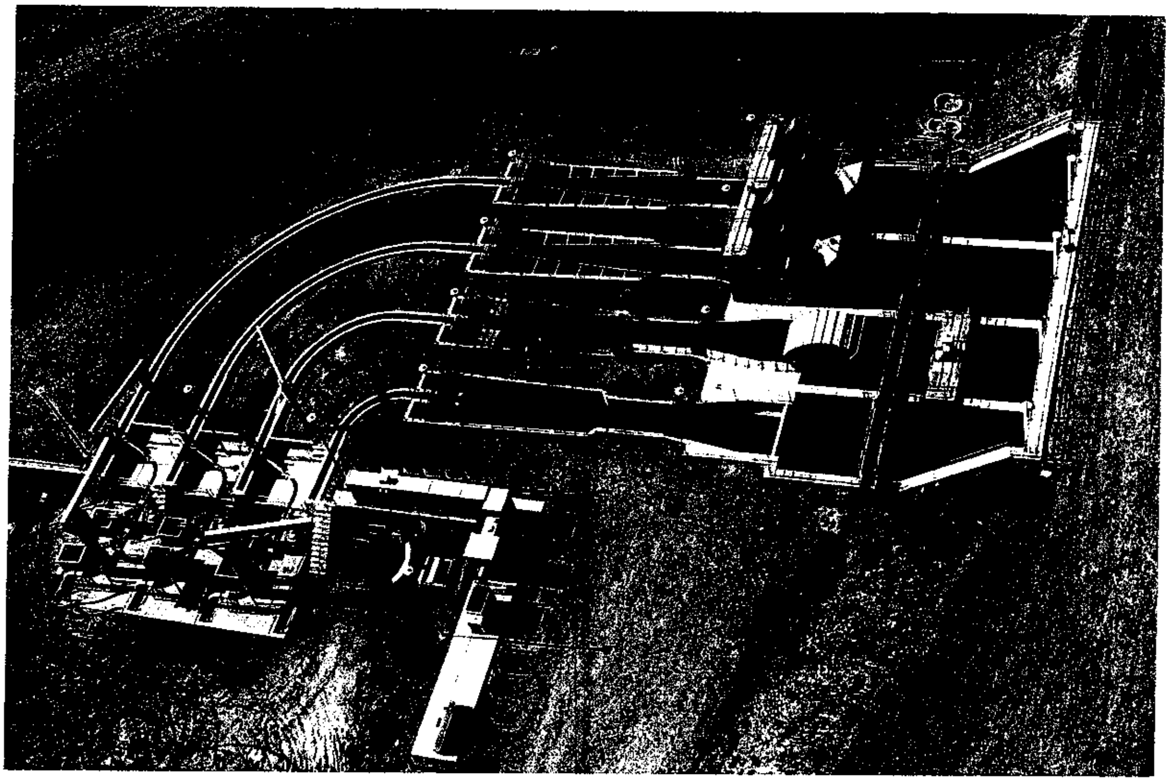

U. S. Department of the Interior
Bureau of Reclamation

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Abstract—Entrainment of larval fishes was monitored at Red Bluff Research Pumping Plant from March 1998 to February 1999 to determine species composition, density, sizes, and screen efficiencies. Samples were collected from a pump's bypass channel just downstream of the vertical wedgewire screens and from an area behind the vertical screens. Eleven species were captured, with prickly sculpin *Cottus asper* and Sacramento sucker *Catostomus occidentalis* composing 99% of the total catch numerically. Suckers were most abundant during April but were captured throughout the spring and summer. Numbers of prickly sculpin peaked in early June, but this species was the most abundant captured during all months. Entrainment rates appeared related to a combination of species abundance in the river and river stage/turbidity. Size-distributions were not significantly different between nets set in the bypass channel and those set behind the vertical screens for any species, indicating the vertical screens did not exclude most non-salmonid larval fish from export to the Tehama-Colusa Canal. Screen efficiency estimates indicated the vertical screens were 24% efficient at screening all species of larval fish combined, 22% at screening prickly sculpin, and 46% efficient at screening Sacramento sucker. Mean catch per unit effort (CPUE) was significantly greater at night than during the day or crepuscular periods for prickly sculpin, Sacramento sucker, and all species combined. Mean CPUE was significantly greater during the crepuscular period than during the day for Sacramento suckers but the difference was not significant for prickly sculpin.

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Introduction

Red Bluff Research Pumping Plant (RPP) is located southeast of Red Bluff, California, 389 km (243 miles) upriver from the mouth of the Sacramento River (Figure 1). The plant was constructed to test whether Archimedes lifts and an internal helical pump could provide water to the Tehama-Colusa (TCC) and Corning canals with minimal direct loss or harm to fish in the Sacramento River. Due to their small size and poor swimming ability, larval fish near the pump intakes were susceptible to entrainment in the pumps. Fish bypass systems of each pump were designed to return fish and debris, along with 10% of the discharged water, to the Sacramento River. About 90% of discharged water passed through vertical wedgewire screens to the forebay of the canal (Figure 2). Screens had 2.4 mm (0.09 in) openings. The screens were designed to exclude juvenile chinook salmon *Oncorhynchus tshawytscha*, but were not expected to be effective at excluding all other species of larval fishes.

Although no listed species were at risk, the goal of this study was to evaluate which species of larval fish were susceptible to entrainment into the RPP and subsequent passage through the screens to the canal forebay. Additionally, we wanted to assess the density of larval fish entrained at each sample location during different seasons and diel periods. Therefore, our objectives were to 1) determine species composition; 2) determine seasonal and diel entrainment patterns; 3) determine densities of non-salmonid larval fishes entrained into the RPP; and 4) examine the efficiency of the vertical wedgewire screens at excluding entrained larval fish from the TCC. This study was described under Objective N of the RPP evaluation plan (Liston and Johnson 1992). Based upon an agreement with the RPP Interagency Fisheries Workgroup during the December 4, 1997 meeting, we did not attempt to quantify the fraction of in-river larval fish production lost to the TCC as stated in Objective N.

A pilot study was conducted from March through mid-September 1997 to develop methods for this study and to obtain preliminary data (Bureau of Reclamation 1999). Day, night, and crepuscular samples were collected during 24-h periods at weekly or biweekly intervals. Valuable information was obtained on species composition, numbers, and sizes of larval fish entrained, seasonal and diel entrainment patterns, and efficiencies of laboratory technicians at sorting larval fish from debris. The findings from the pilot study greatly benefited this study and were compared to results in this study.

Methods

Larval samples were collected every two to four weeks between March 1998 and February 1999 (Figure 3). Each 24-h sampling period included two day, two night, and two crepuscular samples. Crepuscular periods were defined as one-half hour before, to one-half hour after, sunrise or sunset, with one of the samples collected near sunrise and the other near sunset. Within each day, night, or crepuscular period, sampling times were selected randomly. During a 24-h sampling period, all samples were collected from one randomly selected pump and vertical screen (left or right side) combination. Samples were collected from the pump's bypass channel just downstream from the vertical screens, and from the area just behind the selected vertical screen (Figures 2,4). Two nets, one positioned above the other, were deployed at each sample site (Figure 4). A total of 24 samples were collected during each 24-h sampling period (6 sampling times x 2 sites x 2 nets/site). River stage, turbidity, and discharge through the bypass channel and screens were obtained from instruments installed at the RPP each time samples were collected.

Samples were collected by inserting 500-micron mesh plankton nets with plankton buckets attached to the cod ends into the flow stream for fifteen minutes (Figure 4). In the bypass channel, two 0.3 m diameter and 1.2 m long nets were placed one above the other. The bypass channel was 0.46 m wide and water depth was typically 0.6 m resulting in approximately 51% of the bypass flow being sieved through the nets during a sampling period. The volume (m^3) sampled by the nets, therefore, was calculated as 51% of the bypass flows. Two 0.5 m diameter, 1.2 m long plankton nets were placed one above the other behind the sampled vertical screen. The proportion of flow to the canal that passed through the left or right side of the screens was unknown. Therefore, volume sampled could not be calculated as a fraction of the flow to the canal as was done for the bypass-channel site. Instead, the volume sampled was calculated using the area of the nets and the velocity of the water at the mouth of the net. Velocity was measured using a General Oceanics, Inc.® meter.

After each sampling period, net contents were emptied into 250-micron sieves, and non-larval fish were released back into the river via the bypass channel. The remainder of the sample was placed into a plastic container and preserved in a solution of 10% formalin with rose-bengal dye. In the laboratory, the sample contents were placed in a 250-micron sieve, and the formalin solution was rinsed away with water. Fish were sorted from debris under light and magnification. Larval fish from each sample were placed in a separate vial containing 10% formalin. All samples were sorted a second time by a second technician. If the number of larval fish found in the second sort was greater than 20% of the number found in the first sort, the sample was sorted a third time by a third technician. Ten percent of the sorted samples were quality control checked by an experienced sorter at the Denver Technical Services Center. The efficiency of our sorters at finding larval fish in the samples was calculated as the number of fish found by our sorters divided by the sum of the number of fish found by our sorters and the experienced sorter. The resulting percent efficiency value was 94%. Dr. Johnson Wang of National Environmental Services, Concord, California, identified all larval fish and measured total length to the nearest 0.1 mm.

Catch per unit effort (CPUE) was calculated as number of larval fish caught per m^3 of water sampled. Because many samples contained no fish but the data were otherwise log-normally distributed, the data followed a delta-distribution (Aitchison and Brown 1957, Pennington 1983, 1996). Comparisons among diel periods were made by constructing 95% confidence intervals around means of the delta-distributions. This technique adjusts the mean and variance of the logged non-zero values for the probability of obtaining a zero catch in each group.

The efficiency of the vertical screens at excluding larval fish from export to the forebay of the canals was calculated as:

Efficiency = 1 – (fish density behind vertical screens) / (fish density in the pump outfall) where, density [fish/m^3] in the outfall was calculated as:

(channel volume/total volume) x density in channel +
(screen volume/total volume) x density behind screens

Mean screen efficiencies and 95% profile-likelihood confidence intervals were estimated using logistic regression with sampling occasion as the independent variable (Hosmer and Lemeshow 1989). To account for extrabinomial variation, confidence intervals were inflated by the model deviance divided by degrees of freedom. The size-distributions of fish caught in nets set in bypass channels versus those set behind vertical screens were compared using two-sample Kolmogorov-Smirnov tests (Zar 1984) for prickly sculpin, Sacramento suckers, and all other species in combination, with fish grouped by 1-mm length classes.

Measurements of approach and sweeping velocities were taken periodically in front of the vertical screens as part of the engineering evaluations at the plant (Frizell and Atkinson 1999). For Archimedes 1 and the internal helical pump the screens were partially baffled during the entire study period. For Archimedes 2 the screens were partially baffled from the initiation of the study in March 1998 through July 1998. With partially baffled screens, approach velocities were less than 0.12 m/s (0.4 ft/s) at most points, except directly downstream from the end of the baffles. At these points, approach velocities were 0.18 to 0.37 m/s (0.6 to 1.2 ft/s). Sweeping velocities ranged from about 0.61 to 1.22 m/s (2 to 4 ft/s). In July 1998 the screens for Archimedes 2 were fully baffled to create more uniform approach velocities. This resulted in approach velocities less than or very close to 0.12 m/s (0.4 ft/s) at all points measured along the screens and sweeping velocities of about 0.31 to 1.07 m/s (1 to 3.5 ft/s).

Results

Ten species were captured during the study (Table 1) with prickly sculpin and Sacramento sucker composing 99% of the catch numerically. Prickly sculpin were captured throughout the study period but most frequently during summer (Figure 3a). Sacramento suckers were most frequently captured during April but were also captured throughout the summer. Three species that were not previously observed during pilot sampling (Bureau of Reclamation 1999), bluegill *Lepomis macrochirus*, mosquito fish *Gambusia affinis*, and riffle sculpin *Cottus gulosis*, were observed during the study. Three species that were previously captured in small numbers during pilot sampling were not observed: Sacramento blackfish *Orthodon microlepidotus*, threadfin shad *Dorosoma petenense*, and threespine stickleback *Gasterosteus aculeatus*. Numbers captured were very low during the winter months with three or fewer fish in each of the December, January, and early February samples; all were prickly sculpin. Relatively high catches were observed following storm events which increased river stage and turbidity in April and June 1998 (Figure 3b). However, relatively high river stage and turbidity was not accompanied by high catches in February 1999.

Size distributions were not significantly different between nets placed in the bypass channel and those placed behind the vertical screens (Figure 5), suggesting that larval fish readily passed through the screen openings. This finding was consistent with mean screen efficiency estimates (95% CI), which were 24% (20 – 27%) for all fish combined, 22% (17 – 27%) for prickly sculpin, and 46% (30-62%) for Sacramento sucker.

Mean CPUE was significantly higher at night than during the day and crepuscular periods for prickly sculpin, Sacramento sucker, and all species in combination (Figure 6). The crepuscular period had significantly higher CPUE than day for Sacramento suckers but the difference was not significant for prickly sculpin.

Discussion

Catch per unit effort was highest during spring and summer. Very few larval fish were entrained from November through mid-March. In both this and the pilot study, this seasonal pattern of entrainment appeared to be due to a combination of river conditions and species' abundance patterns. High river stage and turbidity in spring and summer when larval fish were relatively abundant resulted in the highest CPUE. Similar river conditions in the winter, however, did not result in high CPUE due to the paucity of larval fish in the river.

Catch per unit effort of larval fish was consistently higher at night than during day or crepuscular periods. This finding is consistent with diel patterns of juvenile fish entrainment (Borthwick et al. 1999). Data from this study and the pilot study suggest species-specific differences in CPUE of larval fish between crepuscular and day samples. While there were no significant differences in CPUE between day and crepuscular samples for prickly sculpin and all fish combined, significantly more Sacramento suckers were entrained during the crepuscular period.

Size distributions did not differ significantly between nets placed in the bypass channel and those placed behind the vertical screens, indicating the screens did not exclude most non-salmonid larval fish from export to the TCC. Corroborating this finding, mean screen efficiency was only 24% for all fish combined. This low efficiency was strongly influenced by the screen efficiency for prickly sculpin (22%), which comprised 87.5% of the larval fish entrained. The screens were more efficient at excluding Sacramento sucker (46%), which were typically larger than prickly sculpin (mean length 13.5 versus 5.2 mm, respectively), but comprised a smaller component (11.5%) of the larval fish entrained. Except for one 35-mm Pacific brook lamprey ammoceote, the screens effectively excluded all fish greater than 19.5 mm total length. Only 2.5% of all larval fish entrained into the plant, however, were larger than 19.5 mm.

The efficiency of technicians at sorting larval fish from samples was greatly improved in this study over the pilot study. The combination of using experienced sorters and sorting each sample at least twice led to the high sorting efficiency. Investigators undertaking larval sampling are advised to incorporate rigorous quality control procedures into their studies to ensure meaningful data.

Although sorting efficiencies were low in the pilot study, the general trends in relative abundance were similar to findings in this study. In both studies, prickly sculpin and Sacramento sucker composed 98 to 99% of the total catch numerically. However, prickly sculpin composed a much higher percentage of the catch in this study (87.5%) than in the pilot study (58.4%). The small size of prickly sculpin larva made them difficult to find amid debris in samples. Therefore, the improved sorting methods incorporated into this study likely resulted in more sculpin being detected in samples compared to the pilot study. Also, pilot study sampling was discontinued in September, while in this study it continued through the fall and winter. During these seasons, prickly sculpin comprised the majority of larval fish entrained, while very few Sacramento suckers were collected.

During August and September of the pilot year, two sets of 24-h samples were collected from the river. These samples revealed that species composition and diel abundance of larval fish in the river were similar to samples collected in the plant. Of the 305 larval fish collected in the river samples, 76.1% were prickly sculpin, 23.6% were Sacramento sucker, and 0.3% were bluegill. The percentages collected during night, crepuscular, and day periods were 70, 24 and 6, respectively.

Under current operations, the RPP is used to provide water to the canals in spring and fall. During summer, Red Bluff Diversion Dam is used, and a series of 32 drum screens divert fish into bypasses and back to the Sacramento River. The openings in the drum screens are larger (3.2-mm, 1/8 in) than the openings in the RPP's vertical screens (2.4-mm, 3/32 in). Therefore, the drum screens are likely less effective than the RPP's vertical screens at excluding larval fish from the canal, especially because small prickly sculpin are the most abundant larval fish during the summer season.

We could find no studies in the literature involving systematic sampling of non-salmonid larval fish in the upper Sacramento River. Therefore, no data were available on larval fish densities or production on which to base estimates of the fraction of larval fish removed from the river by the RPP. Because larval fish are an important food item for chinook salmon and other fish, decreases in their populations could have important effects. If the number of larval fish exported to the canal during pumping becomes a concern, solutions for reducing entrainment include pumping only during the day and avoiding pumping during spring episodes of high turbidity and river stage.

Acknowledgments

Many people deserve thanks for their contributions to this study. Special thanks go to Dr. Charles Liston, Reclamation's Research Director for the Red Bluff RPP Evaluation Program, and Dr. Cal McNabb and Dr. Louis Helfrich, consultants to Reclamation, for their guidance and advice during the development and implementation of this study. Max Stodolski, manager of Reclamation's Red Bluff Fish Passage Program, was instrumental in the success of the project ensuring that our equipment, personnel, and pumping needs were met. Steve Hiebert of Reclamation's Technical Service Center (TSC) in Denver designed and ordered the nets used in the study. His assistance was greatly appreciated. The following on-site biological evaluation staff each spent varied hours of the day and night collecting samples, and/or countless hours sorting samples: Jeremy Brasch, Richard Corwin, Marie-Christine Daems, Susan Hornsby, Sharon Nowak, Christy Skelton, Michael Stroing, Drea Traeumer, and Zachary Wilson. They also entered data into a computer database and checked its accuracy. Judy Lyons, Rick Wydoski, Tom LaCasse, Andrew Montanyo, and Johnnie Boutwell of Reclamation's TSC in Denver helped on-site staff collect and sort samples. Special thanks go to Rick Wydoski for doing the quality control checks on the sample sorting. Special thanks also go to Dr. Johnson Wang for his expertise and promptness in identifying the larval fish collected in our samples. Reclamation's Operations and Maintenance staff at Red Bluff including Wayne Stokes, Steve Quitiquit, Lester Mahan, Bill Warner, and Paul Freeman deserve thanks for fabricating materials necessary for deploying nets and making repairs and modifications as requested. Funding for this program was provided by Reclamation's Mid-Pacific Region, supplemented by Reclamation's Research and Technology Development Program, Study Number AE CO-98.016 (WATR).

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Table 1. Species and size composition of larval fish entrained into Red Bluff Research Pumping Plant during monthly or biweekly sampling from 3/11/98 to 2/24/99.

Species	Percent Of Total Catch	N	Date First Observed	Date Last Observed	Mean Length (mm)	SD	Range (mm)
Prickly Sculpin *Cottus asper*	87.5	4,010	3/11/98	2/24/99	5.2	0.6	4.0-16.0
Sacramento Sucker *Catostomus occidentalis*	11.5	528	4/8/98	11/12/98	13.5	4.2	4.4-28.4
Sacramento Pikeminnow *Ptychocheilus grandis*	0.4	17	4/22/98	7/17/98	10.2	0.7	8.4-11.5
California Roach *Lavinia symmetricus*	0.2	7	4/9/98	7/17/98	8.2	2.7	5.9-14.0
Pacific Lamprey *Lampetra tridentata*	0.2	7	5/1/98	6/17/98	9.4	1.6	8.2-12.5
Carp *Cyprinus carpio*	0.1	3	4/30/98	6/4/98	6.0	0.5	5.5-6.5
Bluegill *Lepomis macrochirus*	0.1	3	6/4/98	8/13/98	5.1	0.6	4.6-5.5
Riffle Sculpin *Cottus gulosis*	0.1	3	6/4/98	6/4/98	7.4	2.2	5.5-9.8
Pacific Brook Lamprey *Lampetra pacifica*	<0.1	2	3/11/98	6/5/98	21.9	18.5	8.8-35.0
Mosquito fish *Gambusia affinis*	<0.1	1	7/16/98	7/16/98	16.4	-	16.4

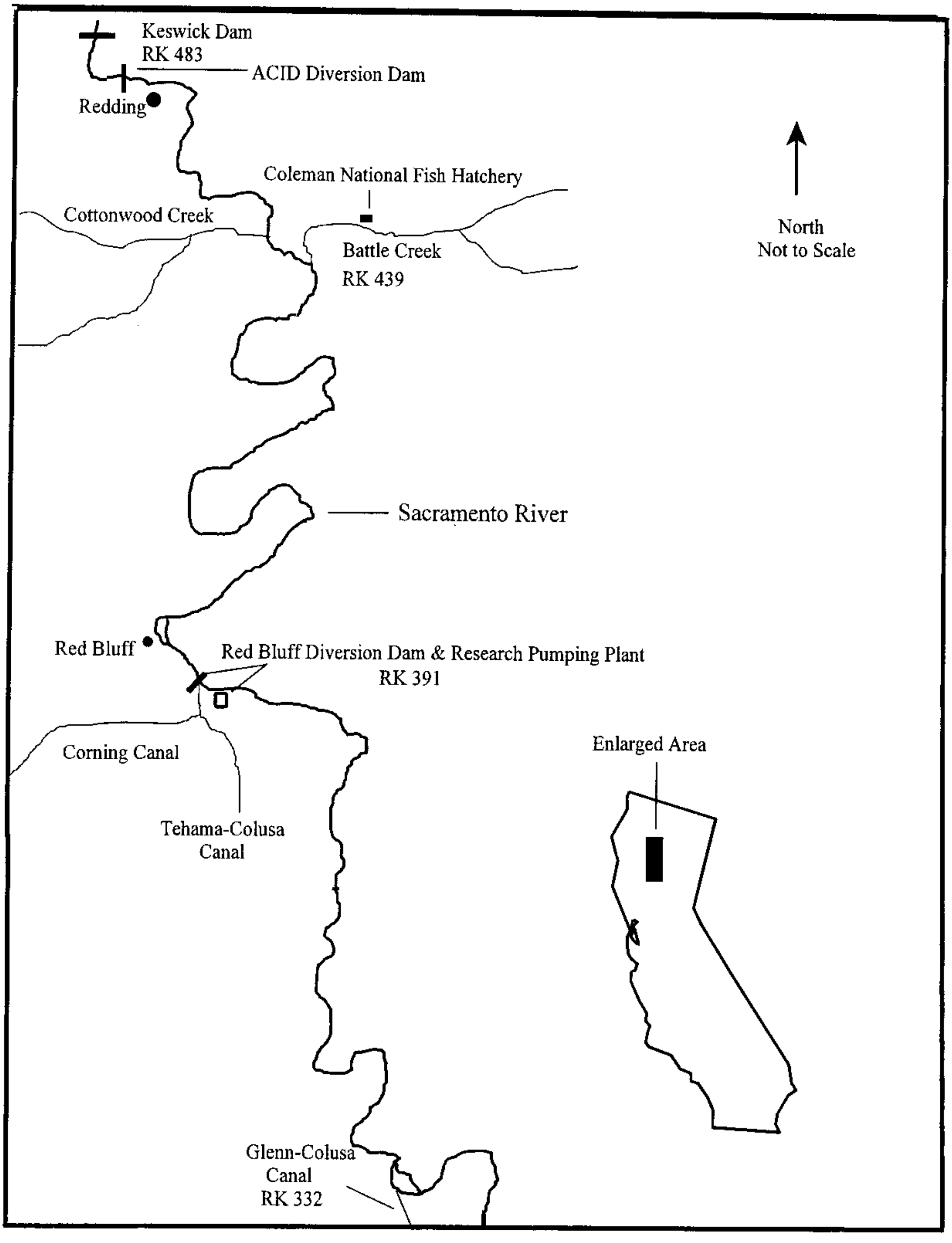


Figure 1. Location of Red Bluff Research Pumping Plant on the Sacramento River at river kilometer 389 (river mile 243).

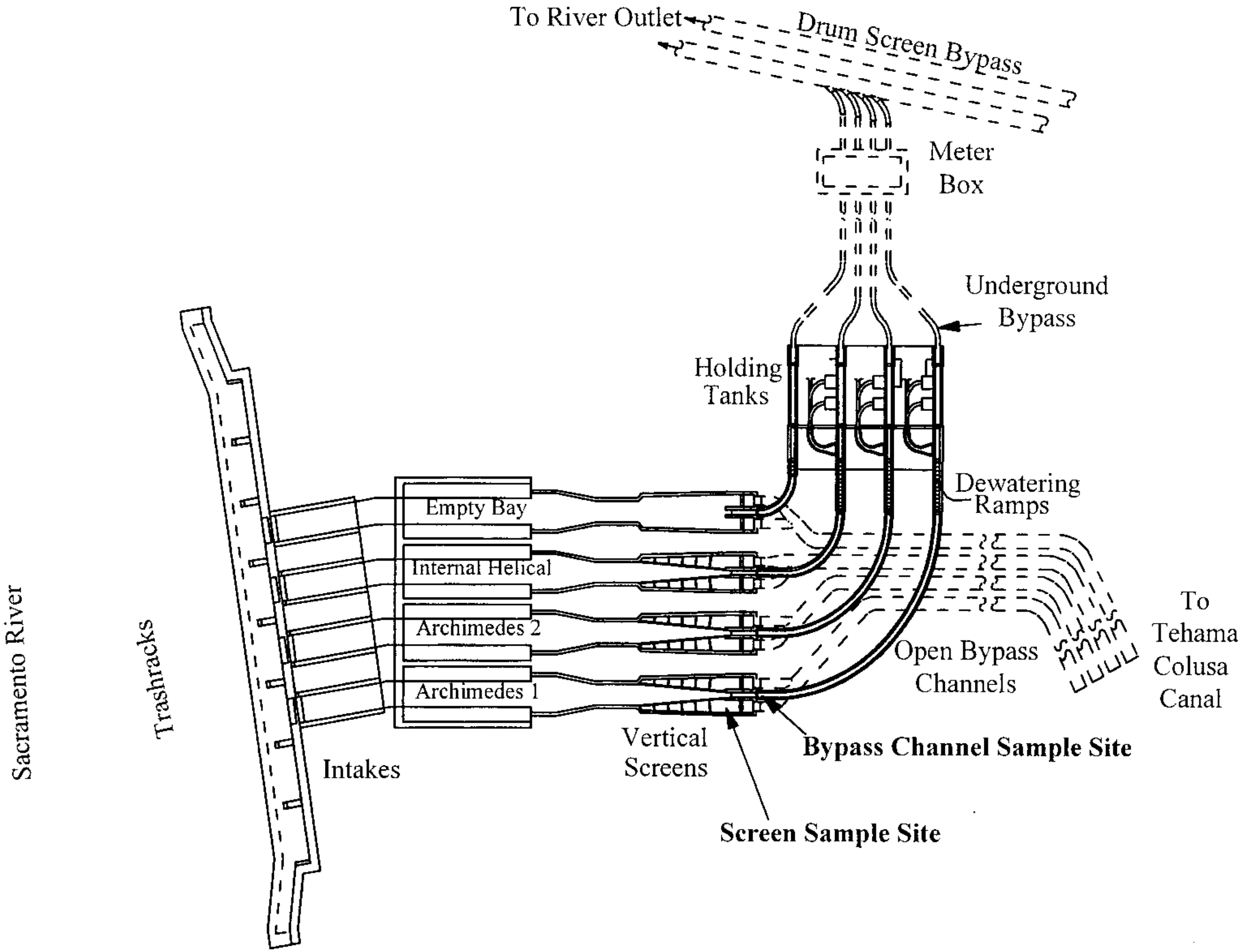


Figure 2. Schematic diagram of Red Bluff Research Pumping Plant. One pump was sampled during each 24-h sampling period. During each sampling period, one net was placed in the open bypass channel and another behind one vertical screen. These locations are indicated on the figure.

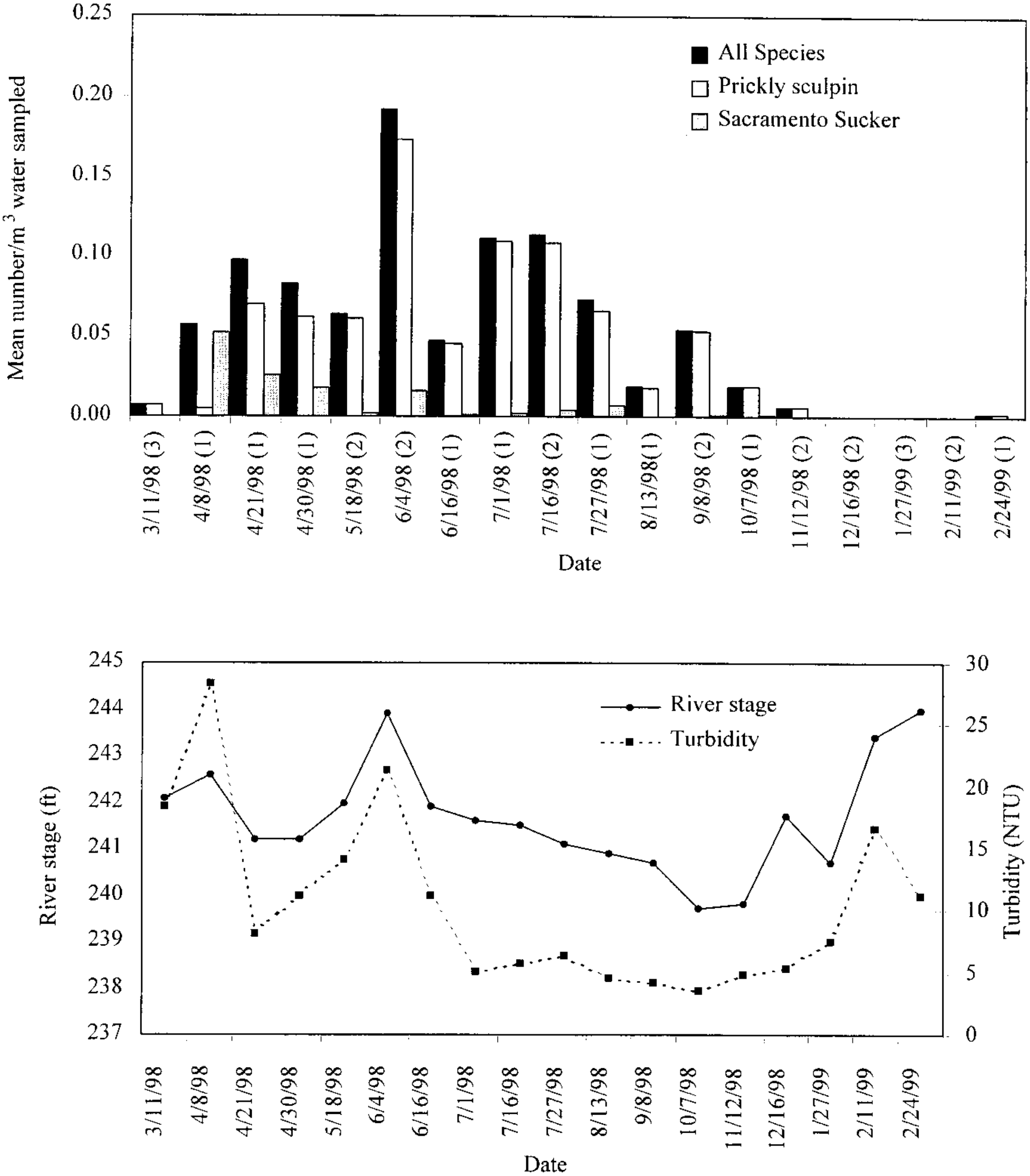
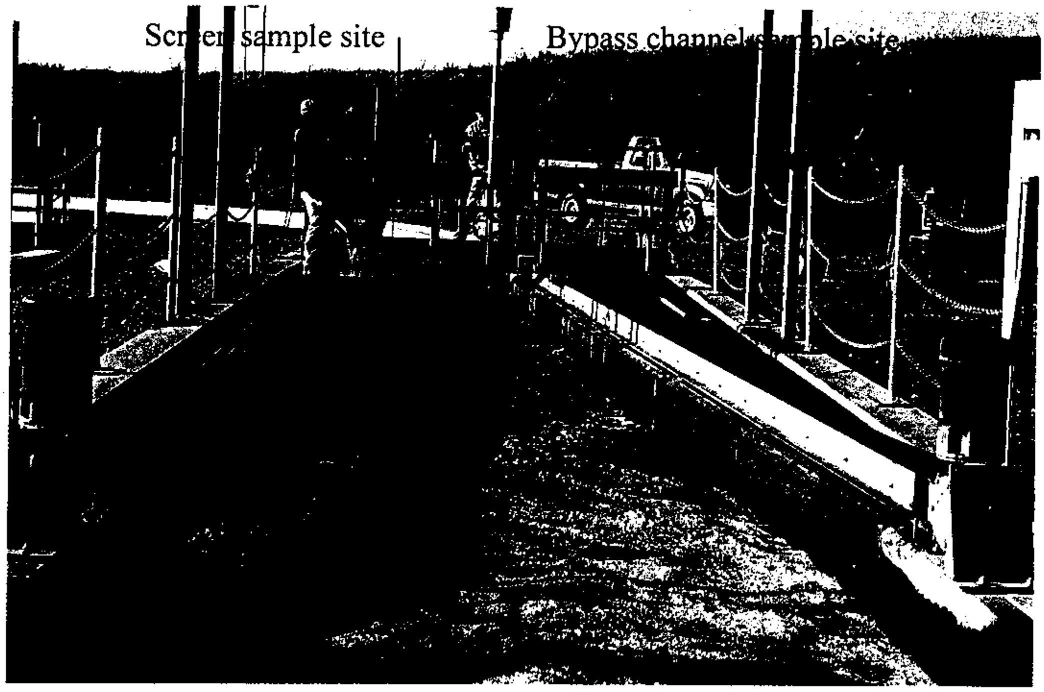
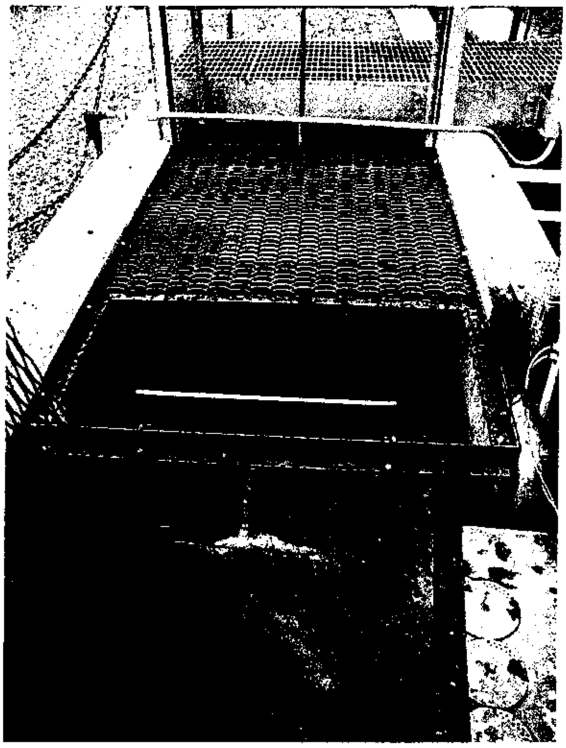


Figure 3. (A) Mean daily larval fish catch, per m^3 of water sampled, of all fish in combination, prickly sculpin, and Sacramento Sucker. Values are averaged over all 24 samples collected in a 24-h period. Numbers after the dates indicate which pump was sampled; 1=Archimedes 1, 2=Archimedes 2, 3=internal helical. (B) Mean daily turbidity and river stage during the same period.

A.



B.



C.

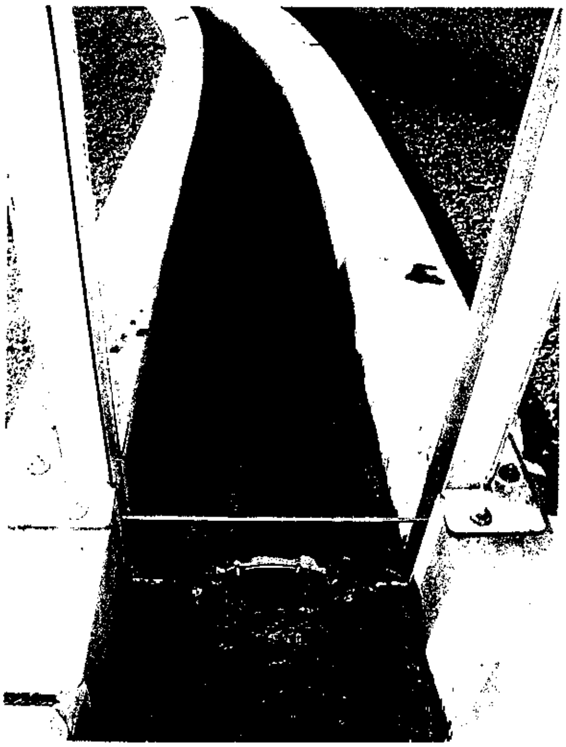
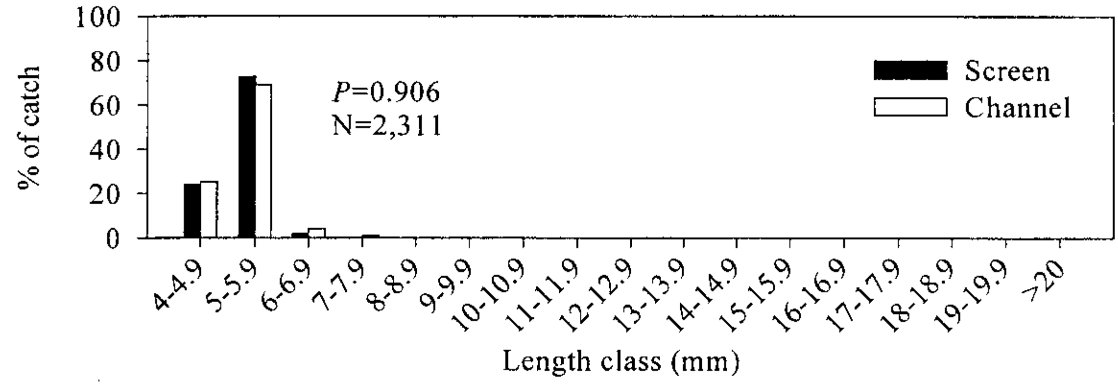
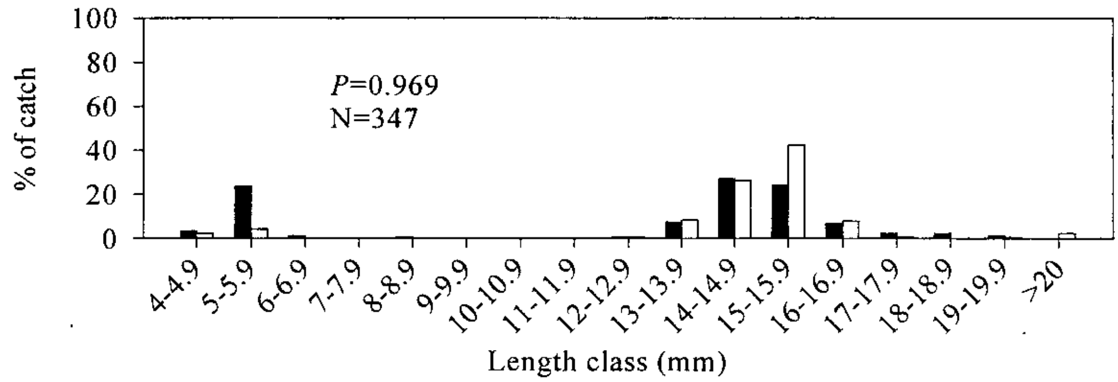


Figure 4. (A) Deploying larval sampling nets at the two sample sites. (B) Nets fishing at the screen sample site. (C) Nets fishing at the bypass channel sample site.

A. Prickly sculpin



B. Sacramento sucker



C. Other fish

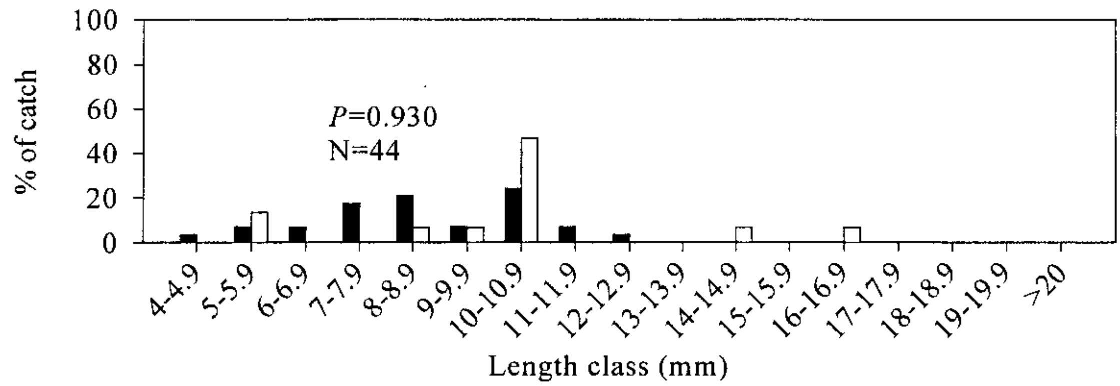
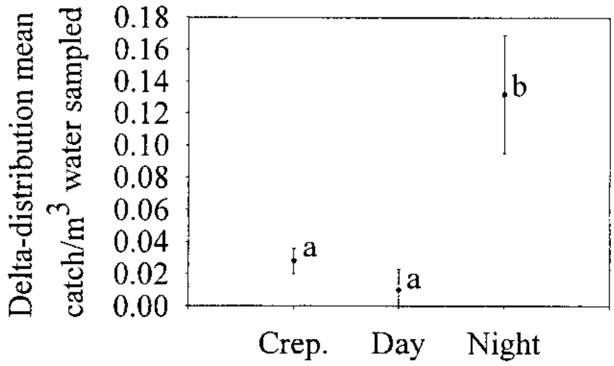
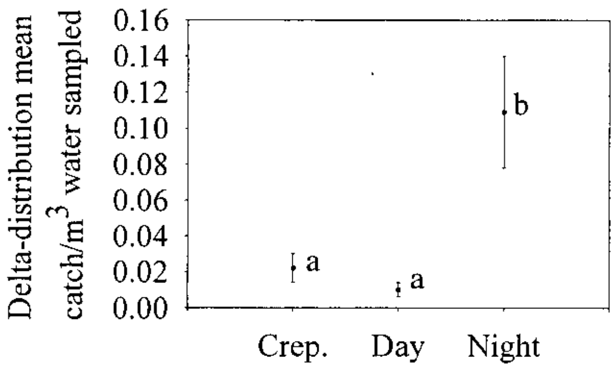


Figure 5. Percent frequency of capture in nets set in bypass channels versus those set behind vertical wedgewire screens. *P* values indicate results of two-sample Kolmogorov-Smirnov tests for differences in distributions. N is the number of fish measured.

A. All fish



B. Prickly sculpin



C. Sacramento sucker

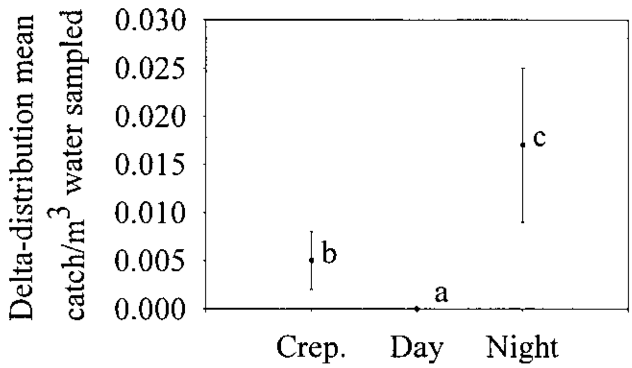


Figure 6. Mean delta-distribution catch per m^3 of water sampled for (A) all larval fish, (B) prickly sculpin, and (C) Sacramento sucker by diel period (crepuscular, day, or night). Error bars indicate 95% confidence intervals. Groups with a common letter within a graph did not differ significantly.