ABUNDANCE, FOOD HABITS AND LIFE HISTORY ASPECTS OF SACRAMENTO SQUAWFISH AND STRIPED BASS AT THE RED BLUFF DIVERSION COMPLEX, INCLUDING THE RESEARCH PUMPING PLANT, SACRAMENTO RIVER, CALIFORNIA, 1994-1996

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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 either Archimedes or internal helical pumps is a viable method for meeting water delivery requirements to the Tehama-Colusa Canal system. The U. S. Fish and Wildlife Service (Service) is contracted to determine the in-river biological implications of the Research Pumping Facility.

This report summarizes Sacramento squawfish *Ptychocheilus grandis* and striped bass *Morone saxatilis* monitoring activities around Red Bluff Diversion Dam (RBDD) and the RPP on the Sacramento River, California, from April, 1994, through July, 1996. Both Sacramento squawfish and striped bass were sampled by angling and electrofishing. The main areas targeted for sampling included RBDD, the RPP, the bypass outfall structure, and a relatively undisturbed area downstream. Sampling occurred weekly, with intermittent periods of higher frequency (2 to 3 times per week). Data and tissues were collected to determine growth rate, age structure, reproductive condition (relative gonad weight), and diet of Sacramento squawfish and striped bass. Most of the fish were tagged and released to estimate population size, movement patterns and actual growth. Data are also presented from the 1st and 2nd Annual Red Bluff Squawfish Derbies.

Sacramento squawfish relative abundance estimates were lower than those reported from previous studies of the area. The highest densities for both Sacramento squawfish and striped bass occurred in the spring and early summer when the dam gates were in and an apparent Sacramento squawfish spawning migration was under way. Nearly all striped bass were captured directly behind the dam while the gates were in (90%, $N = 89$). Diet analysis showed that juvenile salmonids outweighed other food sources in Sacramento squawfish stomachs only during summer, gates in periods. In striped bass stomach samples, juvenile salmonids outweighed other food types by a three to one margin. Other life history parameters were examined and compared to the findings of other authors.

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Introduction

The Red Bluff Diversion Dam (RBDD) is located in the upper Sacramento River at RK 391, about 3.2 km southeast of the city of Red Bluff, Tehama County. It was completed in 1964 and began operation in 1966 (Liston and Johnson 1992). The purpose of the dam is to divert water into the Tehama-Colusa and Corning Canal system, for agriculture and wildlife refuges. 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 (≈ 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 vulnerable to predators. For 20 years this was the situation as the dam gates remained in year-round, until the winter of 1986 when the gates were raised out of the water (gates-out) in an effort to improve anadromous fish passage. The practice of raising the gates for extended periods of time during the fall, winter and spring months was found to have many beneficial effects, and continues today (USFWS 1990).

Problems in juvenile salmonid passage caused by RBDD have been well documented (Vogel and Smith 1984; Hallock 1989; USFWS 1987, 1989, 1990; Vogel et al. 1988). One cause of mortality in juvenile chinook salmon is the dysfunctional predator-prey relationship created by RBDD. The Sacramento squawfish *Ptychocheilus grandis* is a native piscivorous species that co-evolved in the system with salmon and steelhead. In a natural free flowing river setting the predator-prey relationship between Sacramento squawfish and salmon is balanced and has no significant long term effect on salmonid populations (Brown and Moyle 1981). When large man-made structures like RBDD are placed in the river, these structures can alter the natural system by creating increased resting and ambush settings for predators. In addition, the dam may impede upstream passage of Sacramento squawfish resulting in large congregations below the dam, especially during the Sacramento squawfish spawning season when all the fish that might otherwise migrate past the area to spawn upstream are blocked or delayed by the dam. These alterations can tip the predator-prey relationship in the predator's favor. Add to this situation the congregation of non-native striped bass *Morone saxatilis* (another piscivore) below the dam, combined with the disorienting effect for juvenile salmonids being entrained under the dam gates, and a potentially serious predation problem is created. Both Hall (1977) and Vondracek and Moyle (1983) estimated that significant numbers of juvenile salmon were being consumed by Sacramento squawfish at RBDD before the initiation of gates-out operations (pre-1986). A similar situation occurs in the Columbia River system where northern squawfish *Ptychocheilus oregonensis* predation at permanent dams has a major impact on juvenile salmonids (Poe et al. 1991).

Numerous attempts have been made to control Sacramento squawfish abundance near the RBDD. Some of the suggested measures were: trap and remove Sacramento squawfish from the fish ladders, use physical methods to disperse Sacramento squawfish below the dam, develop commercial or sport fisheries for Sacramento squawfish, or reduce Sacramento squawfish holding areas below RBDD (Vogel et al. 1988). Commercial fishing was evaluated in 1989 (Leveen 1990). Leveen used traps and hook and line methods to capture Sacramento squawfish. 620 Sacramento squawfish were captured immediately below RBDD in an undetermined amount of time using hook and line methods (20 salmon were also captured). In 660 trap-days, 3,423 fish (mostly hardheads *Mylopharodon conocephalus*) were captured; including, Sacramento suckers *Catostomus occidentalis* (31), tule perch *Hysterocarpus traski* (16), and carp *Cyprinus carpio* (2). Traps were set in the fishways and therefore had little impact on downstream populations as they removed Sacramento squawfish that had already moved above the dam.

A "permit angler day" designed to remove Sacramento squawfish from the RBDD area occurred in June 1977. This community event was intended to remove Sacramento squawfish from the RBDD area. It resulted in 53 anglers fishing 318 hours in which they caught 484 Sacramento squawfish (Hallock and Hall 1977). Squawfish derbies have been conducted in the spring of 1995 and 1996 and have resulted in the removal of 340 Sacramento squawfish (U. S. Fish and Wildlife Service, Northern Central Valley Fish and Wildlife Office, Red Bluff, California, unpublished data).

During gates-out at RBDD, there is still a seasonal need for irrigation water. To meet this demand the Bureau of Reclamation (Reclamation) is investigating the use of fish friendly pumps with the Red Bluff Research Pumping Plant (RPP). The RPP is located immediately downstream of the dam on the west shore of the Sacramento River. Construction began in 1994 and continued into 1995. Operational testing of the plant began in summer of 1995. The pumping plant may affect the hydrology of the area by changing flow patterns as well as creating new structure within the river channel. These alterations may create predator habitat and influence the predator population size and density. The goal of this study is to determine if the RPP can be built and operated in a manner that creates no new local attraction for piscivorous predators and no increase in predation to downstream migrating salmonids.

This report summarizes Sacramento squawfish and striped bass studies near the RPP and RBDD from late April 1994 through July 1996. In addition to the primary sampling conducted around RBDD and the RPP, creel census data were collected from participants in two public "squawfish derbies" which were put on by the Red Bluff Chamber of Commerce on 10 June 1995 and 8 June 1996.

The major objectives for this study are:

1. Gain insight into predator population dynamics by collecting baseline information on Sacramento squawfish and striped bass life history including data on population age structure, growth rate, and gonadal condition.

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

3. Estimate the seasonal relative and absolute abundance of Sacramento squawfish and striped bass throughout the study area.

4. Differentiate relative abundance of Sacramento squawfish and striped bass at the RPP from other locations within the study area in order to determine if the RPP influences the behavior or abundance of these species.

In order to establish a strong base of information on Sacramento squawfish and striped bass populations within the study area, the first phase of this study (covered by this progress report) focused heavily on the collection of baseline data on the population size, life history and behavior of these two species. Major emphasis was placed on objectives 1, 2 and 3 listed above in order to characterize these populations and to allow comparisons with previous studies of these species. The next phase of this study (currently under way) will shift emphasis toward objective 4 by systematically sampling specific transects within the study area (including the RPP) to set up statistical comparisons between each transect. This analysis will be coupled with information from a new Sacramento squawfish radio telemetry study (project J) in order to determine the specific influences on predator behavior generated by the RPP.

Study Area

Sampling efforts were concentrated in the area starting at RBDD and continuing downstream for approximately two km (Figure 1). This area encompasses three major in-river structures associated with the diversion of water into the Tehama-Colusa Canal system (diversion complex). The diversion complex includes the RPP, RBDD and the bypass outfall structure. Sampling was also conducted within the relatively undisturbed downstream area from Altube Island to the mouth of Salt Creek. While this area is not completely pristine and natural, it is far less heavily impacted than the area around RBDD and is treated as a natural control area throughout this report. RBDD is 226 meters wide, and has eleven gates measuring 18 meters in width between ten concrete piers 2.4 meters in width. Flows past RBDD with gates in can range from 8,000 cubic feet per second (CFS) to 16,000 CFS. Flows with gates out can range from 5,000 to over 100,000 CFS. The RPP is located on the southwest bank of the river, immediately downstream of RBDD. The in-river portions of the plant include a long intake bay covered by a trash rack with five cm spaces between vertical steel slats. The trash rack is approximately 64 meters long and 8 meters tall running parallel to the flow of the river. Immediately downstream of the trash racks, a sheet piling wall extends approximately 30 meters. This wall angles to the south after approximately 10 meters forming a large eddy/backwater along the downstream end of the wall (Figure 2)

During the first five months of the study (April 1994–September 1994) the in-river portion of the RPP was under construction and therefore the size and magnitude of in-river influences within the construction area were continually changing. First a 145 meter coffer dam was constructed around the work area, then the pumping intake structure was built, finally the coffer wall was removed and the final additions to the intake area were made. Following the construction phase, and throughout a good portion of the study period, the pumps were generally non-operational, leaving only the static structure's influence on the riverine environment without the hydrological influences of standard pumping operations.

Methods

Sampling Stratification

Spatial.— Sampling was spatially stratified to concentrate on four main target areas. These included the three major man-made structures within the study area (RBDD, the RPP and the bypass outfall structure; diversion complex) as well as the relatively undisturbed area from Altube Island to the mouth of Salt Creek. In addition to the main target sites, other areas, both upstream and downstream from the dam, were occasionally sampled in an attempt to increase the overall number of target species captured.

Temporal.—Sampling was scheduled at least one day per week with intermittent periods when more frequent sampling took place (2 to 3 times per week) as well as seven weekly periods dispersed throughout the study when sampling was skipped due to inclement weather or equipment failure. Timing of sampling generally alternated each week to include the morning and evening crepuscular periods (6:00 am to 1:00 pm and 1:00 pm to 8:00 pm). In addition to these regularly scheduled sampling trips, supplemental angling was periodically conducted from rotary screw traps attached to the dam. Sampling effort was further stratified into four seasonal strata: spring (March through May), summer (June through August), fall (September through November) and winter (December through February).

Fish Sampling

The number of fish caught and the time spent in each sampling activity were recorded at each site (seconds electrofishing and minutes angling), so that estimates of catch per unit effort (relative abundance) could be made for each season and location.

Electrofishing.—A Smith-Root® 18 ft. electrofishing boat (Model SR-18WW) was used. The actual seconds of active electrofishing were recorded and converted to hours to compute the catch per hour of effort (CPH). The electrofishing power settings were conservative, to allow capture of fish while minimizing injury.

Angling.—Angling activities were conducted from boats, in-river locations (i.e. floating screw traps or the bypass outfall) and from shore. Ordinary spin cast rods and reels were the standard gear although on occasion, fly fishing gear was used in an attempt to capture a wider size range of target species. Fish-imitating lures such as Kastmasters®, countdown Rapalas®, Super-Dupers®, Little Cleos®, and DareDevils® were used in the vast majority of angling.

Occasional attempts at using flies, yarn eggs, and bait were fairly unsuccessful. Fish imitating lures were more successful, and allowed the assumption that all fish caught in this manner were attempting an act of predation on a small fish.

Field processing.—All target fish were temporarily kept in an aerated live well, into which Polyaqua® was added to minimize slime loss and handling stress. Fish were then individually anesthetized in a 15-L tub with 150 mg/L of Finquel® (tricaine methansulfonate, or MS-222), buffered with sodium bicarbonate (Haedrich 1983). Total length and fork length (mm) were measured. Approximately four scales were removed with forceps from each side of the fish, above the lateral line and below the dorsal fin. These were placed directly in scale envelopes, on which the species, date, location and sample number were written. The fish was then placed in a wet nylon mesh bag and weighed with one of a series of Pesola® spring scales such that the weight of the fish and the bag combined was at least 10% of the scale capacity to maintain reasonable precision (Gutreuter and Krzoska 1994). The weight of the bag was subtracted from the total to determine the weight of the fish.

To remove the upper digestive tract contents, the fish was held ventral-side up in an inclined position with the mouth over a tub, while the ventral side was gently stroked anteriorly. Concurrently, a tube was inserted into the mouth, past the esophagus, and river water was gently pumped into the fish's stomach with a modified garden pump sprayer. This series of events forced the regurgitation of stomach contents into the tub (Giles 1980). Contents were then preserved in 10% formalin for lab identification. Each fish to be released was tagged with a 52-mm blaze orange 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 additionally identified with a hole punch in the upper caudal fin lobe. Fish were then placed back into the live well until fully recovered from the effects of the anesthesia, and released in the area where originally captured.

Approximately every fourth fish of each target species was sacrificed for tissue removal by overdosing with anesthetic. All of the above data collection procedures were followed, except that fish were neither tagged nor tail punched. To obtain gonads, a ventral incision was made longitudinally from the vent to the throat with scissors, and all gonadal materials were removed and preserved in 10% formalin. The upper digestive tract was cut open and examined to determine if any contents remained after pumping. All collected tissues and data were brought back to the lab for further analysis.

Sex of fish was determined using several methods. The sex of sacrificed fish was determined through direct examination of gonadal tissues. For live fish, sex was only determinable in mature adult Sacramento squawfish. For these fish, sex was determined by stroking the ventral surface posteriorly towards the vent in an attempt to induce the fish to express gametes. If no gametes were expressed, sex was determined by the shape and appearance of the genital opening using a combination of methods described for northern pike *Esox lucius* (Casselman 1974) and fat head minnow *Pimephales promelas* (Flickinger 1969). While the first two methods of sexual determination were 100% accurate, the latter method did not always reveal an obvious sexual identification, in which case no sexual identity was assigned.

Estimation of Abundance

Relative abundance.—Relative abundance was estimated from catch data of Sacramento squawfish and striped bass and expressed as catch per hour (CPH) at the diversion complex as well as the down-stream natural area. CPH 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.

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 number of seconds that the electricity was actually being pulsed through the water. Electricity was pulsed through the water for several seconds at a time, after which the electrical current was stopped for several seconds to allow any unseen fish (potentially adult salmon) to escape the electrical field. Angling effort was calculated for each person in the boat (usually 3) and is defined as the time a person was engaged in the act of fishing, including time for changing tackle, retrieving snagged lures, landing fish, etc.

Absolute abundance.—Numbers of squawfish and striped bass in the study area were affected by death and migration. Numbers were estimated for the catchable population using a Jolly-Seber experiment and program JOLLY as described by (Pollock et al. 1990). Sampling was conducted weekly. Estimates of population size in the study area were made monthly. The Jolly-Seber model makes the following four assumptions: (1) every fish that is alive and present in the population at the *i*th sample has the same probability of capture; (2) every tagged animal present in the population immediately after the *i*th sample has the same probability of survival until the $I + 1$ sampling time; (3) tags are not lost or overlooked; (4) all samples are instantaneous and each release is made immediately after the sample. Weekly samples were pooled into monthly samples to accommodate program JOLLY which can serve a maximum 50 sampling events.

Food Habits

Preserved stomach contents were separated into three categories and weighed. The three categories included: 1) whole juvenile salmonids and juvenile salmonid parts; 2) other fish and unidentifiable fish parts (sculpin, lamprey, adult salmon flesh, etc.); and 3) other (including rodents, frogs, crayfish and other invertebrates). Data are presented as percent frequency of occurrence and percent composition by wet weight for each prey category (Bowen 1983).

Life History

Aging.—Scales were cleaned and mounted between two glass microscope slides which were bound together with strapping tape at each end. Species, location, date and sample number were printed on the tape. Scales were viewed using a microfiche reader and aged by two independent readers (Jearld 1983; Welch et al. 1993). In cases of discrepancy between readers, scales were reread until readers were in agreement. In cases where agreement could not be met a third independent reader viewed the scales and the majority opinion was used. Annuli were noted as closely spaced rings that included characteristics of "overlapping" or "cutting over" (Jearld 1983; Orsi 1979).

Weight-length relations.—Weight-length relations for Sacramento squawfish and striped bass were described using the power equation:

$$W = aL^{b}$$

where, a and b are constants derived from regressing the logarithms (base 10) of wet weight (W) and fork length (L). Functional slopes and intercepts were estimated using simple linear regression.

Fork lengths were related to total lengths for both species. This allows a comparison to other studies which used only one of the two measurement techniques.

Gonadal development.—Preserved gonadal samples were rinsed in tap water, blotted dry with paper towels, and weighed on a Fisher® Model 200 Answorth Digital Scale to an accuracy of 0.01 g. Relative gonad weight (G_r) was determined for all fish with measurable gonads and calculated as follows:

$$G_r = (gonad\ weight\ X\ 100)/W_s$$

where W_s is the length specific standard weight predicted by the previously calculated weight–length regression (Strange 1996). Relative gonad weight was determined monthly and by sex, to quantify seasonal maturity and peak spawning period(s).

Length-at-age.—Striped bass and Sacramento squawfish were aged by reading scales. Length-at-age data were graphed to show the mean fork length and the range of lengths for each age class.

Monthly average age.—The average age of Sacramento squawfish was determined from scale readings for each month of the study in order to determine if there was a general increase in average age during the spawning season, indicating a migrational population of sexually mature adults moving into the Red Bluff area during that time period (March through June).

Apparent growth.—Growth curves for Sacramento squawfish were fitted to mean lengths-at-age using the von Bertalanffy equation:

$$l_t = L_\infty \left(1 - e^{-K(t-t_\phi)}\right)$$

where l_t is the length of a fish at time t, L_∞ is the asymptotic (theoretical maximum) fork length, K is the Brody growth coefficient and t_ϕ is the hypothetical age the fish would have been at zero fork length if it had always grown in the manner described by the equation (Ricker 1975).

Movement.—Movement of individual fish was determined as the distance between capture and recapture locations. Capture locations were recorded in river kilometers (rk). Rk is defined as the distance in kilometers along the main channel of the Sacramento River starting with rk 0 at Chipps Island at the mouth of the river. Kilometers moved and days between capture were used to calculate average daily movement. These data give the minimum possible movement since the fish were not continually tracked and there is the possibility that additional movement up and/or down stream occurred between captures.

Results

A total of 792 Sacramento squawfish and 88 striped bass were captured throughout the study period. Nearly all of the striped bass (98%) and most of the Sacramento squawfish (73%) were captured at the dam (Table 1). Among Sacramento squawfish, 484 were captured with angling and 308 with electrofishing. Among striped bass, 78 were captured with angling and 10 with electrofishing (Table 2).

Relative Abundance

CPH data for both electrofishing and angling indicate that the abundance of Sacramento squawfish and striped bass around the diversion complex structures was higher than at the downstream natural area throughout the year (Figures 3 through 6).

Angling CPH throughout the entire study area shows an increase in Sacramento squawfish relative abundance corresponding to the spring spawning season indicated by Figure 14 (see gonadal analysis section). The increase began in April prior to gates in, but the peak came in June after the gates had been in for some time (Figure 7). Striped bass did not appear in the study area until gates-in and they disappeared shortly after gates-out (Figure 8).

Jolly-Seber Experiment

Sacramento Squawfish.—Sampling events were pooled into 26 monthly samples. Estimates of squawfish population size within the study area were calculated from May 1994 to June 1996. The Jolly-Seber population estimate for squawfish (≥233 mm) ranged from N=32 in March 1995 to N=18,928 in May 1995 (Table 3; Figure 9). These estimates were calculated from a total of 589 tagged squawfish and 22 single recaptures and 3 double recaptures. The expected survival probability $E(\phi)$ for fish released during most sampling periods was estimated as zero because there were no subsequent recaptures of these fish in later months (R_i=0). This precluded estimates of confidence intervals for population estimates in most months. The reader should be cautious when interpreting these data as recaptures were sparse which may yield highly biased estimates.

Striped Bass.—Captured (N=103), tagged (N=92) and recaptured (N=1) striped bass were rare, preventing use of a Jolly-Seber experiment. Captured and tagged striped bass ranged from 305 to 950 mm FL.

Food Habits

Of 677 Sacramento squawfish stomachs sampled, only 162 (24%) contained food items. Percent frequency of occurrence for fish and fish parts not identified as juvenile salmonids was far greater than for juvenile salmonids or other food items in all seasons (Figure 10). The only season in which percent composition by weight of juvenile salmonids greatly outweighed other fish was in the summer during gates-in.

Due to the relatively small number of samples (N=56), and the short time period in which striped bass were caught (May through October), percent frequency of occurrence and percent composition by weight of striped bass stomach contents were not broken down by season. Instead, single percentage rates were calculated for the entire study period. Of 56 striped bass stomachs sampled, half (28) contained food items. Although percent frequency of occurrence shows a nearly even split between occurrences of juvenile salmonids and other fish, percent composition by weight shows that juvenile salmonids outweighed other fish three to one (Figure 11).

Life History

Weight–length relations.—A near perfect linear relationship was shown between fork length and total length for Sacramento squawfish (TL = 1.05FL + 8.35; r^2 = 0.991; N = 777) and striped bass (TL = 1.06FL + 6.10; r^2 = 0.998; N = 88).

A scatter plot graph of weight versus fork length for Sacramento squawfish (Figure 12) shows an isometric growth pattern with slope (b) of 3.13. A similar graph for striped bass (Figure 13) shows an asymmetric growth pattern with slope (b) less than three (2.85). The length specific weight (W_s) was calculated for all fish using these equations.

Gonadal analysis.—Monthly relative gonad weight (G_r) for Sacramento squawfish shows a peak in gonad development in March and April (Figure 14). The peak spawning season is indicated on these graphs by the decline in G_r in May and June which occurs as fish expel eggs and milt during spawning activities (Strange 1996).

A total of eight gonads were collected from striped bass, all of which were male specimens. Although the data are limited, they suggest a general spring spawning trend with a high G_r in the spring followed by a sharp drop off in the summer and a gradual rebuilding in the fall (Figure 15).

Age and growth.—Age determinations were made from the scales of 255 Sacramento squawfish and 75 striped bass. Sacramento squawfish ranged from one to ten years (65 to 624 mm; Figure 16; Table 4) and striped bass ranged from two to nine years (296 to 888 mm; Figure 17; Table 5). The asymptotic length for Sacramento squawfish calculated from the von Bertalanffy growth equation was 519 mm (Figure 18). Striped bass growth was linear in the sampled population suggesting a younger, actively growing population in the RBDD area (Figure 19).

Monthly average age.—There is a slight peak in monthly average age of Sacramento squawfish corresponding to the spring spawning season in May and June (Figure 20). A similar peak occurs in mid winter during the months of December and January.

Movement.—All fish were originally captured within two km of RBDD and there were no recaptures of Sacramento squawfish more than one km above the dam despite the fact that a tremendous amount of public angling (for trout and salmon) occurs in this area. Additionally, while most Sacramento squawfish were recaptured close to the point of their original capture, three fish were recaptured by public anglers far downstream (246, 303 and 378 km) indicating a long migrational episode (Figure 21; Table 6).

Striped bass also showed significant downstream movement with one fish being recaptured just north of Sacramento at the mouth of the Feather River. Of seven striped bass recaptures only one was found above RBDD at river kilometer 395 (Figure 22; Table 7).

Discussion

Abundance

Relative abundance.—Sacramento squawfish population densities within the study area are lower than historic levels and are far less than those found for northern squawfish in the Columbia River Basin. Predation by northern squawfish in the Columbia River Basin is a significant factor in the loss of out-migrating juvenile salmon (Poe et al. 1991). Numerous studies and programs have been implemented in an attempt to understand and alleviate this problem. However, the data show that the numbers and densities of Sacramento squawfish currently found below the RBDD do not compare to the magnitude of northern squawfish found below the dams on the Columbia and Snake rivers. In 1991, using electrofishing techniques similar to this study, the Oregon Department of Fish and Wildlife captured up to 112 northern squawfish (> 250 mm) per hour in the "boat restricted zone" of the tailrace area below Little Goose Dam. The average CPH for the areas below John Day, Lower Monument and Little Goose Dams was over 82 fish per hour (Ward et al. 1995). Comparing these results to the average electrofishing CPH behind RBDD (12.81 fish per hour) suggests Sacramento squawfish are nowhere near the densities found to be a problem in the Columbia Basin.

Comparing current data to those found in previous studies of Sacramento squawfish indicates that densities within the study area are much lower now than they were when the dam gates were left in year round. Angler surveys conducted in 1977, 1995 and 1996 show a trend of decreasing Sacramento squawfish catch per angler-hour. These were special community events intended to remove Sacramento squawfish from the RBDD area. A survey conducted during a special "permit angler day" in June 1977 resulted in 1.52 fish per angler-hour (Hallock and Hall 1977) which is much higher than 0.027 fish per angler-hour estimated during a squawfish derby in June of 1995 and 0.2 in August 1996 (Appendix 2; U. S. Fish and Wildlife Service, Northern Central Valley Fish and Wildlife Office, Red Bluff, California, unpublished data).

Another indication that Sacramento squawfish densities are lower now than they were in the past is the comparison between counts of Sacramento squawfish passing through the fish ladders at RBDD. Counts were made from 1969 to 1986 with gates in year round and since 1986 when ever the gates were lowered. Nearly four times as many Sacramento squawfish passed through the fish ladders in May and June of 1981 as did in 1994. In 1981 the total number of Sacramento squawfish passing through the fish ladders from May 1–31 was 2,491 and from June 1–30 it was 1,589. In 1994 the total for May was 701 and in June it was 384. This example shows one of the more extreme differences in monthly counts before and after the practice of removing the gates for extended periods began. However, the overall trend has shown a definite reduction in Sacramento squawfish passage since the raising of the gates became a standard practice in 1986 (unpublished USFWS data, Red Bluff, California).

There is additional evidence that Sacramento squawfish densities behind RBDD have continued to decrease even after the policy of raising gates for extended periods was implemented. In the spring of 1989, three years after the policy was first implemented, Laveen (1990) conducted a study which involved angling below RBDD with similar techniques and lures used in this study. Angling catch per unit effort for Laveen's study was not reported but the "best fishing occasion" is described as two anglers catching 77 Sacramento squawfish in less than three hours. This CPH of 12.8 fish far exceeds our best day (11 May 1994) of 15

Sacramento squawfish in 4.75 angler hours for a CPH of 3.2 fish. This apparent reduction in Sacramento squawfish densities may be attributable to the fact that the dam gates were lowered on April 1 in 1989, and not until May 1 in 1994, thereby allowing more Sacramento squawfish to pass before gates-in. Even during the study there was a marked decline in angling CPH below the dam between years when dam gates were lowered on May 1 (1994) and May 15 (1995 and 1996). Angling CPH for May of 1994 was 2.60 fish, and angling CPH for 1995 and 1996 were 0.66 and 0.50, respectively (Figure 23). CPH for May of 1995 and 1996 were calculated only from sampling events occurring after gates-in (between May 15 and 31).

Jolly-Seber Experiment.—Estimates of population size in the study area during 1995 suggest Sacramento squawfish are more abundant during the spring and summer months. In other study years no clear pattern of abundance was evident. These data should be viewed with caution as recaptures were sparse (R=25) and estimates are likely highly biased.

Past estimates of absolute abundance below RBDD ranged from 10,000 to 13,000 fish (Hall 1977). Hall's estimate was made in May and June 1977 when dam gates were always closed. His estimate is likely biased high because he assumed a closed population which would tend to over-estimate the number of marked fish at large. Hall felt his estimate reasonable since it was similar to passage counts of Sacramento squawfish made at the RBDD fishways during that period which ranged from 10,000 to 21,000 fish. These estimates are similar to those for May and June of 1995 in our study but much higher than other months.

The sparsity of recaptures suggest several possible explanations: abundance of Sacramento squawfish is low in the study area, tagged fish had high post-tagging mortality, long term tag retention was low or tagged fish moved quickly from the study area. Because capture rates of unmarked Sacramento squawfish was also low it suggests that both abundance and/or sampling efficiency was low.

Sampling events were pooled within months. This is a violation of assumption four of the Jolly-Seber experiment that all samples are instantaneous events. The ratio of recaptures to marked fish at large decreased over the duration of the experiment which suggests marked fish had a lower probability of capture than expected in the study area. This would tend to positively bias estimates of abundance, since there are fewer marked fish in the population than expected.

Future efforts to estimate absolute abundance at RBDD would benefit from increased sampling effort per sampling event. This would be accomplished by increasing angling or electrofishing effort, or by finding new techniques to more efficiently capture Sacramento squawfish. This may be difficult monetarily and logistically and depending on study objectives, probably unnecessary. The lack of recaptures and difficulty of placing adequate numbers of marked fish at large in the study area suggests that Sacramento squawfish probably are not numerous in the study area. This does not mean that they cannot be problematic in micro-habitats around manmade structures, such as the Research Pumping Plant. However, examination of micro-habitats will be more efficiently accomplished using relative abundance and radio-telemetry techniques.

Food habits

Juvenile salmonids were less important than other fish in the diets of Sacramento squawfish during gates-out (free-flowing riverine conditions). This emphasis on non-salmonids in Sacramento squawfish diets under free flowing conditions is supported by Brown and Moyle (1981) and Vondracek and Moyle (1983). The only time period when the dietary importance of these two food categories is reversed is during the summer months (gates-in) when the percent composition by weight of juvenile salmonids jumped to 66% of total weight of stomach contents, more than twice the weight of other fish and fish parts. This dietary shift toward juvenile salmonids may be attributed to several factors. First, this is the time period when the dam gates are in, altering the natural riverine habitat, so that migrating Sacramento squawfish may be held up and congregate below the dam. At the same time, outmigrating juvenile salmon are passing under the dam gates into extremely turbulent flows where they are likely to be momentarily disoriented and thus easier targets for predators. Additionally, there may be an element of prey size selectivity at work. The bulk of the young of the year fall run chinook salmon, which are by far the largest cohort in the river at that time (Johnson and Martin 1997), are reaching a size of about 90 mm (50–130 mm) during the summer season (Johnson et al. 1992) which is the preferred prey size for adult northern squawfish in the Columbia River (Poe et al. 1991). It is also worth noting that the majority of the lures used for angling in this study were colored and styled to imitate juvenile salmonids from 50 to 130 mm. This sampling technique may therefor have selectively sampled for fish which were keying in on juvenile fall run salmon and thus collected an inordinate number of salmon-eating Sacramento squawfish.

Striped bass showed a strong preference for juvenile salmonids as prey. Although Figure 11 shows that the percent frequency of occurrence for juvenile salmonids and other fish were nearly equal, it also shows that the percent composition by weight favored juvenile salmonids by a three to one ratio. Striped bass appeared to be keying on salmon coming under the dam gates as nearly all striped bass (90%) were captured behind the dam gates during gates-in periods (Figure 24; Table 1). Furthermore, 87% of striped bass captured during this study were angled, primarily with salmon-imitating lures, providing further evidence that striped bass were actively preying upon juvenile salmonids. (Table 2).

Life history

Growth rate and weight-length relations.—Sacramento squawfish captured in this study from the mainstem Sacramento River exhibited isometric growth (shape did not change with length) and are generally larger at a given age than those from tributary streams (Table 8). Similar trends in growth have been noted by other researchers comparing mainstem and tributary populations of Sacramento squawfish (Vondracek and Moyle 1982; Grant 1992). The weight-length relation for Sacramento squawfish generated by this study was similar to those of other researchers in the Sacramento River basin (Table 9; Figure 25)

Striped bass exhibited allometric growth (shape changed with growth tending to become less rotund with length), which is quite typical based on the comparison between this study and several studies of striped bass from the Atlantic coast (Table 10). The growth curve generated by this study fell in the middle of the other three curves (Figure 26).

Monthly average age.— The population of Sacramento squawfish sampled at RBDD were predominantly mature adults and showed only a slight increase in monthly average age during the spring spawning season (Figure 20). If all age classes were sampled equally, and a large migrational population of adult Sacramento squawfish moved through the study area during the spring spawning season, one would expect to see a significant increase in average age during those months, much like is seen in relative gonad weight (Figure 14). The fact that there is not a large spike in average age can be explained by several possible scenarios: 1) That there is no spawning migration and thus no influx of older fish during this period; 2) That there are only older fish in the study area year round; or 3) That the sampling methods and gear used in this study select for larger, older fish so that the majority of the catch are mature adults year round. This latter scenario seems the most likely. The majority of angling efforts involved the use of fairly large fish-imitating lures designed to catch striped bass as well as Sacramento squawfish, which likely selected for larger adult fish. In a study of size selectivity and biases among several northern squawfish sampling techniques on the Columbia River, Beamesderfer and Rieman (1988) showed that vulnerability to electrofishing and angling appeared to increase with size among northern squawfish up to 450 mm and fish in the 401–450 mm size range were approximately three times more vulnerable to these sampling techniques than fish smaller than 350 mm.

Recommendations and Future Plans

Although it does not appear as though the RPP has attracted high numbers of predators nor does it create extensive predator holding habitat, this phase of the study has addressed predator densities in the overall study area and not smaller micro-habitats around the pumping plant structures. In order to distinguish predator densities in these smaller areas, a closer investigation of the RPP will be carried out through modification of this study's sampling protocol as well as a new radio telemetry project which will track individual Sacramento squawfish behavior in and around the RPP and compare it to Sacramento squawfish activities in other parts of the study area.

Sampling protocol will be modified to more closely examine the RPP and to differentiate predator activity at that site from other sites in the study area. Six specific transects (Figure 27) will be uniformly sampled with both electrofishing and angling one day per week. The RPP has been broken into two transects to identify differences in predator abundance between the area directly in front of the trash racks where the pumps may alter river hydrology, and the sheet piling wall immediately downstream from the trash racks where a slow eddy and backwater may provide good resting and ambush habitat for predators. The other four transects include two at the dam, one at the bypass outfall structure and one at a relatively undisturbed control site well downstream from the man made structures. Sampling each site with both techniques for a specified period of time in each sampling day will more accurately identify similarities and differences in predator abundance at each site.

It has been very important to coordinate these studies with those being conducted by Reclamation to determine the effects of the RPP. Unnatural flow patterns in the vicinity of the pumping plant, or those caused by gate manipulations, could cause changes in passage for salmonids as well as potentially create new habitat for predators. Any such changes in flow patterns should be closely monitored. Continued coordination with Reclamation will be very important to ensure the best possible information is collected.

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Table 1.—Total number of Sacramento squawfish and striped bass captured at each of five sampling locations near Red Bluff Diversion Dam, Sacramento River, California from April 1994 through July 1996.

Species	Dam	RPP	Outfall	Altube	Other	Total
Sacramento squawfish	579	10	19	118	66	792
Striped bass	86	1	0	1	0	88

Table 2.—All species caught and observed near Red Bluff Diversion Dam, Sacramento River, California from April 1994 through July 1996, by each sampling technique. While many of the non-target species could easily have been caught, and some actually were brought to the boat for identification, all non-target species were counted as "observed" because they were not kept on board for any length of time and no data were taken from them.

	Number caught		Number observed		
Species	angling	electrofishing	angling	electrofishing	Total
Sacramento squawfish	484	308	34	214	1,040
striped bass	78	10	5	26	119
Sacramento sucker	0	0	4	11,229	11,233
hardhead	0	0	48	351	399
chinook salmon	0	0	68	540	608
steelhead (rainbow) trout	0	0	55	118	173
American shad	0	0	10	339	349
sturgeon	0	0	2	5	7
tule perch	0	0	2	10	12
largemouth bass	0	0	2	60	62
carp	0	0	2	31	33
blue gill	0	0	0	36	36

Table 3.—Absolute abundance estimates (N) of Sacramento squawfish at RBDD calculated by Jolly-Seber experiment for each month of the study, summer 1994 - spring 1996. Confidence intervals (CI) are $1-\alpha = 0.95$. The expected survival probability $E(\phi)$ for fish released during many sampling periods was estimated to be zero because there were no subsequent recaptures of these fish in later months (R_i=0); therefore, no confidence interval could be calculated during these months. These data should be viewed with caution as recaptures were sparse (R=25) and estimates are likely highly biased.

	1994		1995		1996	
Month	*N*	CI	*N*	CI	*N*	CI
January			648	——	308	——
February			288	——	810	——
March			32	——	486	——
April			355	——	387	0-1,191
May	39	——	18,928	——	234	0-757
June	695	0-2,337	8,454	——	34	——
July	1,705	——	384	——		
August	63	——	1,083	——		
September	63	——	2,242	——		
October	855	0-2,946	567	0-1,900		
November	784		151			
December	536	0-1,532	1,066	0-4,157		

Table 4.—Length-at-age statistics for Sacramento squawfish captured near Red Bluff Diversion Dam, Sacramento River, California from April 1994 through July 1996.

	Fork Length (mm)			
Age	n	Mean	SD	Range
1	2	81	16	65 - 97
2	24	301	64	156 - 385
3	80	383	60	243 - 554
4	78	448	64	315 - 624
5	43	457	61	324 - 604
6	24	494	43	383 - 547
7	2	529	28	502 - 557
9	1	607	--	--
10	1	452	--	--
Total	255	404	95	65 - 624

Table 5.—Length-at-age statistics for striped bass captured near Red Bluff Diversion Dam, Sacramento River, California from April 1994 through July 1996.

	Fork Length (mm)			
Age	n	Mean	SD	Range
2	6	359	39	310 - 419
3	26	399	50	296 - 505
4	25	482	38	408 - 564
5	9	576	44	520 - 650
6	5	663	64	573 - 770
7	1	704	---	---
8	2	846	42	805 - 888
9	1	950	---	---
Total	75	486	127	296 - 888

Table 6.—Recapture data for Sacramento squawfish captured near Red Bluff Diversion Dam, Sacramento River, California from April 1994 through July 1996, showing capture locations in river kilometers (rk), number of days between captures, kilometers between capture points and kilometers moved per day (negative numbers indicate downstream movement).

Date 1	Capture 1 (rk)	Date 2	Capture 2 (rk)	Days out	Movement (km)	Daily movement (km)
06/14/94	391	07/06/94	391	22	0.0	0.000
06/01/94	391	10/12/94	391	133	0.0	0.000
11/04/94	391	11/16/94	391	12	0.0	0.000
05/11/94	391	12/02/94	391	205	0.0	0.000
10/12/94	391	12/30/94	391	79	0.0	0.000
12/06/94	391	12/30/94	391	24	0.0	0.000
06/22/94	391	04/20/95	392	302	0.8	0.003
05/26/94	391	06/06/95	391	376	0.0	0.000
04/20/95	391	06/10/95	388	51	-3.2	-0.063
01/31/95	391	06/30/95	145	150	-246.3	-1.642
05/18/95	391	07/10/95	89	53	-302.7	-5.711
08/10/95	391	09/04/95	391	25	0.0	0.000
06/01/95	391	09/06/95	13	97	-378.4	-3.901
10/12/94	391	10/12/95	391	365	0.0	0.000
08/17/95	391	10/26/95	391	70	0.0	0.000
12/30/94	391	10/26/95	391	300	0.0	0.000
06/01/94	391	11/09/95	391	526	0.0	0.000
12/21/95	391	12/28/95	391	7	0.0	0.000
10/05/95	391	12/28/95	391	84	0.0	0.000
09/20/95	390	01/11/96	391	113	1.6	0.014
02/08/96	390	04/08/96	392	60	2.4	0.040
09/20/95	390	04/09/96	391	202	1.6	0.008
12/28/95	391	04/22/96	391	116	0.0	0.000
06/22/94	391	04/23/96	392	671	0.8	0.001
04/22/96	391	05/02/96	391	10	0.0	0.000
05/06/96	391	05/07/96	392	1	0.8	0.805
05/06/96	391	05/30/96	391	24	0.0	0.000
06/08/94	391	06/03/96	388	726	-3.2	-0.004
12/21/95	393	06/08/96	391	170	-1.6	-0.009
05/11/94	391	06/11/96	391	762	0.0	0.000
04/22/96	391	06/11/96	391	50	0.0	0.000
06/25/96	391	07/11/96	391	16	0.0	0.000
12/14/95	393	07/24/96	391	223	-1.6	-0.007

Table 7.—Recapture data for striped bass captured near Red Bluff Diversion Dam, Sacramento River, California from April 1994 through July 1996, showing capture locations in river kilometers (rk), number of days between captures, kilometers between capture points and kilometers moved per day (negative values indicate downstream movement).

Date 1	Capture 1 (rk)	Date 2	Capture 2 (rk)	Days out	Movement (km)	Daily movement (km)
5/26/95	391	8/16/95	386	82	-5	-0.06
6/29/95	391	9/30/95	370	93	-21	-0.23
6/14/94	391	3/07/95	145	266	-246	-0.92
6/25/96	391	7/23/95	391	28	0	0.00
6/08/94	391	7/30/94	320	52	-71	-1.37
6/29/94	391	9/24/94	395	87	4	0.05
6/08/94	391	8/22/94	296	75	-95	-1.27

Table 8.—Length-at-age relations for Sacramento squawfish as given by several investigators.

		Length-at-age (mm)								
Author	Drainage	1	2	3	4	5	6	7	8	9
This study	Mainstem Sacramento	81	301	383	444	457	494	529		607
Moyle et al. (1983)	N. Fork Feather Ri.	104	168	241	317	346	385	433		
Vondracek and Moyle (1982)*	Stony Creek	131	204	266	317	358	404	442		
Brown (1990)	Bear Creek	144	201	257	262	304				

* Lengths reported are standard lengths.

Table 9.—Comparisons between weight-length relations for Sacramento squawfish reported from five different locations. W = weight in grams, FL = fork length in mm and SL = standard length in mm.

Author	Drainage	Equation
This study	Mainstem Sacramento River	log W = 3.13 log FL - 5.32
Grant (1992)	Pine Creek	log W = 3.00 log FL - 5.00
Brown (1990)	Bear Creek	log W = 2.85 log SL - 4.48
Vondracek and Moyle (1982)	Thomes Creek	log W = 2.88 log SL - 4.61
Vondracek and Moyle (1982)	Stony Creek	log W = 2.90 log SL - 4.67

Table 10.—Comparisons between weight-length relations reported from five different studies of striped bass *Morone saxatilis*. W = weight in grams, FL = fork length in mm and TL = total length in mm.

Author	Drainage	Equation
This study	Sacramento River	log W = 2.85 log FL - 4.48
Bulak et al. (1995)	Congaree Ri., SC	log W = 2.83 log TL* - 4.44
Magnin and Beaulieu (1967)	St. Lawrence River, Quebec	log W = 3.01 log FL - 4.85
Harris (1988)	Annapolis River, Nova Scotia	log W = 2.94 log FL - 4.78

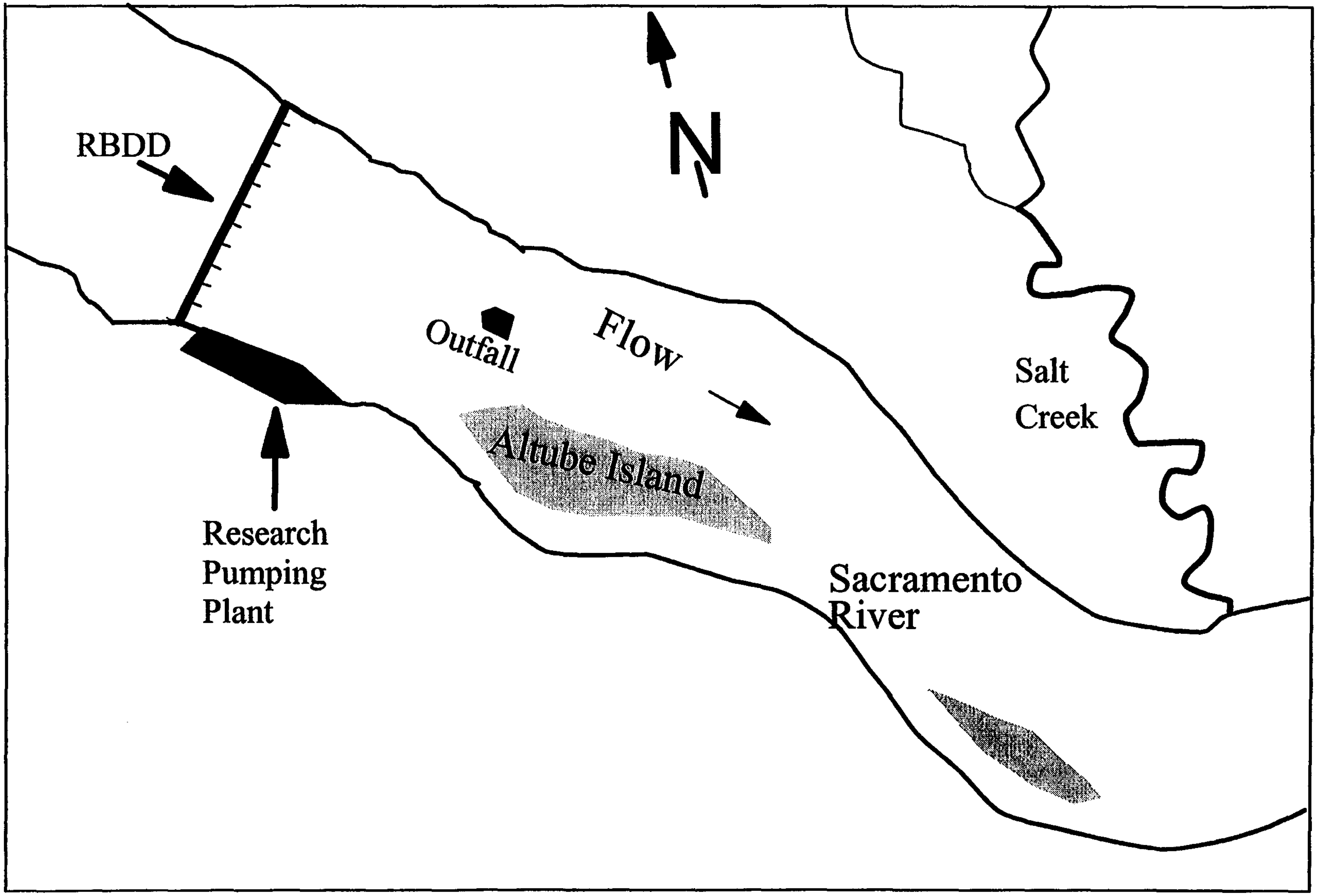

Figure 1.--Overhead view of study area at Red Bluff Diversion Dam (RBDD) on the Sacramento River.

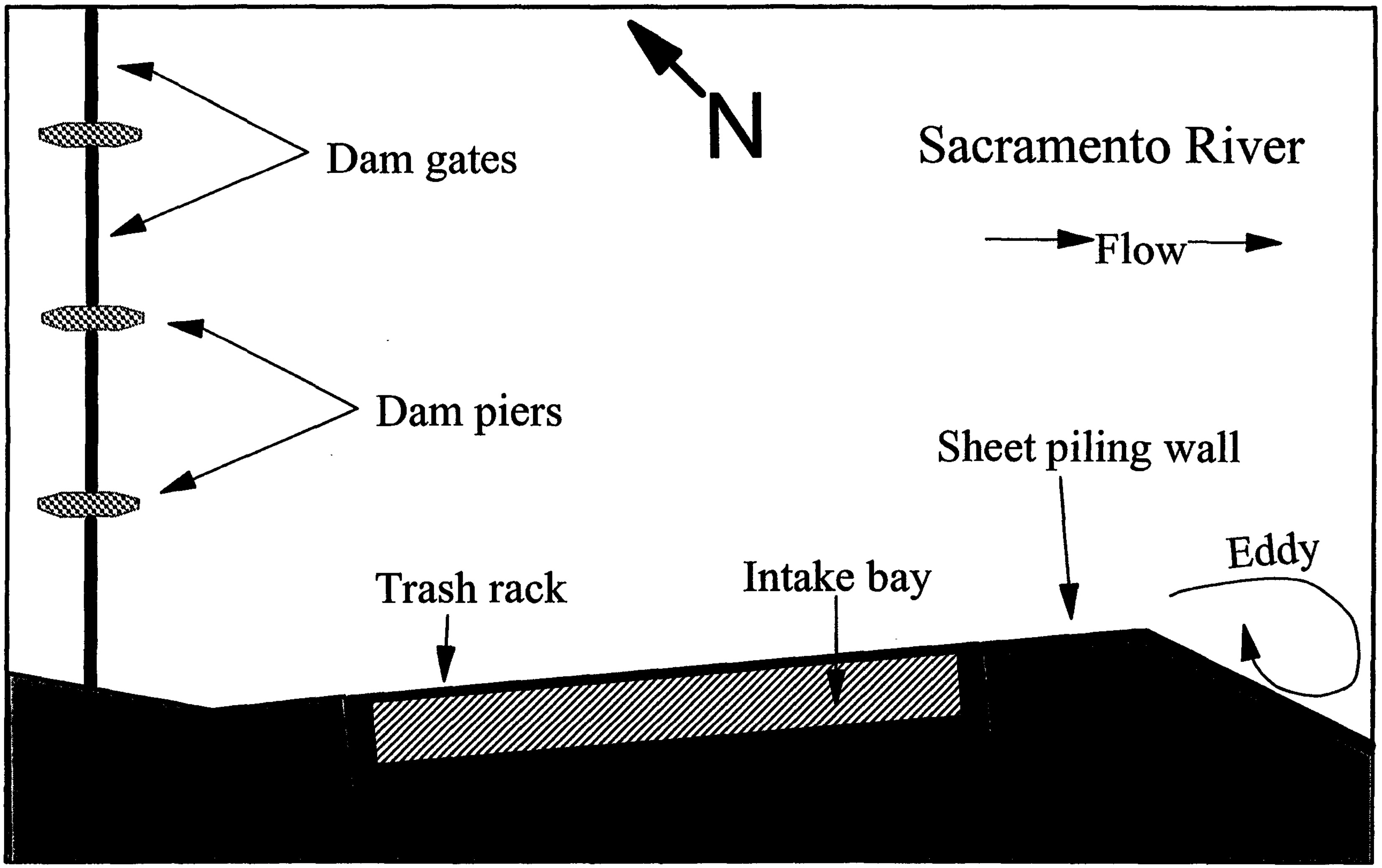

Figure 2.-- Plan view of in-river portions of the Research Pumping Plant and the southwest end of Red Bluff Diversion Dam (not to scale).

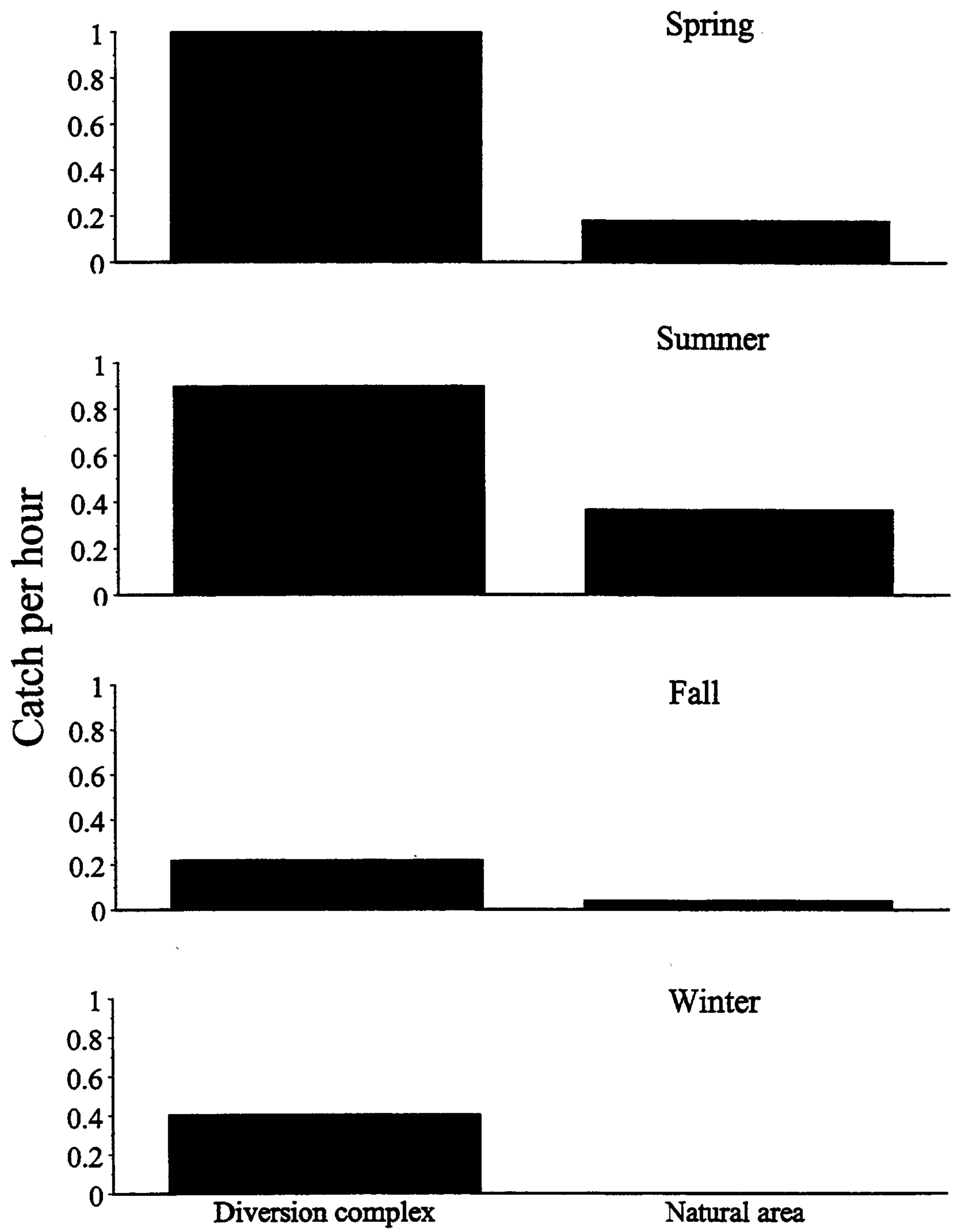

Figure 3.--Angling catch per hour by season for Sacramento squawfish captured near Red Bluff Diversion Dam, Sacramento River, California from April 1994 through July 1996.

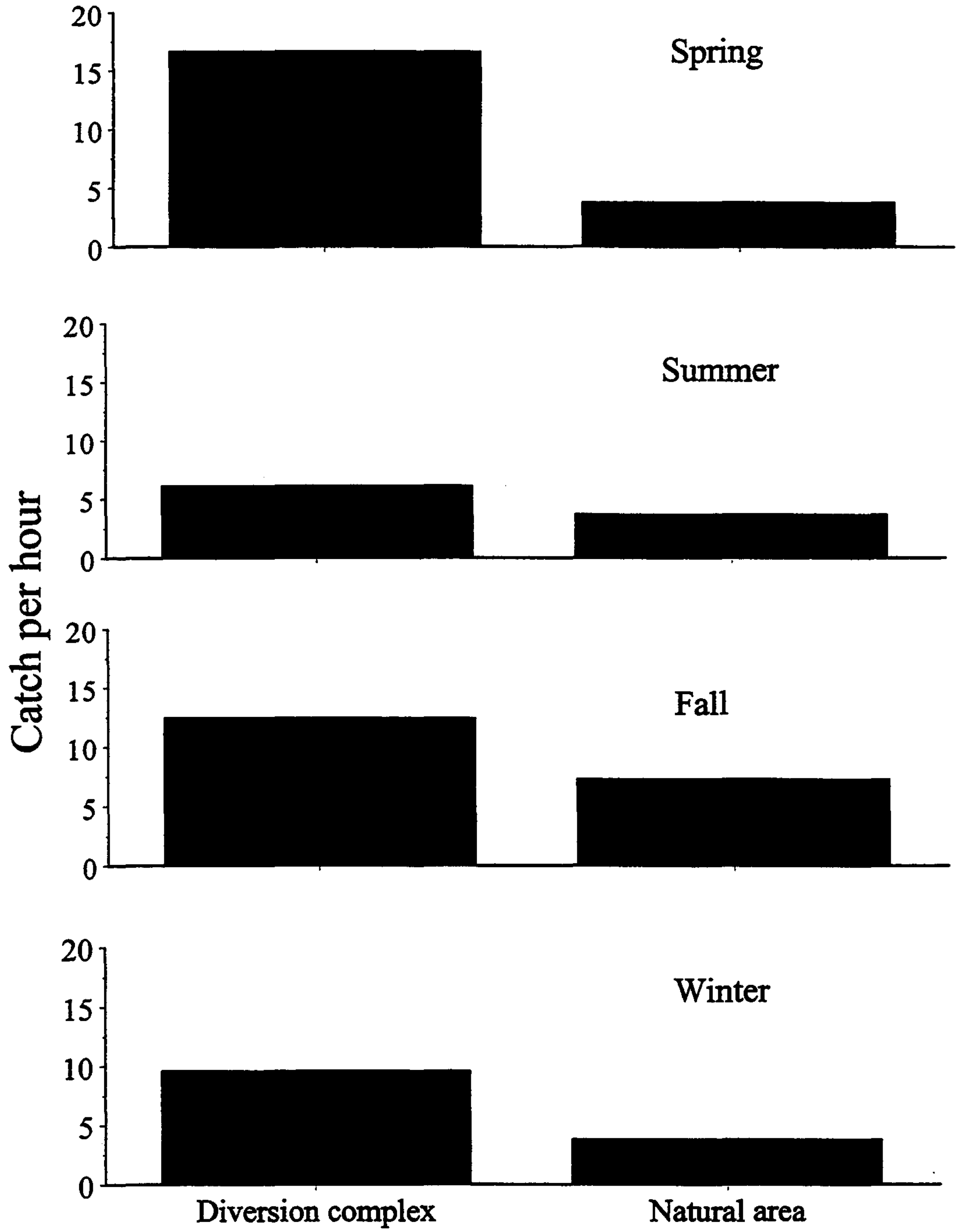

Figure 4.--Electrofishing catch per hour by season for Sacramento squawfish captured near Red Bluff Diversion Dam, Sacramento River, California from April 1994 through July 1996.

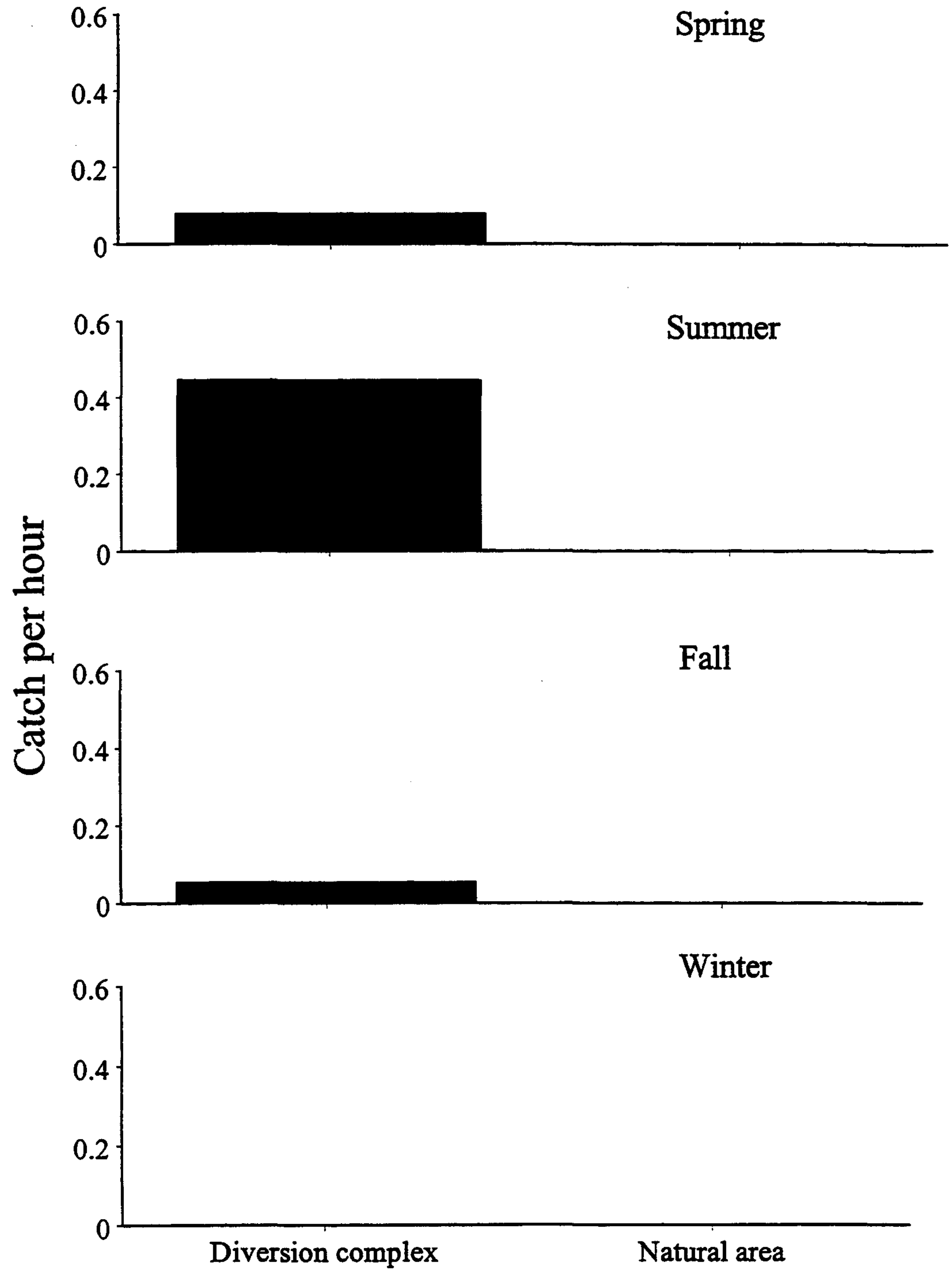

Figure 5.--Angling catch per hour by season for striped bass captured near Red Bluff Diversion Dam, Sacramento River, California from April 1994 through July 1996.

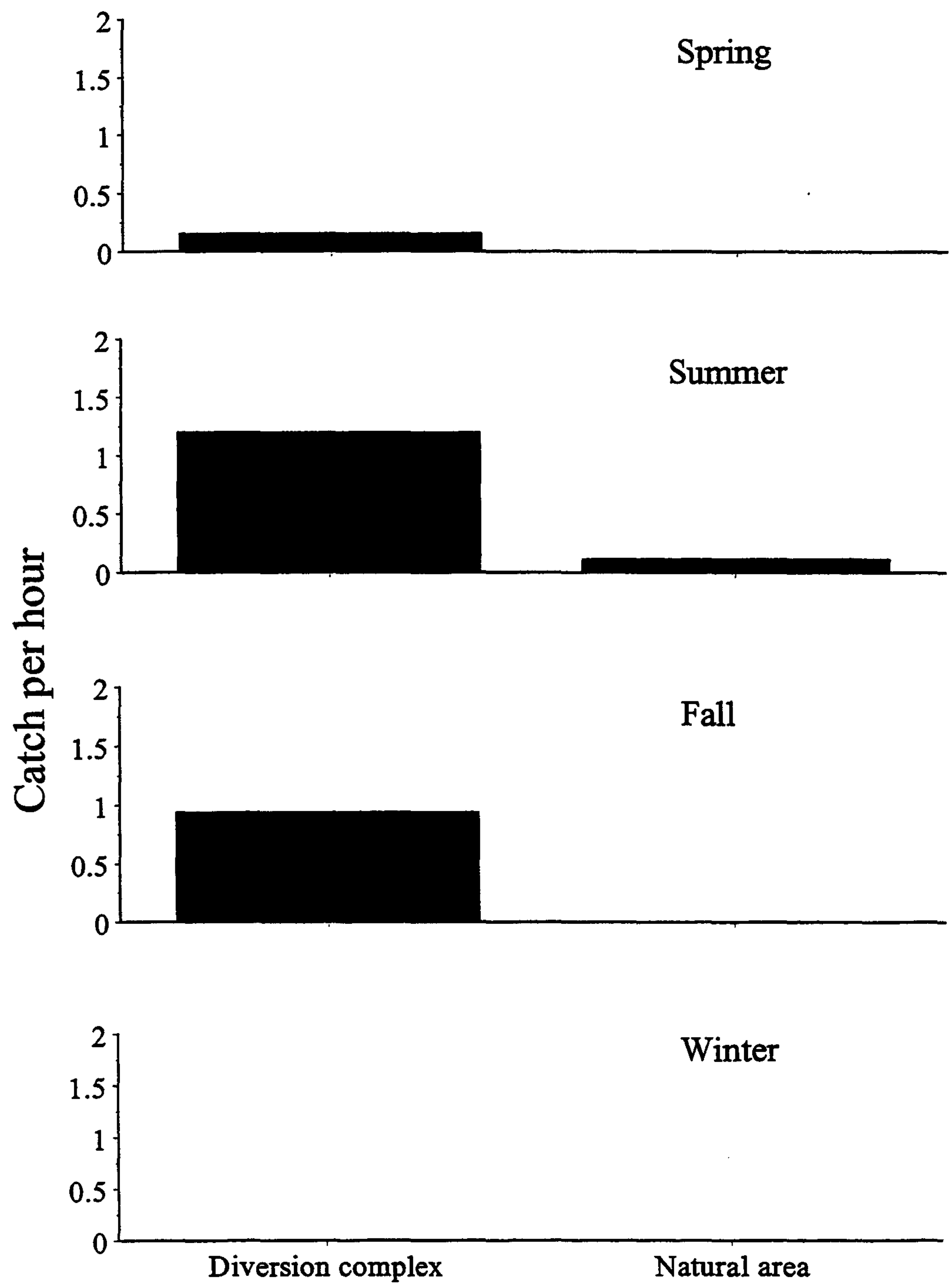

Figure 6.--Electrofishing catch per hour by season for striped bass captured near Red Bluff Diversion Dam, Sacramento River, California from April 1994 through July 1996.

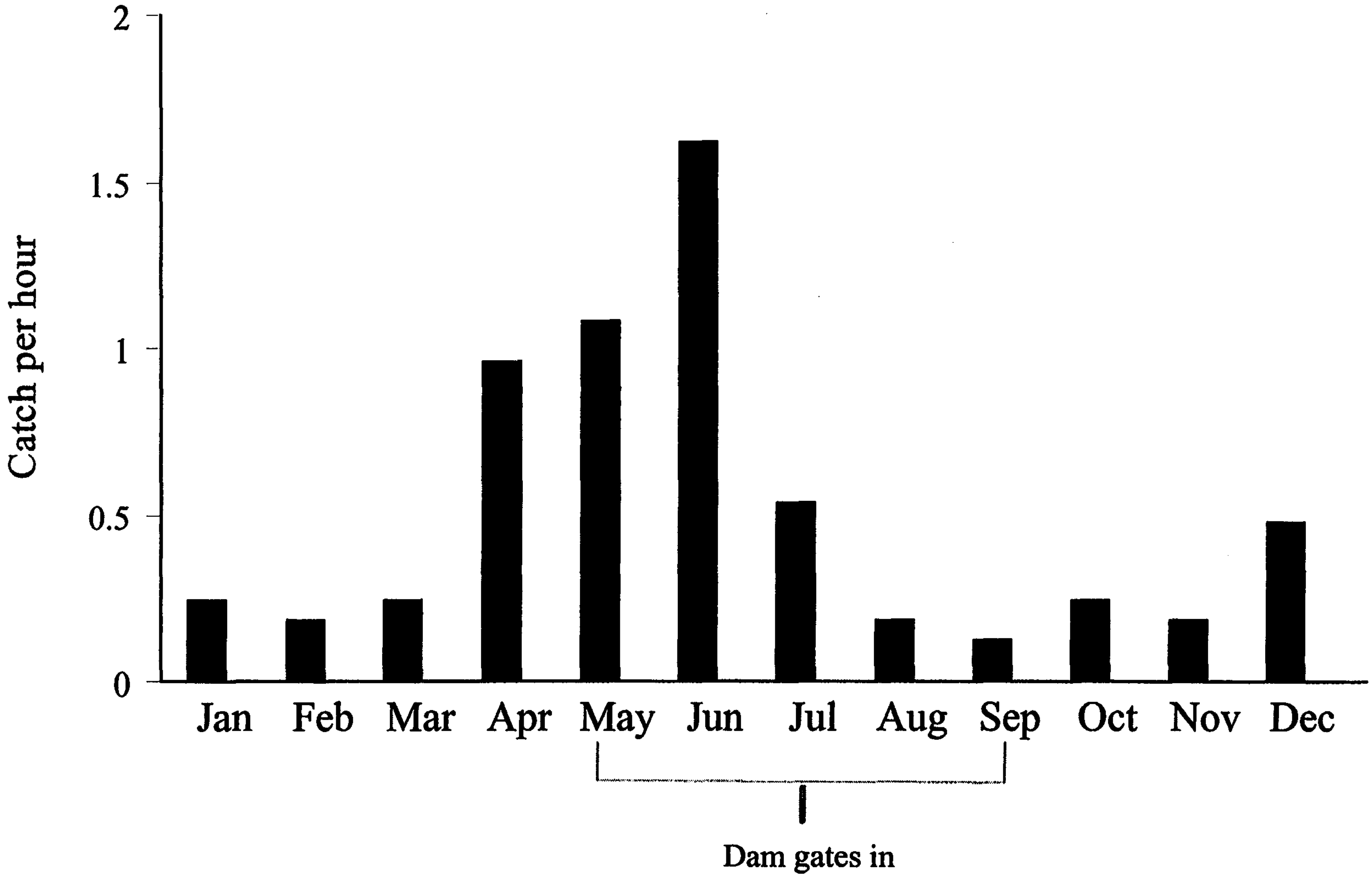

Figure 7.--Monthly average angling catch per hour for Sacramento squawfish captured near Red Bluff Diversion Dam, Sacramento River, California, from April 1994 through July 1996.

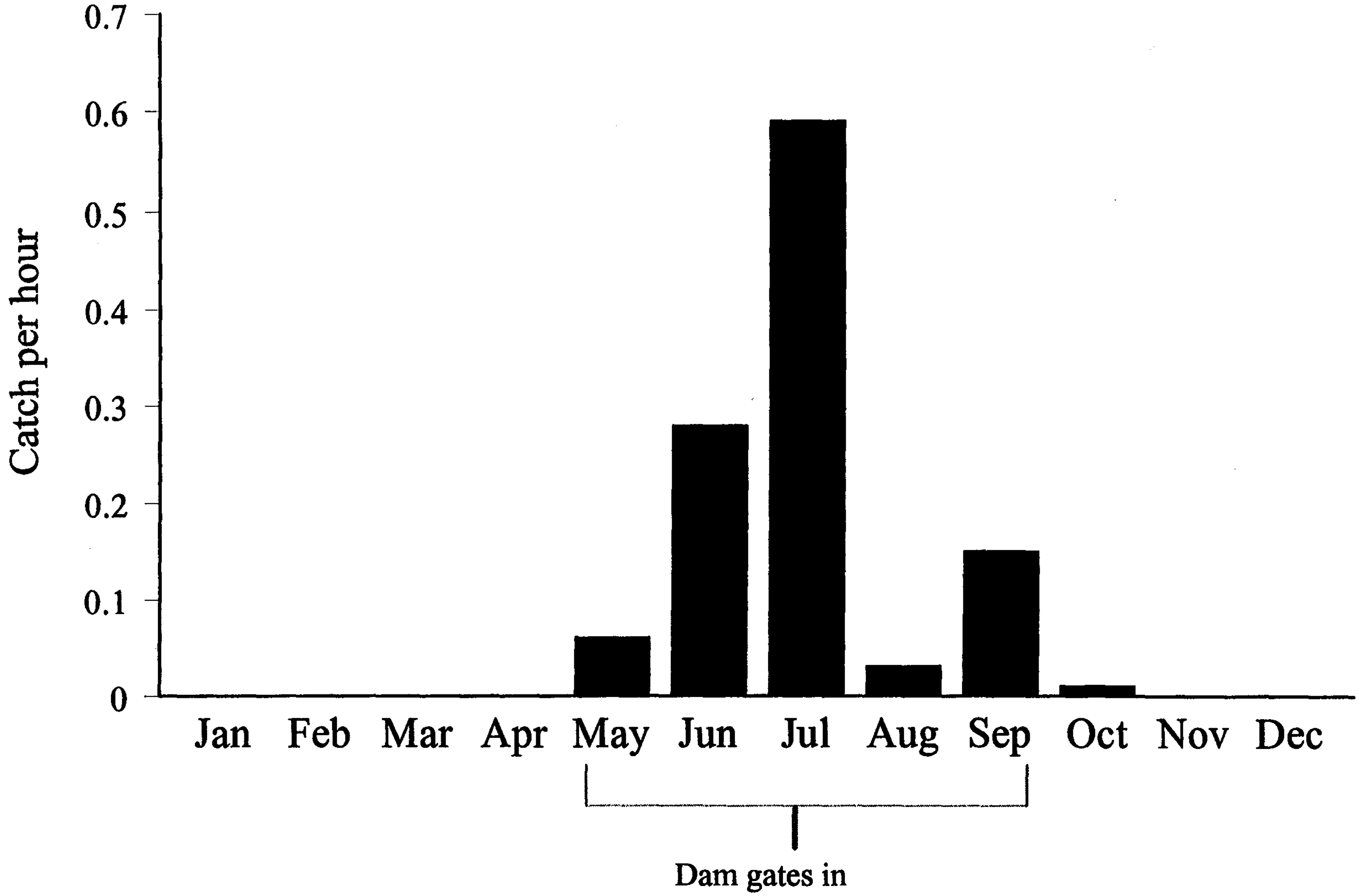

Figure 8.--Monthly average striped bass angling catch per hour for striped bass captured near Red Bluff Diversion Dam, Sacramento River, California, from April 1994 through July 1996.

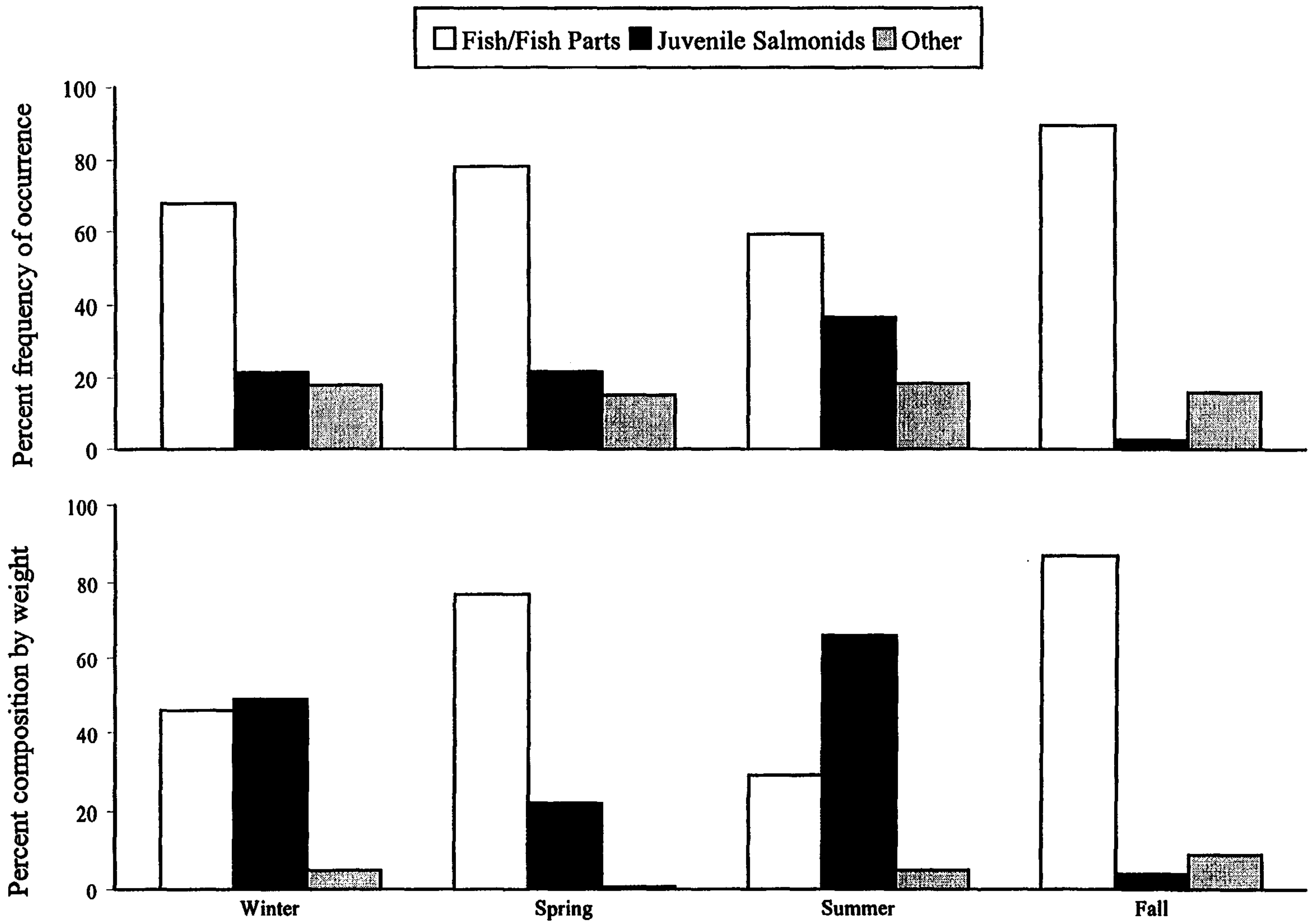

Figure 9.--Percent frequency of occurrence and percent composition by weight of stomach contents in Sacramento squawfish (N=162) captured near Red Bluff Diversion Dam, Sacramento River, California, from April 1994 through July 1996. The "fish and fish parts" category includes all such materials which were not identified as juvenile salmonid. The "other" category includes rodents, frogs, crayfish and other invertebrates.

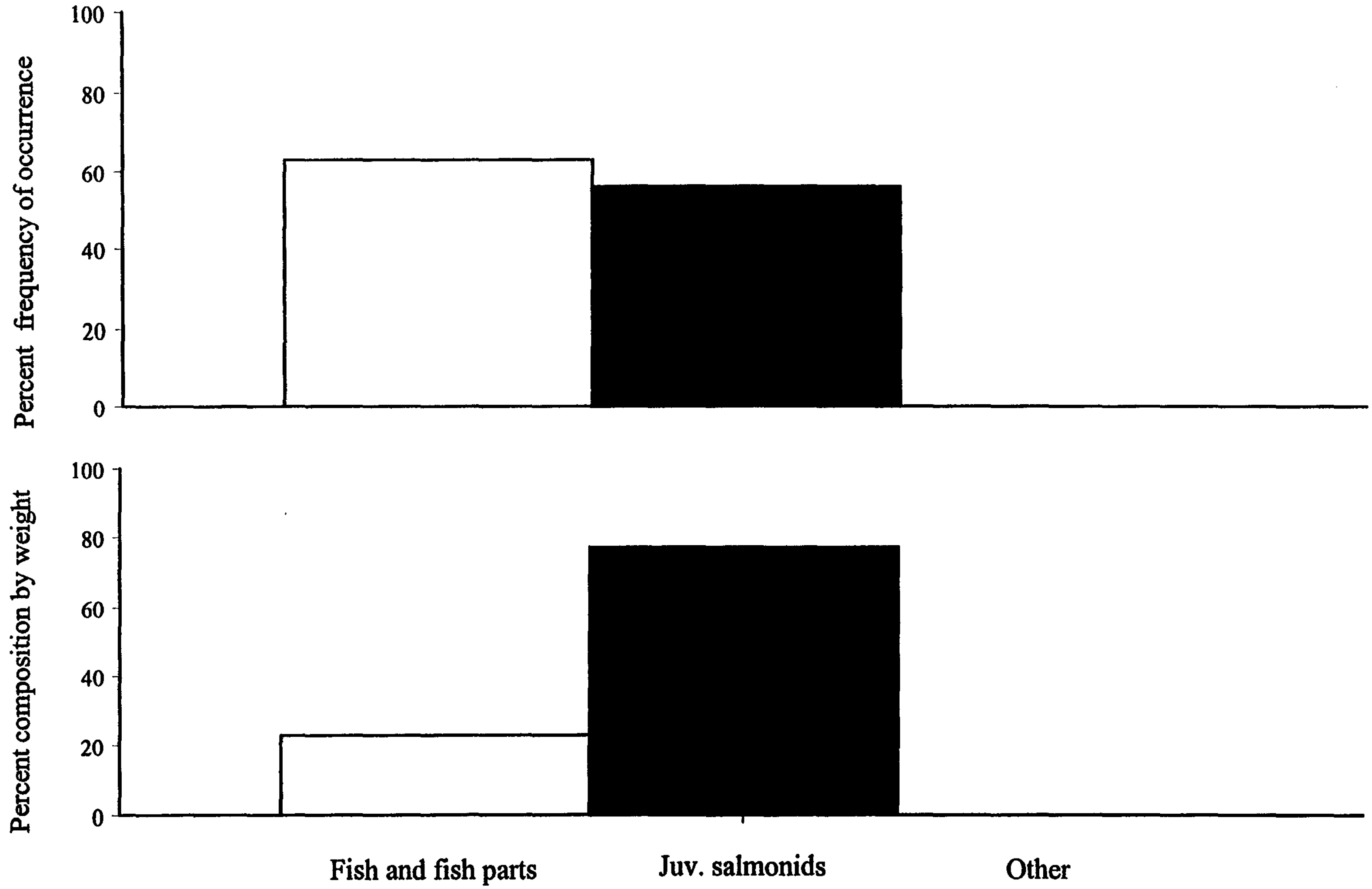

Figure 10.--Percent frequency of occurrence and percent composition by weight of stomach contents in striped bass (*N*=28) captured near Red Bluff Diversion Dam, Sacramento River, California, from April 1994 through July 1996. The "fish and fish parts" category includes all such materials which were not identified as juvenile salmonid. The "other" category includes rodents, frogs, crayfish and other invertebrates.

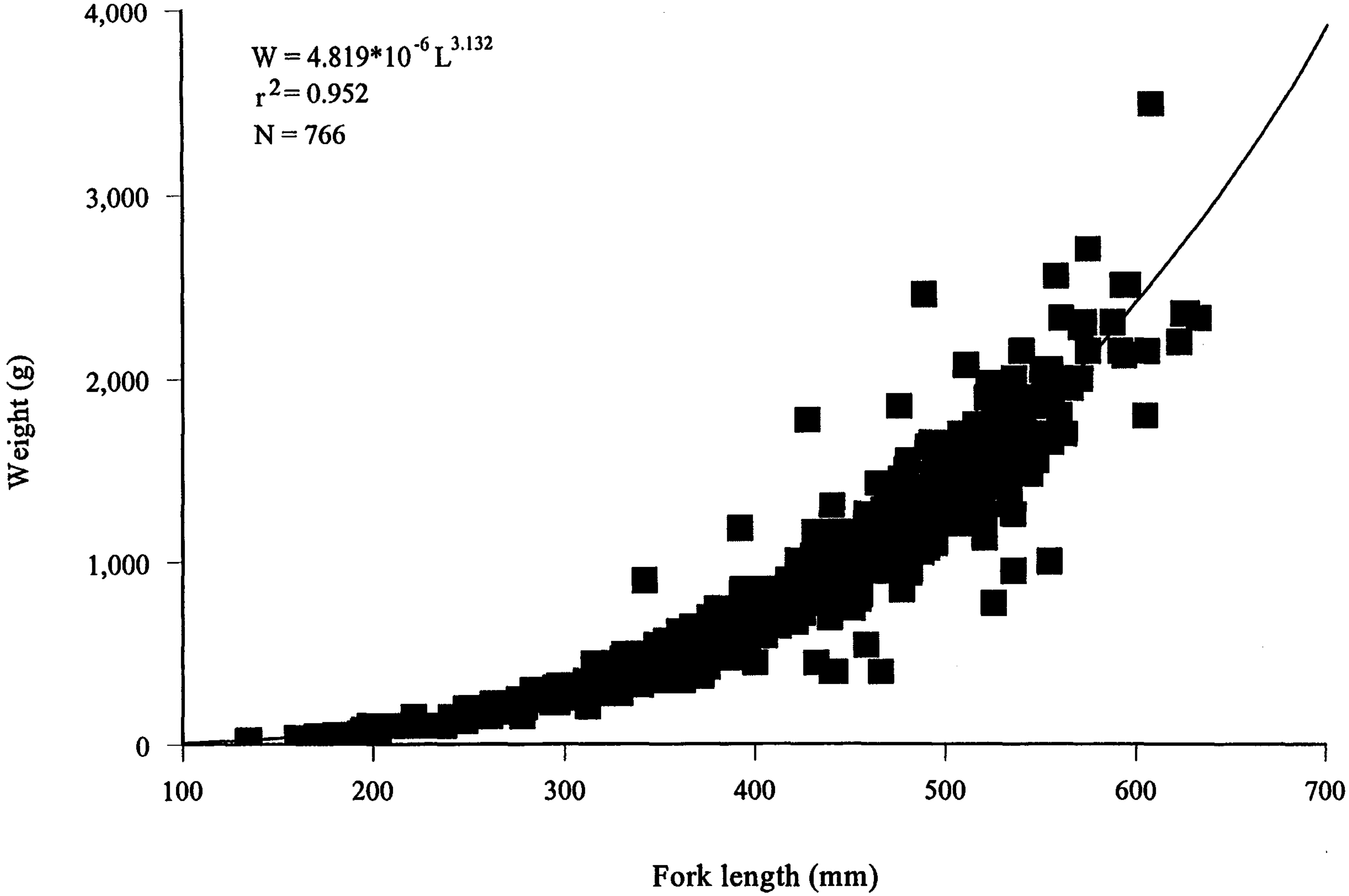

Figure 11.--Weight-length relation for Sacramento squawfish captured near Red Bluff Diversion Dam, Sacramento River, California, from April 1994 through July 1996.

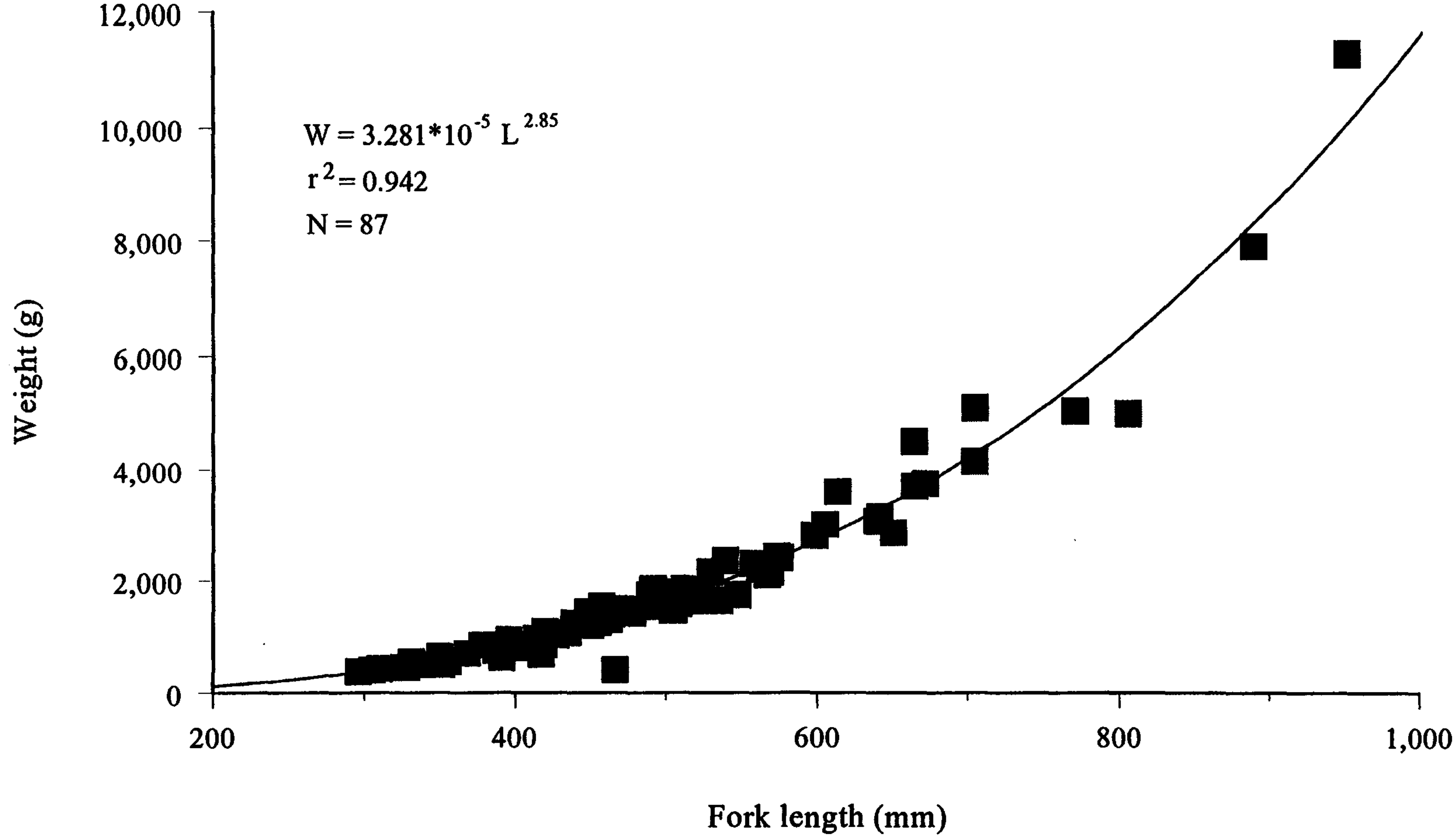

Figure 12.--Weight-length relation for striped bass captured near Red Bluff Diversion Dam, Sacramento River, California from April 1994 through July 1996.

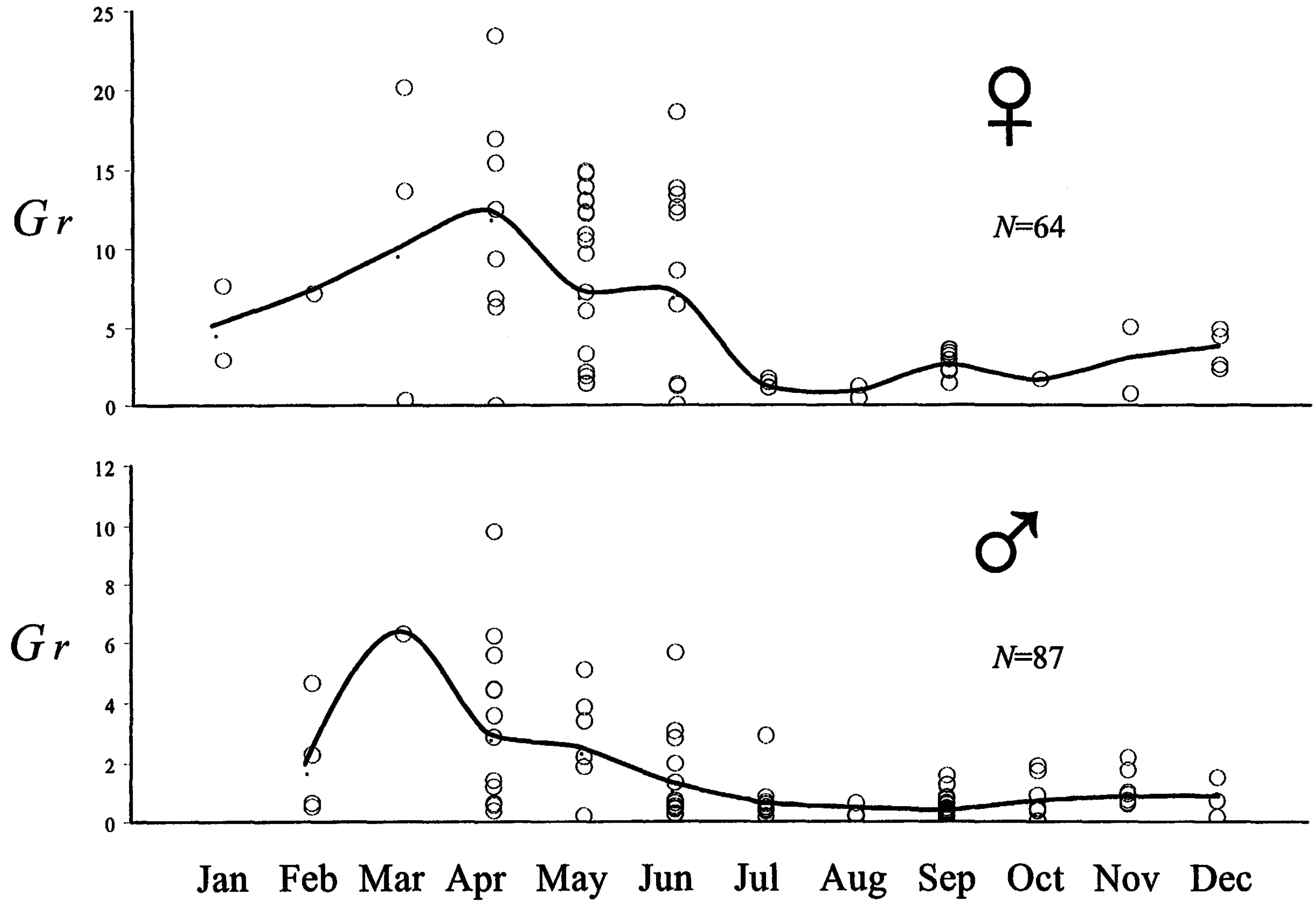

Figure 13.--Monthly relative gonad weight (Gr) for individual male and female Sacramento squawfish captured near Red Bluff Diversion Dam, Sacramento River, California, from April 1994 through July 1996. Lines run through the monthly mean values.

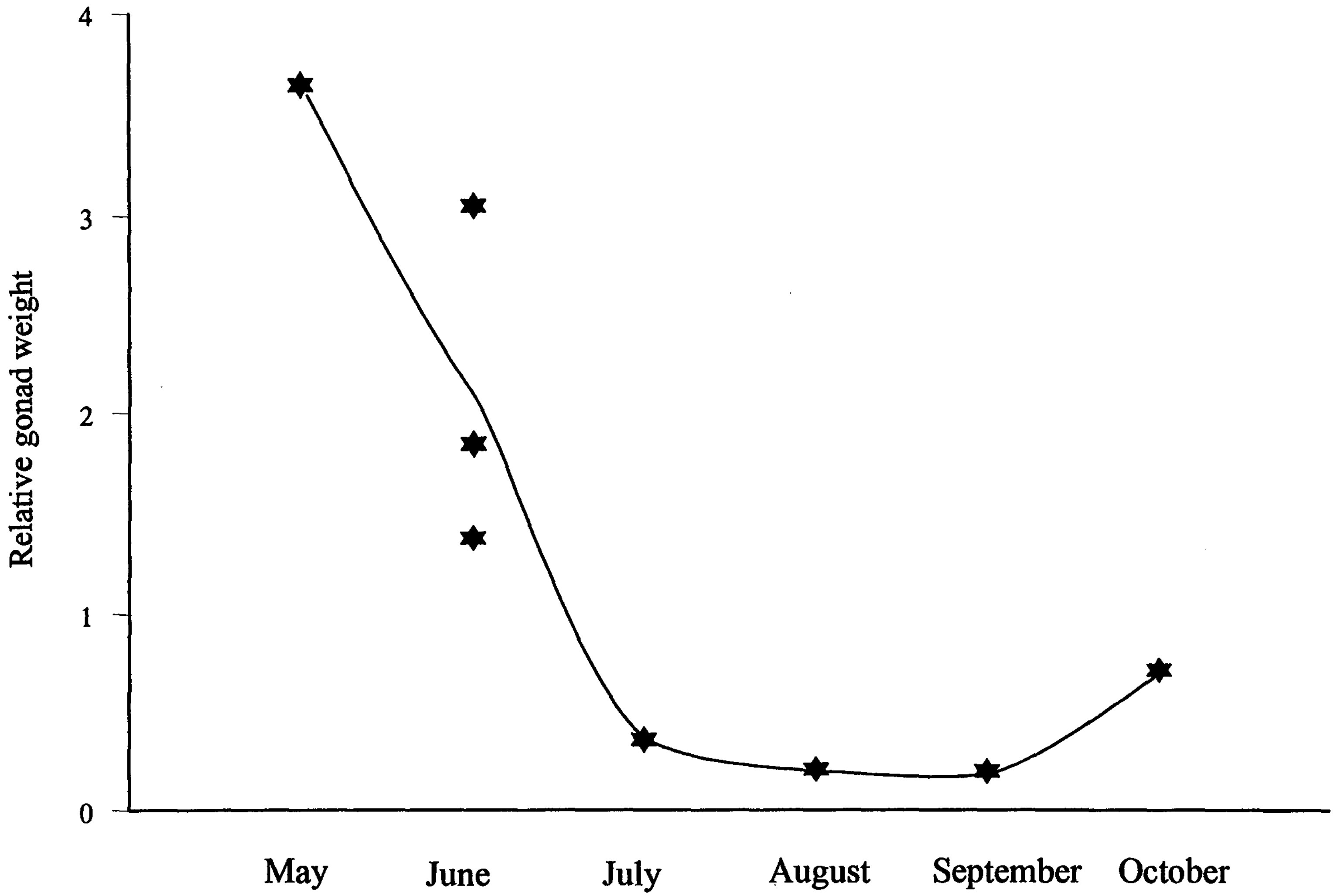

Figure 14.--Relative gonad weight (*Gr*) for male striped bass (*N*=8) captured near Red Bluff Diversion Dam, Sacramento River, California from April 1994 through July 1996.

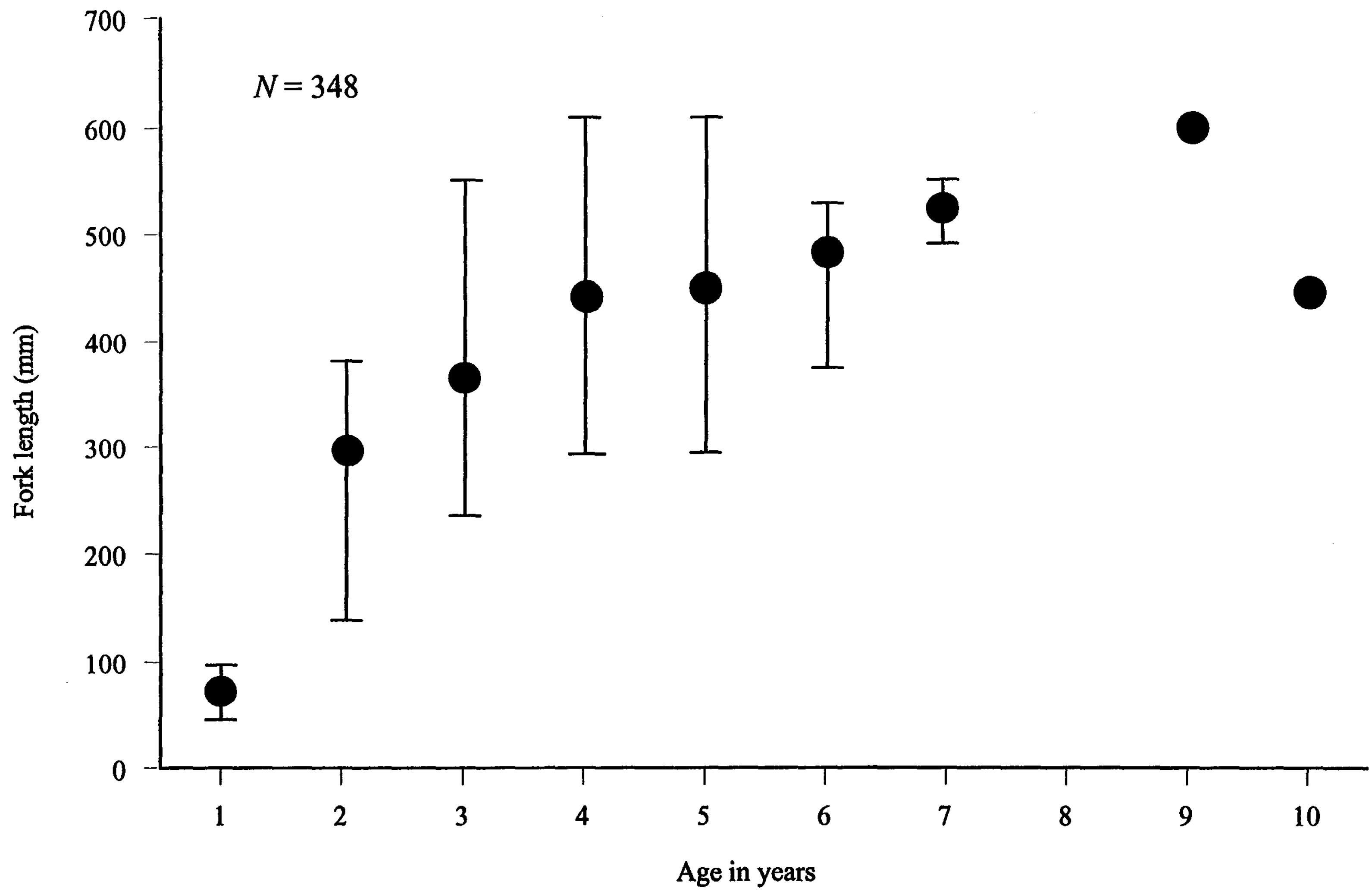

Figure 15.--Length at age data for Sacramento squawfish captured near Red Bluff Diversion Dam, Sacramento River, California from April 1994 through July 1996. Dots show the mean fork length in mm for each age class while bars show the range of fork lengths for that age class.

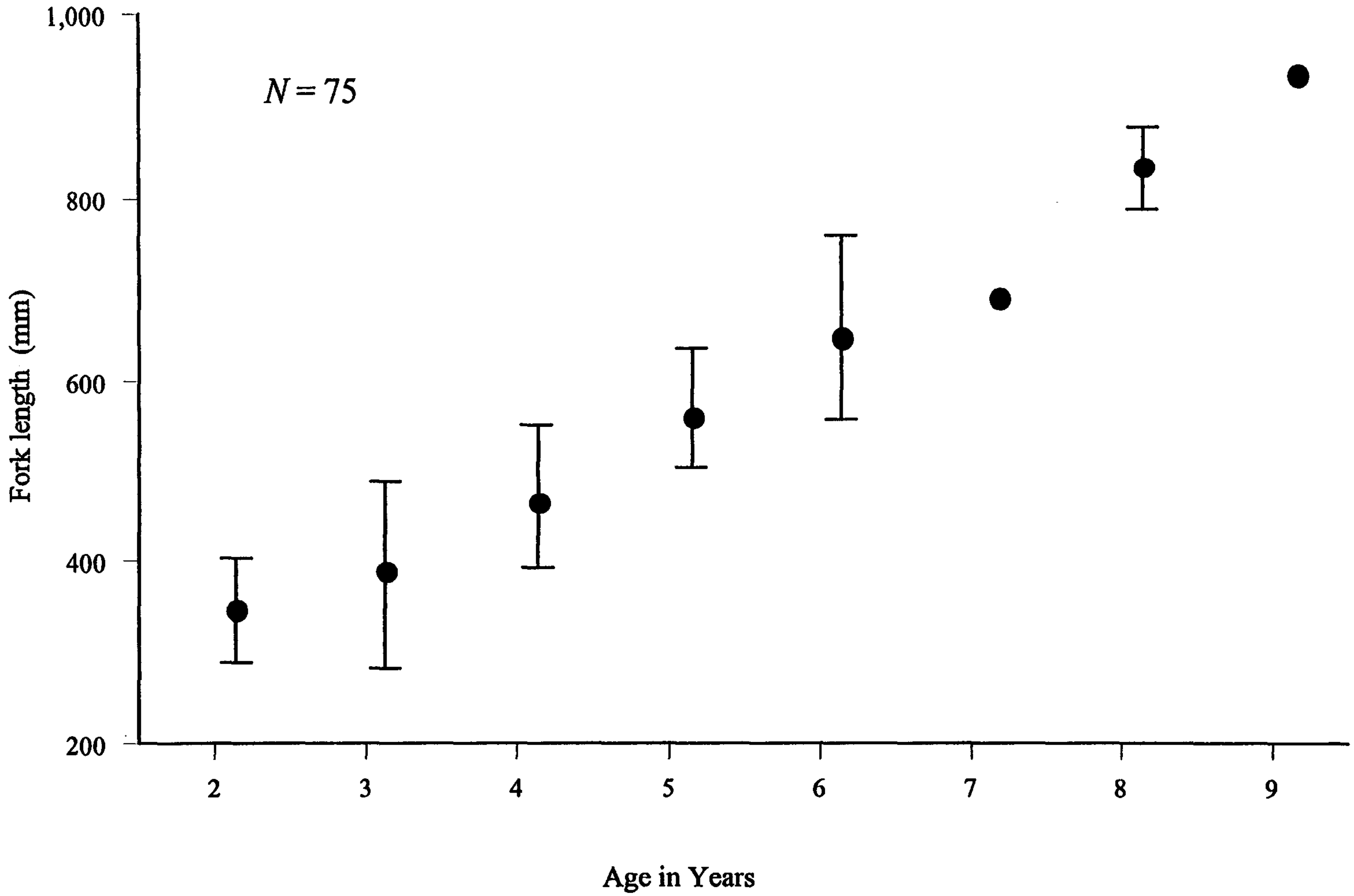

Figure 16.--Length at age data for striped bass captured near Red Bluff Diversion Dam, Sacramento River, California from April 1994 through July 1996. Dots show the mean fork length in mm for each age class while bars show the range of fork lengths for that age class.

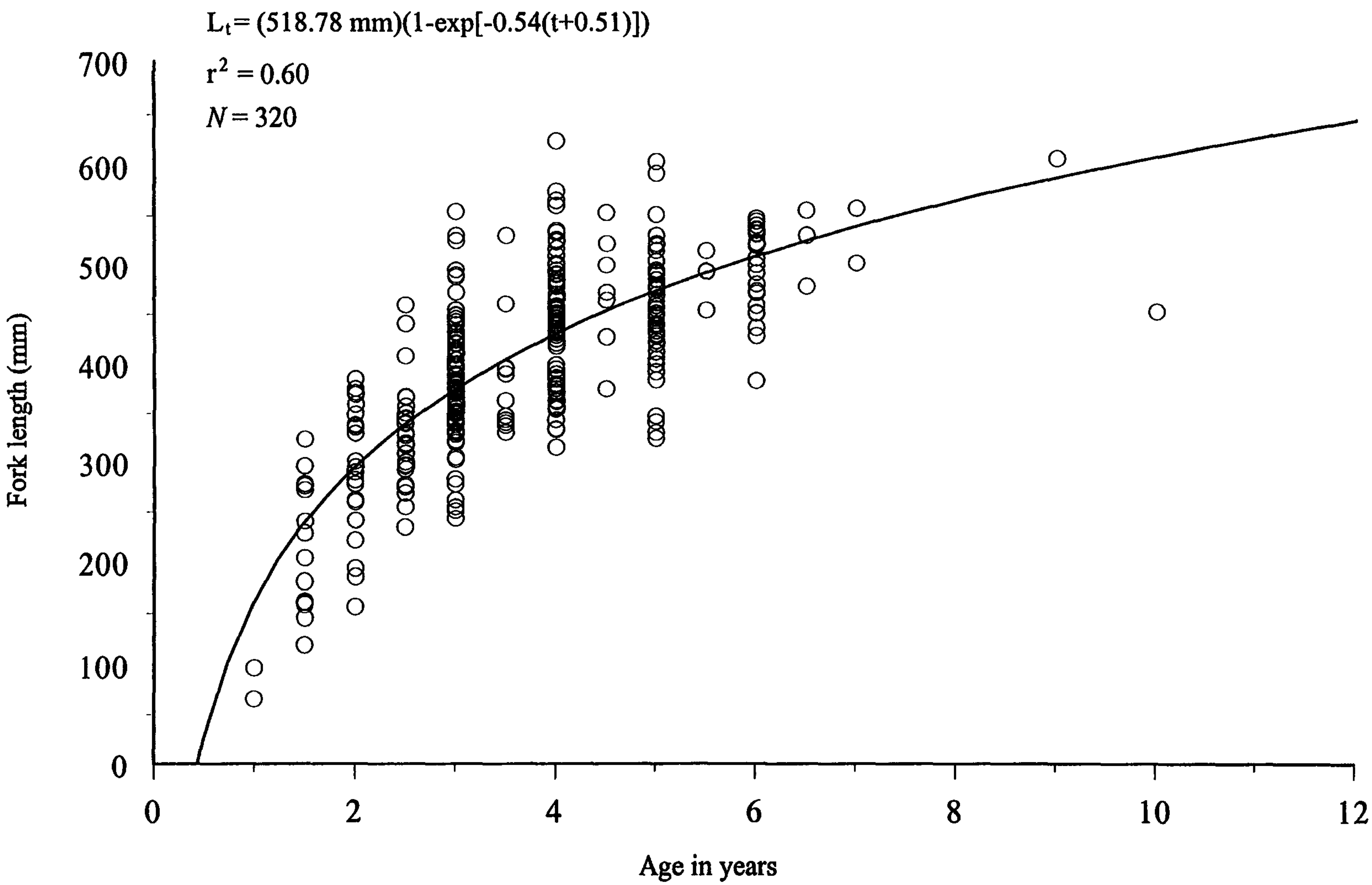

Figure 17.--Von Bertalanffy growth equation and lengths at age for Sacramento squawfish captured near Red Bluff Diversion Dam, Sacramento River, California from April 1994 through July 1996.

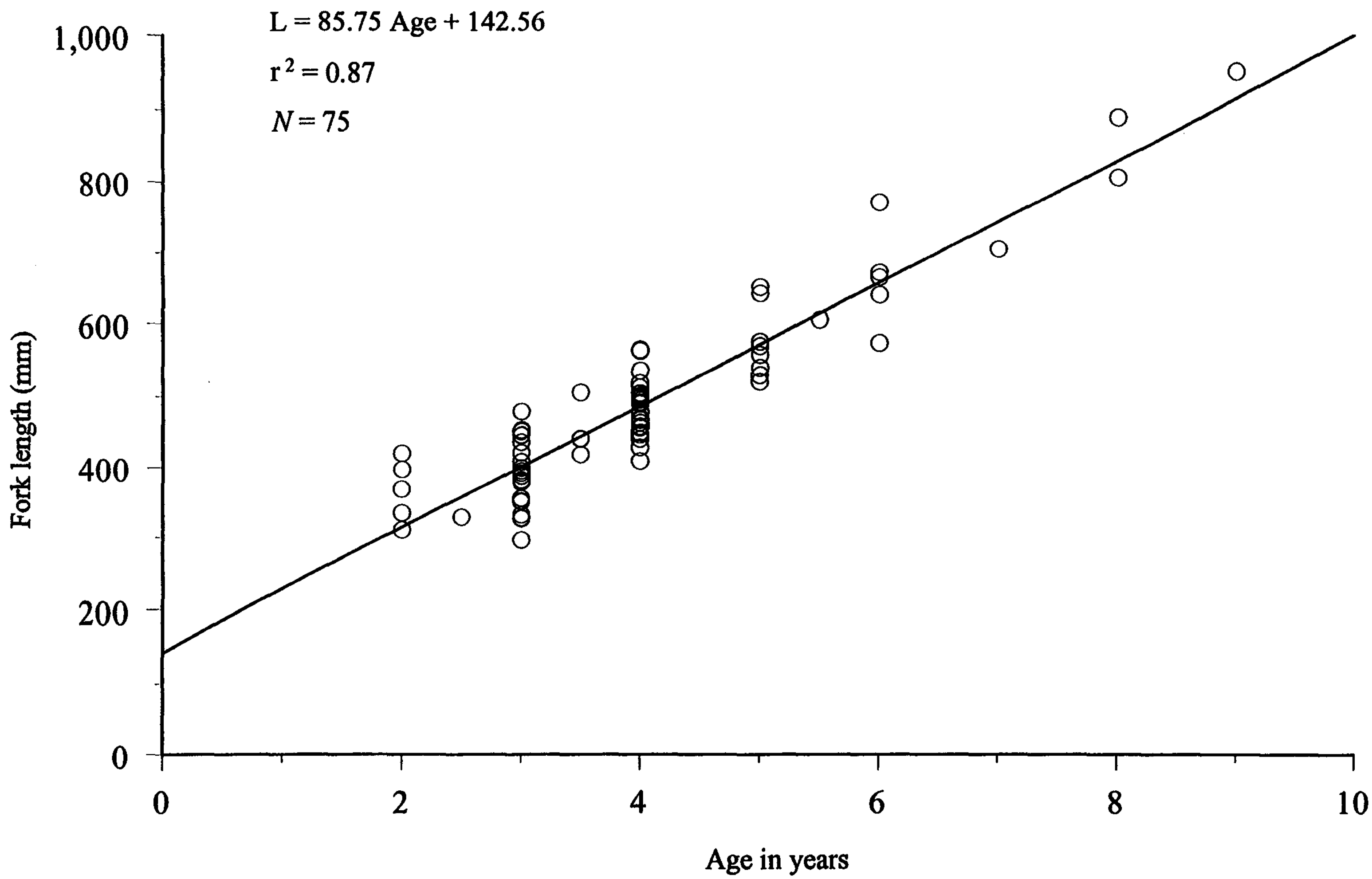

Figure 18.--linear growth equation and lengths at age for striped bass captured near Red Bluff Diversion Dam, Sacramento River, California from April 1994 through July 1996.

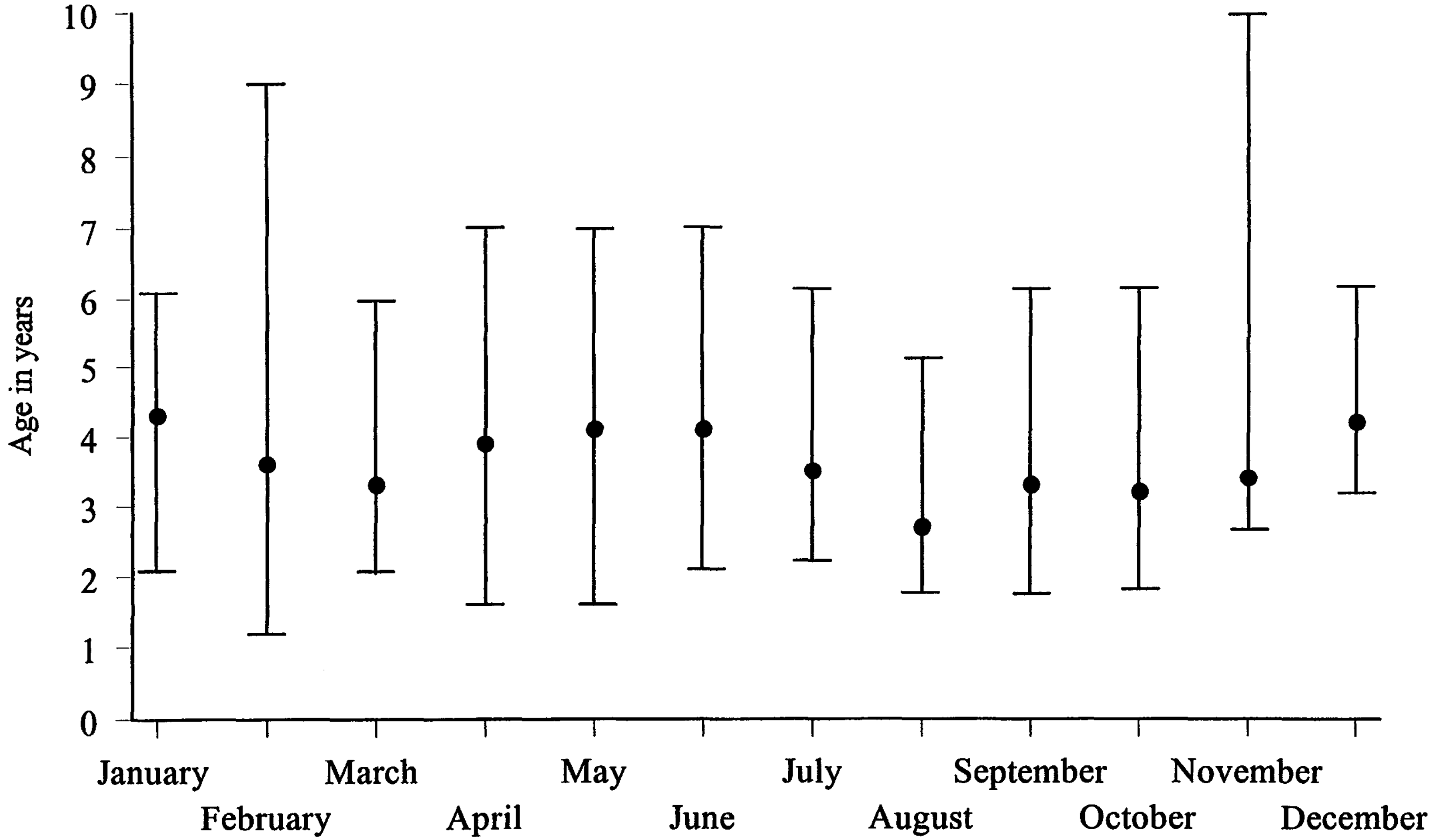

Figure 19.--Monthly average age of Sacramento squawfish captured near Red Bluff Diversion Dam, Sacramento River, California taken over entire study period (April 1994 through July 1996). Points show the mean age for each month while bars show the range of ages for that month.

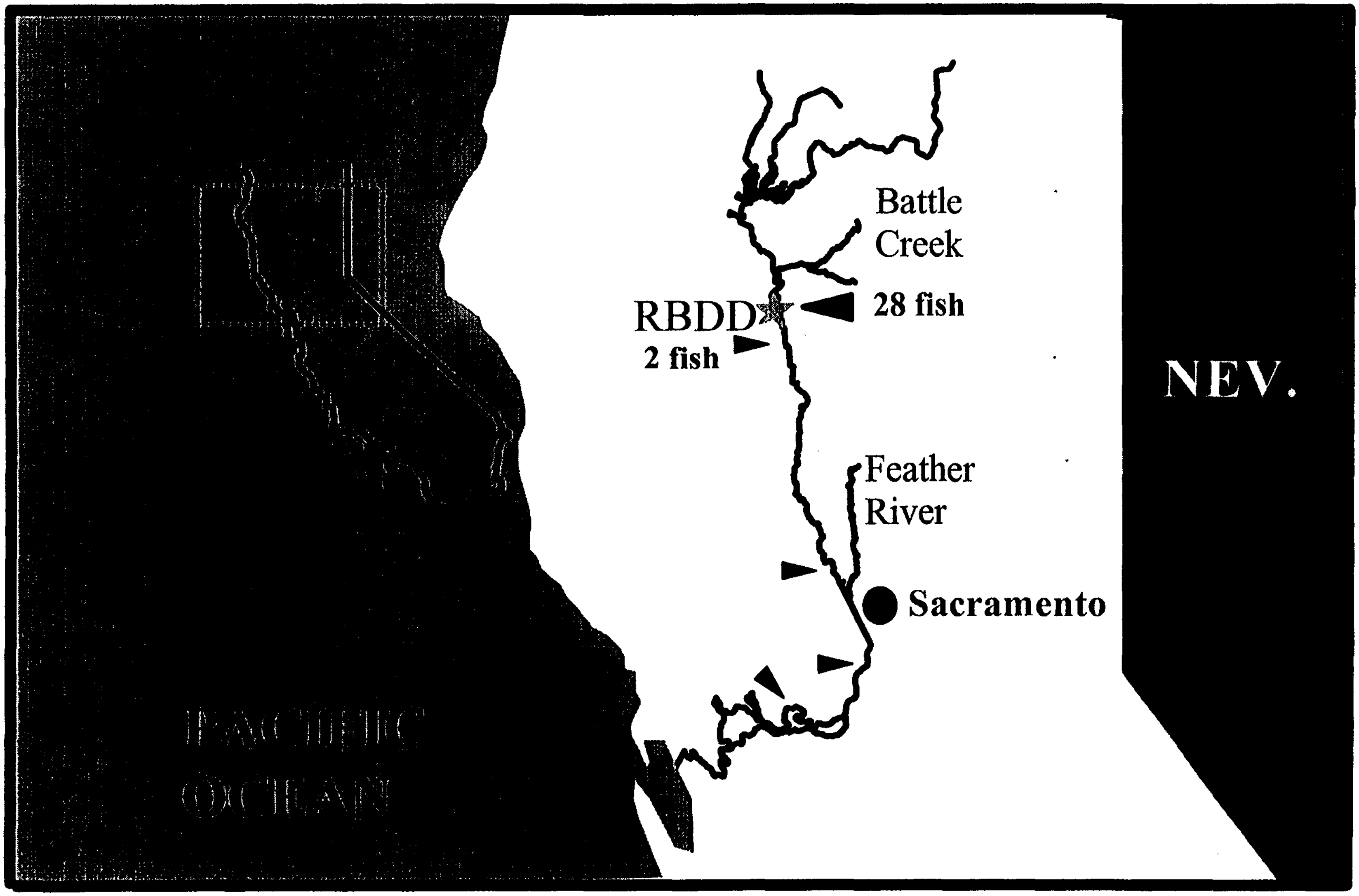

Figure 20.--Recapture locations of Sacramento squawfish. There were 30 fish recaptured in the study area and three others caught well downstream by anglers.

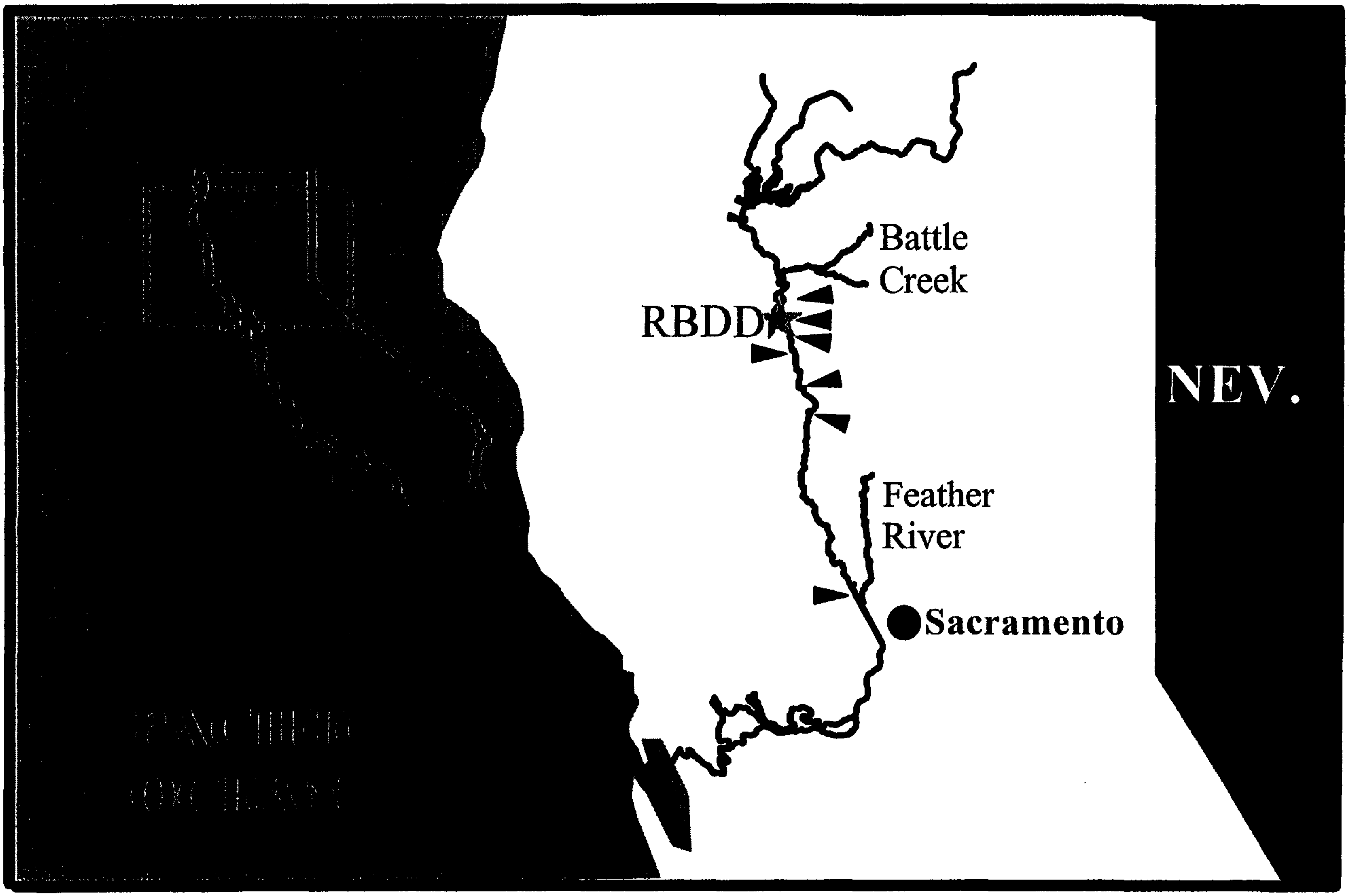

Figure 21.--Recapture locations of striped bass. Each arrow indicates the recapture location of a single striped bass.

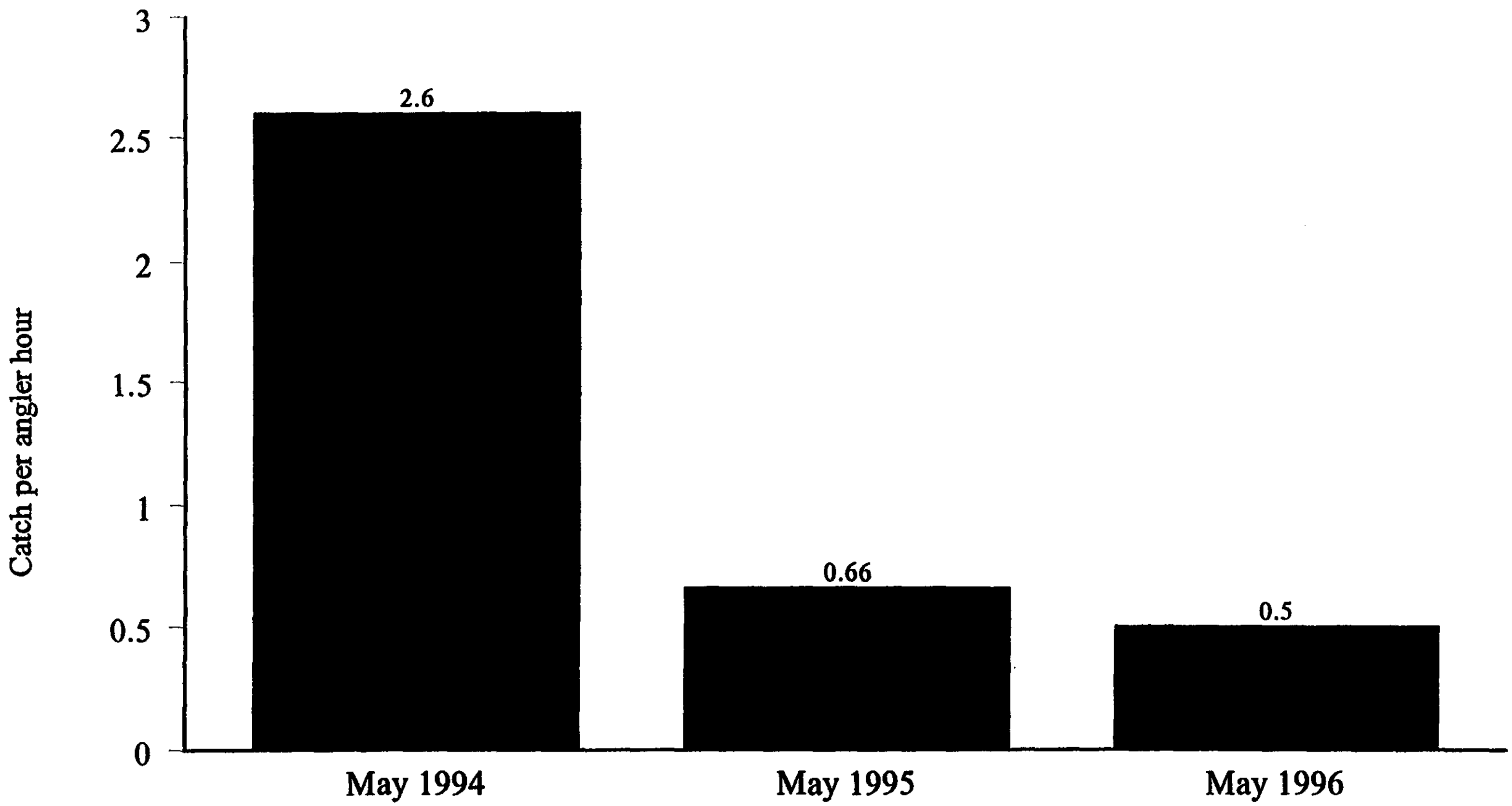

Figure 22.--Catch per angler hour of Sacramento squawfish captured below RBDD in May of 1994, 1995 and 1996.

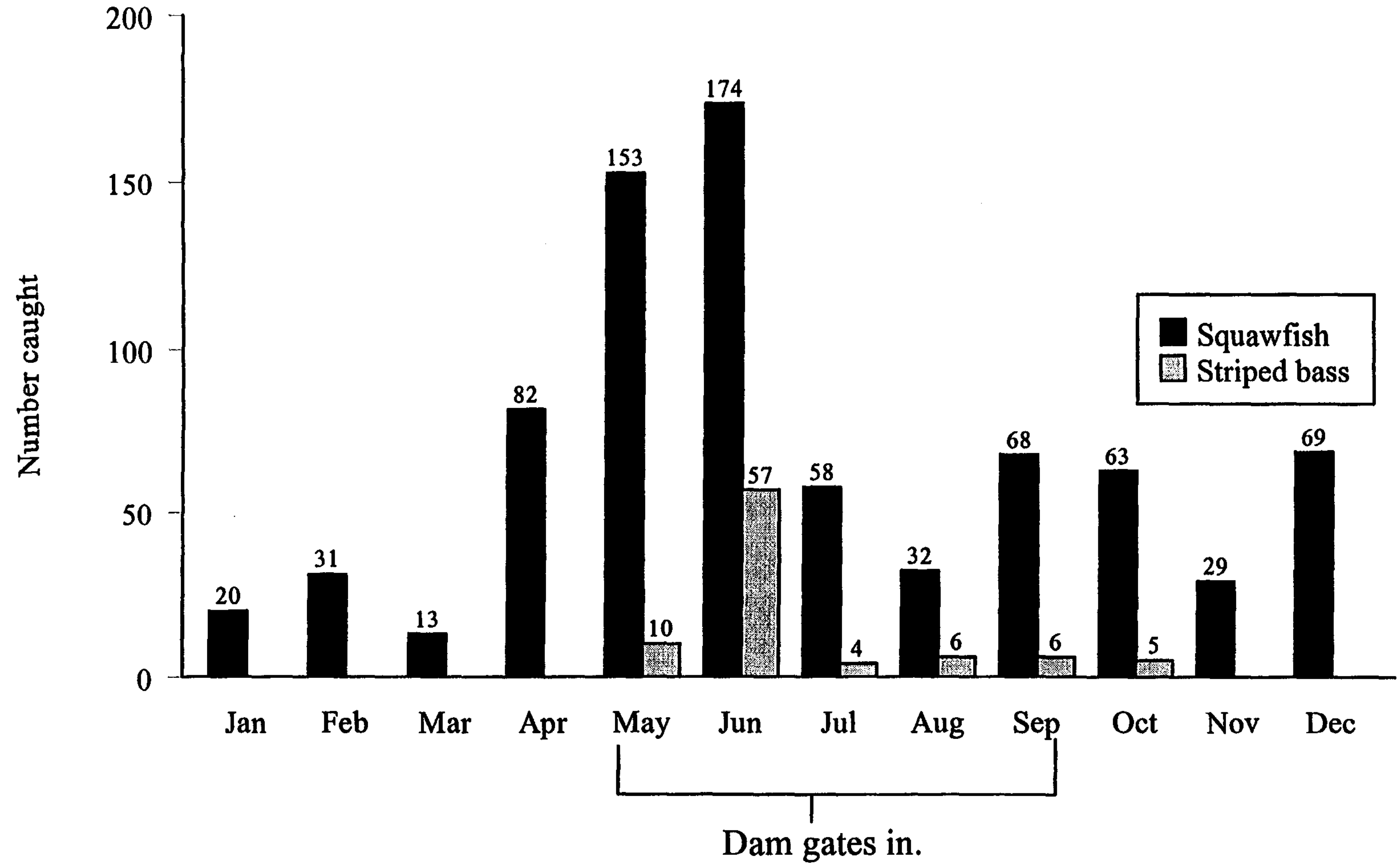

Figure 23.--Total number of Sacramento squawfish and striped bass caught in each month from April 1994 through July 1996, near Red Bluff Diversion Dam, Sacramento River, California.

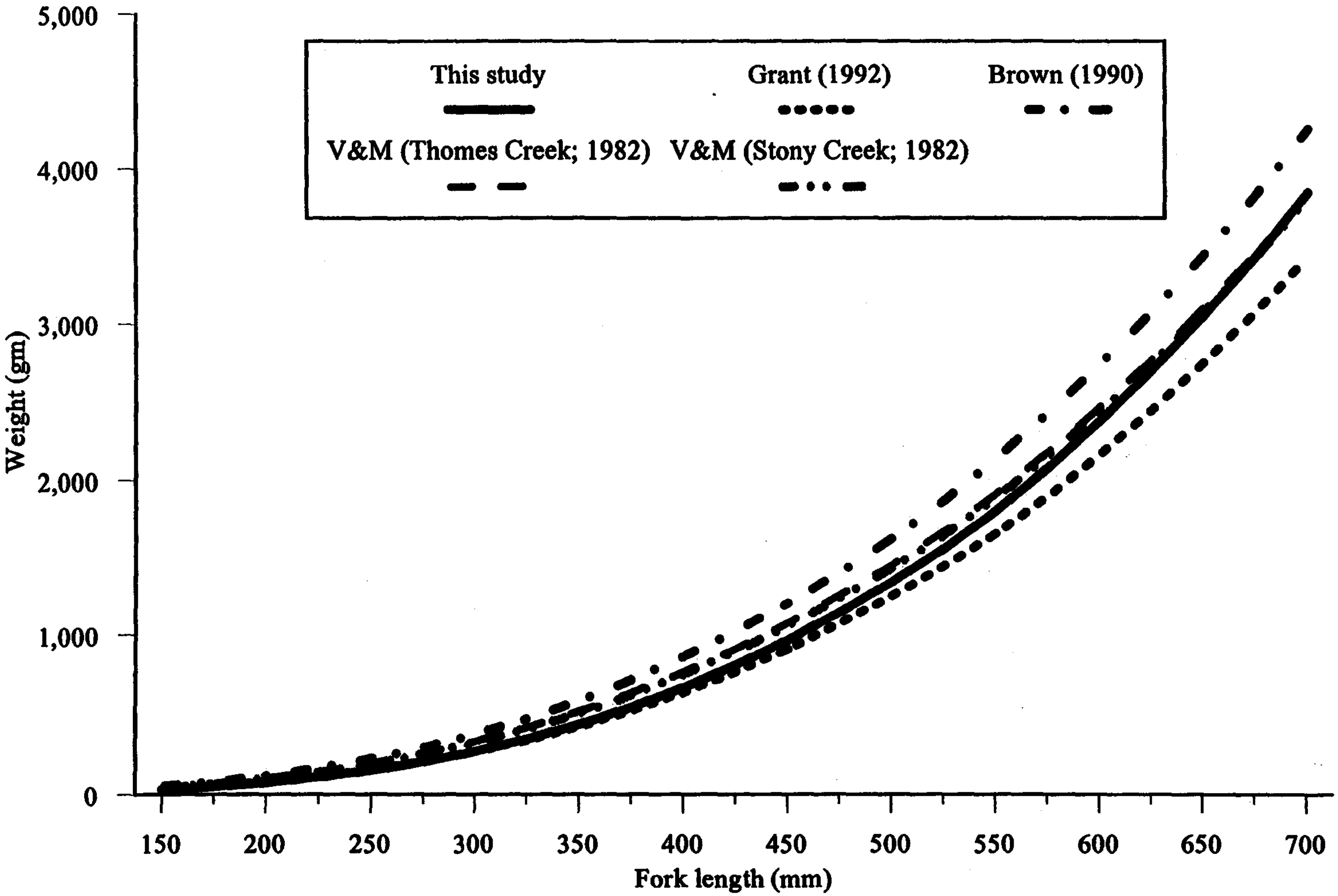

Figure 24.--Comparison of Sacramento squawfish weight-length relation generated by this study to four other models generated from previous studies of tributary populations. The Brown (1990), Vondracek and Moyle (Thomes Creek; 1982) and Vondracek and Moyle (Stony Creek; 1982) models were generated using standard length where as this study and Grant (1992) used fork length.

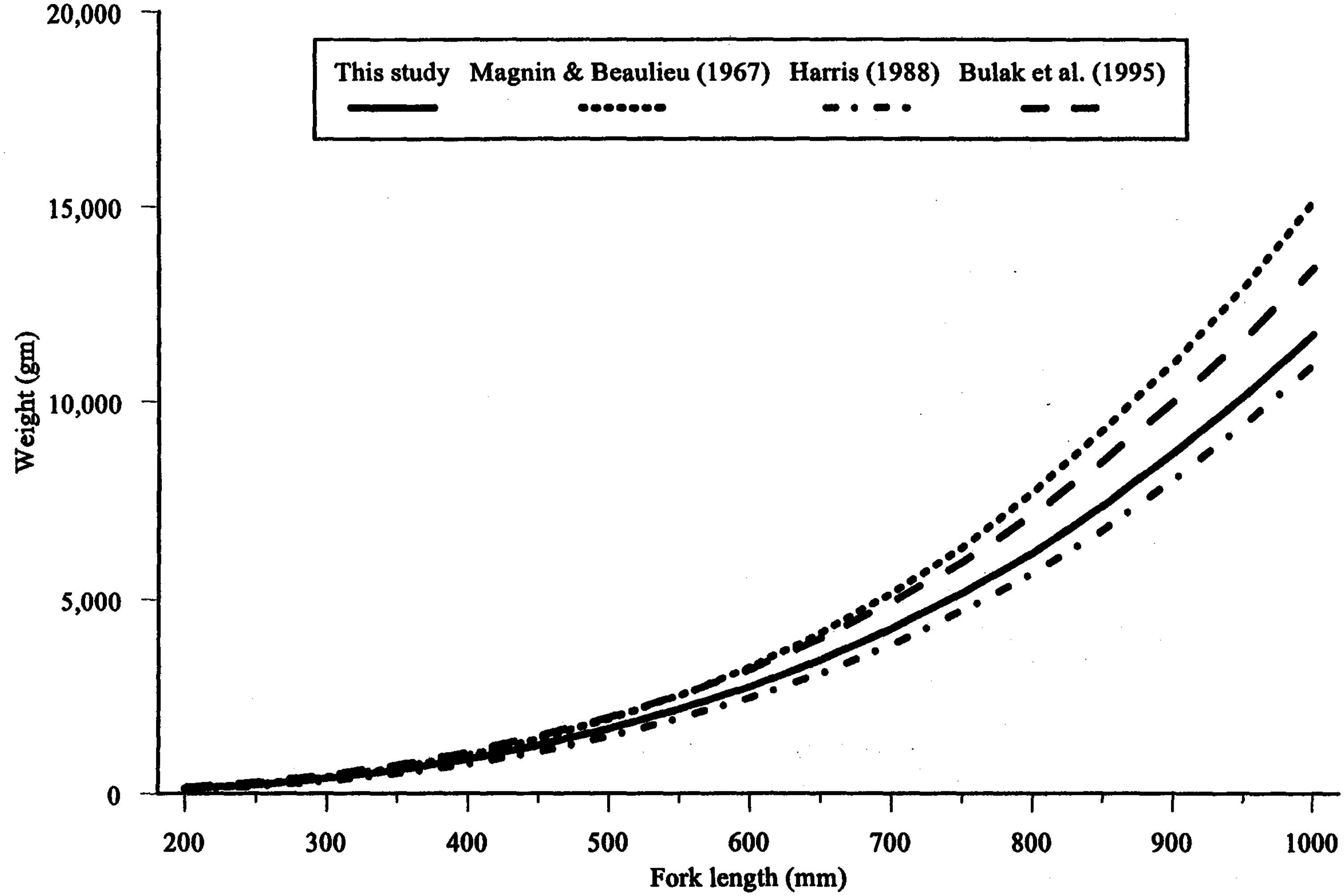

Figure 25.--Comparison of striped bass weight-length relation generated by this study to three other models generated from striped bass populations on the Atlantic coast. The Bulak et al. (1995) model was originally generated using total length. We converted total length to fork length for this analysis using the relation developed in this study.

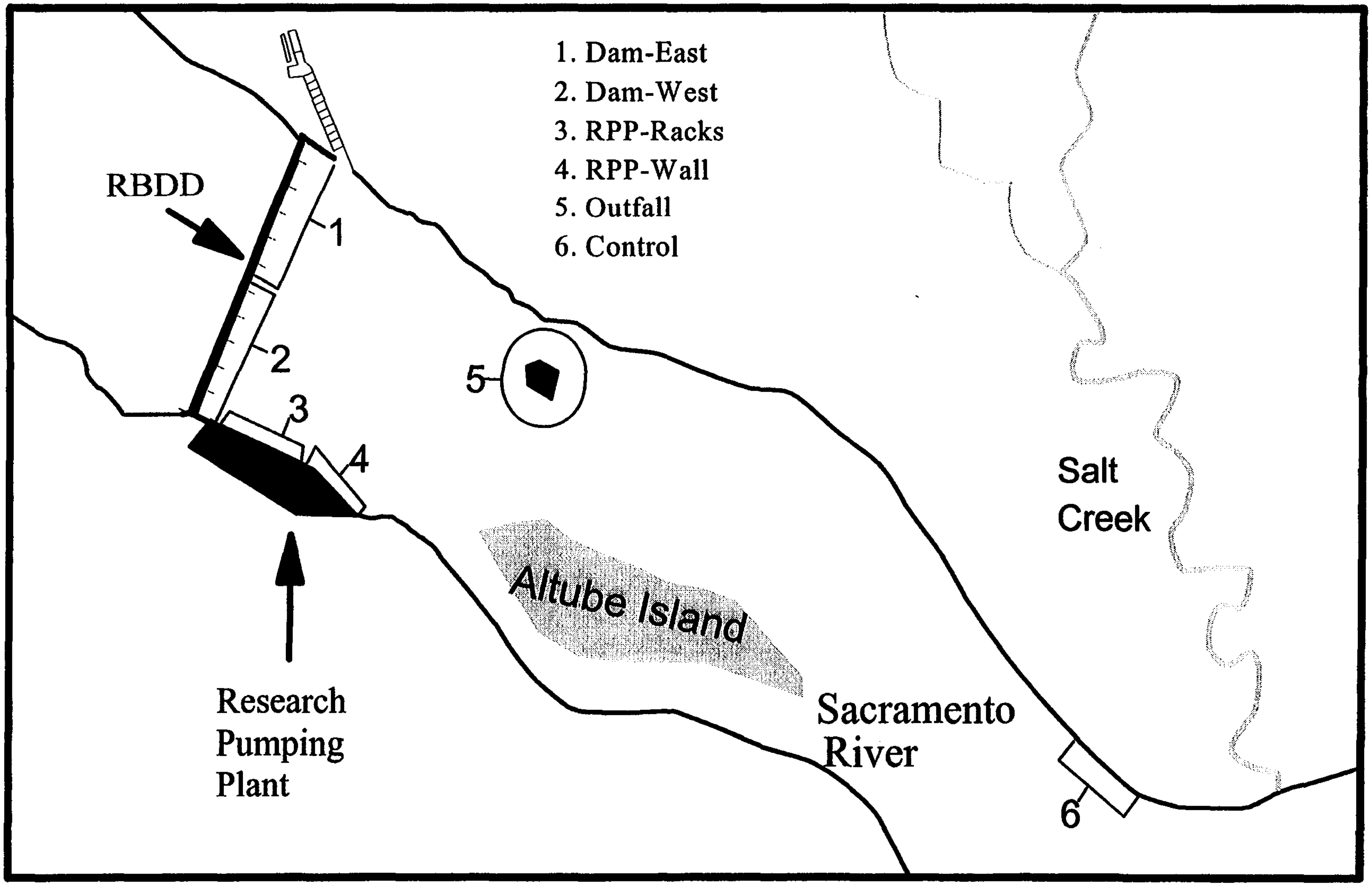

Figure 26.--New sampling protocol as of June 1997. Sampling protocol has been modified such that the six sampling transects delineated above are now consistently sampled with both techniques during each sampling day.

Appendix 1.—Most common settings and outputs for electrofishing gear used in the captured of Sacramento squawfish and striped bass near Red Bluff Diversion Dam, Sacramento River, California from April 1994 through July 1996.

Attribute	Range	Setting
System mode	only 1 setting	pulsed DC
Voltage	336-1685	336 Volts
Output current	5.0 GPP	3 Amps
Pulse frequency		30 pulses per second
Wattage		605 Watts

Appendix 2.—Summary of data collected in the 1995 and 1996 Red Bluff Squawfish Derbies.

Parameter	1995	1996
Total registered anglers	890	500
Number who turned in information sheets at end of day.	310	174
Total documented angler hours	2,424	1,367
Average hours per angler	7.8	7.9
Total Sacramento squawfish caught	66	274
Average catch per angler	0.21	1.6
Average catch per angler hour	0.027	0.2
Average fork length (mm)	344	217
Average weight (gm)	639	252

Appendix 3.—Length specific weights (W_s) calculated at 50 mm length intervals for Sacramento squawfish and striped bass captured near Red Bluff Diversion Dam, Sacramento River, California from April 1994 through July 1996.

Sacramento Squawfish		Striped bass	
Length (mm)	W_s (g)	Length (mm)	W_s (g)
300	276	300	377
350	448	350	584
400	680	400	855
450	984	450	1,196
500	1,368	500	1,615
550	1,844	550	2,119
600	2,422	600	2,715
		650	3,410
		700	4,212
		750	5,128
		800	6,163
		850	7,326
		900	8,622