ABUNDANCE AND SEASONAL, SPATIAL AND DIEL DISTRIBUTION PATTERNS OF JUVENILE SALMONIDS PASSING THE RED BLUFF DIVERSION DAM, SACRAMENTO RIVER, JULY 1994 - JUNE 1995

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ABUNDANCE AND SEASONAL SPATIAL AND DIEL DISTRIBUTION PATTERNS OF JUVENILE SALMONIDS PASSING THE RED BLUFF DIVERSION DAM, SACRAMENTO RIVER, 1994

Annual Report

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Abstract.—This report summarizes information for the pilot year of juvenile salmonid outmigration monitoring in the Sacramento River at Red Bluff Diversion Dam (RBDD), Red Bluff, California. The Northern Central Valley Fish and Wildlife Office is using up to four rotary screw traps (traps) in a transect line across the river to evaluate absolute, relative, temporal, spatial and diel patterns of abundance.

The study period for this report began with the first trap deployment on 18 July 1994 until 30 June 1995. During this period over 90 thousand fish representing 28 species were sampled. Over 90% of the sampled fish were chinook salmon *Oncorhynchus tshawytscha*. Based on length criteria, fall chinook were the most abundant followed by spring, winter and late-fall. Steelhead/rainbow trout *Oncorhynchus mykiss* were sampled infrequently when compared to chinook salmon.

Abundance of naturally produced juvenile chinook salmon (all runs combined) peaked during January and mirrored the abundance of fall chinook salmon; indicating that total juvenile salmon production in the Sacramento River is primarily make up of this run. Abundance of spring chinook peaked in December and were relatively non-abundant during other months of the year. Winter and late-fall chinook, on the other hand, were abundant during peak periods in September and April, respectively, but demonstrated protracted periods of emigration when compared to fall and spring chinook salmon.

Outmigrating salmon exhibited distinct diel patterns of abundance. Catches from traps indicated that during eight of twelve months, juvenile salmonid abundance was significantly ($P<0.05$) greater in nocturnal periods. Typically diurnal levels of abundance were lower than those observed during nocturnal sampling except during months of increased river flows. For instance, abundance of spring chinook salmon was greatest during diurnal periods in December, January and February; demonstrating a propensity by this race for diurnal migrational patterns in months of high river flows, water turbidity and debris loads.

No distinct temporal (monthly) patterns of abundance were observed between the west and east-river-channel at RBDD. However, greater numbers ($P<0.05$) of juvenile salmon outmigrated down the west-river-channel during gates-down and the east-river-channel during gates-up.

Absolute abundance estimates for salmonids were not included in this report because insufficient trap efficiency trials were obtained during this study period. Recent efforts have been directed at conducting efficiency tests to enable the building of a predictive model to accurately estimate the number of juvenile salmon migrating down-stream past RBDD. A wide range of factors such as total river discharge, water velocity, spatial location and additional environmental variables will be used to build the model and estimate abundance.

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Introduction

The Sacramento River system is unique in the fact that it alone supports four runs of chinook salmon *Oncorhynchus tshawytscha*. Named for the time the majority of adults enter San Francisco Bay on their spawning run, these four runs include the fall (FCS), late-fall (LCS), winter (WCS), and spring (SCS) chinook salmon. Steelhead trout *Oncorhynchus mykiss* is another indigenous salmonid in the system.

Populations of all four races of chinook salmon, and steelhead trout, have declined in the last 25 years. The most dramatic is the winter chinook, which have declined from a high count of almost 118,000 in 1969 to a low of 189 in 1994, and were officially listed as endangered in 1994 [1]. In addition to winter chinook salmon, main stem steelhead numbers are currently declining, and are now predominantly of hatchery-origin (Hallock 1989); and, even though steelhead persist in some tributaries, they occur in extremely low numbers (McEwan and Jackson 1996).

Fish ladders at Red Bluff Diversion Dam (RBDD) have been shown to be inefficient at passing migrating adult salmon (Hallock et al. 1982; Vogel and Smith 1984; USFWS 1987, 1989, 1990; Vogel et al. 1988). This results in increased spawning downstream in water too warm for successful egg incubation. Delay at the dam can produce elevated stress conditions in the adult salmon, especially when water temperatures along their migration passageways approach the upper limits of their temperature tolerance. Since 1987 the Bureau of Reclamation (Reclamation) has raised the Red Bluff Diversion Dam gates during a significant portion (approximately 50%) of the non-irrigation season, allowing free passage of adults during that period.

Problems in passage of juvenile salmonids have also been reported (Vogel and Smith 1984; Hallock 1989; USFWS 1987, 1989, 1990; Vogel et al. 1988). The juvenile passage problem at RBDD is two fold: upstream movement of piscivorous fishes is obstructed by the dam causing their accumulation downstream; and, juvenile salmon are disoriented from passing under the dam gates or through the bypass system, making them vulnerable to predation or injury. Vogel et al. (1988) found mortality attributable to physical injury from passage under the dam gates was negligible (at or near 0%). Vogel et al. (1988) reports that fish released above RBDD were recaptured 16 to 55% less than those simultaneously released below the dam. A cause of mortality in juvenile chinook salmon is from the dysfunctional predator-prey relationship created by RBDD-largely from the

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The Sacramento River winter chinook was state listed as "endangered" in May 1989 (California Code of Regulations, Title XIV, section 670.5, Filed 22 September 1989), and federally listed as "endangered" by the National Marine Fisheries Service (NMFS) in February 1994 (59 FR 440).

Sacramento squawfish *Ptychocheilus grandis* (Vondracek and Moyle 1983; Vogel et al. 1988). The Sacramento squawfish is a native species that co-evolved in the river with chinook salmon and steelhead. In the natural free flowing river setting, the predator-prey relationship between the Sacramento squawfish and the native salmonids is intact and has no significant effect on salmonid populations (Brown and Moyle 1981). Whereas, man-made structures can provide increased feeding and ambush settings creating an unnatural advantage for predators. Other piscivors present below RBDD include striped bass *Morone saxatilis* rainbow/steelhead trout, and American shad *Alosa sapidissima* as well as numerous other fish and bird species. Vondracek et al. (1991) estimated an annual loss of 1 to 6% to juvenile downstream migrants during passage at RBDD due to Sacramento squawfish predation; however, peak estimates of mortality in April and May were as high as 80%. The installation of the new fish screening system may reduce entrainment and predation of those fish that are diverted into the Tehama-Colusa Canal forebay, although the effectiveness of this new fish bypass system has only been partially evaluated (Bigelow and Johnson 1996).

Negligible human induced fish mortality is incurred at the dam when gates are raised at RBDD. However, irrigation water is occasionally needed during gates-out and the Reclamation is investigating the use of fish-friendly pumps to deliver irrigation water to the Tehama-Colusa and Corning Canal system during these periods. This pumping facility will entrain small fish including juvenile salmonids. The Reclamation plans to evaluate the effects of these pumps on fish entrained into the system through the Red Bluff Research Pumping Plant (RBRPP). In order to understand the availability of juvenile salmonids for potential entrainment into the pumps, information on the population of fish in the river moving downstream past RBDD is required. The goal of this project is to provide estimates of abundance and outmigration timing for downstream migrating juvenile chinook salmon and steelhead trout near the RBDD. Specific objectives include:

1) Estimate abundance of each of the four runs of juvenile salmon and steelhead trout passing RBDD.

2) Estimate the seasonal and spatial distribution of juvenile salmon and steelhead trout passing RBDD.

3) Estimate diel patterns of abundance of juvenile salmon and steelhead trout passing RBDD.

This report summarizes effort during the pilot year of this project, from the time the first traps were in place 18 July 1994 through 30 June 1995.

Study Area

The Sacramento River is the largest river system in California, flowing south through 400 miles of the state (Figure 1). It originates in northern California near Mt. Shasta as a clear mountain stream, widens as it drains adjacent slopes of the Coast, Klamath, Cascade, and Sierra Nevada mountain ranges, and reaches the ocean at San Francisco Bay. Although agricultural and urban development has occurred and impacted the river, the upper river remains mostly unrestricted and supports areas of intact riparian vegetation. The lower river to San Francisco Bay has sustained intense urban and agricultural development, with riprapped banks and managed flow throughout much of its course.

The RBDD is located at river kilometer 388 on the Sacramento River about 3 km southeast of the city of Red Bluff (Figure 1). 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. The dam consists of eleven moveable gates which can be raised or lowered to impound and divert river flows into the canal. For 20 years the dam gates remained closed year-round, until winter of 1986 when the gates were raised during the nonirrigating season to improve upstream fish passage. This action was found to have many beneficial impacts and continues today (USFWS 1990). However, irrigation water needed during gates-up must be supplied with pumps. The RBRPP was constructed to meet water supply needs while minimizing deleterious impacts on native anadromous fish species in the Sacramento River.

Methods

Fish capture

Sampling gear.—Four rotary screw traps (traps) from E.G. Solutions®, Corvallis, Oregon, were configured with 2.4-m diameter cones, screened throughout with 3-mm diameter perforated plate and mounted on aluminum pontoons (Figure 2). The cone of the trap acts as a sieve separating fish from water sampled. Water flowing into the cone transfers rotational energy to an aluminum helix attached to the cone, causing it to turn. As the cone turns, entrained fish are trapped and guided to an attached live box where they remain until processed. Live boxes were enlarged (122 x 183 cm) and aluminum screens were installed in the rear, floor and sides to dissipate water velocities in the live box. Crowders were used to congregate fish into the stern of the live box and to separate captured fish among sample periods.

Traps were attached to dam gates directly behind RBDD (Figure 3). Gates were raised or lowered in response to stream flow conditions and were lowered to within 92 cm of the water surface to prevent downstream boaters from colliding with traps. When the dam gates were lowered, traps were attached to RBDD just beyond the hydraulic boil caused by the bottom release gates. Traps were fished in areas with minimum water velocity of 61 cm/s; however, sampling equipment, river depths and river hydrology restricted placement of some traps in these areas during low-flow and gates-down periods.

Data collection.—Data was collected for each trap clearing and included: (1) length of time trap was fished, (2) water velocity immediately in front of the cone at depth 61 cm, (3) debris type and amount, (4) captured fish identification, enumeration and fork length and (5) environmental parameters including water and air temperatures, and water turbidity. Water velocity was measured using a Marsh-McBirney® Model 201/ 201-D flow meter or an Oceanic® Model 2030 flow torpedo. Water samples were taken to measure turbidity and were analyzed in the laboratory using a Model 2100A Hach® Turbidimeter. Daily river discharge past RBDD was estimated by the Reclamation and provided to Northern Central Valley Fish and Wildlife Office (NCVFWO).

All salmon and trout were enumerated and fork lengths measured to the nearest 1.0 mm. Exceptions to this protocol occurred when large (>100) numbers of salmon and trout were captured. In these cases, random subsamples were taken to include approximately 100 of each salmonid species with all additional fish being counted and recorded as extras. For non-salmonid fish captured, up to 20 of each species were measured from a random subsample and the remainder counted. Data were entered into two associated Dbase V databases: one for individual fish data (species, size, run, etc.), and the other for environmental data (time fishing, amount of debris, turbidity, total catch by species, etc.). Chinook salmon race was determined from daily length tables [2].

Coleman National Fish Hatchery (CNFH), located about 56 km up-stream from RBDD on Battle Creek, released approximately 150 thousand adipose fin-clipped and 10 million unmarked fall chinook smolts during the study period. In order to characterize and enumerate natural fish production at RBDD, numbers of hatchery-origin fish from CNFH in the catch were estimated by assuming that the expected ratio E(R) of adipose-clipped to non-adipose-clipped hatchery-origin fish in the sample is the same as the ratio at time of release from hatchery (*R*):

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Generated by Sheila Greene, Department of Water Resources, Environmental Services Office, Sacramento (8 May 1992) from a table developed by Frank Fisher, CDFG, Inland Fisheries Branch, Red Bluff (revised 2 February 1992). Fork lengths with overlapping run assignments are placed with the later spawning run.

(1) $$E(R) = R = \frac{Number\ of\ ad\text{-}clipped\ fish}{total\ number\ released}\ .$$

The number of hatchery-origin fish in the catch (*H*) is the quotient of the number of adipose-clipped fish in the sample (*A*) divided by the expected ratio:

(2) $$H = \frac{A}{E(R)}\ .$$

Therefore,

(3) *Number of naturally produced fish in sample = total catch - H.*

Stock assessments

Absolute abundance (AA).—Population estimates for juvenile salmon migrants passing RBDD were estimated by the trap efficiency method (Thedinga et al. 1994; Keenen et al. 1994). Efficiency was defined as the fraction of a fish stock captured by our sampling gear. Trap efficiency (TE) by trap was estimated by mark and recapture techniques and was calculated by dividing the number of recaptures (R) in a trap by the number of marked fish released (M) up-stream.

(4) $$TE = \frac{R}{M}\ ,$$

Experimental juvenile fall chinook salmon (50 - 80 mm) were obtained from CNFH on 19 April 1995, dyed with Bismarck Brown *y* and released 4 km up-stream on the east side of the river. Numbers of fish released were estimated as the product of total weight and number of fish per pound. Mean number per pound was estimated by weighing eight samples ($N > 98$) and counting fish in each sample. A random sample (N=543) of fish were measured (fork length; mm) prior to loading. Fish were dyed with Bismarck Brown *y* in transport (Mundie and Traber 1983). Dye (8 g) was added to water in the distribution (300 gal) tanks immediately after loading. Four screw traps were fished behind gates 2, 5, 9, and 11 for 5 d after time of release.

Typically efficiencies have been developed for rotary screw traps on weekly or seasonal time periods (Thedinga et al. 1994; Keenen et al. 1994); however, these studies were conducted on small streams and used modest numbers of marked fish. Due to sampling limitations on the Sacramento River and the need for large numbers of marked fish, a model was used to predict trap efficiency (TE_p) rates over a broad range of environmental and river conditions. Variables found by other researchers to affect trap efficiency (river discharge, trap positioning, and debris loads; Thedinga et al. 1994), and other hydrological and environmental variables (e.g., water velocity at trap, air and water temperature and water turbidity) were used in TE model building.

Trap efficiency estimates derived for marked fish over a period of days was assumed to be equivalent to efficiency rates for unmarked fish stocks emigrating past our sampling transect over a 24-h period. This assumption biased TE_p toward the period of time when the greatest number of marked fish passed RBDD. To account for this bias in our predictive model, independent variables (e.g., mean daily discharge during the course of a 5-d efficiency trial) were weighted by the number of marked fish captured during that day.

(5)
$$V_{WI} = \frac{V_{D1}\left(\frac{R_{D1}}{R_T}\right) + V_{D2}\left(\frac{R_{D2}}{R_T}\right) + V_{D3}\left(\frac{R_{D3}}{R_T}\right) \ldots\ldots V_{Dn}\left(\frac{R_{Dn}}{R_T}\right)}{n},$$

V_{WI}	=	weighted independent variable used for modeling trap efficiency (e.g., mean water velocity at trap over the course of the efficiency trial),
V_{Dn}	=	point estimate of V_{WI} on day D_n (e.g., daily estimate of water velocity at trap),
$R_{D1 \ldots Dn}$	=	number of marked fish recaptured during day D_n,
R_T	=	$\sum R_{D1} + R_{D2} + R_{D3} \ldots Rdn$.
n	=	number of days during the trap efficiency trial (e.g., 5 days)

Weighted independent variables (V_{WI}) were used for model building for trap efficiency through step-wise regression. TE_p was used to expand single trap catches to unsampled fish numbers (AA) passing RBDD.

(6)
$$AA = \frac{C}{TE_p},$$

AA	=	absolute abundance estimates calculated by trap,
C	=	number of salmonids captured by trap, and
TE_p	=	predicted trap efficiency by trap.

Daily AA estimates by trap were extrapolated to a weekly estimate (e.g., daily AA x 7 d = weekly estimate) and estimates throughout a week were averaged to provide weekly estimates of abundance.

Absolute abundance index (AAI).—Absolute abundance indices were calculated as the proportion of catch per water volume sampled to river discharge as described by Craig (1992).

(7)
$$AAI = C \frac{D}{V} ,$$

AAI	=	absolute abundance index by trap,
C	=	number of salmonids captured by trap,
D	=	discharge past RBDD, and
V	=	acrefeet of water sampled by trap.

Daily AAI estimates were calculated independently by trap and extrapolated to a monthly estimate (e.g., daily AAI x 30 d = monthly estimate). Estimates throughout a month and among traps were averaged to provide a monthly index of abundance. The purpose of weighting the indices by the proportion of river discharge to water volume sampled ($^D/_V$) was to standardize estimates for comparisons between years and among months by taking into account different river stages during these time periods. The AAI, however, assumes fish outmigrate uniformly in the water column and should therefore be only interpreted as an index of AA (Craig 1992).

Relative abundance (RA).—Catch per water-volume-sampled (e.g., catch/acrefoot) was used to measure relative abundance of juvenile salmonids at RBDD.

(8)
$$RA = \frac{C}{V} ,$$

RA	=	relative abundance by trap (catch/acrefoot),
C	=	number of salmonids captured by trap, and
V	=	volume of water sampled by trap.

Volume of water sampled was estimated for each trap as the product of: (1) one-half the cross sectional area (wetted portion) of the cone (23,318 cm^2), (2) water velocity (cm/s) directly in front of the cone at a depth of 61 cm and (3) duration of sampling.

Length selectivity.—Length selectivity is the probability of capture for a given length of fish once it has contacted the gear. Generally, fishing gears are length selective.

Length selectivity was evaluated by: 1) comparing mean length and length distributions of released and recaptured fish during trap efficiency tests, and 2) comparing mean lengths and length distributions of salmonids captured with beach seines and traps at RBDD. Length distributions for fish captured by the two gear types were used to provide baseline information on whether traps were sampling all size classes of salmon passing RBDD. Beach seining was conducted 1-2 times per week concurrently with trap sampling, upstream and downstream, and on the east and west sides of the river at RBDD.

Seasonal, spatial and diel distribution patterns

Seasonal distribution patterns.—Absolute abundance indices (AAI) were used to evaluate seasonal patterns of abundance. Absolute abundance indices for fall, late-fall, winter and spring chinook salmon, and steelhead trout were analyzed by month.

Spatial distribution patterns.—Spatial distribution patterns were analyzed by comparing relative abundance of salmonids between traps. Traps were configured behind RBDD gates to represent east and west sides of the river (Figure 3). Gates 1 - 6 represented the east-river-channel and gates 7 - 11 represented the west-river-channel. Spatial patterns were analyzed by month and between gates-in and gates-out at RBDD.

Diel distribution patterns.—Diel patterns of abundance were analyzed by comparing relative abundance of salmonids between diurnal and nocturnal periods. Traps were typically checked in the morning (≈ 0800 hours) and again in the late afternoon (≈ 1600 hours). Diurnal periods were defined as periods sampled between sunrise and sunset or predominately during the day. Nocturnal periods were defined as periods sampled between sunset and sunrise or predominately during night. In general, traps were fished 24 h a day, four to seven days per week and cleared twice per day. Exceptions to this schedule occurred when in-trap debris loads or in-trap fish mortality was high or the potential existed for excessive winter chinook catches [3]. These situations required an increase in trap clearing, reduction in fishing effort, or cessation of sampling.

Statistical Tests

Random dispersion tests.—A chi-square test was used to test for differences in lateral fish distributions during trap efficiency trials by comparing numbers of marked and unmarked fish between the four traps at RBDD.

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Permit restrictions for take of endangered species limited the number of winter chinook salmon sampled at RBDD.

Length selectivity tests.—T-tests were used to test whether mean fish lengths differed between released and recaptured fish and a Kolmogorov-Smirnov two-sample test (KS test) was used to test for differences between length distributions of released and recaptured fish. Furthermore, a KS test was used to test for differences between length distributions of fish captured in beach seines and traps at RBDD.

Spatial and diel patterns of abundance.—Spatial and diel patterns of abundance were analyzed using a 2x2 factorial arrangement of treatments. Treatments included two spatial strata (west and east) and two diel periods (diurnal and nocturnal). Treatment effects were analyzed using a two-way ANOVA (Hicks 1993). All statistical tests were considered significant at $P \leq 0.05$.

Results

Fish capture

Sampling.—The first screw trap was placed in the water on 18 July 1994 and was fished exclusively for 25 d in gate 11 until a second trap was in place on 19 August (Figure 4). The third and fourth screw traps were in place by the 14 and 18 October, respectively (Figure 5). Four traps were fished continuously during October, November and December until excessive winter chinook catches and the occurrence of high river flows in early January and mid-March necessitated decreasing sampling frequency (Figures 5 and 6). Furthermore, no traps were fished in the west-river-channel during February because of high debris loads. Traps were distributed throughout the river channel in April but insufficient water velocities behind the center fish ladder (gate 6) necessitated trap placement along shorelines during gates-in (May - June; Figure 7). The longest contiguous sampling event occurred behind gates five and nine for 105 d (mid-September to late-December; Figures 4 and 5). Gates one, three, five and nine were fished most frequently while no sampling occurred during the study period behind gates four, six, and eight due to inadequate stream flows and/or stream depths (Figure 8).

Twenty-eight fish species were sampled in rotary screw traps during the 1994 - 1995 study period. Ninety percent ($N \approx 81$ thousand) of the 90 thousand fish captured were chinook salmon (Table 1). Steelhead/rainbow trout composed 1% (N=724) of the total catch during our study period. Sacramento squawfish, Sacramento sucker *Catostomus occidentalis* and prickly sculpin *Cottus asper* were the predominate non-salmonid fish species sampled in traps. Based on the length criteria, fall chinook salmon was the predominate race of chinook salmon sampled in traps (95%), and spring (2%), winter (2%) and late-fall (1%) chinook salmon were sampled less frequently (Table 2).

Abundance

Absolute abundance.—Insufficient trials of trapping efficiency were conducted during this study period to accurately estimate absolute abundance.

Trap efficiency.— About 82 thousand (SD=1.3 thousand) juvenile salmonids were released on 19 April 1996 between 1100 and 1330 hours. Dyed fish (*N*=392) were recaptured shortly after time of release until 2 d after release. Most fish (*N*=280) were recaptured from 19 through 20 April. Even though all traps were used for testing spatial distributions between marked and unmarked fish, data from trap 11 was not included in trap efficiency tests because the live box was damaged by debris.

Random dispersions tests between marked and wild fish indicated that catches differed between traps (χ^2, $P<0.05$; Figure 9) but not from the east (traps 2 and 5) and west (traps 9 and 11) sides of the river (χ^2, $P=0.201$; Figure 10). Wild fish (expected) distributions were the most abundant in trap 5 (47%) with decreasing abundance towards the east (trap 2=31%) and west (trap 9=18%; trap 11=4%) sides of the river. Recaptured marked fish, on the other hand, were most abundant in trap 2 (44%) with lower patterns of abundance occurring on an east to west gradient (Figure 9).

Trap efficiencies for the three traps included in this experiment ranged from 0.08 to 0.21% (Table 3), and were generally lower than those reported in the literature (Table 4). Low efficiency rates indicated that only a small proportion of the overall numbers of juvenile salmon passing RBDD were sampled in traps.

Length Selectivity.—Recaptured fish (mean length, 66.9 mm; SD=4.4 mm; *N*=367) during trap efficiency trials were significantly smaller (t-test, $P<0.05$) than released fish (mean length, 67.6 mm; SD=4.5 mm; *N*=543) though mean differences were less than 1 mm. Additional length frequency analyses also indicated size distributions differed (KS test, $P<0.05$) between these two groups (Figure 11).

Length distributions of fish captured in traps and beach seines differed (KS test, $P<0.05$) suggesting that the two gears were sampling different size classes of juvenile chinook salmon (Figure 12). It appeared as though traps sampled smaller (<40 mm) and larger (>66 mm) size classes more frequently than seining, although smaller (<40 mm) size classes were the most frequently sampled fish with both gear types (Figure 12).

Seasonal, spatial and diel distribution patterns

Seasonal distributions.—Abundance of naturally produced juvenile chinook salmon (all runs combined) peaked during January and mirrored the abundance of fall chinook salmon; indicating that total juvenile salmon production in the Sacramento River is primarily made up of this run (Figure 13). Peak abundance for the different runs of chinook salmon included, late-fall chinook in April, spring chinook in December and winter chinook salmon in September (Figure 14). Winter and late-fall chinook salmon appeared to have a protracted emigration period past RBDD when compared to fall and spring chinook salmon. Abundance of winter chinook salmon peaked in September but were abundant throughout fall, winter and into spring. Rainbow trout were not as abundant as chinook salmon and peak seasonal abundance occurred during August and January (Figure 15).

Spatial patterns.—Data collection for the first five weeks came from one trap and was primarily fished downstream from gate 11 and the west ladder. Two traps were in place by late-August and spatial patterns of abundance were not analyzed prior to this time. Furthermore, traps could not be fished along the west-river-channel in February; therefore, spatial analyses were not included for this month. Spatial abundance for chinook salmon (all runs combined) and fall chinook salmon significantly differed (ANOVA, $P<0.05$) in 30 - 40% of months sampled (Figures 16 and 17). Spatial patterns of abundance were greater in the west-river-channel during August for late-fall chinook salmon (Figure 18), whereas no differences were observed for spring and winter chinook salmon during the study period (Figures 19 and 20).

Juvenile salmonid abundance was significantly greater (ANOVA, $P<0.05$) in the west-river-channel during gates-in and nearly five times greater (ANOVA, $P<0.05$) in the east-river-channel during gates-out at RBDD (Figure 21).

Diel patterns.—Nocturnal abundance of outmigrating chinook salmon was greater in 11 of 12 months (significantly greater in 8) and ranged from 1.1 (February) to 20 (August) times greater than diurnal periods (Figure 22). Although all races of chinook salmon displayed nocturnal patterns of abundance (Figures 23, 24, 25 and 26), spring chinook salmon appeared to have the greatest propensity for diurnal migration patterns (diurnal abundance was greater in three of eight months; Figure 25). Interestingly, this race exhibited these patterns in months of high flow and water turbidity (Jan, Feb and Mar; Appendix 1).

Discussion

Abundance

Absolute abundance.—Insufficient efficiency trials were conducted during this study period to accurately estimate trap efficiency over the broad range of environmental and river conditions present during this study period. Once our model has been refined we will be able to revisit these data to estimate abundance for the pilot year of this study.

Trap efficiency.—Experimental bias in trapping efficiency tests may cause over or underestimation of chinook population numbers (Thedinga et al. 1994). In order for efficiency tests to be unbiased, marked fish need to be randomly mixed with unmarked fish across the river cross-section (i.e., laterally) and vertically within the water column.

Spatial tests during trap efficiency studies indicated that lateral distributions of marked hatchery fish differed (χ^2, P<0.05) from wild fish on a trap to trap basis (Figure 9). Marked fish were released on the east side of the river 4 km up-stream from RBDD, and abundance of marked fish decreased from east to west, suggesting that marked fish may have failed to disperse randomly with wild fish. However, marked fish occurred in higher frequencies than expected along the west shoreline (Trap 11; Figure 9); an unexpected occurrence if marked fish failed to disperse with unmarked fish after being released on the east side. Additional analyses of fish distributions indicated that expected frequencies of marked fish did not differ (χ^2, P=0.201) between the east (Traps 2 and 5) and west (Traps 9 and 11) side of the river (Figure 10). Thedinga et al. (1994) found marked fish randomly mixed when released 1 km up-stream from their sampling transect. Because their study stream is smaller than the Sacramento River, it may or may not be reasonable to assume fish released 4 km up-stream in our study had sufficient distance to distribute randomly with wild fish.

One point of concern for this study is the use of hatchery fish to estimate trapping efficiencies for wild fish. Other researchers have used hatchery-reared fish to estimate trap efficiencies for wild fish (Keenen et al. 1994), but estimates could be biased if hatchery fish outmigrate differently than wild fish or differ with respect to trap vulnerability. Initial tests from this study indicated that hatchery fish were spatially distributed differently from wild fish on a trap to trap basis (Figure 9), but similar distributions were realized from east to west sides of the river (Figure 10). For this reason, additional studies are needed to determine if hatchery-raised salmonids outmigrate differently than wild fish.

Richards and Cernera (1989) found even one month after release into the Yankee Fork of the Salmon River, Idaho, that spring chinook hatchery-reared fry often established residency in localized areas 1 to 2 km from point of release. During our study, 392 marked fish were recaptured and the majority of fish (N=280) were recaptured 24 h after release. Released fish that did not migrate out immediately, may have established residency in a relatively localized reach and remained there until after completion of our sampling. If this occurred, we would have underestimated efficiency estimates and overestimated population numbers.

Well planned controlled experiments are needed to ensure information obtained from efficiency tests are unbiased and reflect the true efficiency of our sampling design and gear. For efficiency tests to be unbiased several assumptions need to be met including:

1) marked fish must be randomly mixed with unmarked wild fish, and

2) efficiency does not differ for marked and unmarked fish.

These assumptions have gone largely untested, and additional studies are needed to establish whether hatchery-reared salmon fingerlings can be used to derive trap efficiency for wild juveniles outmigrating past RBDD. Ultimately we hope to make conclusions as to the efficacy of using hatchery-raised salmonids to estimate rotary screw trap efficiency rates for wild stocks.

Weighted trap efficiencies for our sampling transect ranged from 13 to 36% (Table 3). If we assume no biases were associated with our sampling gear and experimental design, and fish migrate randomly within and across the water column, weighted trap efficiencies of 100% would be expected. Furthermore, absolute abundance indices (AAI) under these assumptions would be unbiased population estimates. Results from trap efficiency tests indicate, however, that AAI underestimates true absolute abundance by nearly three-quarters (Table 3). Biases associated with AAI estimates indicate that:

1) Chinook salmon do not outmigrate randomly within and across the water column, and/or

2) Chinook salmon exhibit avoidance behavior to traps, and/or

3) Chinook salmon selectively avoid or utilize spatial patterns not sampled by traps, and/or

4) Bias in estimating the volume of water sampled by traps and/or discharge past RBDD, and/or

5) Failure of marked fish to pass RBDD during efficiency testing (e.g., due to mortality or residualization) and/or

6) Mark loss by marked fish during efficiency testing.

These data reflect the need to interpret AAI estimates as an index of absolute abundance (Craig 1992). Population estimates (AA), on the other hand, based on the trap efficiency method will be corrected for the biases 1 - 4 above.

Trap efficiencies observed during this study were lower than those reported in the literature (Table 4). Intuitively, TE will be correlated with river discharge (Keenen et al. 1994; Thedinga et al. 1994). For example, as discharge increases, amount of water sampled compared to total discharge will decrease. It would be expected, then, that trap efficiencies in large rivers (e.g., Sacramento River) will be less than those in smaller systems.

Length selectivity.—Results from length selectivity tests indicated that length frequencies of marked fish caught in traps were different from those released (KS test, $P<0.05$; Figure 11). Similar findings have been reported by Thedinga et al. (1994) where recaptures reflected the mid-range of the marked frequency distribution. Additional tests from our study indicated that the mean length of recaptured fish was smaller than those marked (t-test, $P<0.05$). Thedinga et al. (1994) did not test for differences between means of marked and recaptured fish; however, cursory review of their results appeared to indicate that the mean length of recaptured fish was smaller. Based on these findings, traps are length selective for chinook salmon, and trap efficiencies and abundance estimates will, therefore, reflect this bias. Population estimates not corrected for this potential source of bias will ultimately overestimate abundance of fish being selected for and underestimate size classes being selected against. Therefore, to accurately estimate the abundance of the four races of chinook salmon (based on the size structure of the population) passing RBDD, it will be necessary to account for the effect of size selection. On the other hand, even though differences in size distributions and mean length (difference = 0.7 mm) were statistically significant between marked and recaptured fish, the differences were "biologically" small and the effect of length selectivity may be insignificant on population estimates (Thedinga et al. 1994). Further evaluations are needed to evaluate whether length selectivity is occurring and if so what effect it may have on estimates of abundance.

Beach seining was incorporated in the study plan to compare catches between seines (shoreline habitats) and traps (channel habitats), and to determine whether some size classes were going unsampled in traps. Tests between the frequency of size classes caught indicated that the two gears were sampling different (KS test, $P<0.05$) size classes of juvenile chinook salmon (Figure 12). In general it appeared traps sampled smaller (<40 mm) and larger (>60 mm) salmon more frequently whereas medium (40-60 mm) sized fish were sampled infrequently when compared to shoreline (seine) catches. By designating smaller juveniles (<40 mm) as passive emigrants and the larger salmon (>60 mm) as active outmigrants, it appears as though traps are selectively sampling size classes moving down stream. Conversely, medium sized fish (40-60 mm) appear in trap catches infrequently even though they are frequently sampled along the river margins during seining (Figure 12). These fish may be using marginal river channel areas as rearing habitat where they are not susceptible to rotary screw trap gear, but at the same time, large enough to hold position and not be entrained into river flows.

Seasonal, spatial and diel distribution patterns

Seasonal distribution patterns.—Seasonal patterns of abundance were analyzed on a monthly basis. Fall and spring runs exhibited peak emigration periods and were relatively non-abundant during other times. Winter and late-fall chinook salmon, on the other hand, appeared to have prolonged periods of outmigration when compared to the other runs.

Spatial distribution patterns.—Published studies on the spatial distribution of outmigrating/emigrating chinook salmon generally indicate that fry occupy marginal stream channel areas in association with bank cover (Lister and Genoe 1970). Larger juveniles were found to be associated with higher water velocities in or near the mid-channel. Unwin (1986) found that differences in cross-sectional catch distributions between fry and fingerlings suggested differing migration and/or emigration strategies. Fry appeared to drift passively down-stream whereas concentrations of larger fish were greater towards the center of the stream and were consistent with more active down-stream migrations (Unwin 1986).

No consistent trends for wild chinook salmon were evident from the west to east side of the Sacramento River at RBDD when analyzed by month. The largest difference occurred during gates-out in April when catch per acrefoot was on average 75 times greater in the east-river-channel (Figure 16). For this reason, spatial patterns were analyzed for gates-in (1 July to 15 September 1994 and 15 May to 30 June 1995) and gates-out (15 September 1994 to 15 May 1995). Juvenile salmonid abundance was greater (ANOVA, $P<0.05$) in the west-river-channel during gates-in and nearly five times greater (ANOVA, $P<0.05$) in the east-river-channel during gates-out. It appears as though during periods of the year (gates-out) when the RBRPP will be utilized to provide water to the Tehama Colusa and Corning canal, less fish will be entrained with the current pump locations than if the pumps were located in the east-river-channel.

Diel distribution patterns.—Nocturnal chinook salmon abundance was on average five times greater than diurnal patterns of abundance. These trends remained consistent among months except for months of high flows. For example, January was one of the wettest months on record and stream flows, turbidity, and debris loads were extremely high. These factors may have acted in concert to increase juvenile outmigration even though diurnal time periods were typically periods of lower outmigration. Furthermore, our experimental design was compromised during portions of January because we were unable to sample safely during nocturnal periods. Periods of greatest juvenile outmigration may have gone unsampled due to these limitations.

Unwin (1986) found similar diel outmigration patterns (for periods split into three 8-h intervals: 0600 - 1400 hours; 1400 - 2200 hours; and 2200 - 0600 hours). Juvenile chinook salmon were emigrating almost exclusively during nocturnal periods (1400 - 2200 hours and 2200 - 0600 hours) and were primarily sedentary during daylight hours. Johnsen et al. (1988) found the majority of juvenile salmon passage at John Day Dam occurred during night-time hours. Catch per acrefoot of naturally produced juvenile chinook salmon emigrating past RBDD showed distinct diel patterns of abundance (Figure 22). Our catches, however, may not reflect true patterns of abundance, but habitat shifts during diel periods. Edmundson et al. (1968) observed different water column fish distributions for spring chinook salmon during different diel periods. During nocturnal periods, juvenile salmon were found near the surface or bottom in quite water, and near the bottom in flowing water. During diurnal periods fish were distributed throughout the water column. These observations were made for spring chinook salmon during summer, a non-migrating period for this race. If, however, during different periods of the day juvenile chinook salmon use different areas within the water column to outmigrate, incorrect inferences may be drawn from trap data. For instance, if one objective of the RBRPP is to minimize fish entrainment into water diversion pumps, a potential pumping strategy based on our initial findings would be to pump during diurnal periods and not to pump during nocturnal periods. However, traps sample the upper 2.4 m of the water column and abundance patterns may not reflect those that are occurring throughout the water column. Furthermore, we will need to investigate trap avoidance and its potential affect on patterns of abundance. For these reasons it will be imperative to coordinate sampling efforts between NCVFWO and RBRPP to validate patterns of fish entrainment with patterns of fish abundance at RBDD.

CONCLUSIONS

We were unable to obtain sufficient numbers of efficiency estimates during this study period to accurately estimate absolute abundance of juvenile salmon emigrating downstream past RBDD. Additional efficiency tests will be needed over a broad range of river and environmental conditions to fulfill this objective.

Results from length selectivity tests indicated length frequencies of marked fish caught in traps were significantly different ($P<0.05$) from those released. Population estimates not corrected for this potential source of bias will ultimately overestimate abundance of size classes being selected for and underestimate abundance of size classes being selected against. Differences in size distributions and mean length were statistically significant between marked and recaptured fish; however, differences were "biologically" small and the effect of length selectivity may be insignificant on population estimates.

Tests between the frequency of size classes caught in traps and beach seines indicated that the two gears were sampling different size classes of juvenile chinook salmon. In general it appeared as though traps sampled smaller (<40 mm) and larger (>60 mm) salmon more frequently whereas medium (40-60 mm) sized fish were sampled infrequently when compared to shoreline seining.

Abundance of naturally produced juvenile salmon (all runs combined) was greatest during January and largely reflected the abundance of fall chinook salmon. Abundance of spring chinook salmon peaked in December but were relatively non-abundant during other months of the year. Conversely, winter and late-fall chinook were abundant during peak periods in September and April, respectively, but demonstrated protracted periods of emigration past RBDD when compared to the other races of chinook salmon.

No consistent trends of spatial patterns of abundance for juvenile salmon were evident when analyzed by month; however, abundance was greater in the east-river-channel during gates-out and west-river-channel during gates-in. It appears that during periods of the year (gates-out) when the RBRPP will be utilized to provide water to the Tehama Colusa/Corning canal, less fish will be entrained with the current pump locations than if the pumps were located in the east-river-channel.

Juvenile salmon exhibited distinct diel patterns of abundance. Catches from rotary screw traps indicated that during 8 of 12 months, abundance of juvenile salmonids was significantly greater ($P<0.05$) during nocturnal periods. Spring chinook salmon, on the other hand, appeared to have the greatest propensity for diurnal migration patterns (diurnal abundance was greater in three of eight months, although not statistically different) and exhibited this behavior in months of high flows and water turbidity.

Recommendations

— Determine the efficacy of using hatchery-reared salmonids for estimating trap efficiency rates for naturally produced chinook salmon. In addition to these studies additional efficiency tests should be conducted using naturally produced salmon. Salmon obtained from traps or from shoreline beach seining are likely sources of these fish.

— Future efforts should be directed towards obtaining trap efficiency estimates over a broad range of environmental conditions to enable construction of a predictive model.

— Develop weekly estimates of absolute abundance of fall, late-fall, winter and spring chinook salmon, and steelhead trout.

— Further evaluate whether length selectivity is occurring, and if so, what effect it may have on estimates of abundance.

— Continue diel sampling to complete an annual cycle.

— Continue efforts to estimate spatial and seasonal distributions.

— Continue coordinating this study with those being conducted by the RBRPP to ensure research objectives are met by validating patterns of fish entrainment with patterns of fish abundance at RBDD.

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Table 1.—Number of fish captured in rotary screw traps from 1 July 1994 to 30 June 1995.

Common name	Scientific name	No.	Percent of total
Chinook salmon	*Oncorhynchus tschawytscha*	81,080	90
Sacramento sucker	*Catostomus occidentalis*	2,210	2
Sacramento squawfish	*Ptychocheilus grandis*	1,788	2
Prickly sculpin	*Cottus asper*	1,502	2
Pacific lamprey	*Lampetra tridentata*	914	1
Rainbow trout / steelhead	*Oncorhynchus mykiss*	724	1
Bluegill sunfish	*Lepomis macrochirus*	616	1
Green sturgeon	*Acipenser medirostris*	517	1
Hardhead	*Mylopharodon conocephalus*	260	*
Golden shiner	*Notemigonus crysoleucas*	163	*
Threespine stickleback	*Gasterosteus aculeatus*	124	*
Riffle sculpin	*Cottus asper*	123	*
California roach	*Hesperoleucus symmetricus*	80	*
White catfish	*Ictalurus catus*	57	*
Largemouth bass	*Micropterus salmoides*	23	*
Mosquito fish	*Gambusia affinis*	19	*
Hitch	*Lavinia exilicauda*	18	*
Tule perch	*Hysterocarpus traski*	16	*
Green sunfish	*Lepomis cyanellus*	15	*
Speckled dace	*Rhinichthys osculus*	9	*
Channel catfish	*Ictalurus punctatus*	6	*
Black crappie	*Pomoxis nigromaculatus*	5	*
Smallmouth bass	*Micropterus dolomieui*	5	*
Carp	*Cyprinus carpio*	4	*
Redear sunfish	*Lepomis microlophus*	4	*
Brown bullhead	*Ictalurus nebulosus*	3	*
Black bullhead	*Ictalurus melas*	2	*
American shad	*Alosa sapidissma*	1	*
Total		90,288	100

* Less than 1% of total fish captured by rotary screw traps

Table 2.—Number of chinook salmon captured in rotary screw traps between 1 July 1994 to 30 June 1995.

Race	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Total
Fall	19	54	69	1	0	29,591	13,786	5,504	3,539	19,841	1,548	3,216	77,168
Late-fall	6	7	25	16	40	67	3	0	0	355	67	19	604
Spring	0	0	0	10	14	1,457	91	16	13	196	1	1	1,799
Winter	0	20	385	391	293	233	10	60	89	27	1	0	1,509
Total	25	81	479	418	347	31,348	13,890	5,580	3,641	20,419	1,617	3,236	81,080

Table 3.—Trap efficiency trials with dyed hatchery fall chinook salmon (50 to 80 mm) passing the sampling transect at Red Bluff Diversion Dam (RK 391) on the Sacramento River. Fish N = 81,963 (SD=1.3) were released at river kilometer 395 on the east shore, 19 April 1995.

	Trap			Transect
	2	5	9	
Trap efficiency				
Marked (M)	81,963	81,963	81,963	81,963
Recapture (R)	173	130	64	367
Trap efficiency (TE) [a]	0.21%	0.16%	0.08%	0.45%
Weighted trap efficiency				
Volume sampled in acrefeet (V)	415	448	404	1,267
Discharge in acrefeet (D)	67,809	67,809	67,809	67,809
Estimated recapture [b]	28,267	19,677	10,742	19,642
Weighted trap efficiency (TE_w) [c]	35%	24%	13%	24%

[a] TE = R / M; Expressed as a percent.
[b] Estimated = R * D / V
[c] TE_w = Estimated / M; Expressed as a percent.

Table 4.—Efficiency tests reported in the literature for rotary screw traps. Unit conversions were made when appropriate.

Stream and state	Species	Origin	Sample size	Fork length Mean	Fork length Range	Efficiency (%)	Source
Sacramento R., CA	*O. tshawytscha*	Hatchery	81,963	68	50 - 80	0.1 - 0.2 [a]	This study
Trout Brook, NY	*O. tshawytscha*	Hatchery	10 - 461			11.2 - 17.3 [b]	Keenan et al. 1994
Little Sandy Ck, NY	*O. tshawytscha*	Wild	57 - 804			1.3 - 3.2 [b]	Keenan et al. 1994
Orwell Brook, NY	*O. tshawytscha*	Hatchery	32 - 84			3.3 - 5.1 [b]	Keenan et al. 1994
American River, CA	*O. tshawytscha*	Wild	4038	38	31 - 53	0.8 [d]	Snider and Titus 1995
American River, CA	*O. tshawytscha*	Wild	1509	62	35 - 92	0.9 [d]	Snider and Titus 1995
American River, CA	*O. tshawytscha*	Wild	1270	45	32 - 64	0.0 [d]	Snider and Titus 1995
Situk River, AK	*O. tshawytscha*	Wild				24.0 [c]	Thedinga et al. 1994
Situk River, AK	*O. kisutch*	Wild				12.0 [c]	Thedinga et al. 1994
Situk River, AK	*O. nerka*	Wild				7.0 [c]	Thedinga et al. 1994
Situk River, AK	*O. mykiss*	Wild				3.0 [c]	Thedinga et al. 1994
Imnaha River, OR	*O. tshawytscha*	Wild	9 - 101			3.6 - 14.7 [b]	Ashe et al. 1995
Imnaha River, OR	*O. tshawytscha*	Hatchery	1 - 87			13.8 [c]	Ashe et al. 1995
Imnaha River, OR	*O. mykiss*	Wild	5 - 100			5.8- 16.3 [b]	Ashe et al. 1995
Imnaha River, OR	*O. mykiss*	Hatchery	28 - 100			12.8 - 22.8 [b]	Ashe et al. 1995
Grande Ronde, OR	*O. Tshawytscha*	Wild				54.7 - 4.8 [b]	Keefe et al. 1996

[a] Range from point estimates
[b] Range from mean estimates
[c] Mean estimate
[d] Point estimate

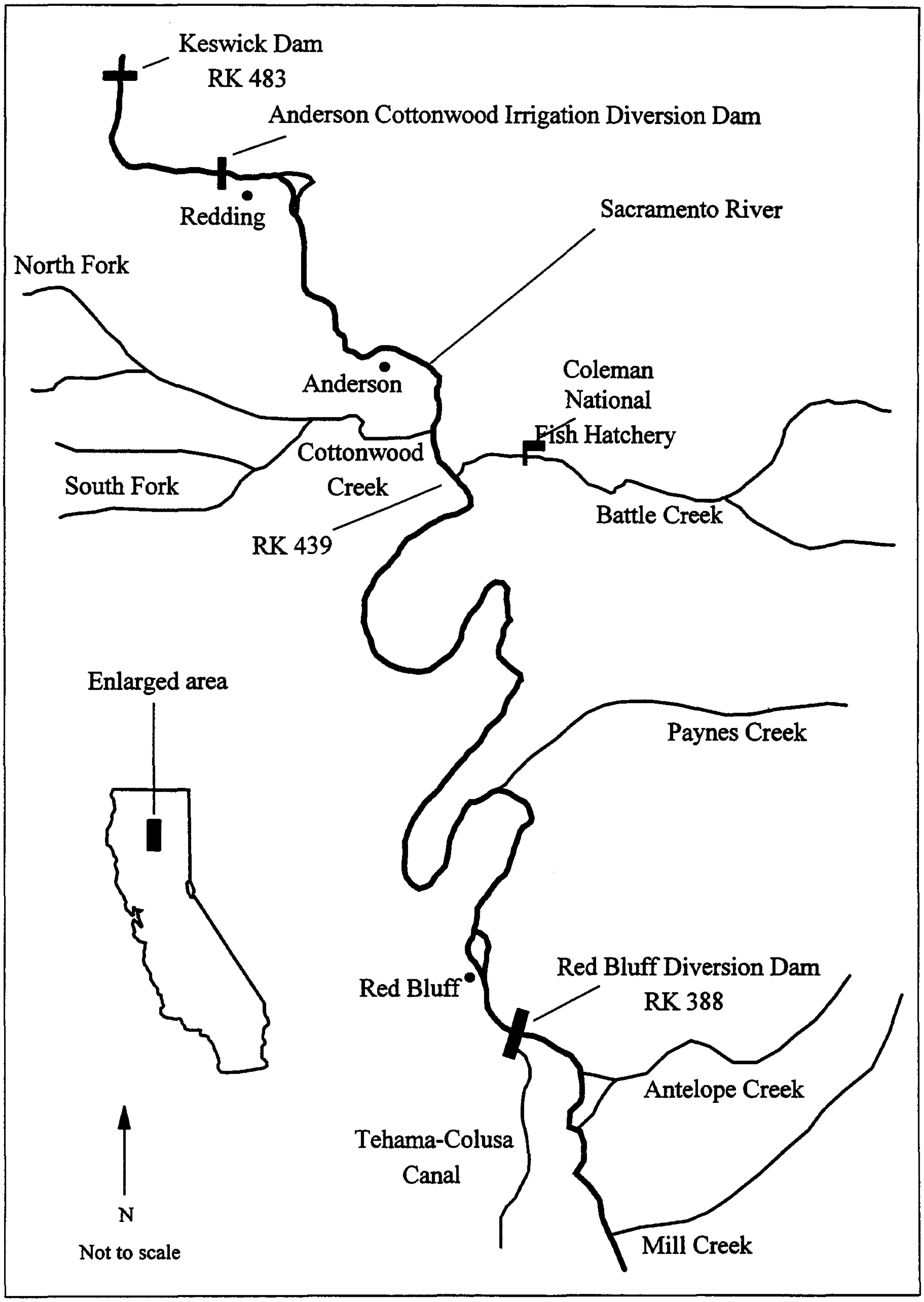


Figure 1.--Location of Red Bluff Diversion Dam on the Sacramento River at river kilometer 388 (river mile 243).

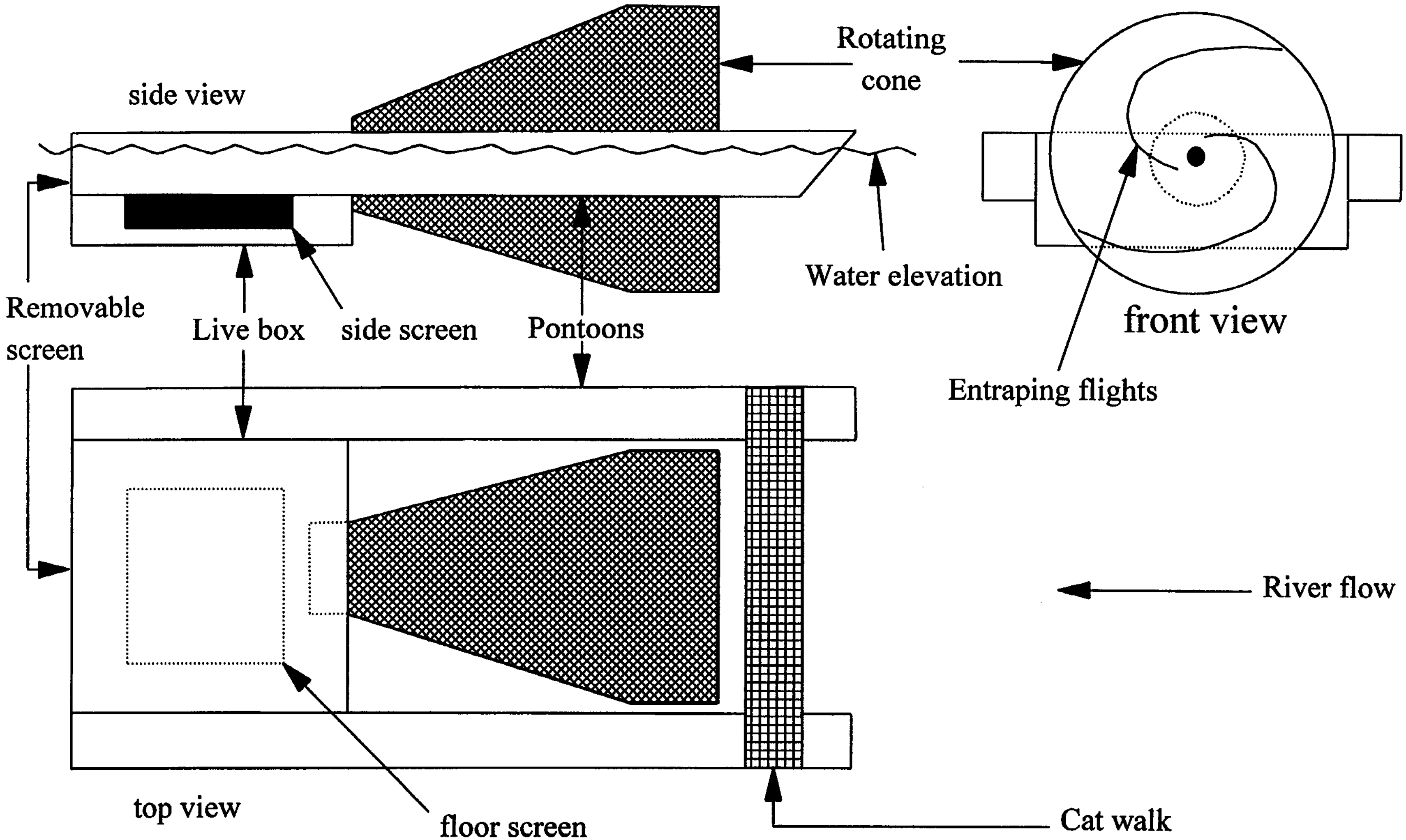


Figure 2.--Schematic view of rotary screw trap. Up to four traps were used in various arrays at Red Bluff Diversion Dam on the Sacramento River to sample outmigrating juvenile chinook salmon.

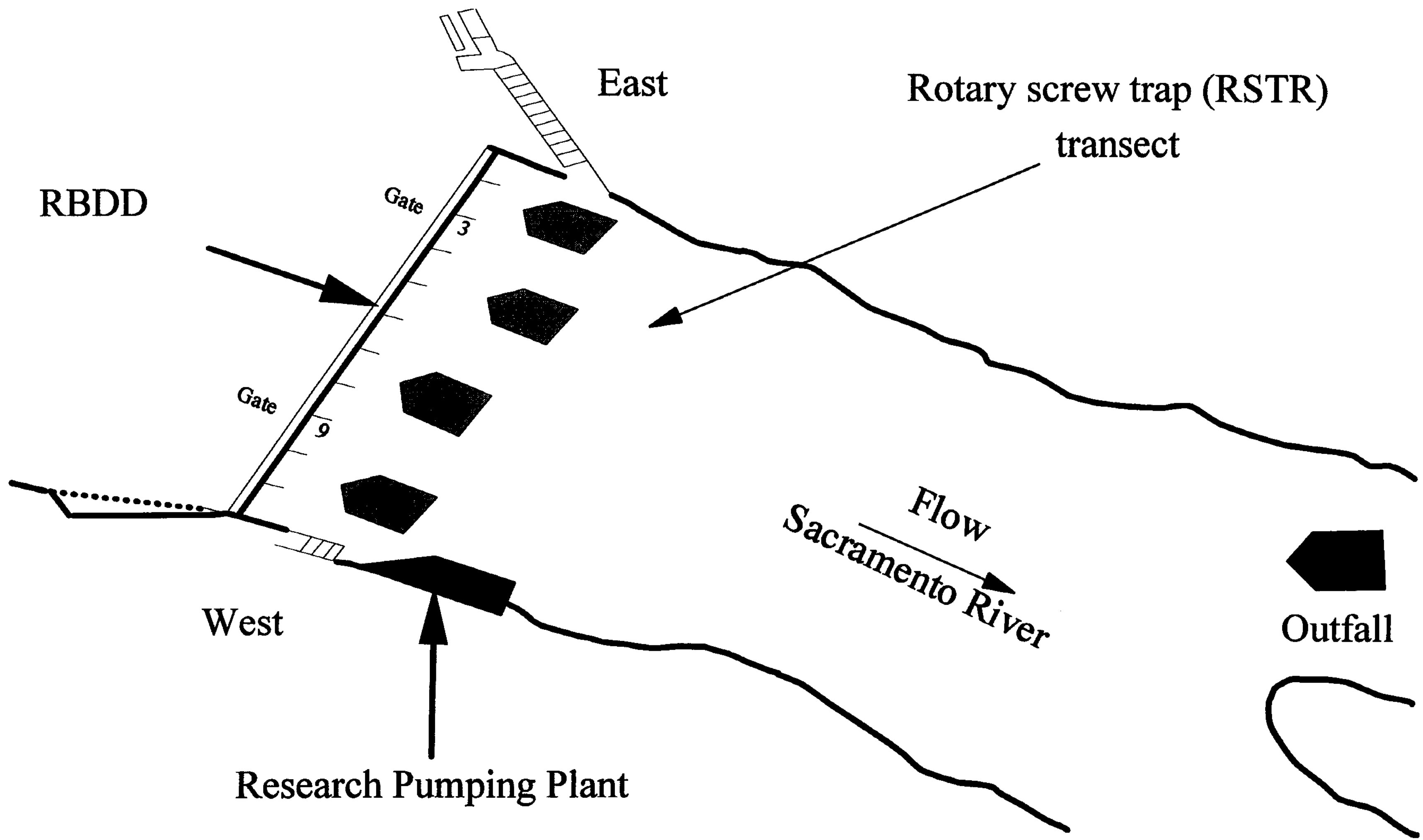


Figure 3.--Rotary screw trap locations at Red Bluff Diversion Dam (RBDD) on the Sacramento River at river kilometer 388 (river mile 243). Gates 1 - 5 represent the east and gates 6 - 11 represent the west-river-channel of the Sacramento River.

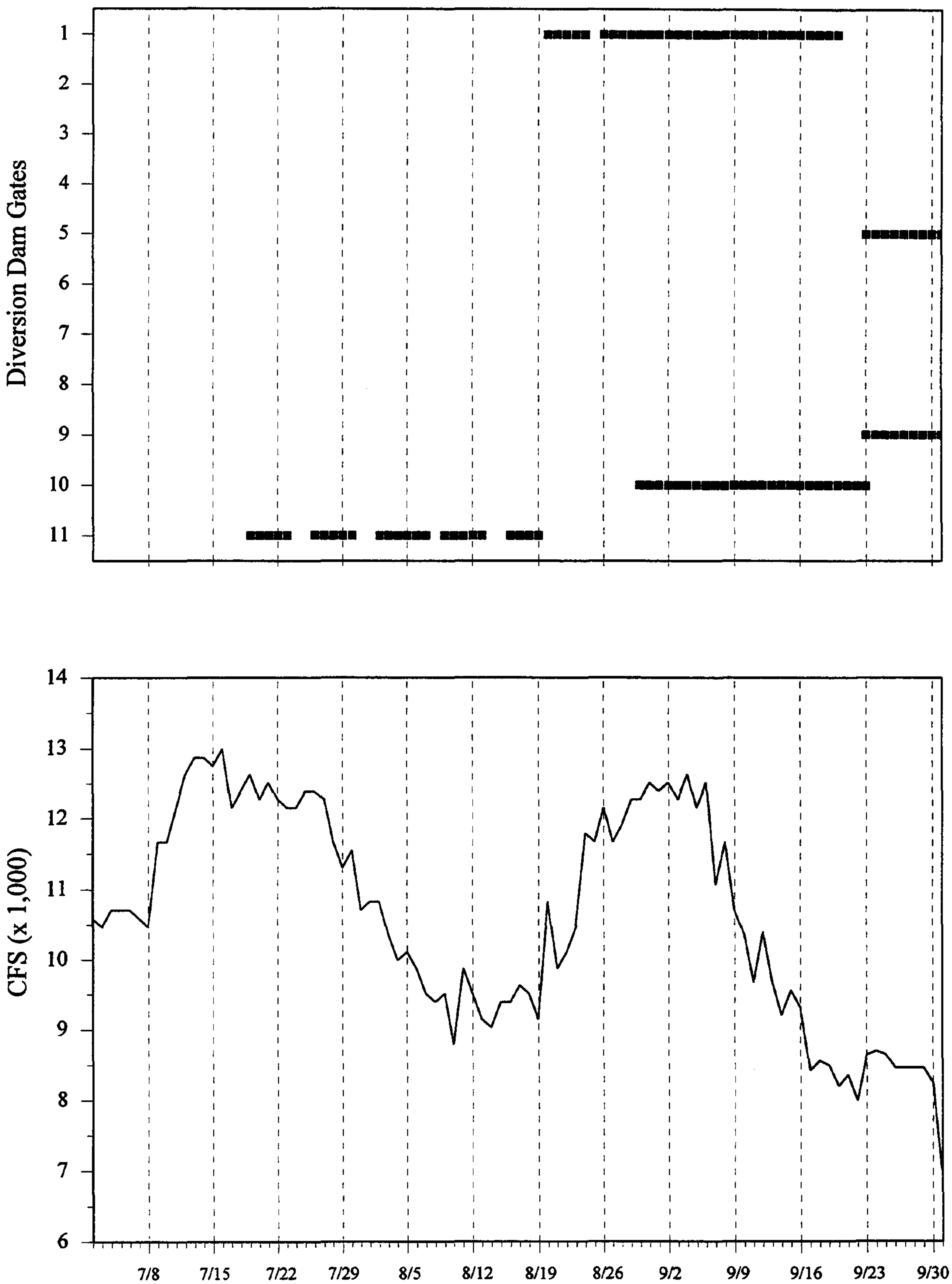


Figure 4.--Rotary screw trap sampling by dam gate and daily flows past Red Bluff Diversion Dam (estimated by Bureau of Reclamation) from 1 July to 30 September 1994. Black bars denote occurrence of sampling behind specified dam gates.

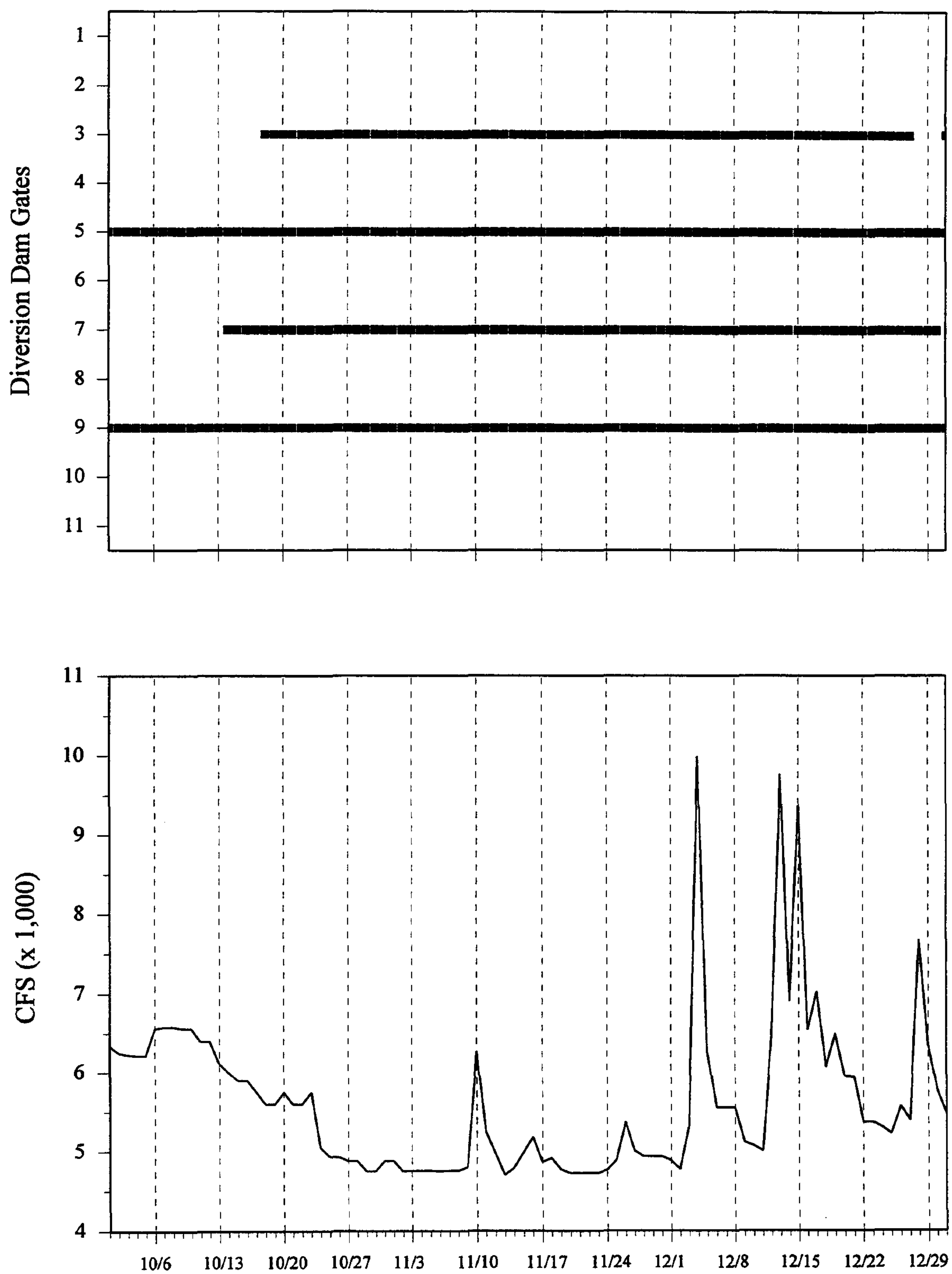


Figure 5.--Rotary screw trap sampling by dam gate and daily flows past Red Bluff Diversion Dam (estimated by Bureau of Reclamation) from 1 October to 31 December 1994. Black bars denote occurrence of sampling behind specified dam gate.

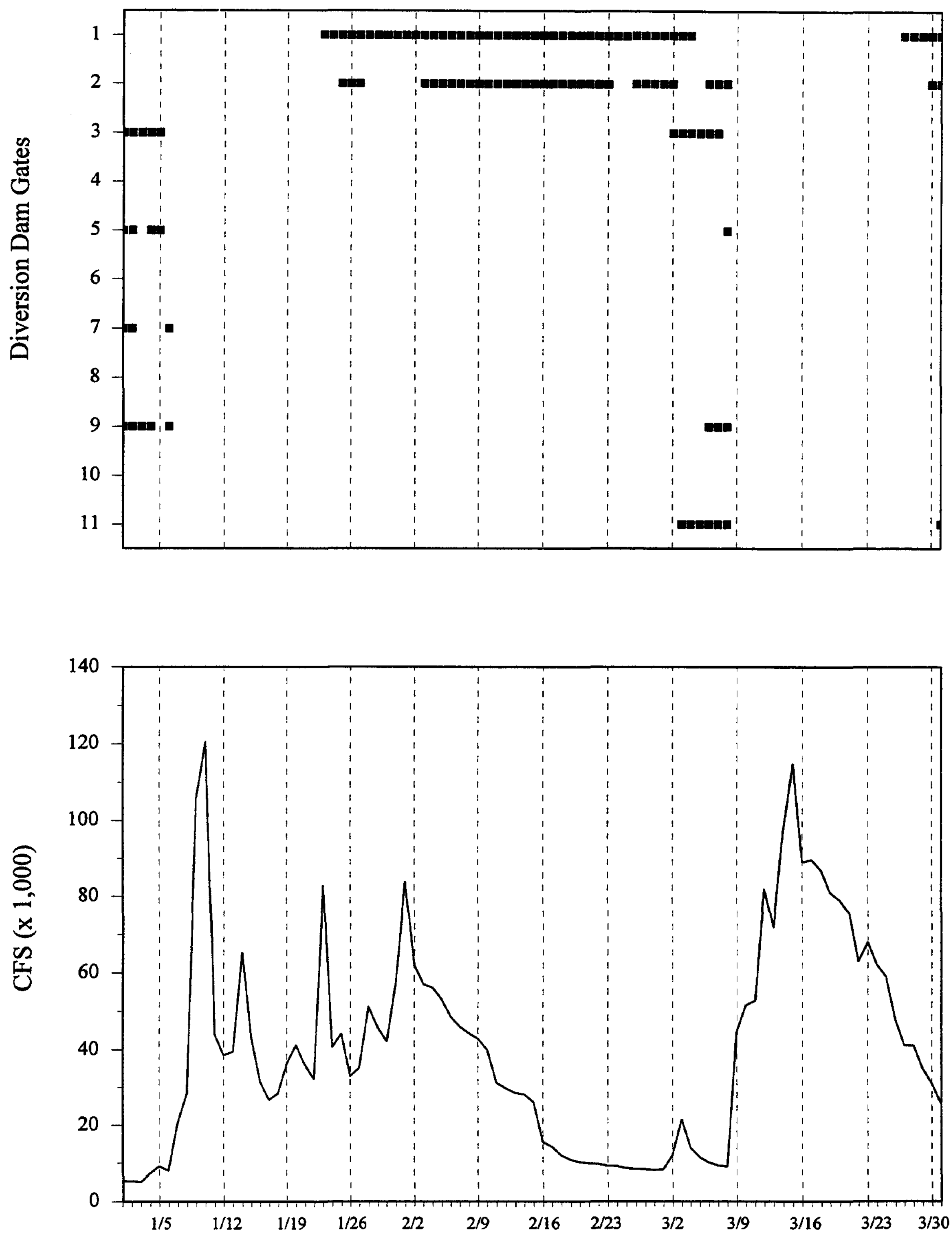


Figure 6.--Rotary screw trap sampling by dam gate and daily flows past Red Bluff Diversion Dam (estimated by Bureau of Reclamation) from 1 January to 31 March 1995. Black bars denote occurrence of sampling behind specified dam gate.

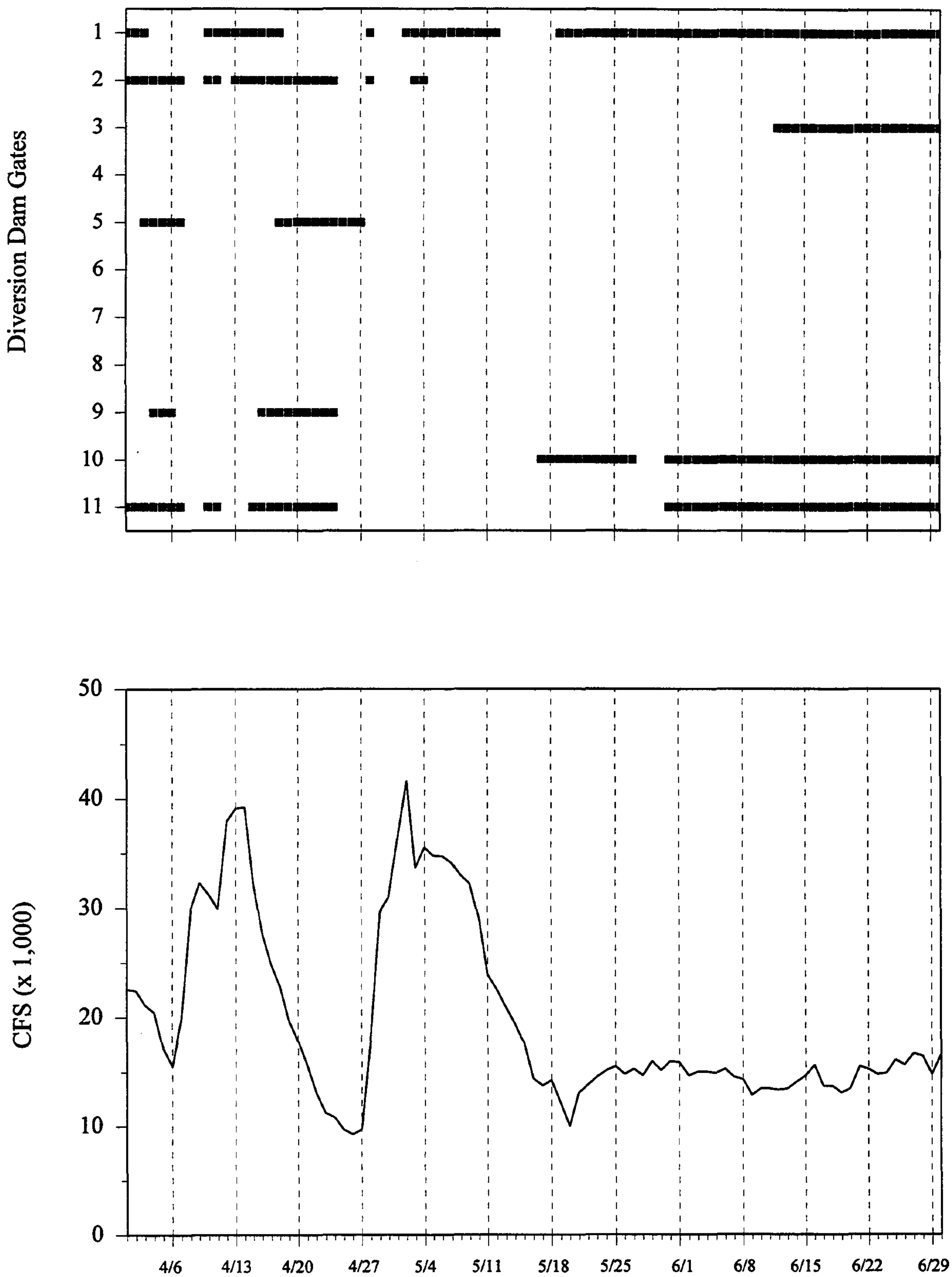


Figure 7.--Rotary screw trap sampling by dam gate and daily flows past Red Bluff Diversion Dam (estimated by Bureau of Reclamation) from 1 April to 30 June 1995. Black bars denote occurrence of sampling behind specified dam gate.

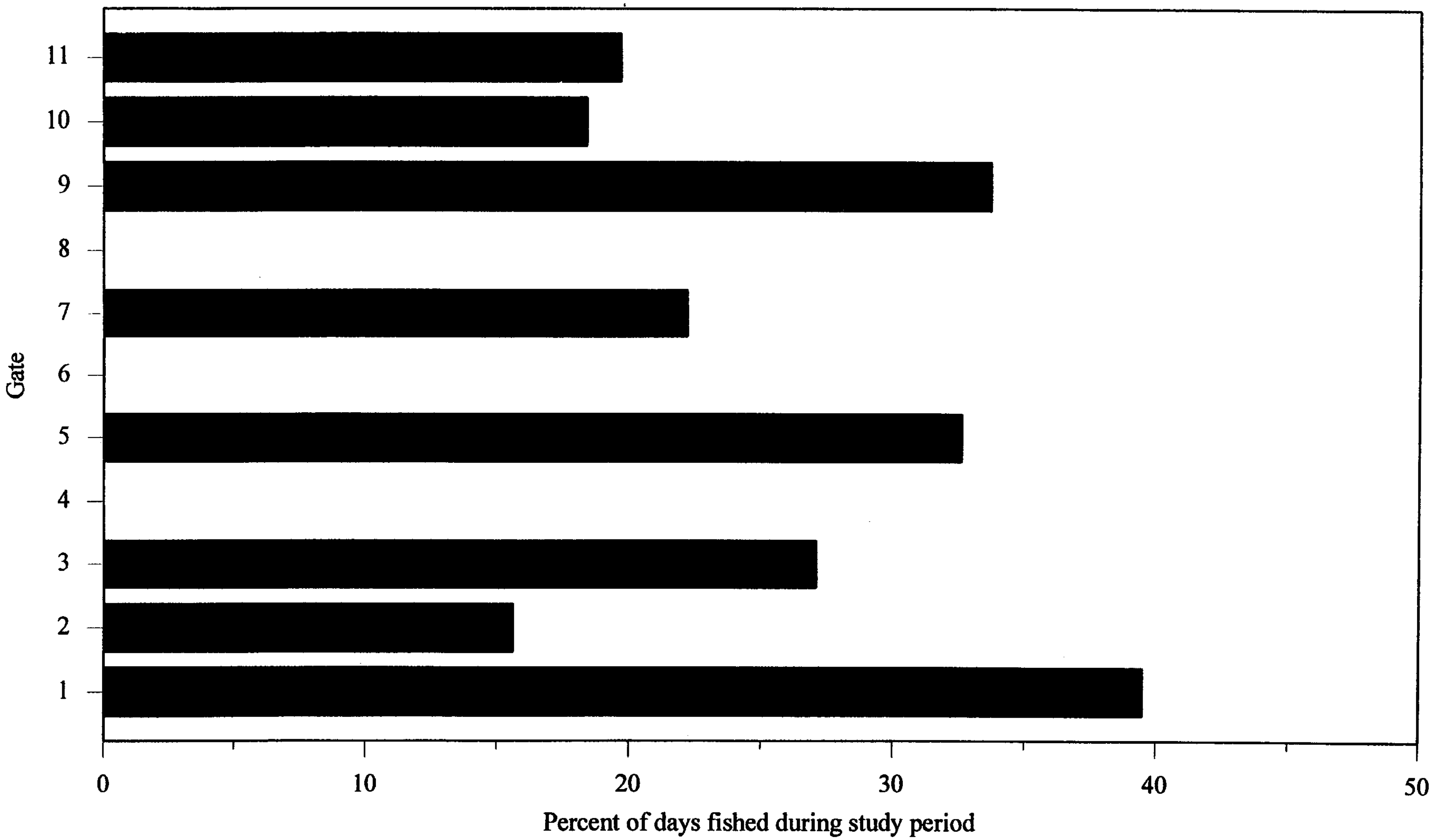


Figure 8.--Percent of days rotary screw trap sampling occurred behind specified dam gates at Red Bluff Diversion Dam during the study period 1 July 1994 to 30 June 1995.

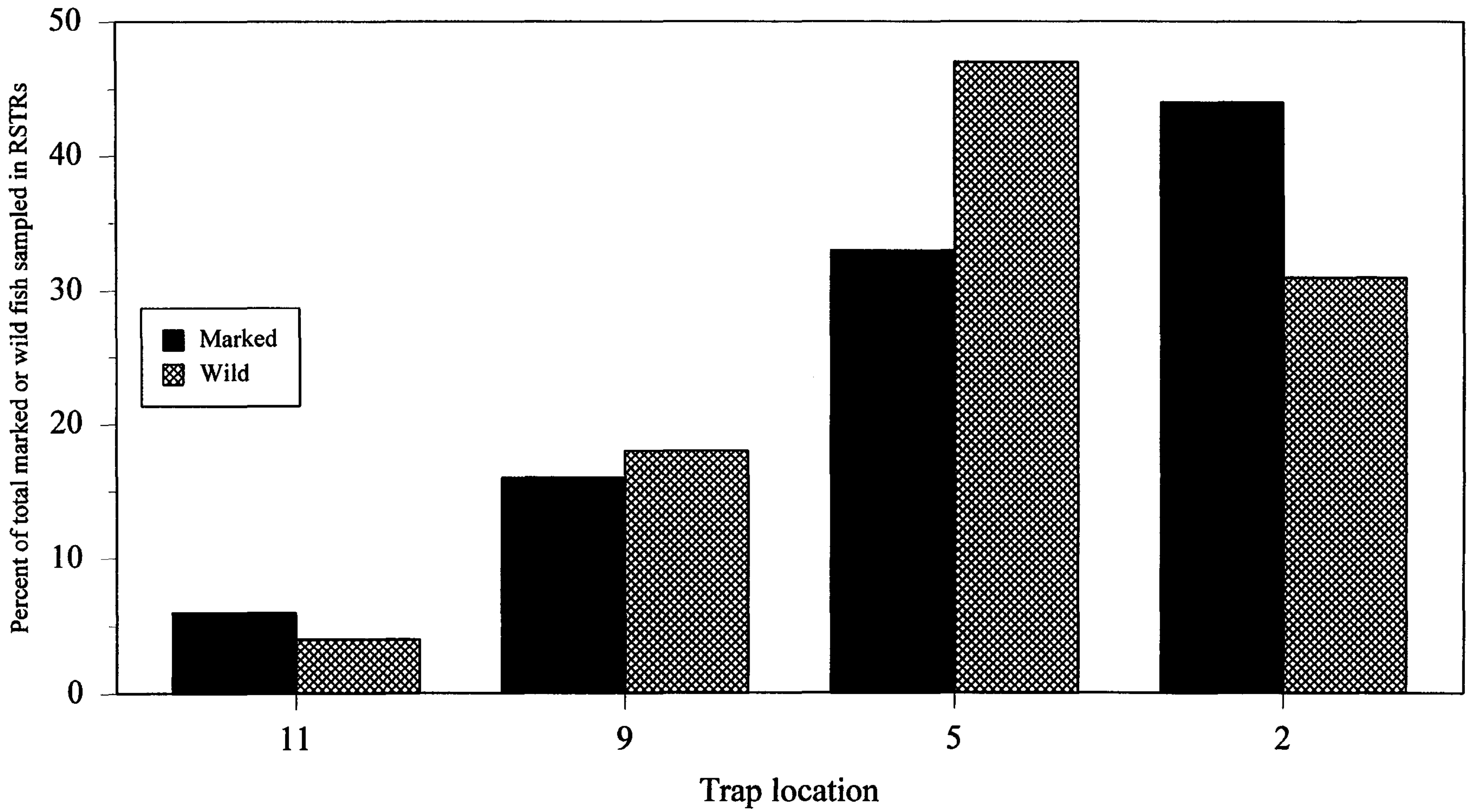


Figure 9.--Expected (wild fish) and observed (marked fish) spatial distributions of chinook salmon reported by trap location during sampling efficiency tests. Wild includes all unmarked chinook salmon captured in traps between 35 - 100 mm fork length. Chi-square tests for differences in proportions between marked and wild (chi-square, P=0.000, df=3, N=1,485) were significantly different between traps.

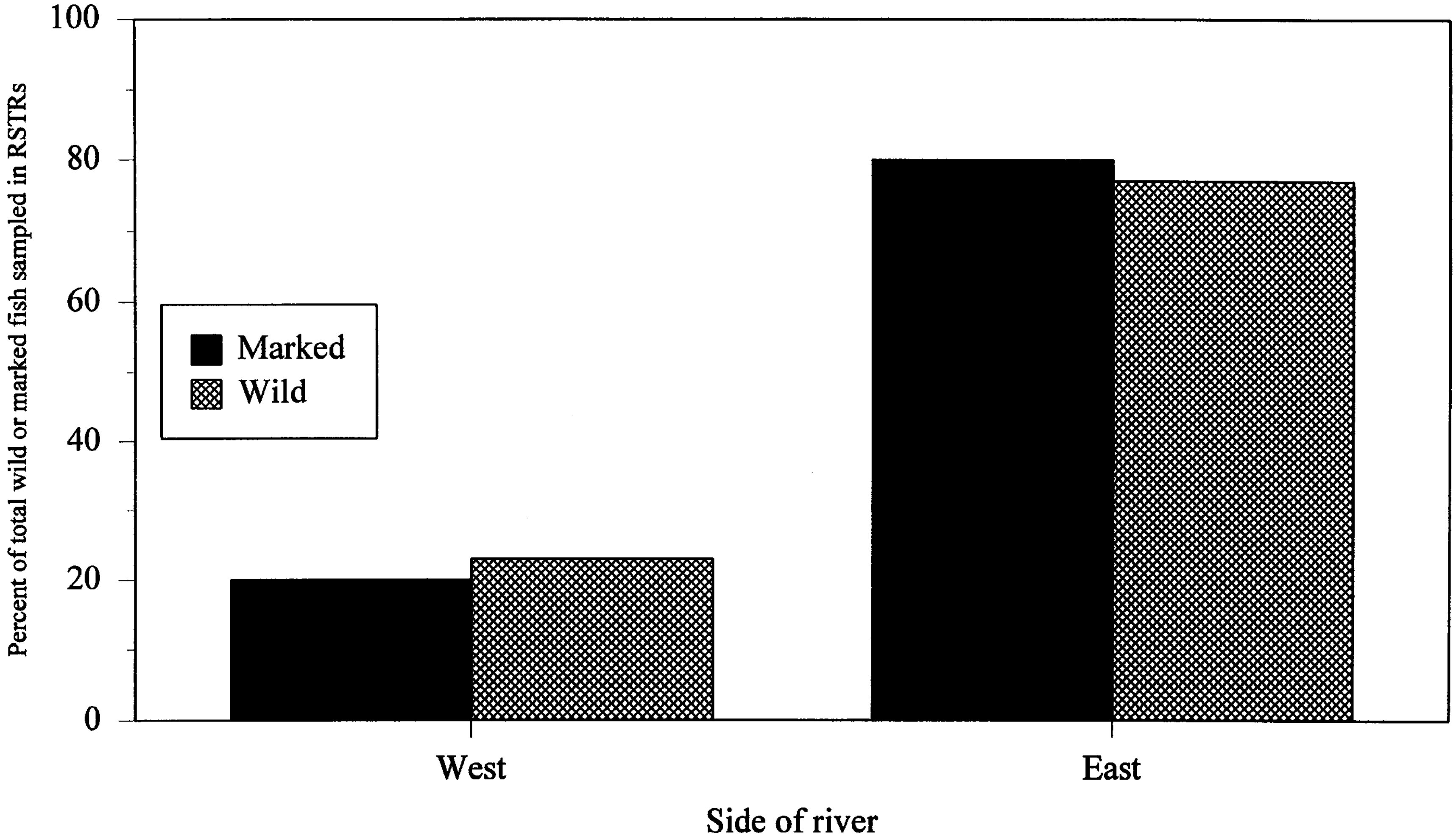


Figure 10.--Random dispersion tests of marked with wild chinook salmon between the east (gates 2 and 5) and west (gates 9 and 11) side of the Sacramento River at Red Bluff Diversion Dam. Marked = observed frequencies. Wild = expected frequencies. Chi-square test for differences in proportions was not significantly different (chi-square, P=0.201, df=1, N=1,485) between marked and wild fish.

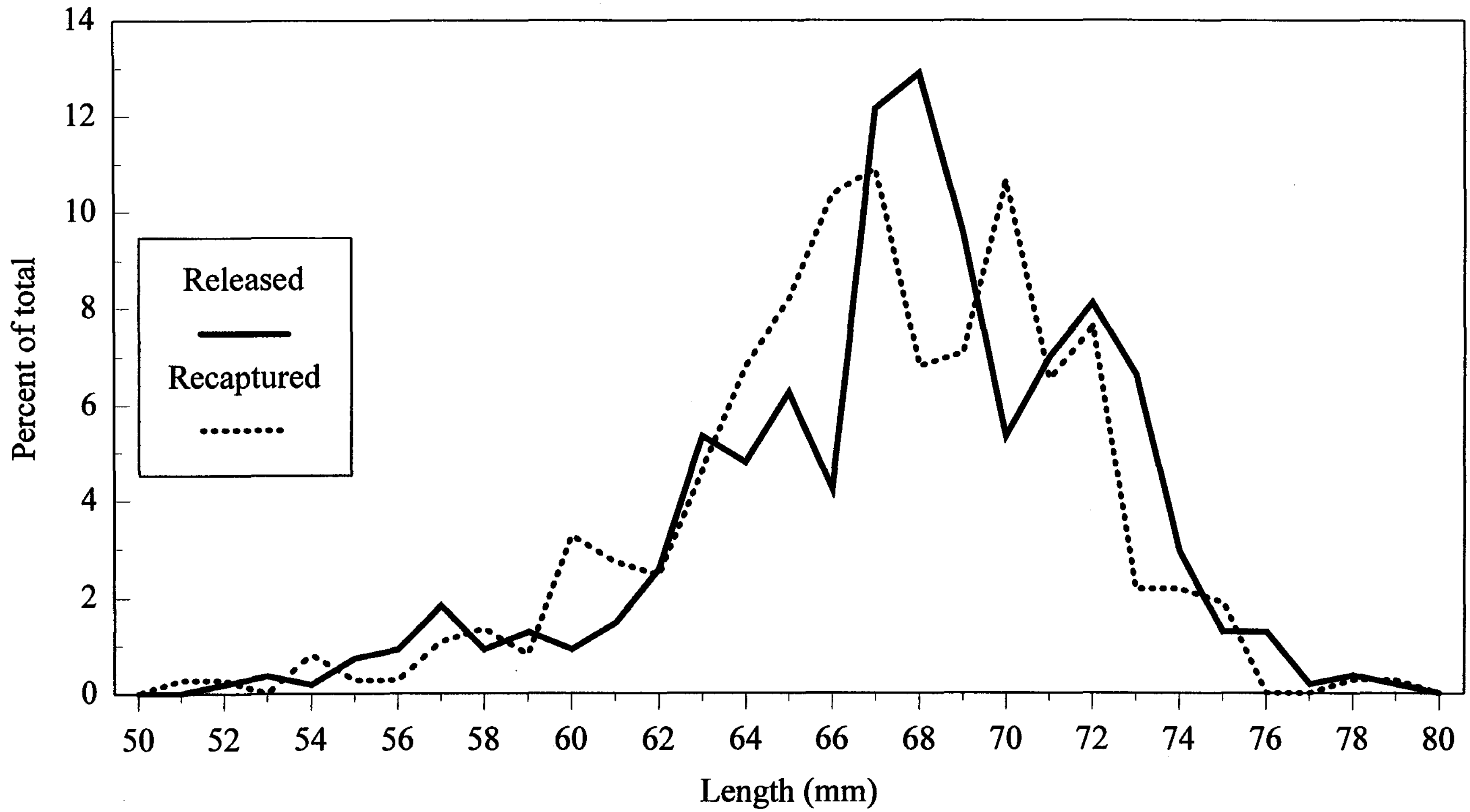


Figure 11.--Results from length selectivity tests between released and recaptured fish in traps at Red Bluff Diversion Dam. Release = length frequencies of marked fish released. Recapture = length frequencies of marked fish sampled in traps. Kolmogorov-Smirnov two-sample test differed (KS test, P=0.000, df=29, N=910) between released and recaptured juvenile salmonids.

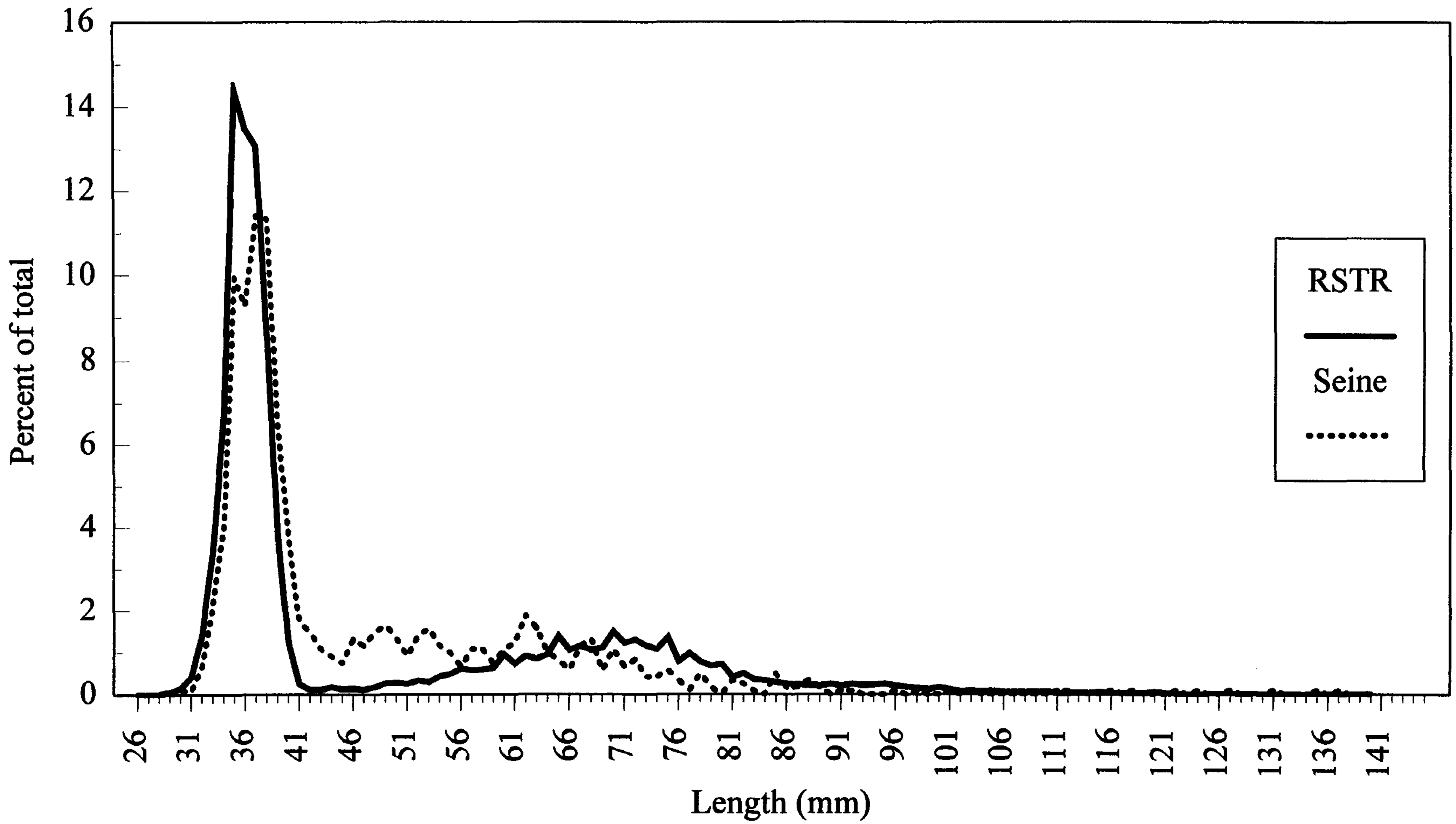


Figure 12.--Results from comparisons between shoreline seining and trap length selectivity for chinook salmon (all runs combined) captured at Red Bluff Diversion Dam. Kolmogorov-Smirnov two-sample test significantly differed (KS test, P=0.000, df=118, N=81,080) for length frequencies of wild juvenile salmonids sampled in traps and seines.

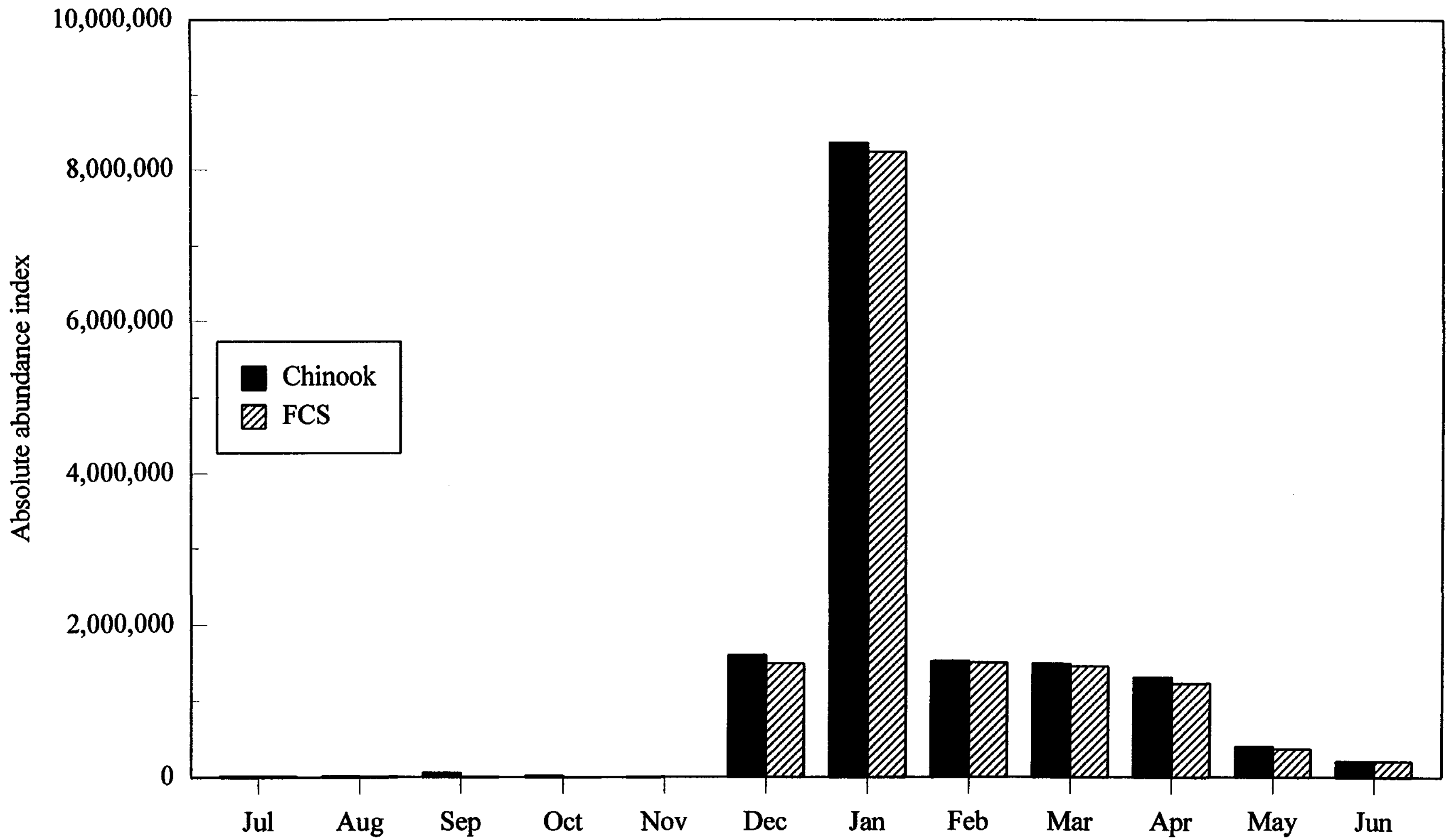


Figure 13.--Monthly mean absolute abundance indices (AAI) for naturally produced chinook (all runs combined) and fall chinook (FCS) salmon emigrating past Red Bluff Diversion Dam from 1 July 1994 to 30 June 1995.

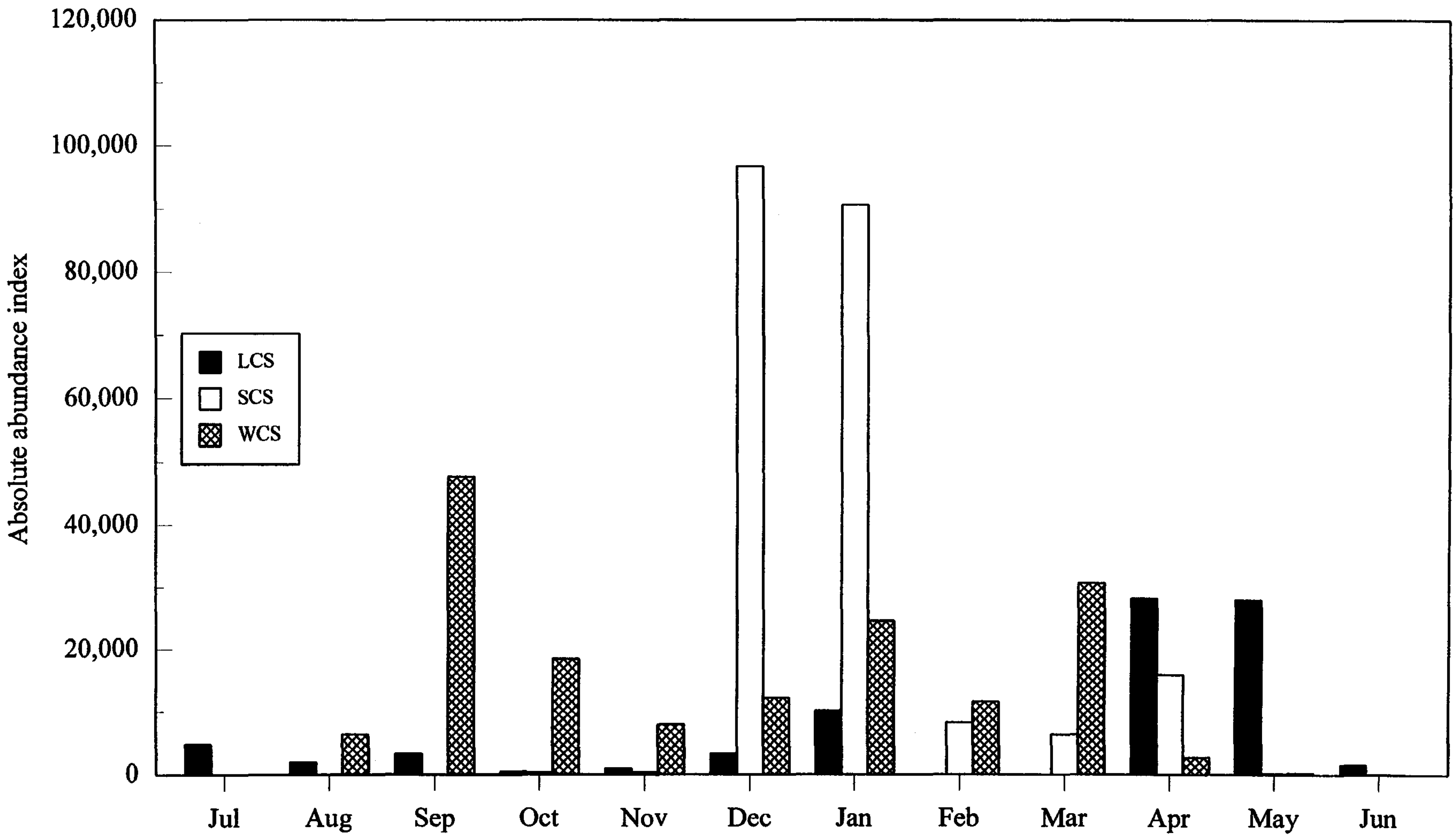


Figure 14.--Monthly mean absolute abundance indices (AAI) for naturally produced late-fall (LCS), spring (SCS), and winter (WCS) chinook salmon emigrating past Red Bluff Diversion Dam from 1 July 1994 to 30 June 1995.

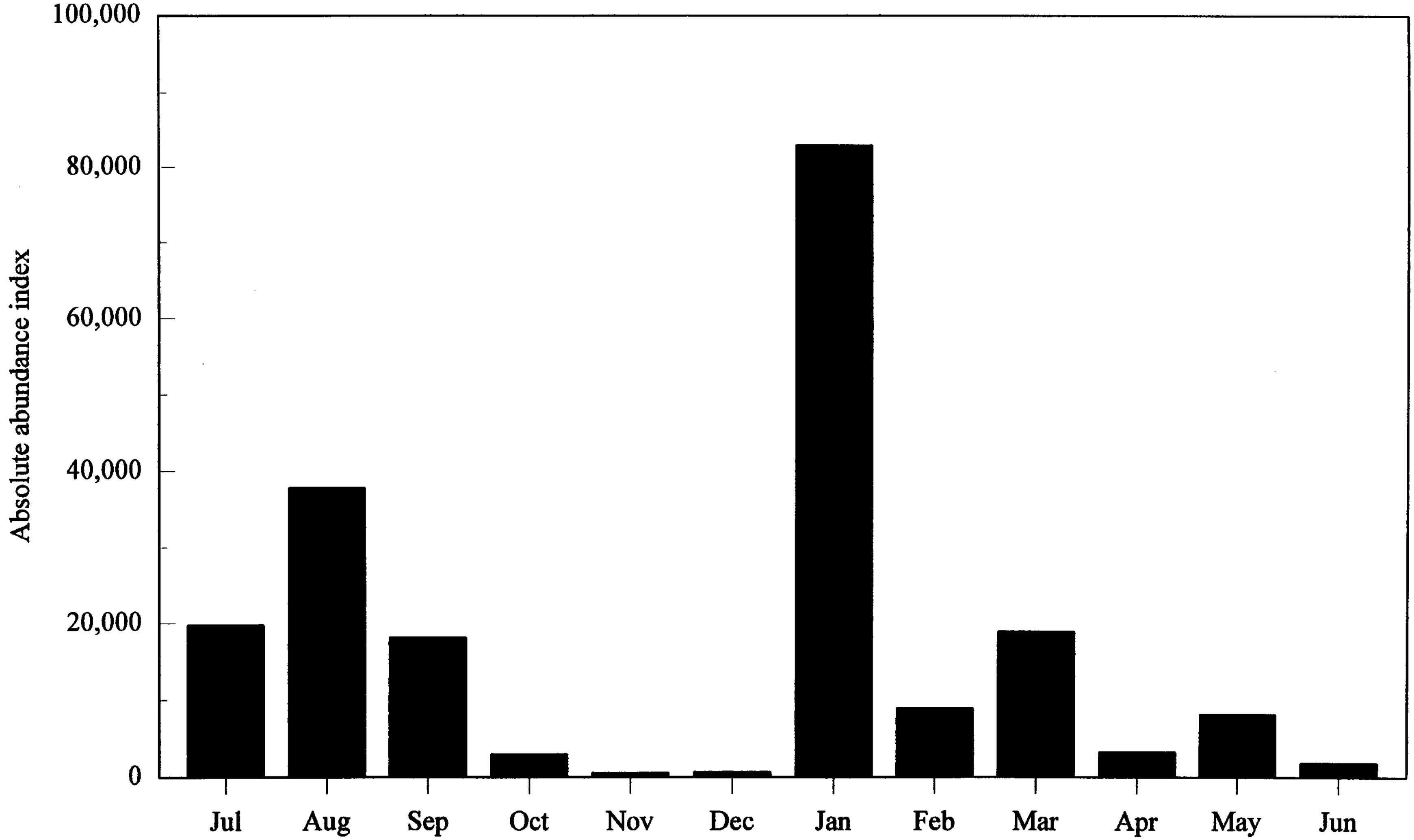


Figure 15.--Monthly mean absolute abundance indices (AAI) for steelhead/rainbow trout emigrating past Red Bluff Diversion Dam from 1 July 1994 to 30 June 1995.

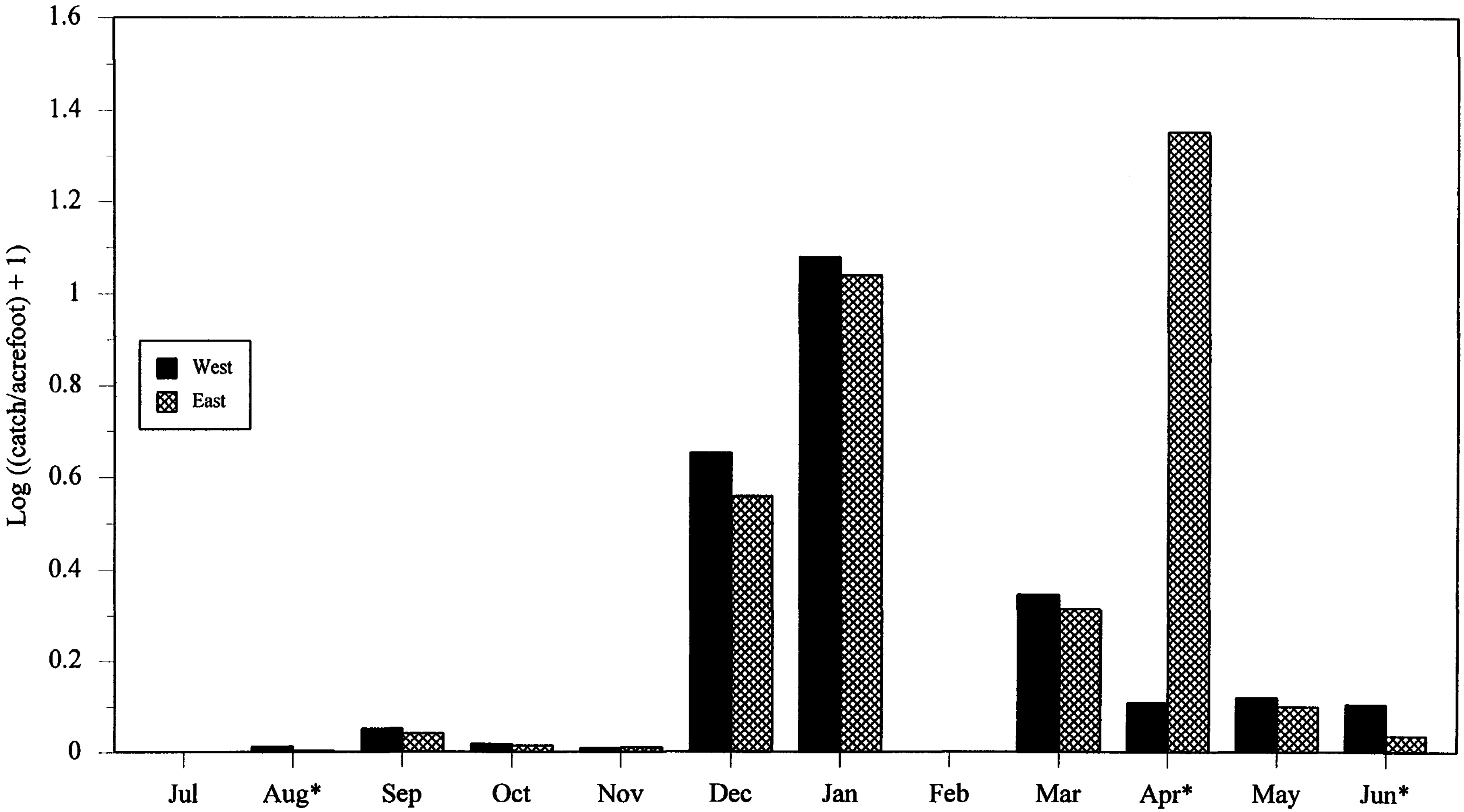


Figure 16.--Spatial patterns of abundance for naturally produced chinook salmon (all runs combined) at Red Bluff Diversion Dam from 1 July 1994 to 30 June 1995. Stars denote significant differences (ANOVA, $P<0.05$) between monthly mean west and east catch per acrefoot. Because of the large range in estimates, catch per volume sampled has been rescaled using the transformation Log_{10} ((catch/acrefoot) + 1) so that values range from > 0 to 1.4 fish per acrefoot.

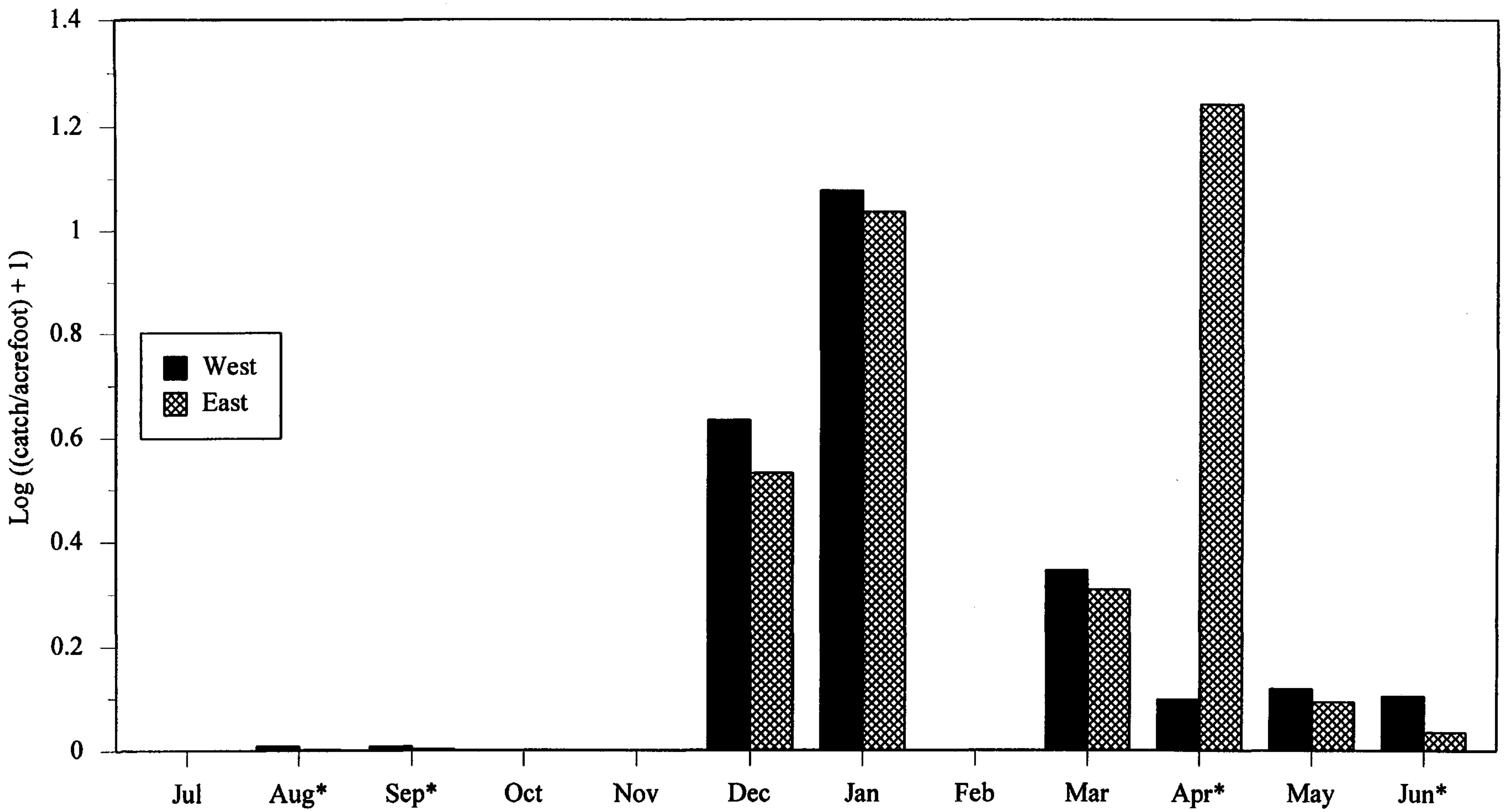


Figure 17.--Spatial patterns of abundance for naturally produced fall chinook salmon (FCS) at Red Bluff Diversion Dam from 1 July 1994 to 30 June 1995. Stars denote significant differences (ANOVA, $P<0.05$) between monthly mean west and east catch per acrefoot. Because of the large range in estimates, catch per volume sampled has been rescaled using the transformation Log_{10} ((catch/acrefoot) + 1) so that values range from > 0 to 1.3 fish per acrefoot.

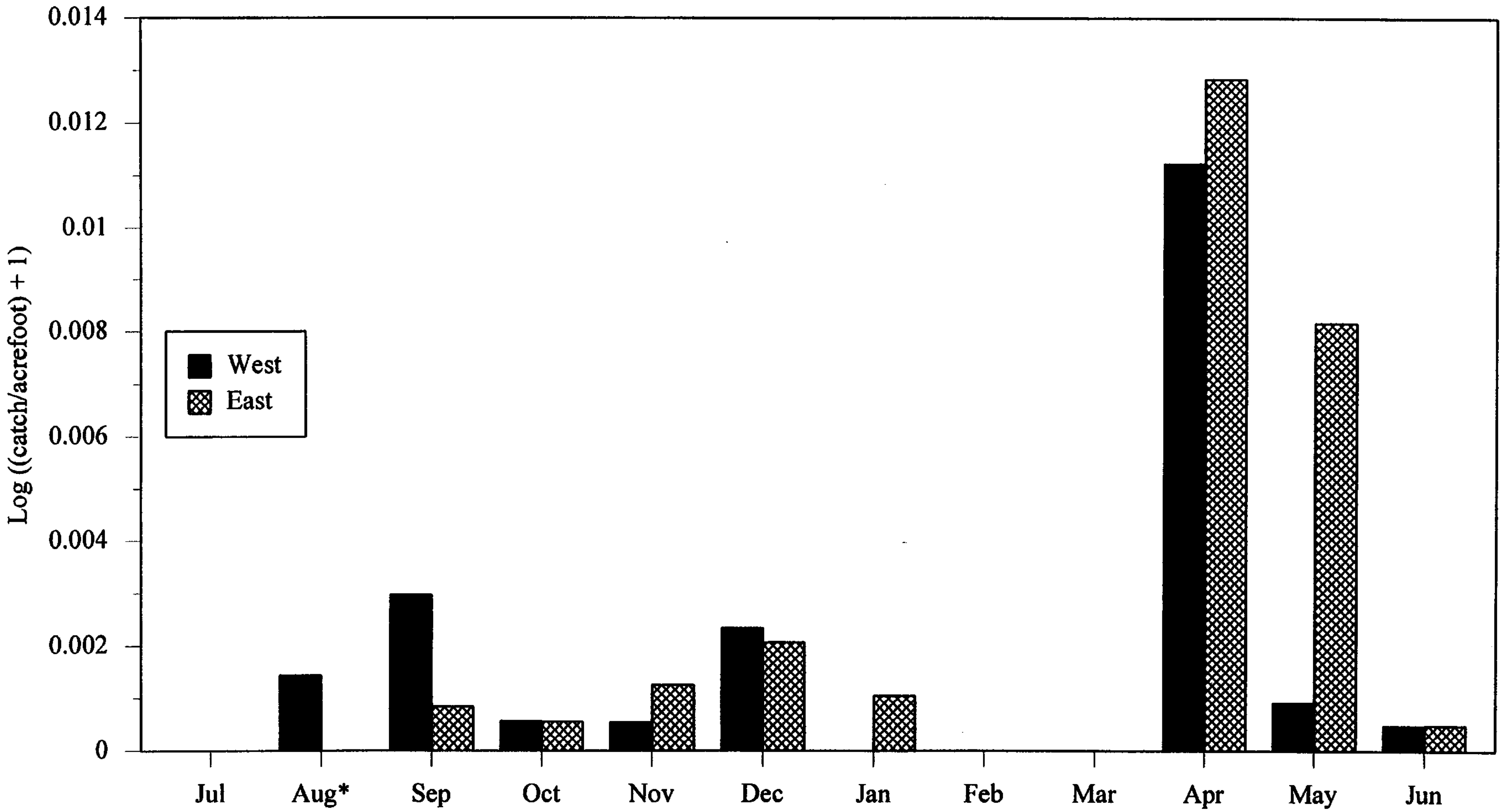


Figure 18.--Spatial patterns of abundance for naturally produced late-fall chinook salmon (LCS) at Red Bluff Diversion Dam from 1 July 1994 to 30 June 1995. Stars denote significant differences (ANOVA, $P<0.05$) between monthly mean west and east catch per acrefoot. Because of the large range in estimates, catch per volume sampled has been rescaled using the transformation Log_{10} ((catch/acrefoot) + 1) so that values range from > 0 to 0.013 fish per acrefoot.

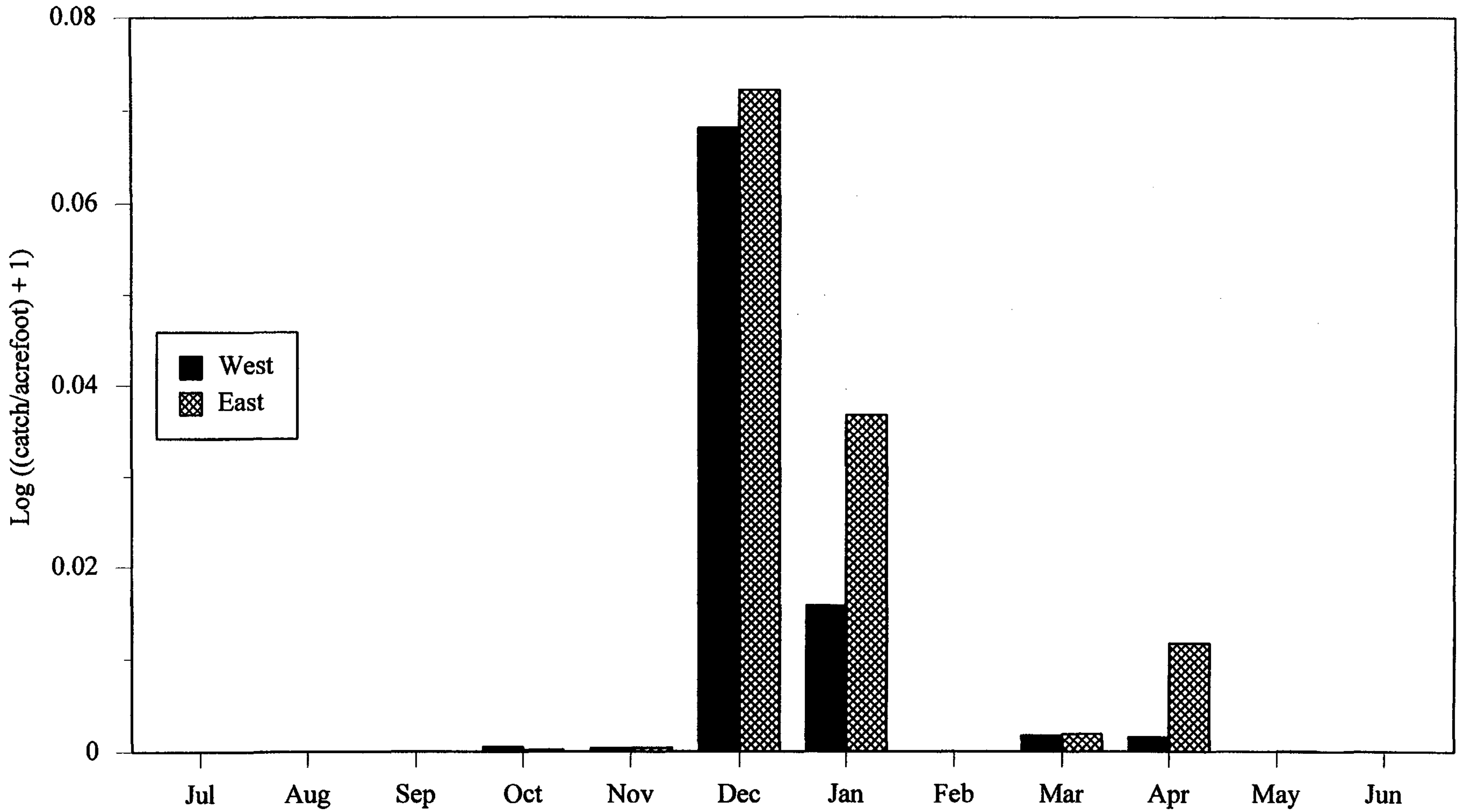


Figure 19.--Spatial patterns of abundance for naturally produced spring chinook salmon (SCS) at Red Bluff Diversion Dam from 1 July 1994 to 30 June 1995. Stars denote significant differences (ANOVA, $P<0.05$) between monthly mean west and east catch per acrefoot. Because of the large range in estimates, catch per volume sampled has been rescaled using the transformation Log_{10} ((catch/acrefoot) + 1) so that values range from > 0 to 0.07 fish per acrefoot.

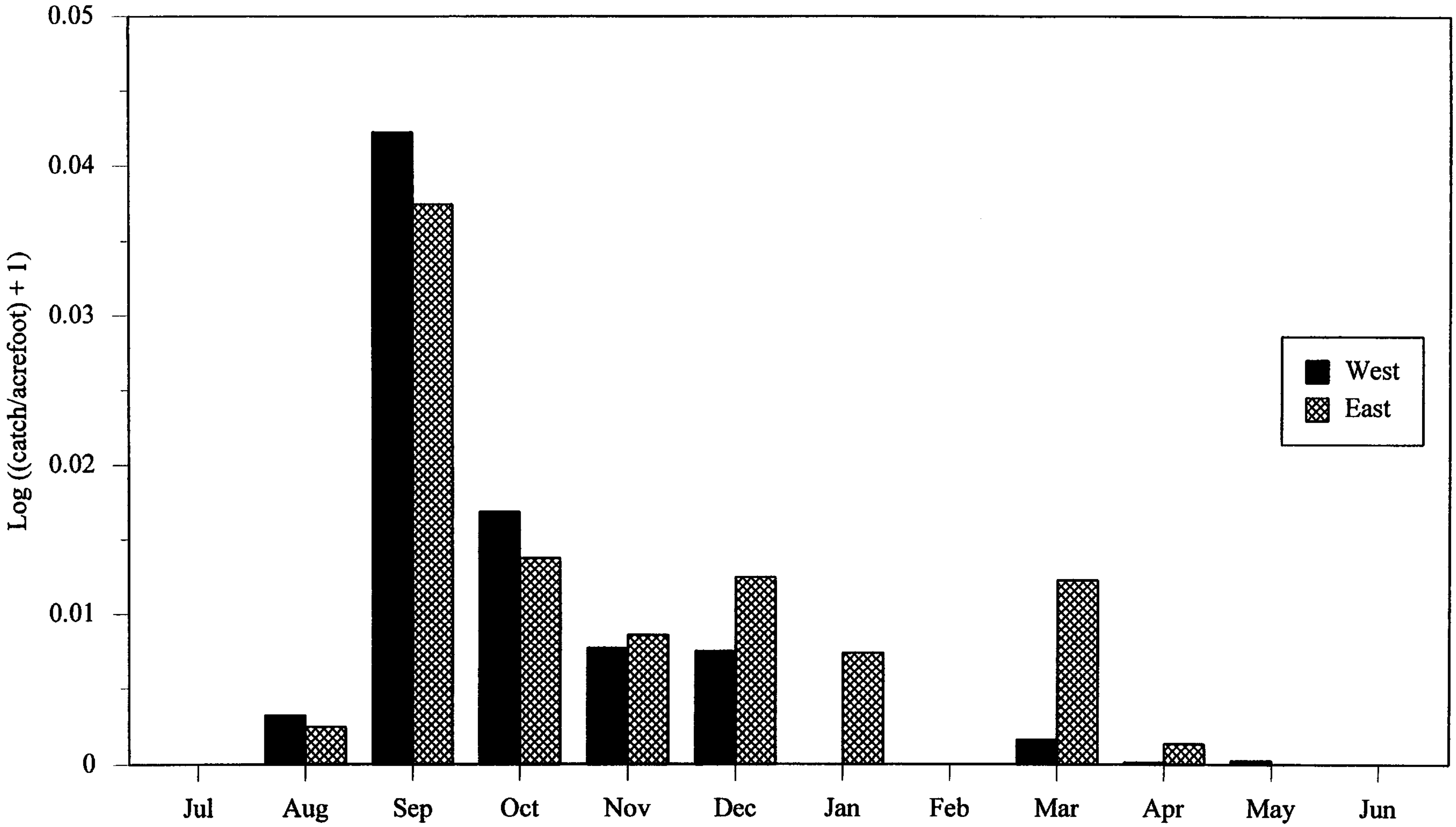


Figure 20.--Spatial patterns of abundance for naturally produced winter chinook salmon (WCS) at Red Bluff Diversion Dam from 1 July 1994 to 30 June 1995. Stars denote significant differences (ANOVA, $P<0.05$) between monthly mean west and east catch per acrefoot. Because of the large range in estimates, catch per volume sampled has been rescaled using the transformation Log_{10} ((catch/acrefoot) + 1) so that values range from > 0 to 0.045 fish per acrefoot.

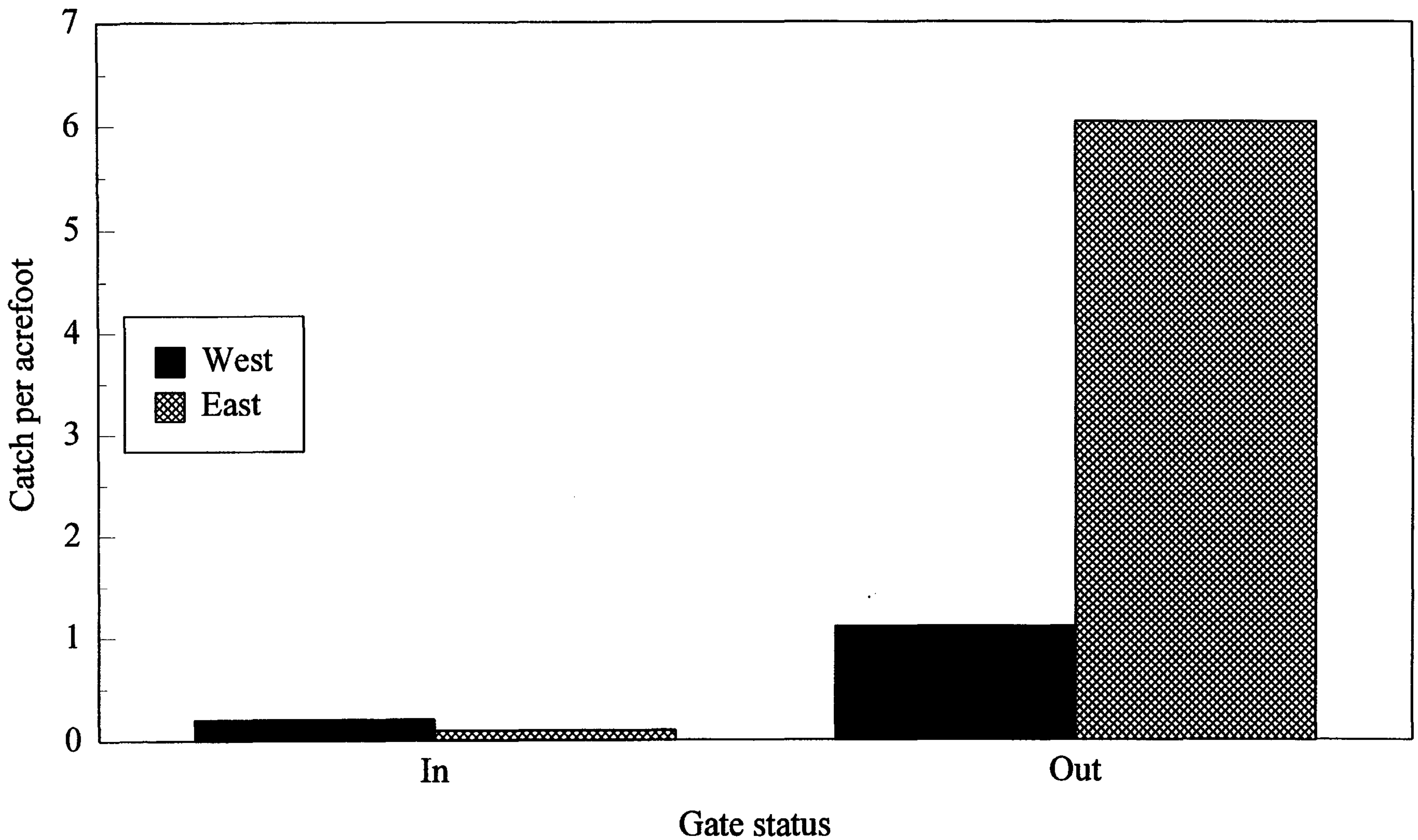


Figure 21.--Spatial patterns of abundance for chinook salmon (all runs combined) between gates-in and gates-out at RBDD. Patterns of abundance differed (ANOVA, $P<0.05$) for gates-in and gates-out.

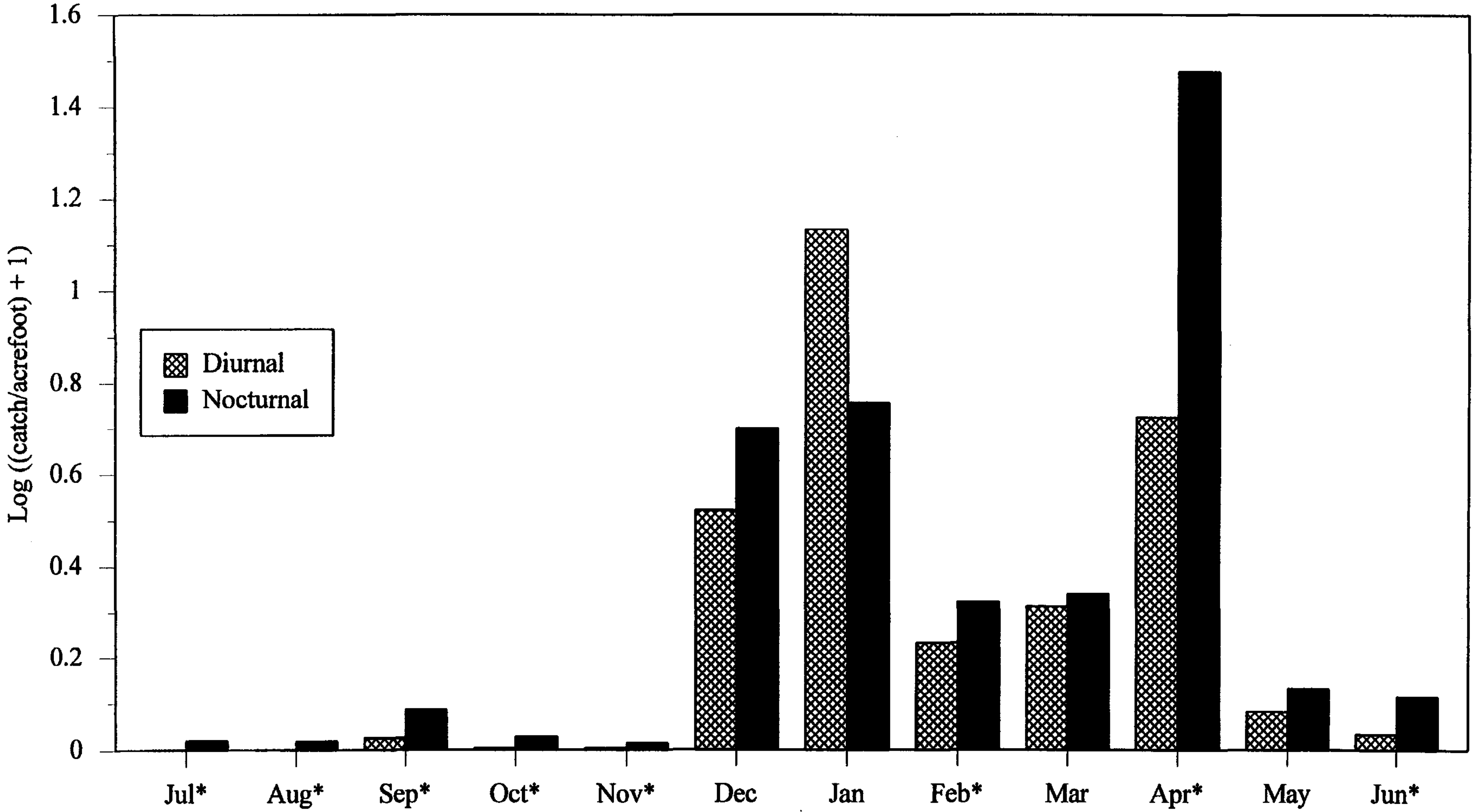


Figure 22.--Diel patterns of abundance for naturally produced chinook salmon (all runs combined) in rotary screw traps at Red Bluff Diversion Dam from 1 July 1994 to 30 June 1995. Stars denote significant differences (ANOVA, $P < 0.05$) between monthly mean diurnal and nocturnal catch per acrefoot. Because of the large range in estimates, catch per volume sampled has been rescaled using the transformation Log_{10} ((catch/acrefoot) + 1) so that values range from > 0 to 1.5 fish per acrefoot.

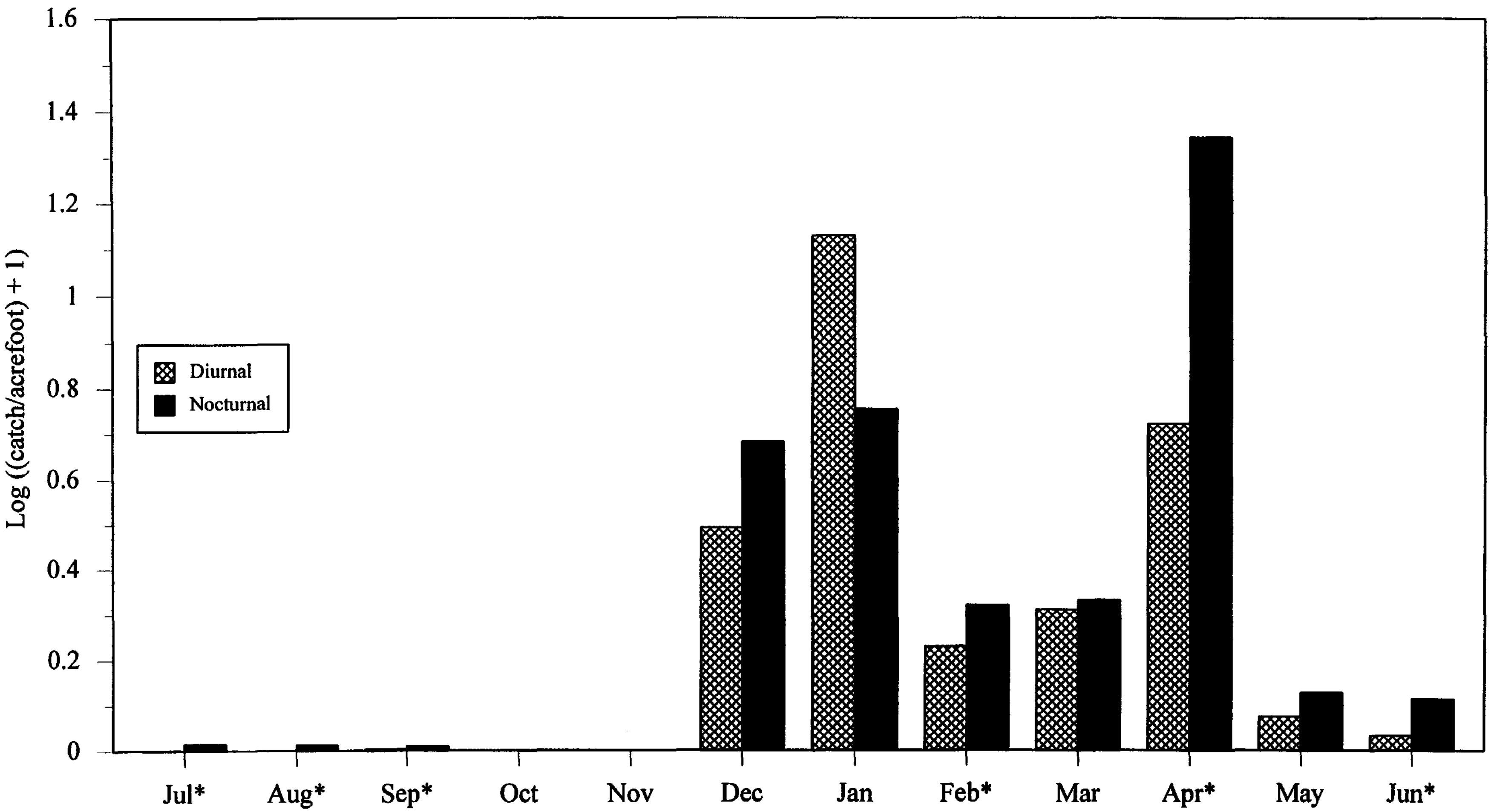


Figure 23.--Diel patterns of abundance for naturally produced fall chinook salmon (FCS) in rotary screw traps at Red Bluff Diversion Dam from 1 July 1994 to 30 June 1995. Stars denote significant differences (ANOVA, $P<0.05$) between monthly mean diurnal and nocturnal catch per acrefoot. Because of the large range in estimates, catch per volume sampled has been rescaled using the transformation Log_{10} ((catch/acrefoot) + 1) so that values range from > 0 to 1.4 fish per acrefoot.

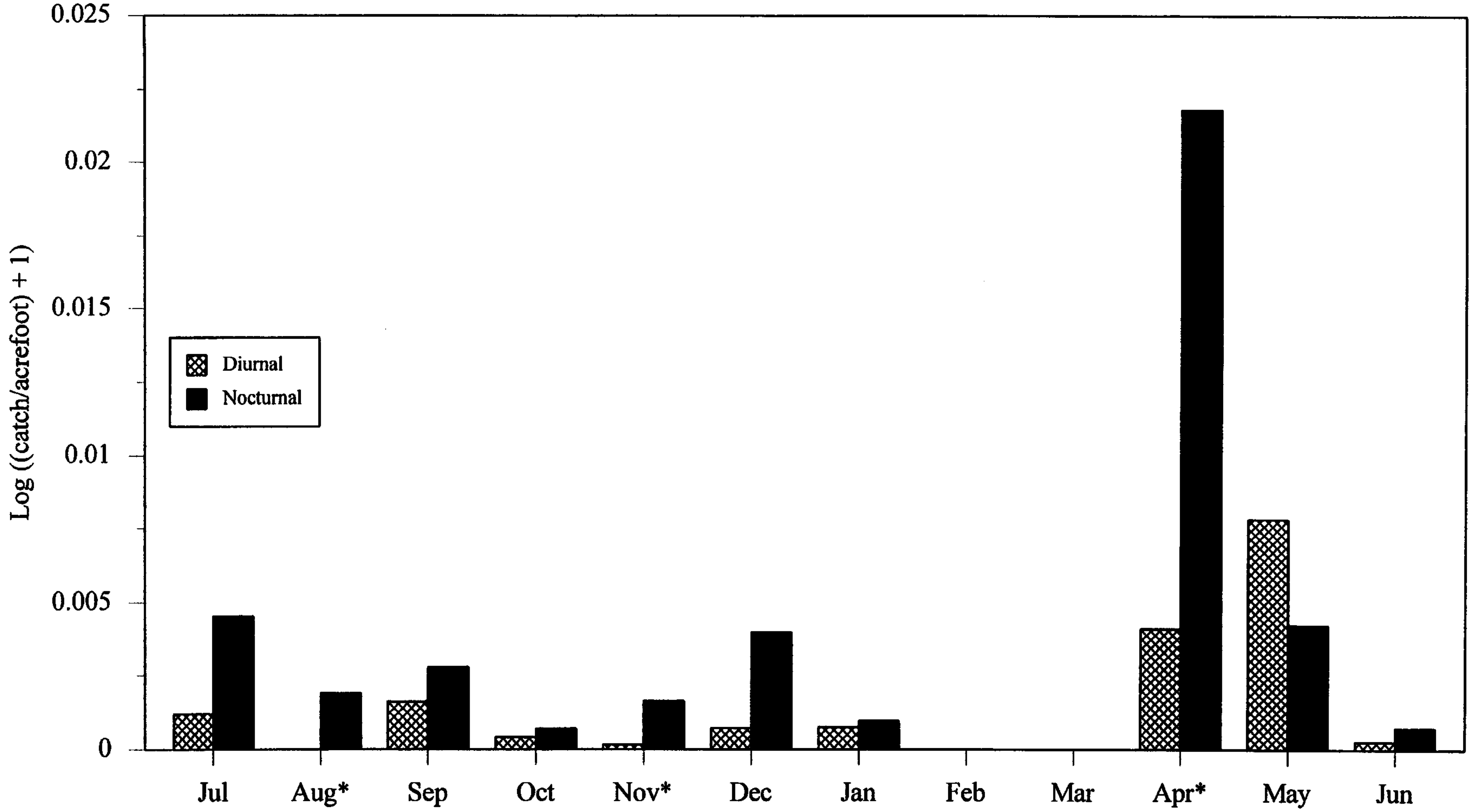


Figure 24.--Diel patterns of abundance for naturally produced late-fall chinook salmon (LCS) in rotary screw traps at Red Bluff Diversion Dam from 1 July 1994 to 30 June 1995. Stars denote significant differences (ANOVA, $P<0.05$) between monthly mean diurnal and nocturnal catch per acrefoot. Because of the large range in estimates, catch per volume sampled has been rescaled using the transformation Log_{10} ((catch/acrefoot) + 1) so that values range from > 0 to 0.025 fish per acrefoot.

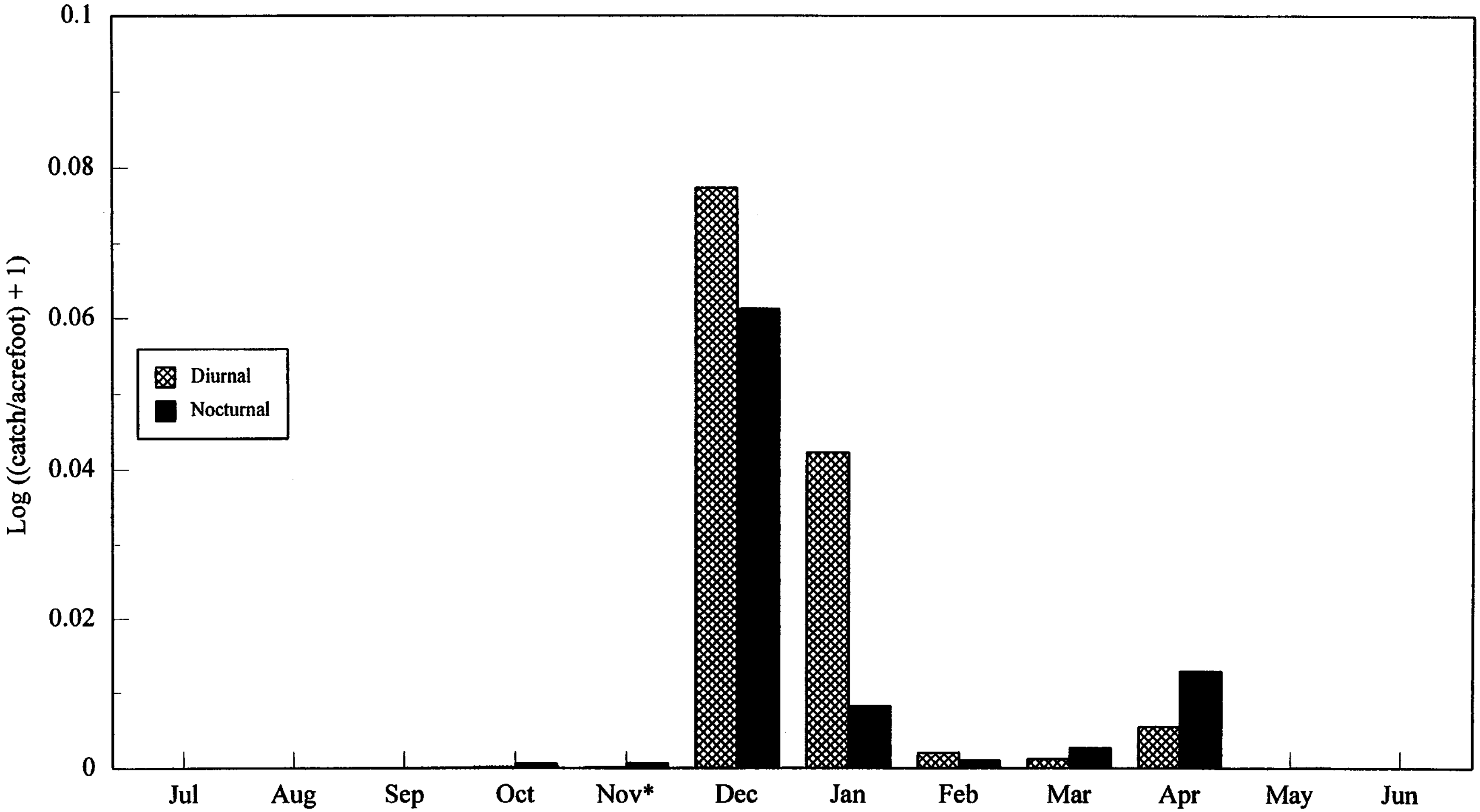


Figure 25.--Diel patterns of abundance for naturally produced spring chinook salmon (SCS) in rotary screw traps at Red Bluff Diversion Dam from 1 July 1994 to 30 June 1995. Stars denote significant differences (ANOVA, $P<0.05$) between monthly mean diurnal and nocturnal catch per acrefoot. Because of the large range in estimates, catch per volume sampled has been rescaled using the transformation Log_{10} ((catch/acrefoot) + 1) so that values range from > 0 to 0.08 fish per acrefoot.

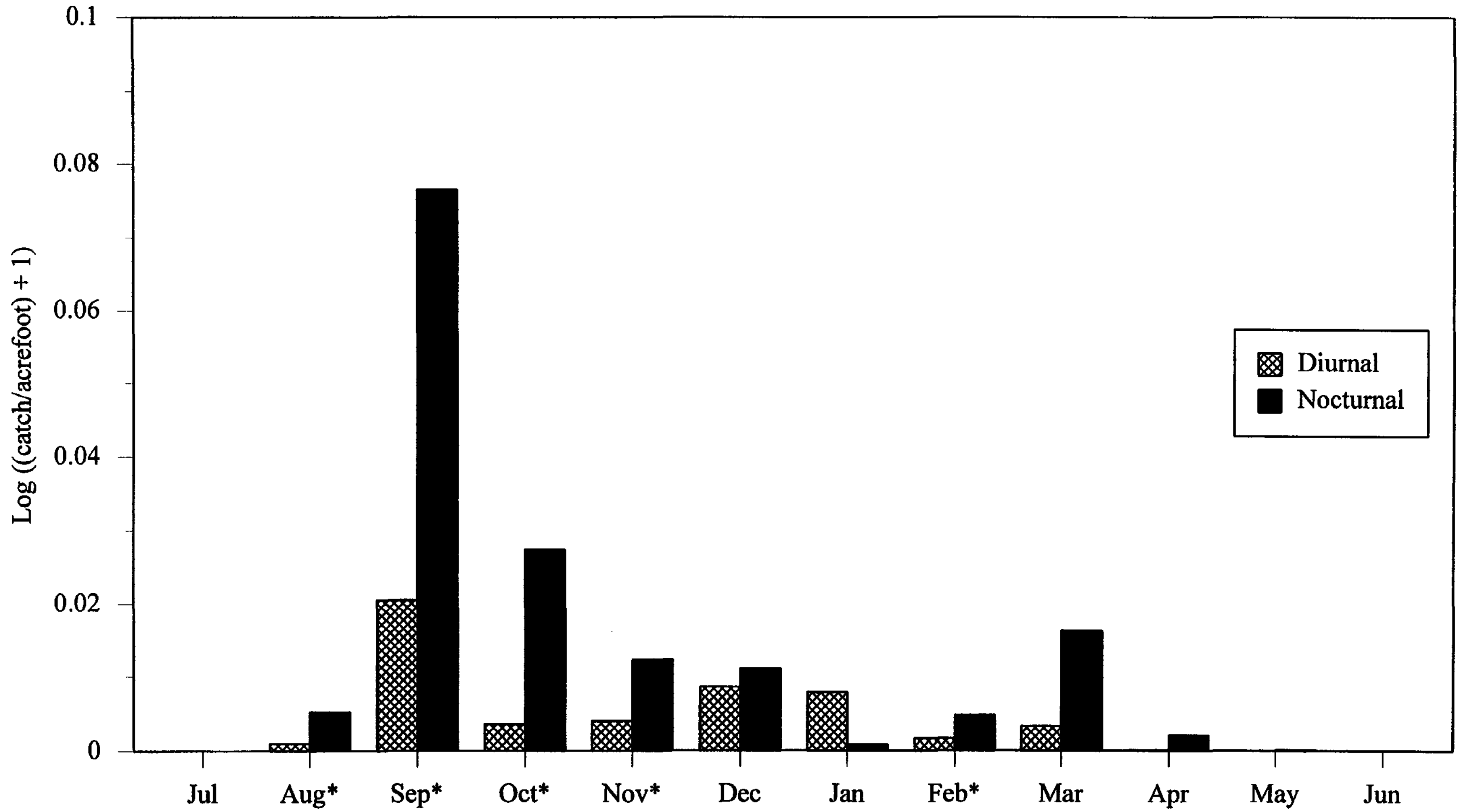
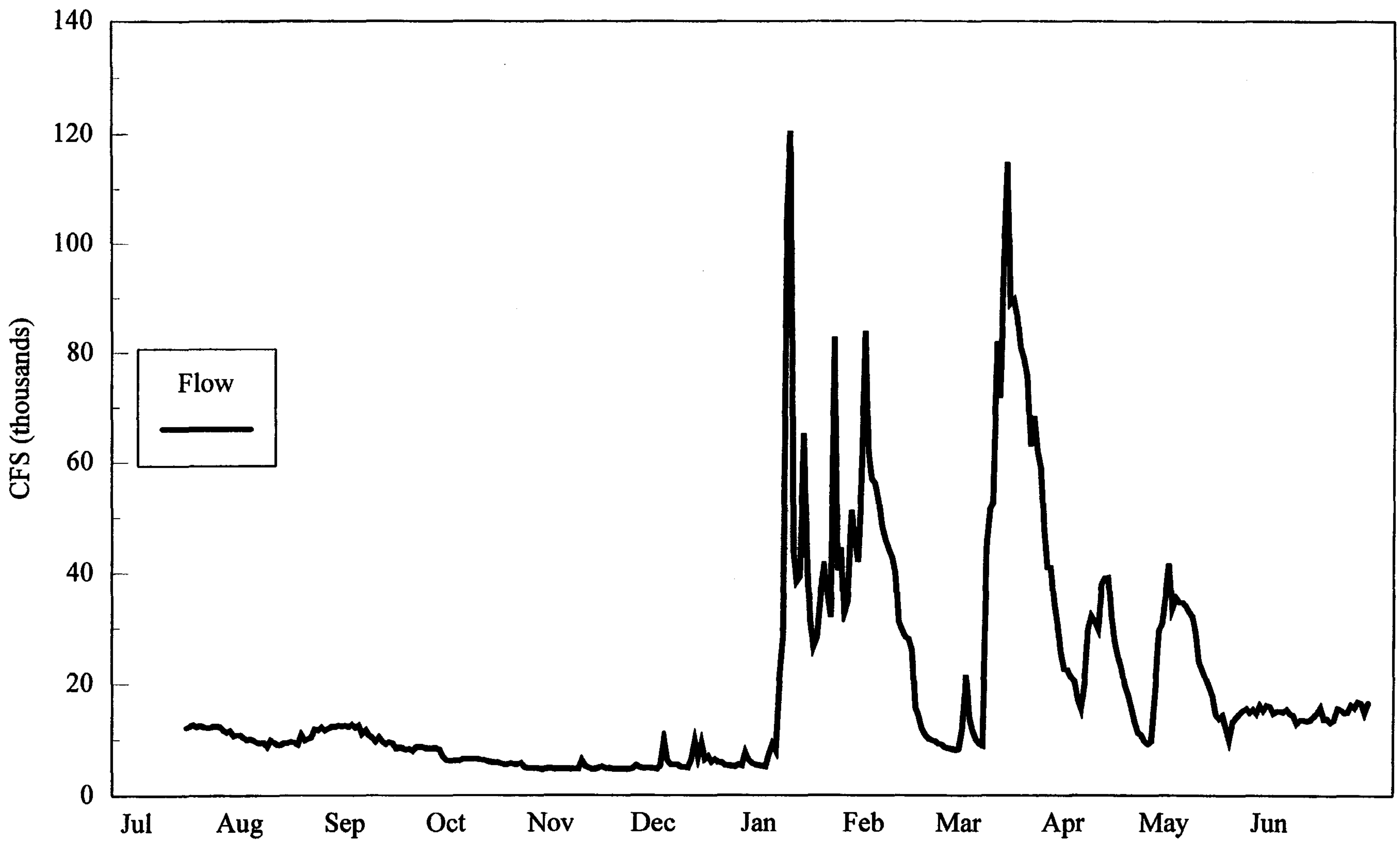


Figure 26.--Diel patterns of abundance for naturally produced winter chinook salmon (WCS) in rotary screw traps at Red Bluff Diversion Dam from 1 July 1994 to 30 June 1995. Stars denote significant differences (ANOVA, $P<0.05$) between monthly mean diurnal and nocturnal catch per acrefoot. Because of the large range in estimates, catch per volume sampled has been rescaled using the transformation Log_{10} ((catch/acrefoot) + 1) so that values range from > 0 to 0.08 fish per acrefoot.

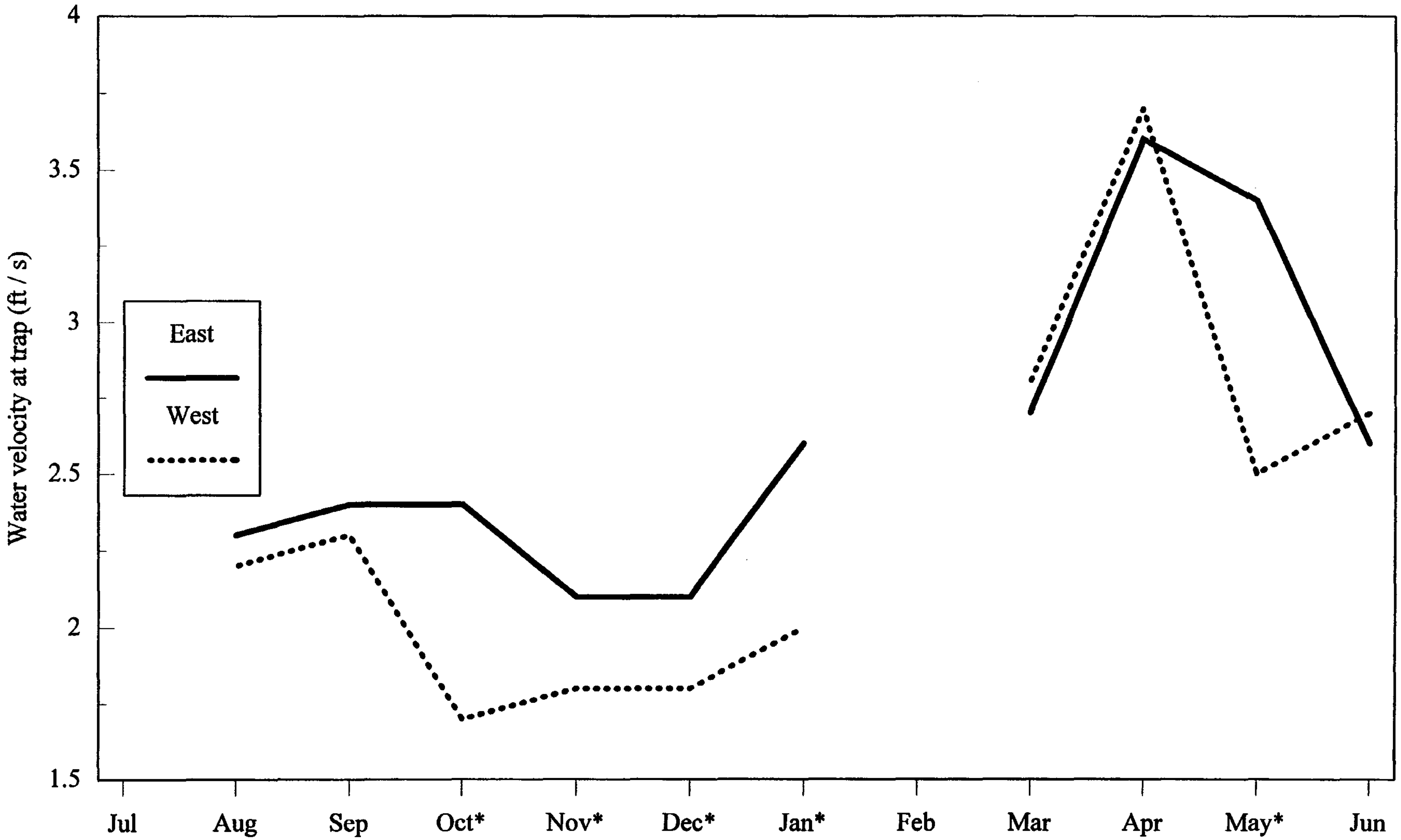
Appendices

Appendix 1.—Daily flows past Red Bluff Diversion Dam from 18 July 1994 to 30 June 1995.

Appendix 2.—Monthly mean water velocity (ft/s) recorded at traps in the east and west-river-channel. Months with asterisks significantly (t-test, $P<0.05$) differed.



Appendix 1.--Daily flows (estimated by the Bureau of Reclamation) past Red Bluff Diversion Dam from 18 July 1994 to 30 June 1995.



Appendix 2.--Monthly mean water velocities (ft/s) recorded at traps in the east and west-river-channel. Months with asterisks significantly (t-test, $P<0.05$) differed.