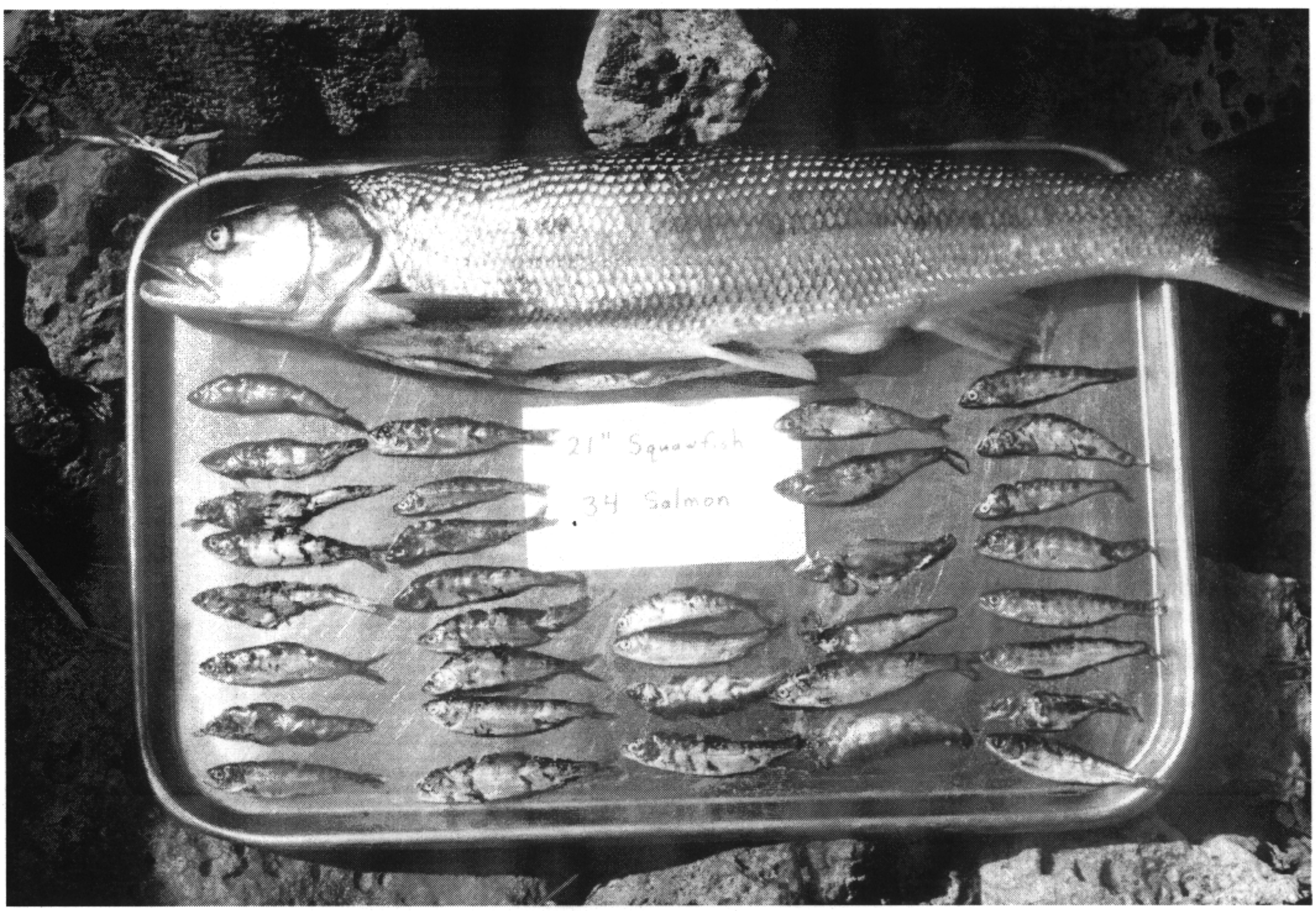
U.S. Fish & Wildlife Service

Spatial and Temporal Distribution of Sacramento Pikeminnow and Striped Bass at the Red Bluff Diversion Complex, Including the Research Pumping Plant, Sacramento River, California: January, 1997 to August, 1998



Cover photograph:

Archival image from the files of the Red Bluff Fish and Wildlife Office, showing a Sacramento pikeminnow (*Ptychocheilus grandis*) and its stomach contents (34 juvenile Chinook salmon (*Oncorhynchus tshawytscha*). Sacramento pikeminnow were previously known as "Sacramento squawfish". Photograph was scanned from a 35 mm slide, taken by David A.Vogel, April 1984.

SPATIAL AND TEMPORAL DISTRIBUTION OF SACRAMENTO PIKEMINNOW AND STRIPED BASS AT THE RED BLUFF DIVERSION COMPLEX, INCLUDING THE RESEARCH PUMPING PLANT, SACRAMENTO RIVER, CALIFORNIA: JANUARY, 1997 TO AUGUST, 1998

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Abstract.—The Red Bluff Research Pumping Plant (RPP) is being evaluated by the Bureau of Reclamation (Reclamation) to determine if pumping water through Archimedes or internal helical pumps is a viable method for meeting water delivery requirements to the Tehama-Colusa Canal system. Pumps were installed at the RPP and were operated on an experimental basis. The U. S. Fish and Wildlife Service (Service) was contracted to determine the in-river biological implications of the RPP. A goal of these investigations was to determine if construction and operation of the RPP may influence local population size and distribution of Sacramento pikeminnow (*Ptychocheilus grandis*) and striped bass (*Morone saxatilis*), and possible predation impacts on emigrating juvenile salmonids.

This report summarizes monitoring activities at Red Bluff Diversion Dam (RBDD) from January, 1997 through August, 1998. Sacramento pikeminnow and striped bass were sampled by angling and electrofishing, during daylight hours. The areas sampled included RBDD, the RPP, the bypass outfall structure and a relatively undisturbed area downstream of RBDD. Specific sample sites were selected and a uniform sampling protocol was implemented. Mean catch per hour (CPH) was calculated at each site for both species and each sampling technique. A three-way block analysis of variance (ANOVA) was used to determine if significant differences in mean CPH existed among sampling sites, operational protocols at RBDD (gates raised versus gates lowered), and periods when experimental pumps were running versus when pumps were idle.

Pronounced differences in temporal distribution of predators was observed between gates raised and lowered, with increases in CPH during gates lowered periods. Possible reasons for the increase may include the spring spawning migration of Sacramento pikeminnow, increased prey availability, and prey vulnerability related to physical conditions created by the RBDD gate operations. Significant differences in mean CPH existed among sampling locations and between gates lowered versus gates raised operation of RBDD, for each species and sampling technique. Intensive sampling during unusual RBDD gate operations in 1997 strongly suggested that seasonal increases in Sacramento pikeminnow densities within the study area is directly related to the RBDD gate operations.

Few Sacramento pikeminnow and zero striped bass were caught in the RPP Intake (Rack) area. The paucity of these species in this area created difficulties in determining if the localized structure and hydrological impacts of pump operation affected predator distribution. While the RPP Intake area did not appear to attract predators, the sheet pile area just downstream of the RPP Wall appeared to create an attractive environment for Sacramento pikeminnow. The RPP Wall sample site consistently had the highest CPH for Sacramento pikeminnow, for both

sampling methods. Striped bass were caught almost exclusively directly below RBDD during periods when the RBDD gates were lowered.

The catch data indicated that many of the Sacramento pikeminnow and most of striped bass were captured in areas around the RBDD where the water was deeper and more turbulent than in the RPP Rack area. Striped bass density was closely related to the RBDD operations, nearly to the point of absence/presence. Striped bass were caught almost exclusively during periods when the RBDD gates were lowered. Most were captured directly below RBDD where they concentrated along the edges of the turbulent boils produced by water forced under the RBDD gates. The effect of the RPP operations on predator distribution was not as definitive as the effect of RBDD gate operations. Although a higher mean CPH was observed for Sacramento pikeminnow when RPP pumps were running, the results were variable for sampling methods and among locations. The difference may be attributable to coincidental factors such as gate operations and seasonal abundance of predators.

Based upon the information gathered from this study, we conclude that the design and operation of the RPP, and its intake area appears to provide little attraction to predatory fish, during daylight hours. Although the small area of habitat created at the RPP Wall may attract and concentrate Sacramento pikeminnow at certain times of the year, the size (5 x 10 m) of the area would limit the number of predators, and predation levels should not substantially increase within the entire study area.

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INTRODUCTION

Red Bluff Diversion Dam (RBDD) was built on the Sacramento River, at river kilometer (rkm) 391 in the mid 1960's to divert water into the Tehama-Colusa and Corning Canal systems for agriculture and wildlife refuges. The RBDD began operation in 1966 and is operated by the Bureau of Reclamation (Reclamation). The RBDD is a bottom release low head dam consisting of eleven adjustable gates spanning the entire river. When the dam gates are in the lowered (gates-in) position there is a narrow space left open under most of the gates where water passes under the dam at high velocity (about 10 meters/sec.). At this velocity, fish are unable to swim upstream against the flow and those passing downstream underneath the gates find themselves in a great boil of rushing water formed in the tailrace. It is likely that juvenile fish passing underneath the dam in these conditions are somewhat disoriented and thus more susceptible to predation. For nearly 20 years the retention gates at RBDD were in a lowered position (except during periods of winter flood flows), retaining water year round, and forming Lake Red Bluff.

Problems in juvenile Chinook salmon (*Oncorhynchus tshawytscha*) passage at RBDD have been well documented (Vogel and Smith 1984; Hallock 1989; USFWS 1987, 1989, 1990; Vogel et al. 1988). The seasonal accumulation of predatory fish such as Sacramento pikeminnow (*Ptychocheilus grandis*; formerly known as Sacramento squawfish) and striped bass (*Morone saxatilis*) below man-made structures such as the RBDD has altered the natural system by creating increased resting and ambush settings for predators, resulting in a dysfunctional predator-prey relationship. In a natural free flowing river setting, the predator-prey relationship between Sacramento pikeminnow and salmon is balanced and has no significant long-term effect on salmonid populations (Brown and Moyle 1981). The RBDD may also impede upstream migration of Sacramento pikeminnow and thereby create large congregations below the dam, especially during periods of their spawning migration. Non-native striped bass also congregate below the dam and prey on disoriented fish that have passed under the dam gates. These accumulations of predatory fish potentially create a serious predation problem. Hall (1977) and Vondracek and Moyle (1983) estimated that significant numbers of juvenile salmon were being consumed by Sacramento pikeminnow at RBDD before the initiation of gates-out operations (pre-1986). A similar situation occurs in the Columbia River where northern pikeminnow (*P. oregonensis*) predation at permanent dams has a major impact on juvenile salmonids (Poe et al. 1991). Background information on past efforts to control Sacramento pikeminnow at RBDD are detailed in Tucker et al. (1998).

In 1993, in response to declining winter-run Chinook salmon populations, the National Marine Fisheries Service (NMFS) issued a Biological Opinion (BO) for the operation of the Federal Central Valley Project and the California State Water Project (NMFS 1993). As a result of the BO, Reclamation implemented new operational procedures which called for the gates on RBDD to be raised each fall to restore free flowing river conditions throughout the winter and early spring.

The Red Bluff Research Pumping Plant (RPP) was designed and constructed by Reclamation, and is situated on the west bank immediately downstream from RBDD. The purpose of the RPP is to evaluate the use of "fish friendly" pumps in supplying water to the Tehama-Colusa canal system during periods when gates are raised at RBDD. Construction of the RPP began in 1994 and was completed in 1995. Operational testing of the pumps began in summer of 1995. The construction and operation of the RPP has altered the hydrology of the area by changing flow patterns and creating new structure within the river channel. These alterations may increase or decrease habitat of predatory fish such as Sacramento pikeminnow and striped bass as well as influence their population size and distribution.

The goal of this study was to determine if the RPP could be built and operated in a manner that minimized attraction of piscivorous predators and their impacts on juvenile salmonids. To reach this goal, four study objectives were developed:

1. Collect baseline information on Sacramento pikeminnow and striped bass population dynamics including data on age structure, growth rates, and gonadal condition.

2. Determine Sacramento pikeminnow and striped bass food habits to evaluate predation on migrating juvenile salmonids.

3. Estimate the seasonal relative and absolute abundance of Sacramento pikeminnow and striped bass within the study area.

4. Evaluate spatial and temporal distribution patterns of Sacramento pikeminnow and striped bass to determine if operations of the RPP influence their distribution.

To establish a base of information on Sacramento pikeminnow and striped bass populations, a first phase of this study focused on population size, life history and behavior (objectives 1, 2 and 3 listed above), in order to characterize these populations (Tucker et al. 1998) and to allow comparisons with previous work (Poe et al. 1991). A second phase covered by this report ran from January 1997, through August 1998. During this phase emphasis was shifted to objective 4 by analyzing spatial and temporal distribution patterns between specific sampling locations under pump-on and pump-off, gates-up, and gates-down operational conditions.

STUDY AREA

Red Bluff Diversion Dam and the RPP are located on the upper Sacramento River at river kilometer (km) 391, approximately 3.2 km southeast of the city of Red Bluff, Tehama County, California (Figure 1). Sampling effort was concentrated in the area starting at RBDD and continued downstream for approximately two km (Figure 2). This area encompassed three major in-river structures associated with the diversion of water into the Tehama-Colusa Canal system (diversion complex) including: the RPP, RBDD and a bypass outfall structure. Sampling was also conducted within a relatively undisturbed area approximately 2 km downstream of RBDD which was treated as a "natural" control site.

Red Bluff Diversion Dam is 226 meters (m) wide and has eleven gates each 18 m in width located between ten concrete piers that are each 2.4 m in width. The RPP is located approximately 100 m downstream of RBDD. The in-river portion of the plant includes an intake bay covered by a steel grid that prevents large debris from being entrained into the RPP. This "trash rack" is approximately 64 m long and 8 m tall. Immediately downstream of the trash rack is a sheet piling wall extending approximately 30 m. This wall angles southward creating an eddy along the downstream end (Figure 3). The bypass outfall is a concrete structure (4 x 10 m) in the center of the main channel of the Sacramento River approximately 500 m downstream of RBDD. The outfall structure forms the terminus of a bypass system from which entrained fish are returned via a pair of conduits back to the river from the RPP or the Tehama-Colusa Canal system. A large slow-water eddy is also formed at the downstream end of the bypass outfall when the bypasses are not in operation (Figure 3).

METHODS

Sampling Procedures

Electrofishing.—A Smith-Root® 6 m electrofishing boat (Model SR-18WW) was used for all electrofishing. The time of active electrofishing was recorded to compute catch per hour of effort (CPH). Power settings were conservative to allow capture of fish while minimizing the chance of injury. The effective capture range included a radius of approximately two meters from each of two bow mounted anodes. Two netters standing on the bow of the boat attempted to capture all Sacramento pikeminnow and striped bass encountered. Non-target species were visually identified and counted but no attempt was made to capture (net) them.

Angling.—Angling was conducted from boats, from in-river locations (i.e. floating screw traps or the bypass outfall), and from shore. Ordinary spin cast rods and reels with twelve pound test monofilament were standard gear. Fishing lures such as Kastmasters®, countdown Rapalas®, Super-Dupers®, Little Cleos®, and DareDevils® were used most in angling. Occasional attempts with flies, yarn eggs, and bait were unsuccessful. Fish imitating lures were more successful, and supported the assumption that all fish caught in this manner had reached a developmental stage where they had begun preying on small fish (potentially juvenile salmon). All non-target species captured were noted and immediately released. The number of target fish caught and the time spent in each sampling activity were recorded at each site (seconds electrofishing and minutes angling).

In order to collect life history data for the first phase of this study, all target fish were held in an aerated live-well with Polyaqua® added to minimize slime loss and handling stress. Fish were individually anesthetized in a 15-L tub with 150 mg/L of Finquel® or tricaine methanesulfonate (MS-222) buffered with sodium bicarbonate. Total length and fork length were measured to the nearest millimeter (mm) and the fish placed in a wet plastic bag and weighed with Pesola® spring scales. Each fish was tagged with a 52-mm Floy® anchor tag. Tags were inserted on the left side of the fish, just ventral to the dorsal fin and at a slightly ventro-anterior angle to ensure tag bar placement between the proximal pterygiophores. Tagged fish were also marked with a hole punch in the upper caudal fin lobe in order to identify tag loss on recaptured fish. Fish were then allowed to fully recover from the effects of anesthesia and released in the area where originally captured.

Experimental design.— Sampling was conducted at five locations adjacent to RBDD and RPP (Figure 2). A sixth site was selected approximately 2 km downstream of RBDD and RPP to serve as a control site for comparison. Sample sites were selected with the intent to evaluate utilization of any specific habitat and hydrological conditions created by the operation of RBDD and the RPP, by predatory fish. These locations included two sites at the face of RBDD, one along the eastern half of the dam (Dam East) and one along the western half (Dam West). Dam East provided turbulent flows from water releases in gates #2 through #5 and a "slack water" refugia created by reduced flows from gate #1. This area of refugia could be utilized as an ambush point by predatory fishes. Flows were reduced from gate #1 to provide fish attraction flow to the east fish ladder. Dam West was an area of high turbulence created by gate (#11) with a trash sluice-way and with automated regulating capabilities. Water levels in Lake Red Bluff were generally maintained through use of gate #11. The bypass outfall structure (Outfall) provided a mid-river refugium as well as a potential source of previously entrained prey fishes redirected from the RPP and the Tehama-Colusa Canal system. The sampling at RPP was done in two separate sections to identify differences in predator densities between two different habitat types created by the plant. One site included the area directly in front of the pump intake trash racks (RPP Racks), a fast, deep run where pumping could alter river hydrology. The other site included an area along a sheet piling wall immediately downstream of the trash racks (RPP Wall) where a slow eddy and backwater created by the plant could provide resting and ambush area for predators. The RPP Wall was not singled out as a sampling location until February 1997 when it was determined that this section of the RPP warranted individual examination. This area had different habitat characteristics than those found at the RPP racks, and predator densities appeared much higher at the RPP Wall than in other areas. The control site (Control) was downstream enough to dilute the effects of operation of RBDD and the RPP.

Each site was sampled by angling and electrofishing one day per week. The sampling work was generally performed during the morning, between 0700 and 1200 hrs. Each angling session consisted of three anglers sampling each location for 20-minute intervals (one angler hour per location). Electrofishing activities were not limited to a set amount of time, but were based on coverage of the six sampling sites. In general, all shallow water (<2 m) and shoreline areas within each site were covered once each sampling day. However, from September through November of 1998, electrofishing was not conducted due to equipment failure. Time of active electrofishing was used to compute CPH.

Statistical analysis.—Spatial and temporal distributions of target species were determined from catch data and expressed as mean CPH at each of the six sampling locations. Catch Per unit Hour was calculated for these locations during each sampling period using the formula:

$$CPH = \frac{\sum_{j=1}^{n} \frac{K_j}{h_j}}{n},$$

where, K_j was the catch by species from the *j*th sample, h_j was the number of hours fished during the *j*th sample and n was the number of samples by location during each sample period. The analysis was also broken down to examine differences in CPH under varying operational conditions of the pumping plant and RBDD. We compared mean CPH during sampling periods when experimental pumps were running and when they were idle, as well as when RBDD gates were raised and when they were lowered.

Because CPH is not directly comparable between electrofishing and angling due to differences in sampling intensity, each method was analyzed independently. Electrofishing effort was calculated as the time that electricity was pulsed through the water. The electrical current was pulsed through the water for several seconds at a time, then stopped for several seconds to allow any unseen fish (potentially adult salmon) to escape the field. Angling effort was calculated for each person and was defined as the time a person was engaged in the act of fishing, including time for changing tackle, retrieving snagged lures, and landing fish. For boat-based angling, effort was accordingly calculated for each person in the boat (usually 3).

A three-way-block analysis of variance (ANOVA) was conducted to determine if significant differences ($P < .05$) in CPH existed between location, dam gate operation (raised or lowered), and pump operation (running or idle). Because CPH data was not distributed normally, a bootstrap technique was employed to establish 95% confidence intervals (CI) for ANOVA *P*-values. In situations where ANOVA indicated significant interaction effects, each factor was analyzed separately with a one-way ANOVA. A Tukey's multiple comparison procedure (MCP) was then used to determine where significant differences existed for the different locations.

RESULTS

Numbers Captured

Sacramento pikeminnow.—A total of 192 Sacramento pikeminnow were captured between 28 January 1997 and 13 August 1998. Of those, 98 were captured by electrofishing and 94 were captured by angling. There were 143 Sacramento pikeminnow captured with gates lowered and 49 captured with gates raised. A total of 121 were captured while pumps were running and 71 were captured while pumps were idle (Table 1). Significant interaction differences in mean CPH of Sacramento pikeminnow existed between location and status of gate operations (Tables 3 and 4).

Striped bass.—A total of 33 striped bass were captured during the study with 31 captured by angling and 2 captured by electrofishing. Nearly all striped bass were captured with gates lowered ($n = 32$), with only one captured on 26 May 1998 after gates were temporarily removed due to high spring flows. Seven striped bass were captured while pumps were running and 26 were captured while pumps were idle (Table 1). For striped bass captured by angling, the ANOVA results identified a significant interaction effect between gates and location. A separate analyses for each gate status detected significant differences in CPH between location and "gates lowered" periods of operation (Table 7).

Other species.—A total of 14 other species were observed during sampling activities; Sacramento sucker (*Catostomus occidentalis*), American shad (*Alosa sapidissima*), Chinook salmon (*Oncorhynchus tshawytscha*), rainbow/steelhead trout (*O. mykiss*), hardhead (*Mylopharodon conocephalus*), largemouth bass (*Micropterus salmoides*), Sacramento splittail (*Pogonichthys macrolepidotus*), common carp (*Cyprinus carpio*), green sturgeon (*Acipenser medirostris*), Sacramento blackfish (*Orthodon microlepidotus*), bluegill (*Lepomis macrochirus*), goldfish (*Carassius auratus*), tule perch (*Hysterocarpus traski*), and white catfish (*Ictalurus catus*) (Table 2). The most common observed species was the Sacramento sucker (2804) followed by American shad (289), Chinook salmon (234), and rainbow/steelhead trout (102).

Distribution

Sacramento pikeminnow angling.— The angling data collected on Sacramento pikeminnow revealed significant ($P < 0.05$) differences in mean CPH among sampling locations and between gate status (Table 3; Figure 3). However, because the interaction effect was also significant ($P = 0.00069$), the simple effects of location were analyzed separately for each level of gate operation. Significant differences in mean CPH existed between locations for gates lowered ($F = 10.68$, $P < 0.00001$, CI = 0.00001 - 0.00004; Table 3). Tukey's MCP detected significant differences between RPP Wall and all other sites except the Outfall. Mean CPH also differed between the Outfall and both the Control and RPP Rack locations (Table 4; Figure 5).

Mean CPH differed significantly among locations for gates raised ($F = 2.49$, $P = 0.035$; Table 3). However, the 95% CI around this P-value (generated using a bootstrap technique) greatly exceeded $\propto \leq 0.05$ on its upper bound (CI = 0.0001 - 0.3404; Table 3). Furthermore, Tukey's MCP did not detect any significantly different means even with the moderate P-value of 0.035 (Table 4; Figure 5). No significant differences in CPH were detected between periods when pumps were running versus idle (Table 3).

Sacramento pikeminnow electrofishing.—Significant differences in mean CPH were detected among the six sampling locations ($P = 0.0013$; Table 5), between gates lowered versus gates raised ($P = 0.0098$), and between pumps running versus pumps idle ($P = 0.0166$; Table 5). Catch per hour during gates lowered was significantly greater ($P = 0.0098$) than gates raised (Figure 6). Tukey's MCP indicated that the RPP Wall had a significantly higher CPH than all other sites except Dam East. No other significant differences occurred between the other five sites (Table 5;

Figure 7).

Striped bass angling.—Significant differences in mean CPH for striped bass occurred among sampling locations and between gate status (Table 7; Figure 8). The simple effect of location was analyzed separately for each level of gate operation because a significant interaction between gates and location was detected. Significant differences in mean CPH existed among locations for gates lowered ($F = 3.73$, $P = 0.0033$, CI = 0.0001 - 0.0745; Table 7). Tukey's MCP detected significant differences between Dam East and all other sites except Dam West. No significant differences occurred among the other five sites (Table 8; Figure 9).

There were no significant differences in mean CPH among sampling locations with dam gates raised, and no significant difference between periods when pumps were running and idle (Table 7; Figure 8).

Striped bass electrofishing.—The fact that only two striped bass were captured with electrofishing throughout the study period made it impossible to conduct meaningful statistical analyses on these data. Both fish were captured at Dam West with gates lowered and pumps running.

DISCUSSION

Spatial Distribution

Sacramento pikeminnow.—The RPP was the main focus for this study and it produced interesting Sacramento pikeminnow distribution patterns. Reclamation designed the RPP to minimize attraction to salmonid predators (Liston and Johnson 1992). This goal was met in regards to the RPP Rack area where fast, deep water with no current breaks or protruding structure consistently produced the lowest CPH of all sampling sites. There was concern that the depth and velocity of the water at the RPP Racks (depth ≈ 4 to 5 m, velocity ≈0.7 m/sec) may have rendered our sampling techniques ineffective, thereby giving a false indication of low predator density in this area. However, close examination of our catch data revealed that many Sacramento pikeminnow and most of the striped bass were captured in areas around RBDD where the water was deeper and more turbulent than in the RPP Rack area.

The design characteristics of the downstream portion of the RPP (RPP Wall) appear to have created an attractive environment for Sacramento pikeminnow. This area consists of a sheet piling wall extending downstream from the trash racks, and angling away from the current to create a break-line in the flow which produces a large slow eddy along the wall. A substantial pile of rock rip-rap placed at the angled section of the wall increases the area of slow water, providing resting and ambush habitat for Sacramento pikeminnow (Figure 3). High CPH levels at this site for both sampling techniques indicate that this structural design may be attracting Sacramento pikeminnow to the site, especially during gates lowered periods.

In comparing the two sampling techniques, angling and electrofishing proved to be equally effective methods of capturing Sacramento pikeminnow. Both techniques caught similar numbers of Sacramento pikeminnow, and the proportional distribution of mean CPH across sampling sites was very similar between the two (Figure 10).

Striped bass.—Striped bass did not display the same attraction to the RPP Wall or any other in-river structure. Instead they were found concentrated (during gates down only) along the edges of the large turbulent boils produced by water forced under the dam gates. The fact that striped bass were located almost exclusively in this habitat explains why so few were captured with electrofishing. The area was not safely accessible by boat, therefore the boil areas were not sampled. Nearly all striped bass were captured by securing the boat outside of the boil areas and by casting into the turbulent water to make the lure imitate a disorientated fish that had just been washed under the dam gates.

The rotary trapping operations for juvenile salmonids below the RBDD indicate that the salmonids are migrating mostly during non-daylight hours (Gaines and Martin, 2002). Thus, this raises questions whether the behavior and distribution of Sacramento pikeminnow and striped bass would differ during non-daylight hours in response to increased juvenile salmonid availability. During the 1998 first phase studies, angling and electro-fishing sampling was conducted during early morning and crepuscular time periods. However, differences in CPU were not observed between time periods, which led to only daylight sampling for this study. Therefore, this study inherently assumed that the distribution, of the Sacramento pikeminnow and striped bass did not differ between daylight and non-daylight hours. This assumption warrants testing, since the implications and results of this study may be profound if actual differences exist.

Temporal Distribution

RBDD gates.—Along with the differences in spatial distribution, there were pronounced differences in temporal distribution for both species between gates raised and gates lowered. Possible reasons for the increase in CPH during gates lowered periods were explored in Tucker et al. (1998). They include a spring spawning migration of Sacramento pikeminnow coupled with an increase in optimal foraging habitat, and increased prey availability and vulnerability. Striped bass seem to move into the study area primarily for increased foraging opportunities. Unlike the Sacramento pikeminnow, they do not reside in the area year-round and it is unlikely that they spawn at or above RBDD. Water temperatures in this area remain well below preferred spawning levels for striped bass (Carmichael et al. 1998), and six years of rotary screw trap sampling and extensive larval fish monitoring have not documented juvenile striped bass in the study area (Borthwick and Corwin 2001; Borthwick and Weber 2001; Gaines and Martin 2002).

Intensive sampling during unusual RBDD gate operations in the spring of 1997 provided strong evidence that the seasonal increase in Sacramento pikeminnow densities within the study area is directly related to gate operations at RBDD. In 1997, an extremely dry spring with high demand for irrigation water forced an early closure of dam gates during the last week in April to provide water for the Tehama-Colusa Canal. Following this temporary closure, gates were raised from 5 May through 15 May, after which they were lowered for the remainder of the summer. Sampling throughout each stage of the gate manipulation period provided unique information on the effects of gate operations on Sacramento pikeminnow densities within the study area. On 21 April, before gates were first lowered, there was a typical early-spring Sacramento pikeminnow CPH of 3.6 (Figure 11). On 1 May, during the gates lowered period, CPH jumped to 76.6. Gates were then removed again for two weeks and sampling was conducted on May 7 and 13, during which the average CPH dropped back to 7.1. Finally on 21 May, after gates were lowered for the summer, CPH increased to 25.3 (Figure 11). Although this series of gate changes was an unusual one time event, the rapid fluctuations in Sacramento pikeminnow CPH corresponding to the dam gate manipulations is a strong indication that RBDD is a dominant factor in the annual increase in Sacramento pikeminnow densities within the study area.

Striped bass density in the study area is also related to RBDD operations, nearly to the point of presence/absence. One striped bass was captured while gates were raised, in the late spring of 1998 when heavy rains forced gates to be raised after they had been in for nearly two weeks. In fact, throughout our sampling activities dating back to April of 1994, there has never been a striped bass captured prior to gates being lowered each spring, although several have been captured less than one week after gates were lowered (USFWS unpublished data).

RPP pumps.—The effect of RPP pump operations on the distribution of Sacramento pikeminnow and striped bass is not as definitive as the effect of RBDD gate operations. While the analysis indicates a slightly higher mean CPH for Sacramento pikeminnow when pumps are running, results are variable among locations and between electrofishing and angling (Figures 3 and 5). It is unlikely that running the pumps significantly impacted the behavior of fish in other parts of the river away from the pump intake area. It is more likely that coincidental factors such as gate operations and seasonal abundance caused the variations in CPH in these areas. The fact that so few fish were captured directly in front of the pump intake makes it difficult to determine if the localized structural and hydrological impacts of pump operations affected predator distribution. While the absence of fish allows for the interpretation that pumping operations repel fish, it seems that running the pumps did not attract predators into the area. Striped bass were never caught near the pump intake area and therefore we could not infer any behavioral effects to this species from pumping activities.

Predation impacts.—Tucker et al. (1998) found that Sacramento pikeminnow abundance within the study area has been greatly reduced since the initiation of gates-raised operations at RBDD in 1986 and is currently far lower than that found for northern pikeminnow in the Columbia River Basin where predation impacts are an important factor in the decline of salmon stocks (Poe et al. 1991). During eight months of the year, including the time when the vast majority of juvenile salmon migrate through the study area (Johnson and Martin 1997), the RBDD gates are raised, striped bass are virtually non-existent and Sacramento pikeminnow densities remain at a relatively low level. Therefore, with the current RBDD gate operations (gates lowered for four months), it is unlikely that the predation impacts produced by these two species within this area will have any profound long term effects on salmonid populations. Although the data does show a distinct increase in predator densities during gates-in periods, this may not necessarily be indicative of actual increases in predation mortality of juvenile salmonids during those periods. The increased densities of adult pikeminnow during the RBDD gates-in period coincides with the adult pikeminnow migration period, thereby resulting in the congregation of pikeminnow below the dam. The potential for increased predation upon juvenile salmonids exists, however, this study did not attempt to validate or quantify this question.

As previously stated, this study sampled only during daylight hours. The distribution of Sacramento pikeminnow and striped bass during non-daylight hours was not an objective of this study. However, pikeminnow are known to feed at night (Brown 1990, Petersen and Gadomski 1994), and apparently feed most heavily between dusk and dawn (Steigenberger and Larkin 1974). Also, given the fact that juvenile salmonids are migrating past the RBDD primarily during hours of darkness (Gaines and Martin 2002), it would seem advantageous for pikeminnow to seek prey in locales and time periods of greatest availability. This study was not intended to draw inferences on whether the distribution and abundance of adult pikeminnow below the RBDD and RPP during daylight hours, would differ from non-daylight hours. The role of the RBDD and RPP operations in influencing the nocturnal behavior (i.e. diel movements) of these predatory species is also unknown. Harvey and Nakamoto (1999) studied the diel and seasonal movements of Sacramento pikeminnow in the Eel River, California and observed that at night, pikeminnow moved out of pools previously occupied during the day, and into adjacent areas of fast water, presumably for purposes of feeding.

During 1998 to 2000, the USFWS (unpublished data) conducted radio-telemetry studies on pikeminnow below RBDD, and preliminary results suggest that during the spring through early fall months, the lowest daily mean numbers of radio-tagged pikeminnow was typically observed during the time interval of 1200 to 2000 hrs (USFWS unpublished data). The daily mean numbers of radio-tagged pikeminnow increased slightly during all other hours, with the highest numbers occurring consistently from about 2200 to 0800 hrs. These preliminary results may suggest that at night, pikeminnow are moving to assume positions directly below the RBDD, perhaps for purposes of feeding on prey.

With regards to the small pocket of habitat created at the downstream end of the RPP, even though this area appears to attract and concentrate Sacramento pikeminnow during certain times of year, this should not substantially increase predation levels in the overall study area. The small size of the habitat area (approximately 5 x 10 m) limits the number of Sacramento pikeminnow that will hold there, and the prey in this area would not be subject to disorientation (i.e. passing beneath the dam gates, or at the bypass outfall). Therefore, we would not expect a predation problem here. Even if the RPP Wall area were somehow altered to diminish its attractiveness to Sacramento pikeminnow, the fish that now hold there would likely just move to another nearby location (i.e. the eddy behind the bypass outfall or to the face of the dam).

In assessing the design of the RPP with regards to its suitability as a prototype for use in other water diversion applications, it seems that the intake area has been well designed to provide little attraction to predatory fish. Moreover, if the downstream wall were designed to avoid the creation of a back eddy, the in-river habitats adjacent to the entire plant should create very little predator attraction.

Acknowledgments

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Table 1.—Total numbers of Sacramento pikeminnow (*Ptychocheilus grandis*) and striped bass (*Morone saxatilis*) captured using angling and electrofishing sampling techniques. Data are presented to show the number of fish caught with gates lowered, gates raised, pumps running and pumps idle. Because gate operation and pump operations are not mutually exclusive, summed row totals exceed the number of fish captured.

	Sacramento pikeminnow			**Striped bass**		
	Angling	Electrofishing	Total	Angling	Electrofishing	Total
Gates Lowered	73	70	143	30	2	32
Gates Raised	21	28	49	1	0	1
Pumps Running	50	71	121	5	2	7
Pumps Idle	44	27	71	26	0	26

Table 2.—Total numbers of "non-target" species observed during sampling.

Species	No.	Species	No.	Species	No.
Sacramento sucker	2804	Largemouth bass	4	Goldfish	1
American shad	289	Sacramento splittail	3	Tule perch	1
Chinook salmon	234	Common carp	2	White catfish	1
Rainbow trout/steelhead	102	Green sturgeon	2	Sacramento blackfish	1
Hardhead	77	Bluegill	1		

Table 3.—Summary of results from a three-way ANOVA on CPH data for Sacramento pikeminnow (*Ptychocheilus grandis*) sampled with angling equipment. Results include main and simple effect *P*-values, degrees of freedom (df) and *F*-ratios. Upper and lower 95% confidence intervals were generated for ANOVA *P*-values using a bootstrap technique. Because of the significant interaction effect between Gates and Location, separate analyses were conducted for each level of Gates.

				Confidence Interval	
Source	df	*F*-ratio	*P*-value	Lower 95%	Upper 95%
Location	5	10.24	0.00001 [a]	0.00001 [a]	0.00006
Pumps	1	1.85	0.17474	0.00386	0.95128
Gates	1	17.55	0.00004	0.00001 [a]	0.01133
Location*Pumps	5	1.47	0.19828	0.00002	0.76138
Location*Gates	5	4.42	0.00069	0.00001 [a]	0.10992
Pumps*Gates	1	0.07	0.79568	0.04270	0.90614
			Gates lowered		
Location	5	10.68	0.00001 [a]	0.00001 [a]	0.00004
Pumps	1	1.05	0.30718	0.00296	0.89957
Location*Pumps	5	1.19	0.31458	0.00004	0.81578
			Gates raised		
Location	5	2.49	0.03516	0.00013	0.34038
Pumps	1	0.82	0.36666	0.03731	0.95128
Location*Pumps	5	0.36	0.87805	0.00635	0.97984

[a] $P \leq 0.00001$

Table 4.—Results of Tukey's multiple comparison procedure to determine where significant differences in mean CPH existed among locations, for Sacramento pikeminnow (*Ptychocheilus grandis*) sampled with angling techniques. Preliminary results of a three-way ANOVA indicated a significant interaction effect existed between the Location and Gates variables. Therefore, separate analyses were conducted for each level of Gates. *P*-values are given for each pairwise comparison.

Location	Control	Dam East	Dam West	Outfall	RPP/Rack	RPP/Wall
			Gates lowered			
Control	1.00000					
Dam East	0.81868	1.00000				
Dam West	0.99267	0.98518	1.00000			
Outfall	0.01494	0.31600	0.07351	1.00000		
RPP/Rack	0.99999	0.82389	0.99400	0.01349	1.00000	
RPP/Wall	0.00001 [a]	0.00008	0.00001 [a]	0.15011	0.00001 [a]	1.00000
			Gates raised			
Control	1.00000					
Dam East	0.30638	1.00000				
Dam West	0.99863	0.56201	1.00000			
Outfall	0.99999	0.46894	0.99952	1.00000		
RPP/Rack	0.99992	0.22950	0.98999	0.99991	1.00000	
RPP/Wall	0.16981	0.99920	0.36330	0.30251	0.12313	1.00000

[a] $P \leq 0.00001$

Table 5.—Summary of results from a three-way analysis of variance on CPH data for Sacramento pikeminnow (*Ptychocheilus grandis*) using electrofishing equipment. Results include main and interaction effect *P*-values, degrees of freedom (df) and *F*-ratios. Upper and lower 95% confidence intervals were generated for ANOVA *P*-values using a bootstrap technique.

				Confidence Interval	
Source	df	*F*-ratio	*P*-value	Lower 95%	Upper 95%
Location	5	4.09	0.00132	0.00001 [a]	0.13081
Pumps	1	5.80	0.01664	0.00018	0.37730
Gates	1	6.76	0.00982	0.00016	0.08336
Location*Pumps	5	1.97	0.08263	0.00004	0.59509
Location*Gates	5	2.05	0.07125	0.00005	0.67420
Pumps*Gates	1	2.56	0.11081	0.00356	0.83903

[a] $P \leq 0.00001$

Table 6.—Results of Tukey's multiple comparison procedure to determine where significant differences in mean CPH existed among locations, for Sacramento pikeminnow (*Ptychocheilus grandis*) sampled with electrofishing equipment. *P*-values are given for each pairwise comparison.

Location	Control	Dam East	Dam West	Outfall	RPP/Rack	RPP/Wall
Control	1.00000					
Dam East	0.74029	1.00000				
Dam West	0.99952	0.90337	1.00000			
Outfall	0.94049	0.99797	0.99133	1.00000		
RPP/Rack	0.99840	0.47397	0.97731	0.76788	1.00000	
RPP/Wall	0.00430	0.21256	0.01426	0.08418	0.00093	1.00000

Table 7.—Summary of results from a three-way analysis of variance on CPH data for striped bass (*Morone saxatilis*) using angling equipment. Results include main and interaction effect *P*-values, degrees of freedom (df) and *F*-ratios. Upper and lower 95% confidence intervals were generated for ANOVA *P*-values using a bootstrap technique. Because of the significant interaction effect between Gates and Location, separate analyses were conducted for each level of Gates.

				Confidence Interval	
Source	df	*F*-ratio	*P*-value	Lower 95%	Upper 95%
Location	5	4.34	0.00082	0.00001 [a]	0.02453
Pumps	1	2.12	0.14684	0.01629	0.51326
Gates	1	7.30	0.00731	0.00018	0.06710
Location*Pumps	5	0.91	0.47209	0.00159	0.94723
Location*Gates	5	2.69	0.02161	0.00001 [a]	0.23338
Pumps*Gates	1	1.69	0.19486	0.02301	0.79218
		Gates lowered			
Location	5	3.73	0.00325	0.00001 [a]	0.07450
Pumps	1	2.35	0.12742	0.01295	0.66873
Location*Pumps	5	0.54	0.54098	0.00291	0.95485
		Gates raised			
Location	5	1.26	0.28525	0.00018	0.67349
Pumps	1	1.11	0.29368	0.02784	0.52432
Location*Pumps	5	1.26	0.28525	0.00018	0.67349

[a] $P \leq 0.00001$

Table 8.—Results of Tukey's multiple comparison procedure to determine where significant differences in mean CPH existed among locations, for striped bass (*Morone saxatilis*) sampled with angling techniques. Preliminary results of a three-way ANOVA indicated a significant interaction effect existed between the Location and Gates variables. Therefore, separate analyses were conducted for each level of Gates. *P*-values are given for each pairwise comparison.

Location	Control	Dam East	Dam West	Outfall	RPP/Rack	RPP/Wall
			Gates lowered			
Control	1.00000					
Dam East	0.02198	1.00000				
Dam West	0.33975	0.86722	1.00000			
Outfall	1.00000	0.02199	0.33975	1.00000		
RPP/Rack	1.00000	0.01783	0.31603	1.00000	1.00000	
RPP/Wall	0.99997	0.03000	0.418282	0.99997	.99997	1.00000
			Gates raised			
Control	1.00000					
Dam East	0.37498	1.00000				
Dam West	1.00000	0.38275	1.00000			
Outfall	1.00000	0.51857	1.00000	1.00000		
RPP/Rack	1.00000	0.41348	1.00000	1.00000	1.00000	
RPP/Wall	1.00000	0.39161	1.00000	1.00000	1.00000	1.00000

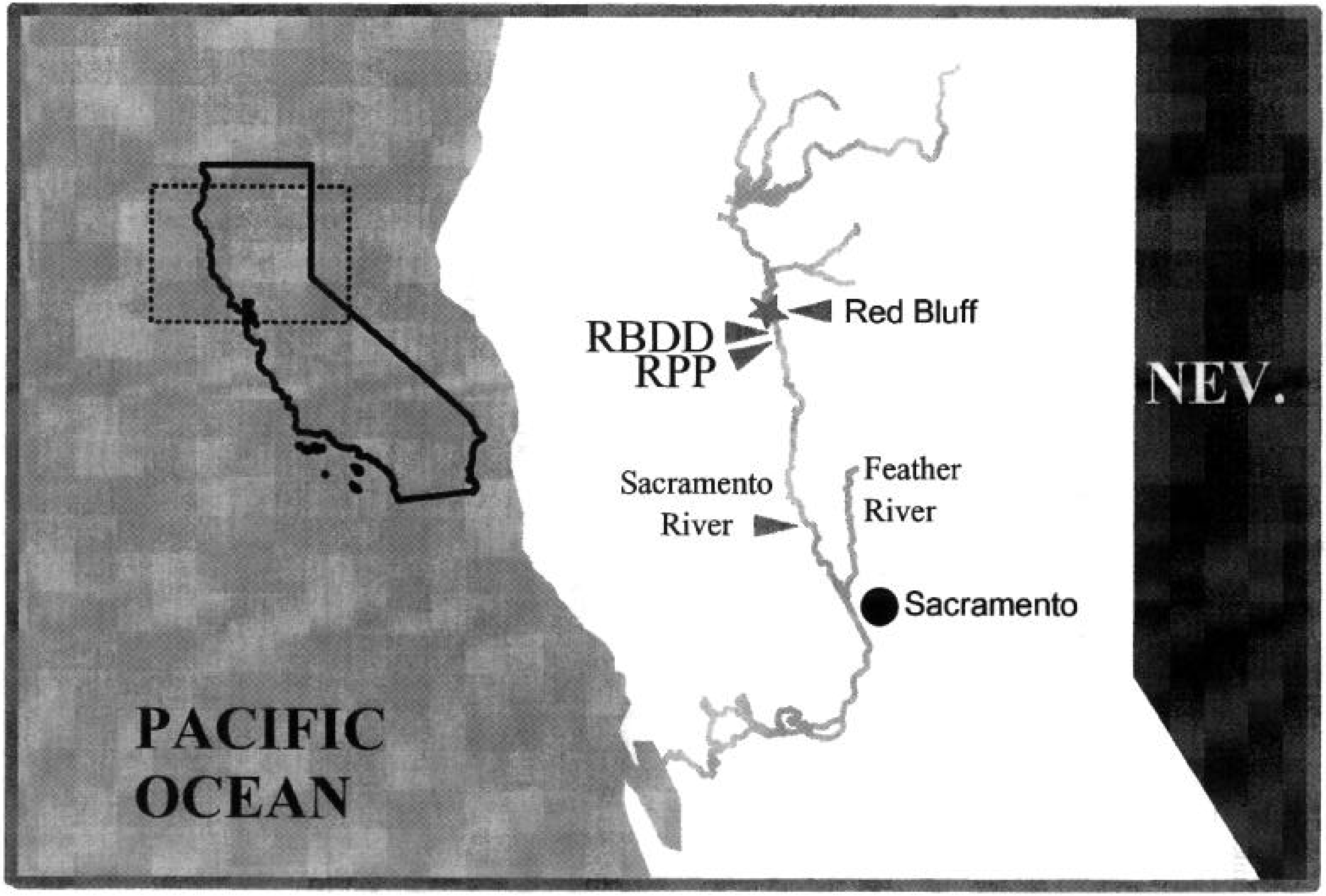

Figure 1.--Area view of northern California showing the location of Red Bluff Diversion Dam (RBDD) and the Red Bluff Research Pumping Plant (RPP).

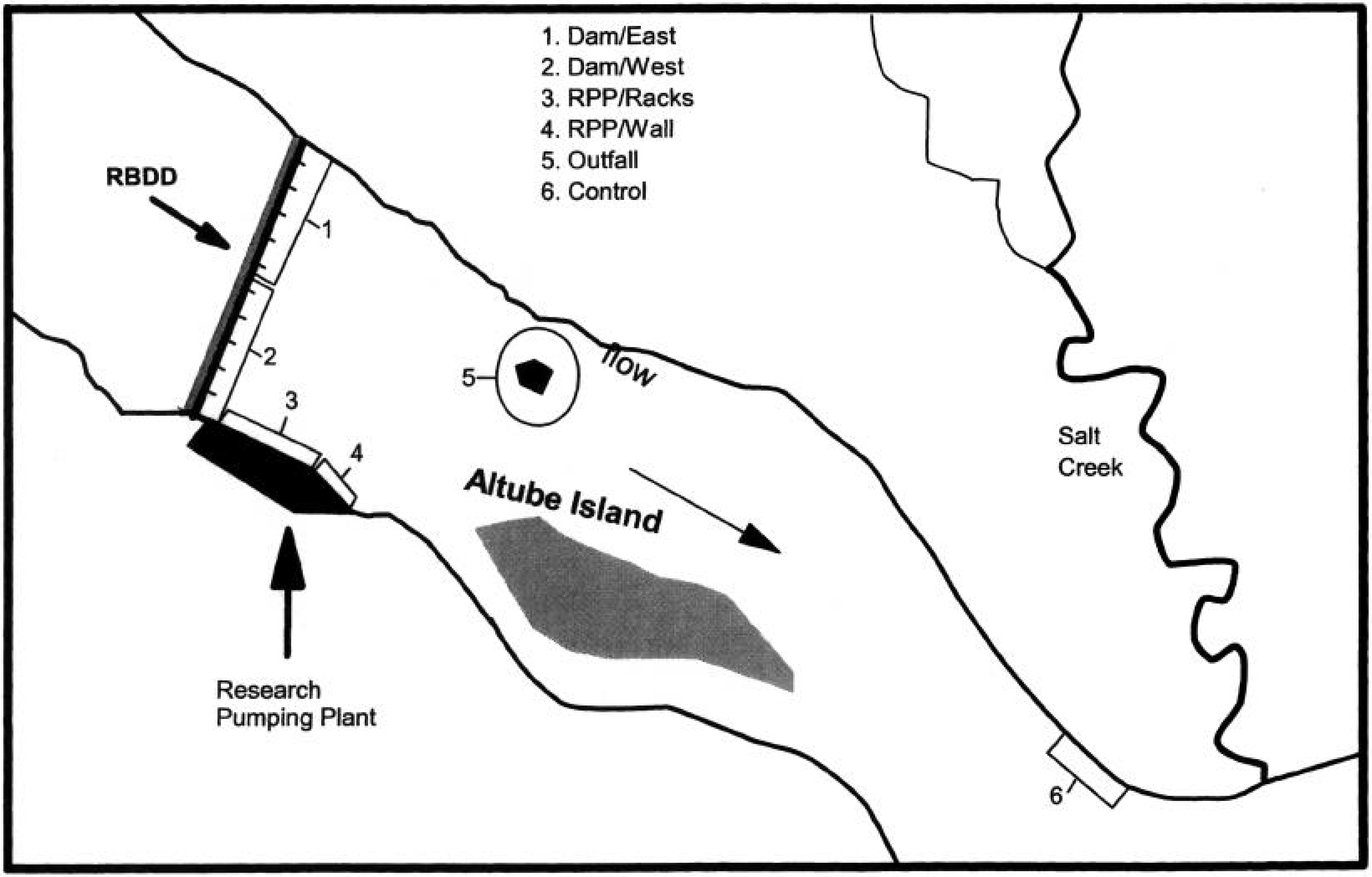

Figure 2.--Overhead view of study area at Red Bluff Diversion Dam (RBDD) on the Sacramento River in Tehama County, CA. Specific sampling sites are bracketed and labeled.

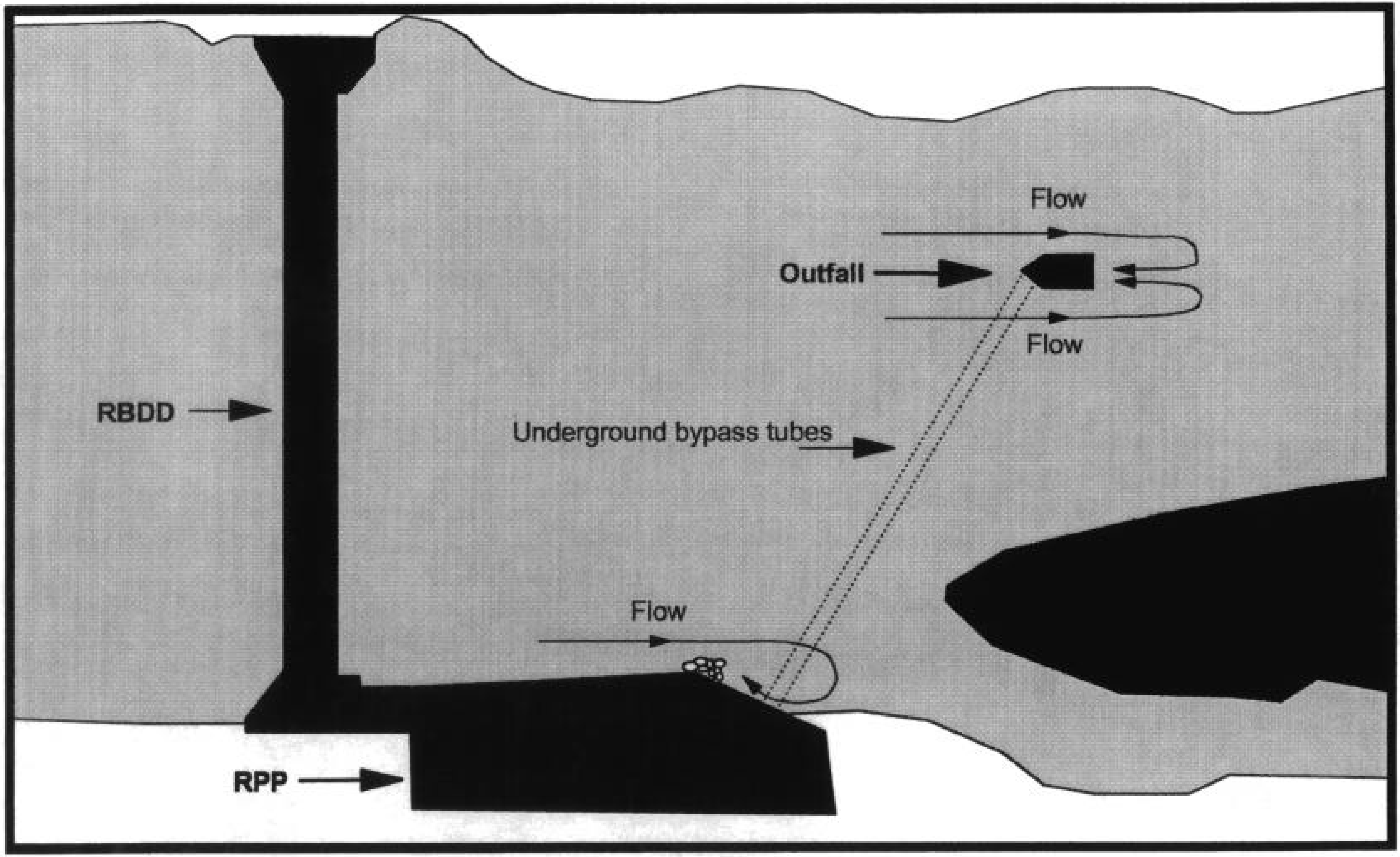

Figure 3.--Overhead view of study area at Red Bluff Diversion Dam (RBDD) on the Sacramento River, Tehama County, CA. Flow patterns are shown for the areas around the Research Pumping Plant (RPP) sheet piling wall and the bypass outfall structure (Outfall), during periods when dam gates are raised and the RPP is not in operation.

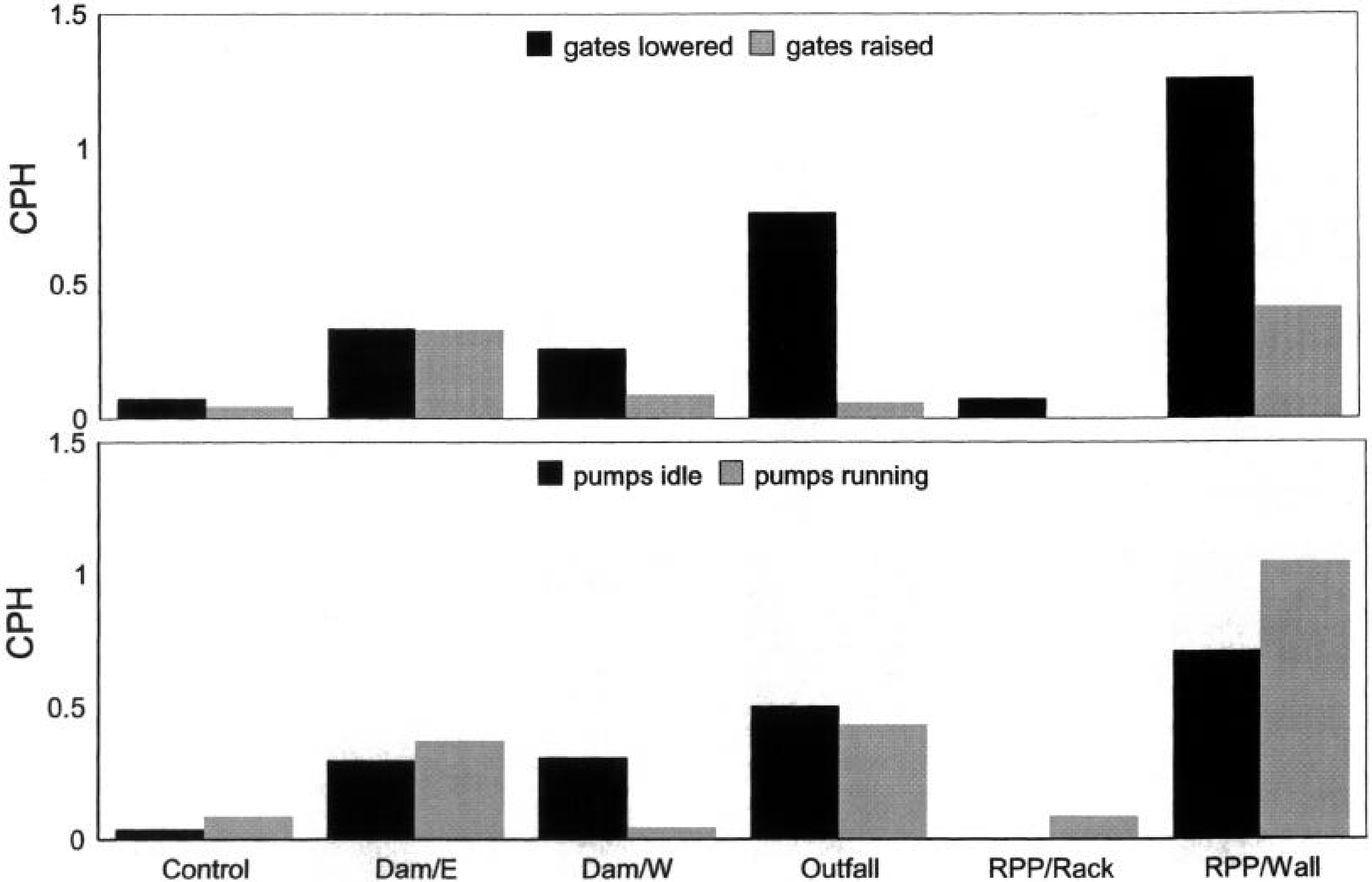

Figure 4.--Comparison of Sacramento pikeminnow (*Ptychocheilus grandis*) angling catch per hour (CPH) across all sites with gates lowered versus gates raised and with pumps running versus pumps idle.

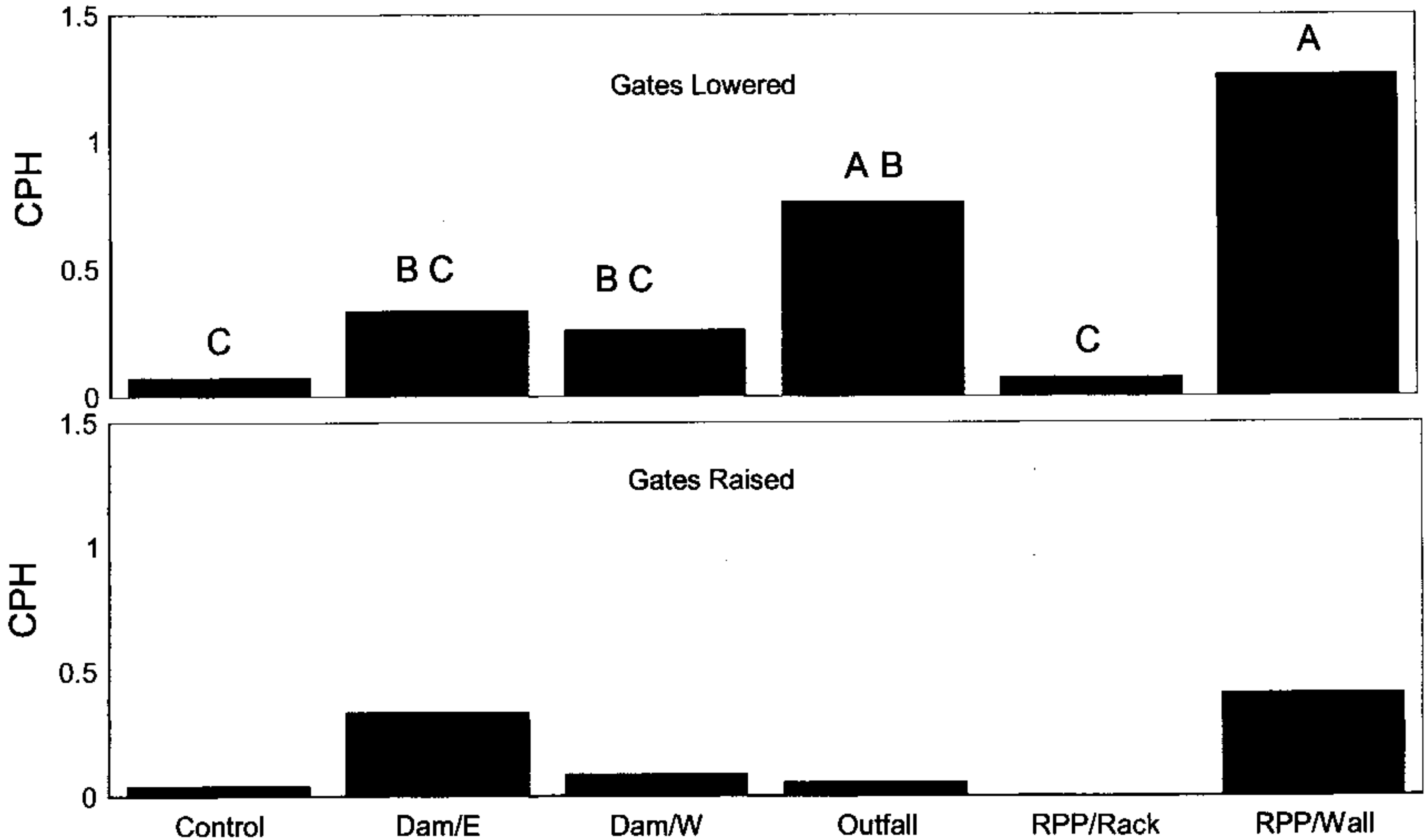

Figure 5.--Mean angling catch per hour (CPH) for Sacramento pikeminnow (*Ptychocheilus grandis*) with gates lowered and gates raised at six sites near Red Bluff Diversion Dam, Sacramento River, California. Tukey's multiple comparison procedure detected significant differences ($P < 0.05$) between sites during gates lowered periods. Sites with the same letter above them were not significantly different. No significant differences were detected with gates raised.

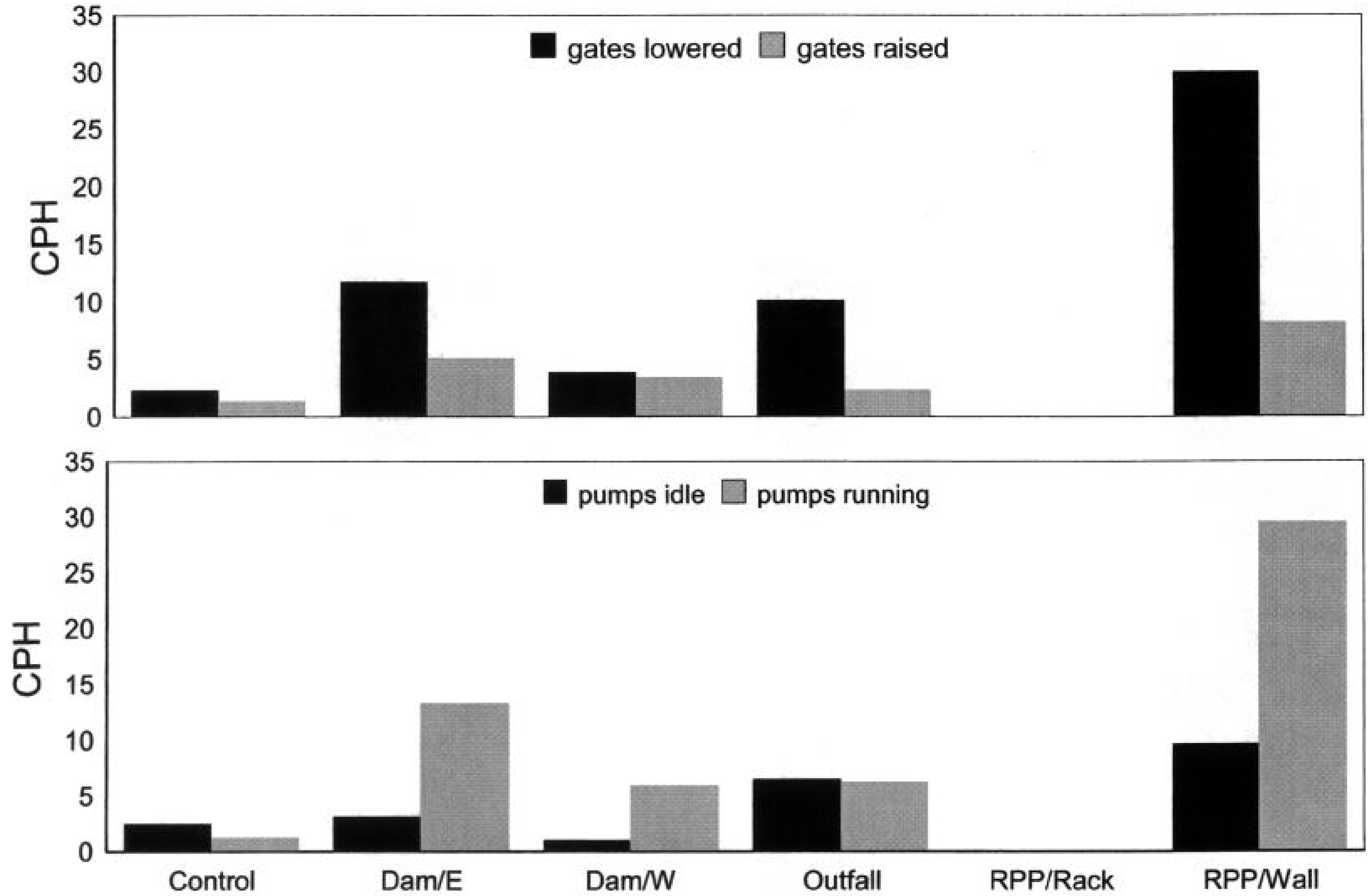

Figure 6.--Comparison of Sacramento pikeminnow (*Ptychocheilus grandis*) electrofishing catch per hour (CPH) across all sites with gates lowered versus gates raised and with pumps running versus pumps idle.

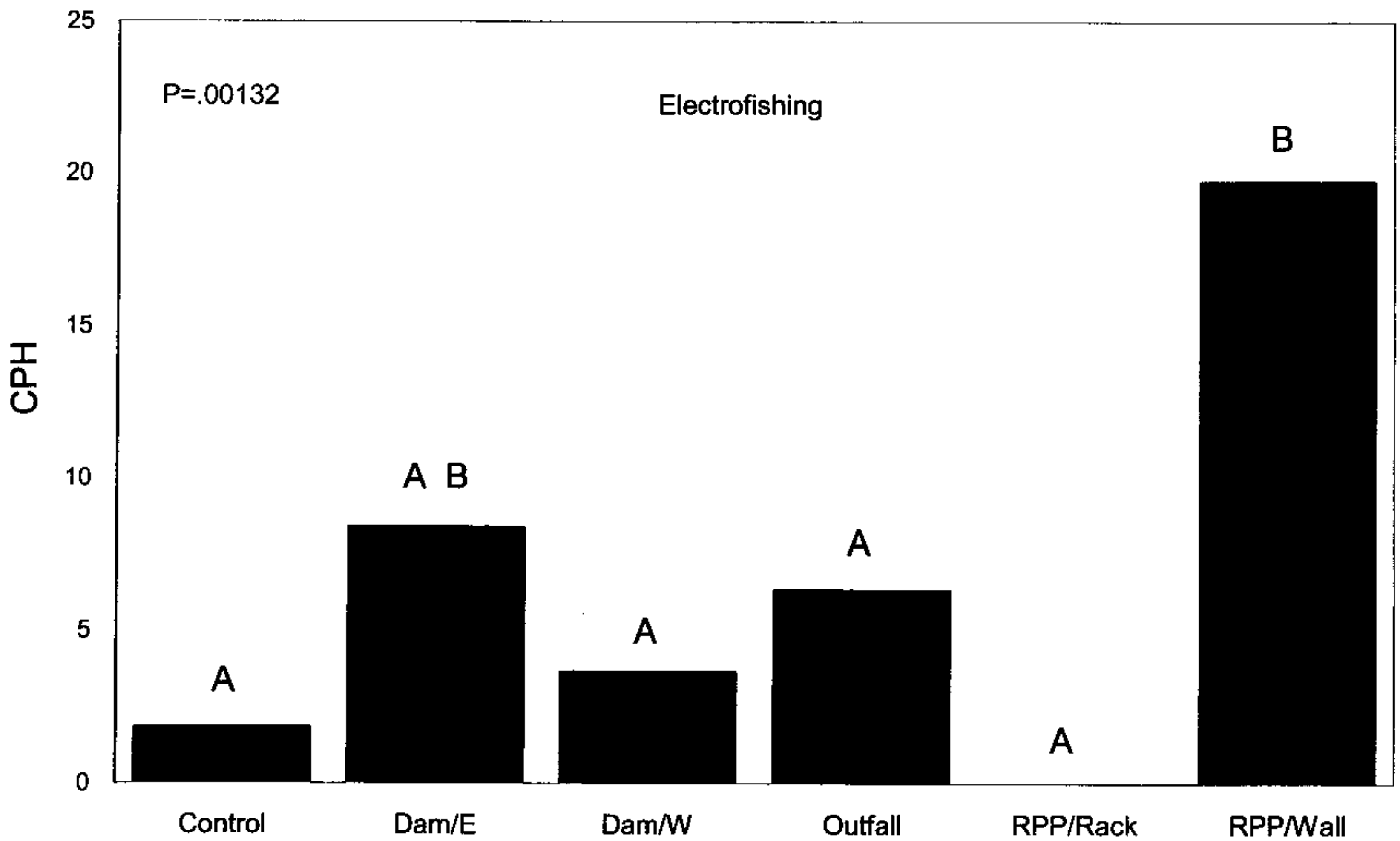

Figure 7.--Mean catch per hour (CPH) for Sacramento pikeminnow (*Ptychocheilus grandis*) using electrofishing at six sites near Red Bluff Diversion Dam, Sacramento River, California. A three-way ANOVA indicated a significant difference between locations ($P = 0.00132$), and a Tukey's multiple comparison revealed which sites differed from the others. Sites with the same letter above them were *not* significantly different.

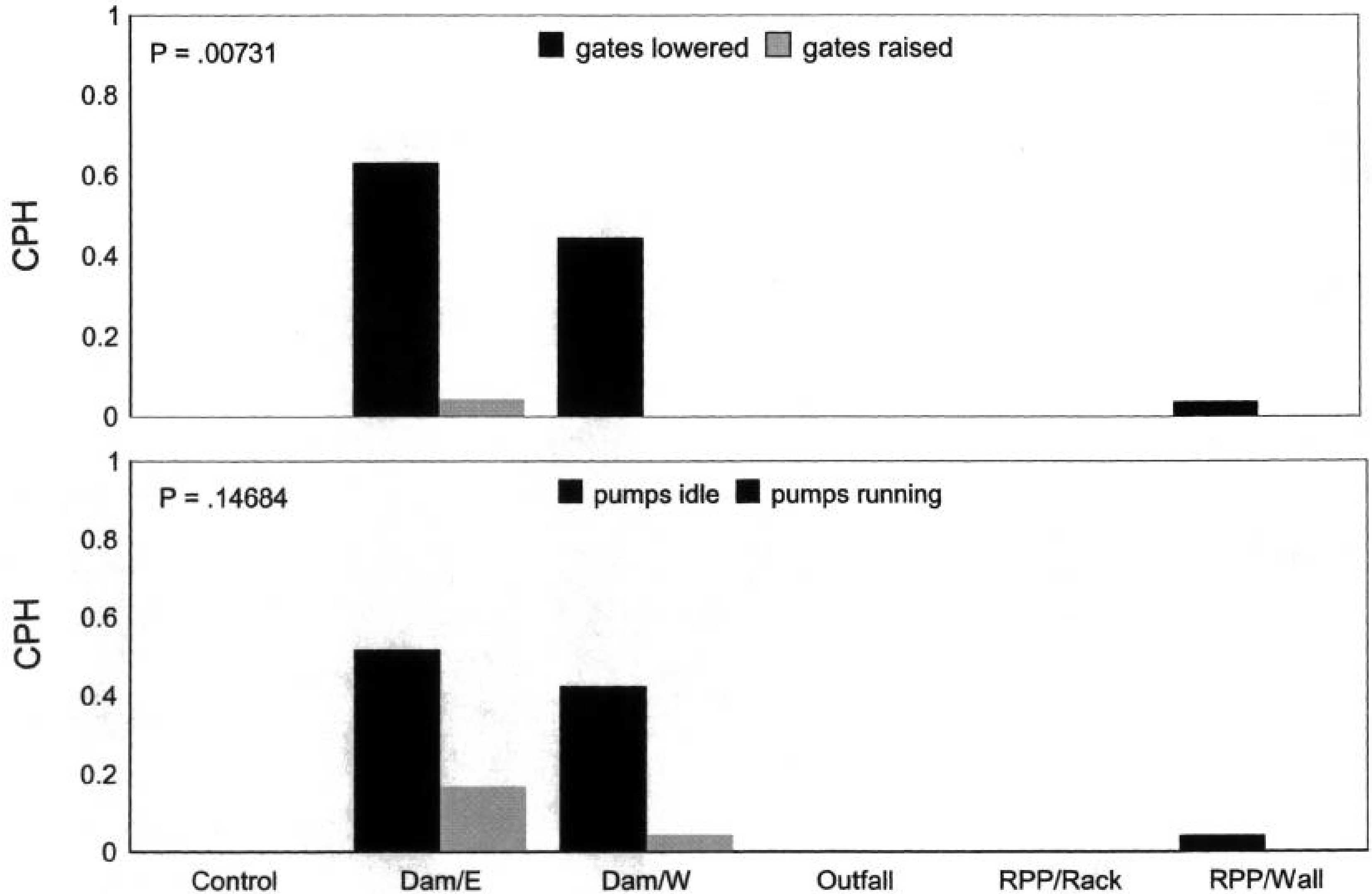

Figure 8.--Comparison of striped bass (*Morone saxatilis*) angling catch per hour (CPH) across all sites with gates lowered versus gates raised and with pumps running versus pumps idle.

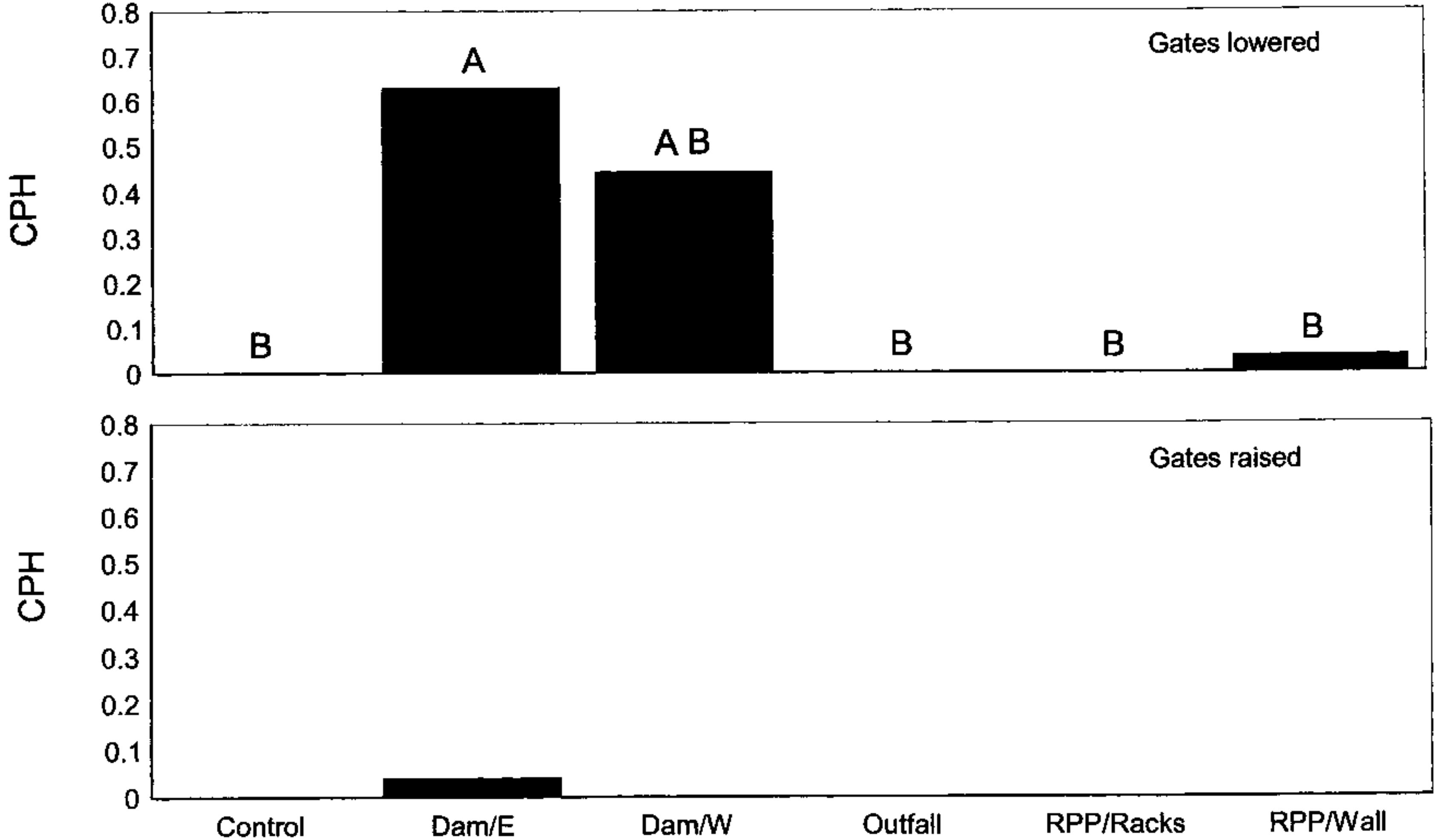

Figure 9.--Mean angling catch per hour (CPH) for striped bass (*Morone saxatilis*) with gates lowered and gates raised at six sites near Red Bluff Diversion Dam, Sacramento River, California. Tukey's multiple comparison procedure detected significant differences ($P < 0.05$) between sites during gates lowered periods. Sites with the same letter above them were not significantly different. No significant differences were detected with gates raised.

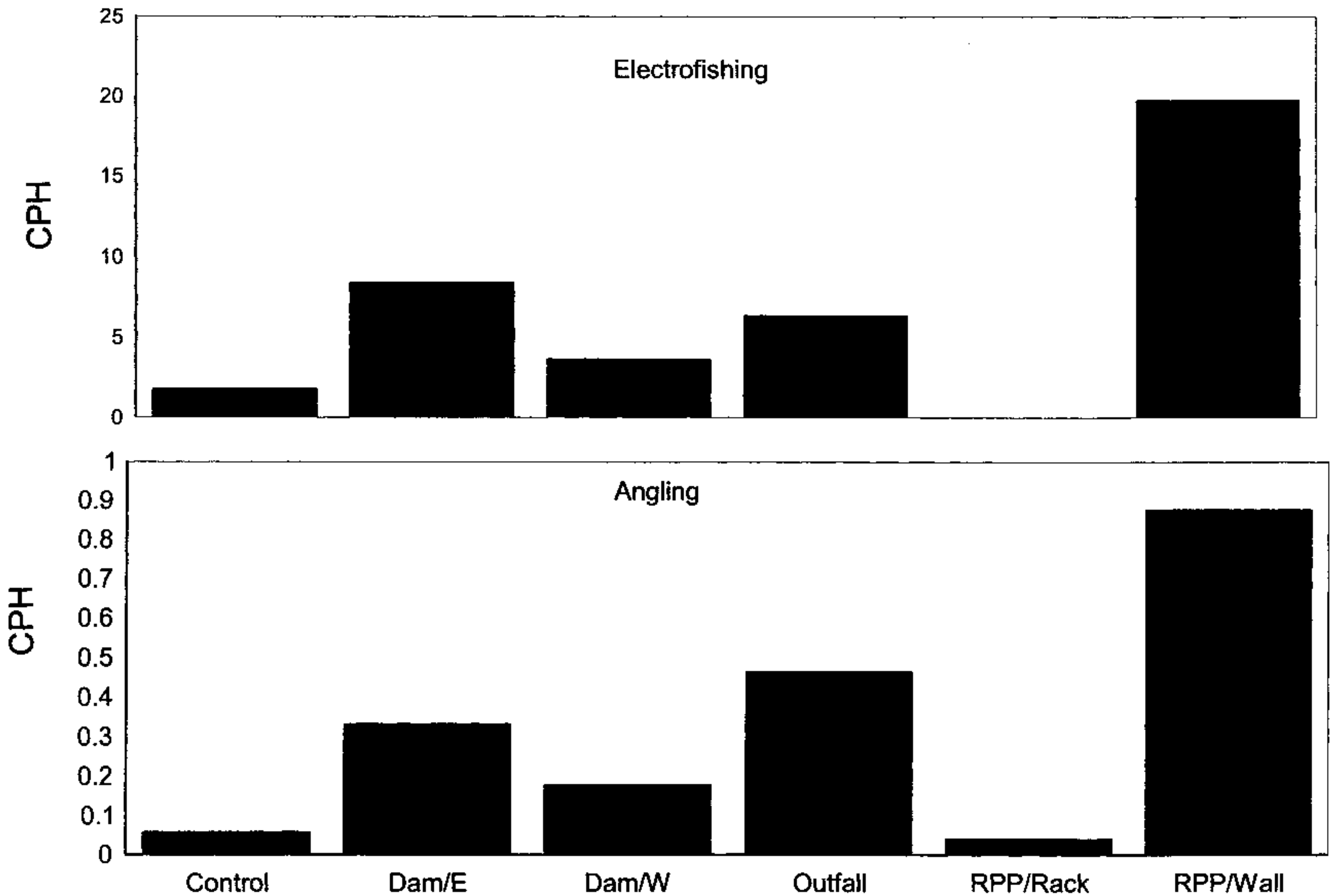

Figure 10.--Mean catch per hour (CPH) for Sacramento pikeminnow (*Ptychocheilus grandis*) at six sites near Red Bluff Diversion Dam, Red Bluff, California shown for two different sampling techniques.

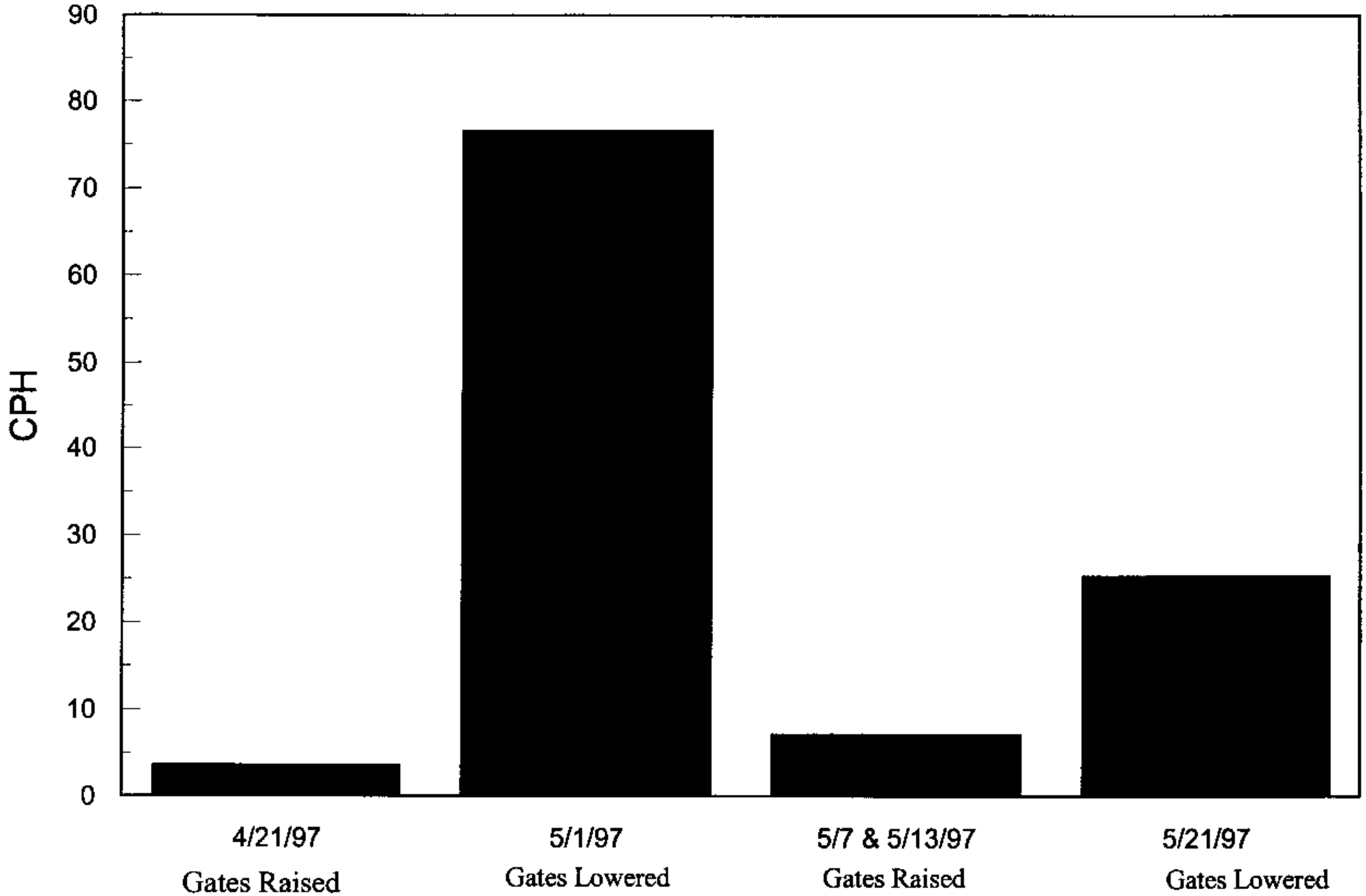

Figure 11.-- Electrofishing mean catch per hour (CPH) for Sacramento pikeminnow (*Ptychocheilus grandis*) in the spring of 1997 during the time period when the Red Bluff Diversion Dam gates were subject to changes in operation.

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