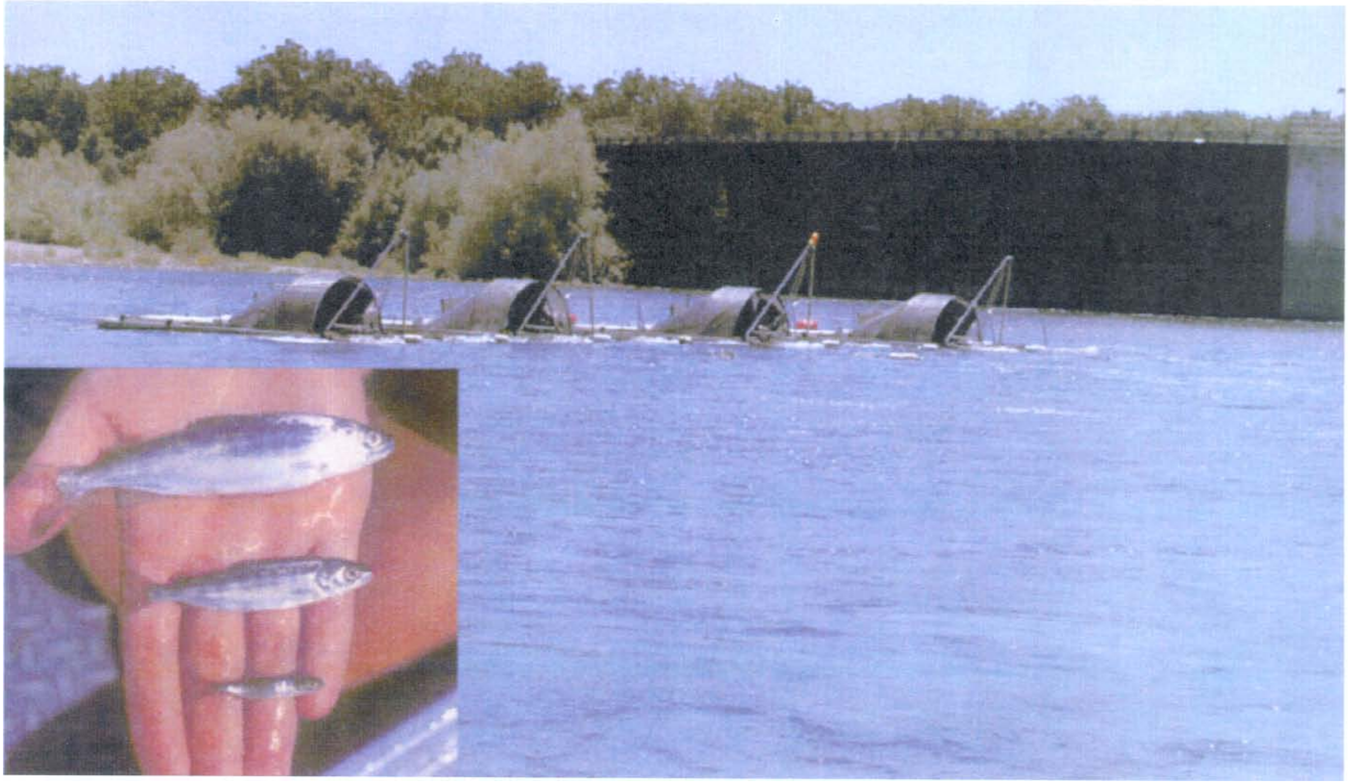
U.S. Fish & Wildlife Service

Abundance and Seasonal, Spatial and Diel Distribution Patterns of Juvenile Salmonids Passing the Red Bluff Diversion Dam, Sacramento River



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Abstract.—The objective of our juvenile monitoring program was to generate in-river estimates of passage of juvenile chinook salmon *Onchorhyncus tshawytscha* and rainbow trout *O. mykiss* emigrating past Red Bluff Diversion Dam (RBDD). These data were utilized by the Bureau of Reclamation (BOR) for their evaluation and assessment of the potential for entraining emigrating salmonids into experimental water lifts (pumps) at the Red Bluff Research Pumping Plant (RPP).

Four distinct races or "runs" of chinook salmon were documented emigrating past RBDD based on length-at-date criteria. Length frequency distributions were bimodal for each race, but were more pronounced for late-fall and spring chinook. Diel patterns in abundance existed below RBDD in close proximity to the RPP. Relative abundance was greater for nocturnal periods (71-74%) than diurnal periods (26-29%), especially for pre-smolt/smolt sized juveniles. Differences in the horizontal distribution of juveniles existed as well. Relative abundance was greater in mid-channel habitats than for either river-margin. Juvenile chinook salmon were more abundant in the upper-water column than the lower-water column as evidenced by high relative capture of chinook salmon by rotary-screw traps, compared with low relative entrainment of chinook by RPP pumps. Also, relative entrainment of benthic fishes (lamprey ammocoetes and prickly sculpins) was greater for RPP pumps than relative capture by rotary-screw traps.

For all chinook captured, 83.8% were fry (< 46 mm FL) and 16.2% were pre-smolt/smolt sized (> 45mm FL) juveniles. Fall chinook were numerically dominant relative to the other races of chinook. On average, 87.7% of chinook captured were fall chinook versus 1.4, 8.6 and 2.3% for late-fall, winter and spring chinook, respectively. The annual proportion of fall chinook juveniles available for entrainment into the RPP was 21.0%, but is likely to be much less due to their horizontal, vertical and diel distributions. We believe that only a small fraction of fall juveniles was exposed to entrainment. However, greater proportions of late-fall and winter chinook juveniles were vulnerable. On average, 34.8% of late-fall emigrants will pass the RPP when pumps are in operation. Therefore, the potential for entraining a greater proportion of late-fall chinook relative to fall chinook exists. A large proportion of annual winter chinook juveniles (38.8%) will emigrate past the RPP during operational periods. For winter chinook, the ability of the RPP to pass fish harmlessly back to the river will be critical.

Two temporally distinct age-0 cohorts of rainbow trout emigrated past RBDD. Emergence of the first cohort began in early March and continued through May. On average, 29.3% of all juvenile rainbow trout emigrated during this period. The second cohort began to emerge in June and continued through August, representing 18.9% of all juvenile rainbow trout. Annual production of rainbow trout and timing of emigration is such that we expect minimal exposure to entrainment by RPP pumps. Fry were only abundant from June through August when RPP pumps were not in operation. Larger fish were available for potential entrainment in March, April and May, but we feel that their greater size and swimming performance may preclude entrainment for great majority of these individuals.

Over 30 fish species were sampled during the course of this project. Chinook salmon was the predominate species and represented 87% of all fish captured. The predominate non-salmonid species captured were Sacramento pikeminnow *Ptychocheilus grandis* (4%), Sacramento sucker *Catostomus occidentalis* (4%) and prickly sculpin *Cottus asper* (1%). Species of special interest such as green sturgeon *Acipenser medirostris* and adult Sacramento splittail *Pogonichthys macrolepidotus* were also captured, but in low numbers.

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Introduction

The Sacramento River system is unique in that it supports four runs of chinook salmon. Named for the season the majority of adults enter San Francisco Bay on their spawning run, these four runs include fall, late-fall, winter and spring chinook salmon. Resident and anadromous forms of rainbow trout *O. mykiss* are also indigenous to the Sacramento R. In the text of this document, the term "rainbow trout" will be used to refer collectively to both anadromous (steelhead) and non-anadromous forms of *O. mykiss*.

Winter chinook salmon and the majority of fall and late-fall chinook salmon (> 70%) in the upper main stem of the Sacramento R. spawn upstream from Red Bluff Diversion Dam (Vogel and Marine 1991). For this reason, the majority of salmonid production in the upper river may be exposed to and potentially entrained by the Red Bluff Research Pumping Plant (RPP) water lifts. Migration patterns of newly emerged fry and fingerling smolts, and diel and spatial abundance patterns for fish moving past Red Bluff Diversion Dam (RBDD) were needed to fully evaluate the potential for entrainment of Sacramento R. fish stocks into the RPP.

Populations of all four races of chinook salmon, and rainbow trout, have declined in the last 25 years. The most dramatic was the winter chinook. In 1969, an estimate of 118,000 adults returned to the upper river. By 1994, their numbers had declined to a low of 189. They were officially listed as endangered in 1994 [1]. In addition to winter chinook salmon, main stem rainbow trout numbers are currently declining, and are now predominantly of hatchery origin (Hallock 1989); even though rainbow trout persist in some tributaries, they occur in extremely low numbers (McEwan and Jackson 1996).

Fish ladders at RBDD have been shown to be inefficient at attracting 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 (BOR) has raised the RBDD gates during a significant portion (approximately 75-100%) of the non-irrigation season and portions (approximately 15-50%) of the irrigated season, allowing free passage of adults during that period.

Problems with juvenile chinook passage at RBDD have also been reported (Vogel and Smith 1984; Hallock 1989; USFWS 1987, 1989, 1990; Vogel et al. 1988). The problem at RBDD is twofold: 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

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[1] 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).

from passage under the dam gates was negligible (at or near 0%). Vogel et al. (1988) report that fish released above RBDD were recaptured 16 to 55% less than those simultaneously released below the dam. One cause of mortality in juvenile chinook salmon is the dysfunctional predator-prey relationship created by RBDD, largely from the Sacramento pikeminnow (Vondracek and Moyle 1983; Vogel et al. 1988). The Sacramento pikeminnow is a native species that co-evolved in the river with chinook salmon and rainbow trout. In the natural free flowing river setting, the predator-prey relationship between the Sacramento pikeminnow and the native salmonids is intact and has no significant effect on salmonid populations (Brown and Moyle 1981). Man-made structures can provide increased feeding and ambush settings creating an unnatural advantage for predators. Other piscivores present below RBDD include striped bass *Morone saxatilis,* rainbow 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% of juvenile downstream migrants at RBDD due to Sacramento pikeminnow 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 RBDD when gates are raised. However, water is needed for irrigation and wildlife refuges during the gates-raised period (September 15 - May 15). The BOR is investigating the use of fish-friendly water lifts (pumps) to deliver water to the Tehama-Colusa and Corning Canal systems during these periods. The RPP was constructed and the pumps entrain small fish including juvenile salmonids. The BOR has evaluated the effect of these pumps on fish entrained by the RPP (McNabb et al. 2000, Borthwick and Corwin 2001). In order to understand the availability of juvenile salmonids for potential entrainment into these pumps, estimates of the in-river abundance of emigrants moving past the RPP was needed. The goal of this project was to evaluate the impact of the RPP on emigrating juvenile salmonids in the Sacramento R. by estimating their availability for potential entrainment. Additional goals were to provide concomitant information for evaluations being conducted at the RPP by the BOR. Specific objectives include:

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

2) Estimate temporal patterns of abundance for juvenile salmon and rainbow trout passing RBDD.

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

This report summarizes information gathered between April 1995 through June 2000.

Study Area

The Sacramento R. is the largest river system in California, flowing south through 600 km (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 below Shasta Dam and supports areas of intact riparian vegetation. The lower river to San Francisco Bay has sustained intense urban and agricultural development, with tremendous channelization and managed flow throughout much of its course.

Red Bluff Diversion Dam is located at river-kilometer 391 (RK391) on the Sacramento R. about 3 km southeast of the city of Red Bluff. This diversion complex encompassed three major in-river structures associated with the diversion of water into the Tehama-Colusa Canal and Corning Canal systems; (1) the RPP, (2) RBDD and (3) a bypass outfall structure. This bypass outfall structure was designed to return juvenile salmon and other fish entrained into the RPP or diverted into the canal system headworks back to the river, harmlessly. Red Bluff Diversion Dam is 226 m wide and has eleven gates measuring 18 m in width between ten concrete piers 2.4 m in width. Dam gates can be raised or lowered to impound and divert river flows into the canal. The RPP is located approximately 100 m downstream of RBDD (Figure 2) and consists of two Archimedes screw pumps and one internal helical pump. The in-river portion of the plant includes a long intake bay covered by a steel grid "trash rack" that prevents large debris from being entrained into the RPP. The trash rack is approximately 64 m long and 8 m tall. Pump intakes are located near the river bottom at a depth of approximately 4-6 m depending on river stage.

Red Bluff Diversion Dam was completed in 1964 and began operation in 1966 (Liston and Johnson 1992). For 20 years the RBDD gates remained lowered year-round, until the winter of 1986 when the gates were raised during the non-irrigation season to improve upstream fish passage. This action was found to be beneficial to fish and continues today (USFWS 1990). To further improve fish passage, RBDD gates have been raised between 15 September and 15 May each year since 1994. This period encompasses the entire non-irrigation period and parts of the irrigation season. Water needs during gates-raised periods are supplied with pumps, including those at the RPP. Under the current eight-months gates-raised operations at RBDD, the RPP typically operates between 1 March to 15 May and 15 September to 31 October. The RPP was constructed to evaluate whether two types of experimental pumps could be used to provide water to the canal headworks without causing deleterious impacts on native anadromous fish species in the Sacramento R.

Methods

Fish capture

Sampling gear.—Four rotary-screw traps (traps) from E.G. Solutions®, Corvallis, Oregon, were configured with 2.4-m diameter cones, externally screened with 3-mm diameter perforated plate and mounted on aluminum pontoons. 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 turned, entrained fish were trapped and guided to an attached live box where they remain until processed. Live boxes were122 x 183 cm, and aluminum screens were installed in the rear, floor and sides to allow water exchange in the boxes. Crowding devices (screened panels) were used to congregate fish in the stern of live boxes, and to separate captured fish among sample periods.

Cables were used to attach rotary-screw traps directly to RBDD. Rotary-screw traps were fished in areas with water velocities 61 cm/s; however, sampling equipment, river depth and river hydrology restricted placement of some traps in these areas during low-flow and gates-lowered periods.

Data collection.—Data were collected for each trap clearing and included:(1) species, number and lengths of captured fish, (2) length of time trap was fished, (3) water velocity immediately in front of the cone at a depth of 61 cm, (4) debris type and amount, and (5) and water temperature and turbidity. Debris was quantified by placing it in 40-L plastic tubs and summing the number of full and partially filled tubs. 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 BOR and provided to Red Bluff Fish and Wildlife Office.

All salmonids were enumerated and fork lengths measured to the nearest 1.0 mm. Exceptions to this protocol occurred when large numbers (>100) of chinook salmon were captured. In these cases, a random sub-sample was taken to include approximately 100 chinook salmon, with all additional fish being enumerated and recorded. For non-salmonid fish captured, up to 20 of each species were measured from our random sub-sample and the remainder enumerated and recorded. Chinook salmon race was assigned using a length-at-date criteria developed by Greene (1992) [2].

Coleman National Fish Hatchery (CNFH), located approximately 56 km up-stream from RBDD on Battle Creek, released approximately one million adipose fin-clipped and 12 million non-adipose fin-clipped fall chinook smolts annually during the study period. To characterize and enumerate natural fish production at RBDD, numbers of hatchery-origin fish in each sample were estimated by assuming that the expected ratio E(R) of adipose fin-clipped to non-adipose fin-clipped hatchery fish was the same as the ratio at time of release from hatchery ®):

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[2] 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 were placed with the later spawning run.

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

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

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

Therefore,

(3) Naturally produced fish = total catch - *H*.

Trap efficiency trials

Both naturally produced and hatchery produced fish were used in experimental mark/recapture trials to investigate rotary-trapping efficiency (i.e., what proportion of the emigrating population were sampled). Trials were conducted as often as possible when fish were available and weather permitted.

Fish were marked with fluorescent pigments using spray-dye techniques (Phinney 1966), Bismark brown stain (Mundie and Traber 1983) or both (Gaines and Martin 2001; draft). Spray-dye marking equipment consisted of a 1.5 hp compressor and regulator valve capable of maintaining hose pressure of 26.8 kg/cm^2, a sandblast gun fitted with a 0.95 L canister and a 2.4 mm diameter siphon orifice, and fluorescent, granulated pigment. Spray-dyed fish were additionally marked in a solution of eight grams Bismark brown per 380 liters of water for 40-50 minutes. Fish were held in fresh water for 24-h so that those acutely affected by the marking procedure (usually < 2%) could be removed from use in trials. Fish were transported either 2 km or 4 km upstream of RBDD for release. Fish were released along a cross-sectional transect of the river in three, four or five groups of equal number, spaced equidistantly apart. The number of groups used for release was determined by the total number of fish to be released. Using this protocol enabled investigators to assume a spatially "quasi-uniform" distribution at release.

Several release strategies or contrasts were investigated including (1) hatchery and naturally produced fish, (2) diurnal (sunrise) and nocturnal (sunset) releases, (3) fry (median FL 45 mm), pre-smolt (46-80 mm median FL) and smolt (> 80 mm median FL) releases, (4) RBDD gates lowered and RBDD gates raised, and (5) location of release (2 km or 4 km upstream from RBDD). The distribution of expected (unmarked) and observed (marked) capture frequencies across traps during efficiency trials were tested with a chi-square test to determine whether catches from multiple traps could be combined for an unbiased estimate of trap efficiency.

Stock assessments

Stock assessments were estimated using a model developed by Martin et al. (2001) to predict trap efficiency. Data for this model was generated by conducting 54 trap efficiency trials at RBDD. Trap efficiencies were regressed against %Q (percent river volume sampled) to develop a least squares regression equation (eq. 8) from which daily trap efficiencies were predicted.

Daily passage (P_d).—The following procedures and formulae were used to derivedaily and monthly estimates of total numbers of juvenile salmonids passing RBDD.

Define C_{di} as catch at trap i (i=1,...,t) on day d (d=1,...,n), and X_{di} as volume sampled at trap i (i=1,...,t) on day d (d=1,...,n). Daily salmonid catch and water volume sampled was expressed as:

(4) $$C_d = \sum_{i=1}^{t} C_{di}$$

and;

(5) $$X_d = \sum_{i=1}^{t} X_{di}$$

The percent river volume sampled (%Q) was estimated from the ratio of water volume sampled (X_d) to river discharge (Q_d) on day d.

(6) $$\%Q_d = \frac{X_d}{Q_d}$$

Total salmonid passage was estimated on day d (d = 1,...,n) by

(7) $$\hat{P}_d = \frac{C_d}{\hat{T}_d}$$

where,

(8) $$\hat{T}_d = (0.0091)(\%Q_d) - 0.00252$$

$\hat{T}_d$ = Predicted trap efficiency on day d.

Monthly passage ($\hat{P}$).—Population totals for numbers of chinook salmon passing RBDD by month were derived from $\hat{P}_d$ where there are N days within the month:

(9) $$\hat{P} = \frac{N}{n}\sum_{d=1}^{n}\hat{P}_d$$

Estimated variance.—

(10) $$Var(\hat{P}) = (1-\frac{n}{N})\frac{N^2}{n}s^2_{Pd} + \frac{N}{n}\left[\sum_{d=1}^{n}\text{var}(\hat{P}_d)+2\sum_{i\neq j}^{n}\text{cov}(\hat{P}_i,\hat{P}_j)\right]$$

The first term in Equation (10) is associated with sampling of days within the month.

(11) $$s^2_{\hat{P}_d} = \frac{\sum_{d=1}^{n}(\hat{P}_d - \bar{\hat{P}})}{n-1}$$

The second term in Equation (10) is associated with estimating $\hat{P}_d$ within the day.

(12) $$Var(\hat{P}_d) \doteq \frac{\hat{P}_d(1-\hat{T}_d)}{\hat{T}_d} + Var(\hat{T}_d)\frac{\hat{P}_d(1-\hat{T}_d)+\hat{P}_d\hat{T}_d}{\hat{T}_d^3}$$

where

(13) $$Var(\hat{T}_d) = \text{error variance of trap efficiency model}$$

The third term in equation (10) is associated with estimating both $\hat{P}_i$ and $\hat{P}_j$ with the same trap efficiency model.

(14) $$Cov(\hat{P}_i,\hat{P}_j) = \frac{Cov(\hat{T}_i,\hat{T}_j)\hat{P}_i\hat{P}_j}{\hat{T}_i\hat{T}_j}$$

where

(15) $$Cov(\hat{T}_i,\hat{T}_j) = Var(\hat{\alpha}) + x_i Cov(\hat{\alpha},\hat{\beta}) + x_j Cov(\hat{\alpha},\hat{\beta}) + x_i x_j Var(\hat{\beta})$$

for some $\hat{T}_i = \hat{\alpha} + \hat{\beta}x_i$

Seventy-five and ninety-five percent confidence intervals (C.I.) were constructed around $\hat{P}$.

(16) $$\hat{P} \pm t_{(a/2;n-1)} \sqrt{Var(\hat{P})}$$

Juvenile passage was estimated by summing $\hat{P}$ across months for individual chinook races and rainbow trout, for each brood-year (BY). Brood-year assignment was based on length-at-date criteria developed by Greene (1992) and was defined as; fall chinook, 1 December through November 30; late-fall chinook, 1 April through 30 March; winter chinook, 1 July through 30 June, spring chinook, 15 April through 14 April; and rainbow trout, 1 January through 31 December.

(17) $$JPI = \sum_{month=1}^{12} \hat{P}$$

Relative abundance (RA).—Catch per unit volume (CPUV) was used as an index of relative abundance of juvenile salmonids at RBDD.

(18) $$RA_{dt} = \frac{C_{dt}}{V_{dt}}$$

RA_{dt} = relative abundance on day *d* by trap *t* (catch/acrefoot),
C_{dt} = number of salmonids captured on day *d* by trap *t*, and
V_{dt} = volume of water sampled on day *d* by trap *t*.

The volume of water sampled was estimated for each trap as the product of one-half the cross sectional area (wetted portion) of the cone, water velocity (cm/s) directly in front of the cone at a depth of 61 cm and duration of sampling.

Temporal and horizontal distributions

Relative abundance was used to evaluate temporal and horizontal distributions of emigrating juvenile chinook salmon and rainbow trout.

Stratified diel distributions.—A stratified random sampling design (Figure 3, Scheaffer et al. 1996) was implemented to contrast relative abundance of salmonids among strata for *N* 24 h periods/month. With this protocol, each 24 h day was split into eight non-overlapping strata. Length/duration of strata remained consistent throughout the year except for 1 h adjustments for daylight savings time. Strata were not adjusted for day-length increases or decreases due to a cooperative effort to provide in-river estimates of passage at RBDD while the RPP simultaneously conducted entrainment trials. Official sunrise and sunset always occurred within crepuscular periods, except for the longest days of the year. Traps sampled continuously over 24 h periods and were checked and cleared every 3 h.

When traps were not sampling continuously due to high river flows, heavy debris loading or excessive fish catches, a systematic random sampling scheme was incorporated. With this sampling scheme, one of three possible sampling schedules (wheels) was randomly selected each week, and traps were fished for 1 h during each diel strata. Shaded areas on Figure 3 illustrate 1 h sampling periods within the sampling schedule.

Diurnal/nocturnal distributions.—Diurnal and nocturnal distributions were evaluated by comparing relative abundance between these periods. Traps were serviced at sunrise and sunset to differentiate diurnal from nocturnal capture of fishes. This sampling protocol was conducted at least twice monthly (3-4 times per month on average) and simultaneously with RPP entrainment trials, except when high flows and heavy debris loading made rotary trapping impossible or prevented the RPP from operating their pumps.

Horizontal distributions.—Horizontal distributions were analyzed by comparing relative abundance of salmonids among traps. Traps were configured behind RBDD such that samples were gathered from three distinct spatial zones: (1) west-river-margin, (2) mid-channel and (3) east-river-margin (Figure 2). Traps sampling river-margin habitats were positioned behind RBDD gates nearest to the river margins that provided sufficient water depth (1.2 m) and water velocity (0.6 m/s). Mid-channel positioning was defined as traps positioned between the west and east-river-margin. If all three spatial zones could not be sampled simultaneously, then catch across traps was not used for analyses of spatial distributions of juvenile salmonids. Generally, gates 11-10 represented the west-river-margin, gates 9-4 the mid-channel, and gates 3-1 the east-river-margin (Figure 2). Simultaneous sampling of spatial zones was maintained unless river levels, river morphology or RBDD gate positioning inhibited trap groupings in these areas. When this occurred, traps were positioned where water velocities and river depths allowed for proper rotary-screw trap operation.

Sampling regimes

In general, traps were set on Monday mornings and sampled continuously through Friday morning. Traps were checked for fish and cleared of debris every morning (Tues. - Fri.), on 24 h cycles. A minimum of two intensive samples were conducted each month. Intensive sampling consisted of clearing the traps of fish and debris every three hours over a 24 h period. Exceptions to these sampling protocols occurred when (1) additional trap clearings were planned, (2) debris loading could induce high in-trap fish mortality, (3) personnel limitations and (4) potential existed for excessive winter chinook catches [3]. Under these conditions traps were cleared more frequently, subsampling was initiated, or sampling effort was reduced or stopped.

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

Statistical tests

Horizontal and diel analyses.—Horizontal and diel patterns of abundance were analyzed using a one-way ANOVA, t-test or a non-parametric equivalent, when appropriate. Treatments included the three spatial zones and eight diel strata. The following hypotheses were tested to evaluate patterns of abundance.

H_o : Juvenile chinook salmon do not exhibit spatial patterns of abundance;
H_a : Juvenile chinook salmon exhibit spatial patterns of abundance; and

H_o : Juvenile chinook salmon do not exhibit diel patterns of abundance;
H_a : Juvenile chinook salmon exhibit diel patterns of abundance.

Length analyses.—Length distributions were evaluated by comparing size at capture among spatial zones, diel strata and nocturnal and diurnal periods.

Results

Over 30 fish species were captured by rotary-screw traps at RBDD during the course of this project. Juvenile chinook salmon dominated catches (90%) while juvenile rainbow trout (<1%) were captured less frequently (Table 1). The predominate non-salmonids captured were the Sacramento pike minnow *Ptychocheilus grandis*, Sacramento sucker *Catostomus occidentalis*, and prickly sculpin *Cottus asper*. Presentation and discussion of rotary-trap capture of non-salmonids are not presented further in the text of this report. However, graphic summarization of length distributions and relative abundance for each species captured are presented in Appendix II.

Trap efficiency

Trap efficiency was inversely related to discharge with higher efficiencies occurring at low discharge, and low efficiencies occurring at high discharge. Fifty-four trap efficiency trials were conducted to model %*Q* with trap efficiency and resulted in a significant relationship (Martin et al. 2001, $P<0.001$, $r^2 = 0.459$, $N = 53$; Figure 4). Most experimental fish were recaptured shortly after release with 92% of recaptures occurring within 24 h of release, 98.5% within two d, 99.5% within three d, 99.9% within four d, and 100% within five d. Four traps were fished for most trials ($N = 48$). However, six 3-trap trials were included in the model. Efficiency for combined traps at RBDD ranged from 0.37% (excluding a zero recapture trial) to 5.27%. River discharge during trials ranged from 5,950 to 36,508 cfs. The percent of river volume sampled (%Q) was highest during low-flow trials (6,404 cfs; 4.09 %*Q*) and lowest during high-flow trials (36,508 cfs; 0.88 %*Q*). The square root of efficiency minimized model error when linearly regressed against %*Q* (Box-Cox transformations, Neter et al.1989). Size of release group averaged 1,035 fish (*SD* = 595, range = 255 to 2,820) and the number of recaptured fish per trial averaged 21 (*SD* = 20, range = 0 to 100). Recaptured fish were slightly larger, on average (71.0 mm FL), than released salmon (70.4 mm FL) although they did not differ significantly ($P = 0.202$, df = 50, paired t-test).

Juvenile passage

Four distinct races or "runs" of chinook salmon emigrated below RBDD, as defined by length-at-date criteria. Juvenile passage was highest from December through March of each year, coinciding with fall chinook emergence and high flow events. Newly emerged (< 37 mm FL) juveniles were present at RBDD throughout the year except during the months of June and much of July. However, smolts greater than 100 mm were present year-round. Lowest median lengths occurred from January through February, and August through September reflecting emergence of fall and winter chinook salmon, respectively. Juveniles between 40 and 60 mm were captured infrequently and in lower abundance than juveniles less than 40 mm and greater than 60 mm (Figure 6).

Fall chinook passage.— Fall chinook juvenile passage increased each year of the study except for brood-year 1996 (BY96), when estimated passage was only 6,061,659 (90% C.I. = 2,940,541 - 15,419,076; Appendix I-Table A1). In contrast, highest passage occurred for BY99 at 32,461,765 fall chinook (90% C.I. = 17,153,894 - 48,178,135).

Capture of fall chinook juveniles began in December of each year, increased rapidly, and was generally highest in January and February. Average monthly passage for December, January, and February was 9.3%, 27.9% and 37.1%, respectively (Table 2).

Highest incidence of capture of fall chinook was usually concomitant with high flow events, increased turbidity and heavy debris loading in January, February and March. Fall chinook passage estimates generally began to decline in March and continued this trend through November (Figure 7). By 1 May, 94.1% of fall chinook that annually emigrated past RBDD had done so (Table 2).

On average, 83.1% of fall chinook emigrants passed RBDD as fry (range = 62.0-90.8%, Table 3). Length-frequency distributions were bimodal and marked by reduced capture of 40 - 50 mm FL juveniles (Figure 6). As juvenile passage began to decline in March of each year, median fork lengths increased (Figure 7). First capture of smolt sized fall chinook (> 46 mm FL) occurred in late January (Figure 8) and catch of smolts increased and began to outnumber catch of fry beginning in April and continuing through November.

Late-fall chinook passage.—Like fall chinook, late-fall juvenile abundance increased each year of the study except for BY96, when estimated passage was only 82,277 (90% C.I. = 43,521 - 139,678; Appendix I-Table A2). Highest passage occurred in BY99 at 577,364 (90% C.I. = 440,791 - 713,937).

Capture of late-fall chinook juveniles began and was greatest in April, then declined through June and generally increased again in July, August and September (Figure 9). Average monthly passage for April was 30.9%. From BY95 to BY99, April passage ranged from 13,698 to 241,824 (Table 4). August passage was second to April and ranged from 2,762 to 110,316. The late-fall temporal pattern of emigration was much more protracted than emigration patterns demonstrated by other runs of chinook salmon in the Sacramento R. For example, only 68.2% of late-fall chinook emigrated to areas below RBDD within five months of first emergence (Table 4), versus 90% for fall chinook (Table 2).

No fry-sized (< 46 mm FL) late-fall juveniles were collected after August (Figure 10). Pre-smolt/smolt sized (> 46 mm FL) individuals began to be captured in June (Figure 10) and dominated late-fall catch from July through February.

As with fall chinook, late-fall emigration was bimodal and marked by infrequent or reduced captured of 40 - 50 mm FL juveniles (Figure 6). However, unlike fall chinook, only 46.6% of late-fall chinook emigrated as fry (range = 20.6 - 73.9%, Table 3). The majority emigrate as pre-smolt/smolt size individuals.

Winter chinook passage.— Juvenile winter chinook passage was greatest for BY98 with estimated passage at 4,617,473 (90% C.I. = 3,427,579 - 5,807,366; Appendix I-Table A3). Lowest passage occurred for BY96 at 384,124 (90% C.I. = 189,230 - 669,762).

Capture of winter chinook juveniles began in July of each year, increased rapidly, and peaked in September (Figure 11). Winter chinook passage declined in October, but was still high. Average monthly passage for August, September and October was 19.5%, 50.4% and 13.6%, respectively (Table 5).

The temporal pattern of emigration for winter chinook was very similar to that of fall chinook, in that, greater than 90% of winter chinook emigrated to areas below RBDD within five months of first emergence (Figure 12, Table 5). As with fall chinook, and in contrast to late-fall chinook, on average, 81.0% of juvenile winter chinook emigrate as fry (Table 3).

Spring chinook passage.—Spring chinook juvenile passage was greatest in BY95 with estimated passage at 850,844 (90% *C.I.* = 339,180 - 1,365,318; Appendix I-Table A4). Lowest passage occurred in BY96 at 253,985 (90% *C*.I. = 118,401 - 700,966).

The temporal pattern of emigration for spring chinook was protracted, highly variable and not similar among years (Figure 13). Capture of spring chinook juveniles began in October of each year and was generally greatest in April. Average monthly passage was 27.4% in December, declined to less than 7.0% in January and February, and then increased in March and April to 34.3% and 21.7%, respectively (Table 6).

Fry-sized spring chinook were not captured after the fourth month of their emigration (Figure 14), compared to five months duration for fall, late-fall and winter chinook. Pre-smolt/smolt sized spring chinook were initially captured in December and their capture continued through July (Figure 14). Spring chinook were somewhat similar to late-fall chinook in that a relatively larger proportion were captured as pre-smolt/smolt sized individuals (> 60.0%, on average) rather than as fry (Table 3) .

Rainbow trout passage.—Annual passage of rainbow trout ranged from 58,874 (90% C.I. = 31,867 - 87,547; Appendix I-Table A5) in 1999 to 145,749 (90% C.I. = 37,925 - 348,986) in 1995.

Two temporally distinct age-0 cohorts of rainbow trout emigrated past RBDD (Figure 15). Emergence of the first cohort began in early March and continued through May. Relative passage for this period was 29.3%, on average (Table 7). The second cohort began to emerge in June and continued through August. Relative passage from June through August was 18.9%. However, passage estimates were highly variable on a temporal scale among years (Figure 16). For example, in 1997 and 1998, passage was much greater in January and February (primarily yearlings from the previous brood year) than for other months of the year (Table 7). Whereas, greatest passage occurred in September for BY96 and in August and September for BY99. These individuals were primarily fry and sub-yearlings.

Rainbow trout temporal patterns of abundance were different from patterns for chinook salmon. First, emigration periods typical of newly-emerged chinook salmon were not observed for rainbow trout. This trend was illustrated by the fact that few newly-emerged rainbow trout (25 - 40 mm) were captured at RBDD (Table 3), whereas newly emerged chinook salmon (34 - 40 mm) were abundant. Secondly, weekly median fork lengths were never less than 52 mm for rainbow trout (Figure 17); contrary to median lengths for chinook salmon (all runs combined) that were routinely less than 40 mm. Moreover, only 4.7% of rainbow trout captured from 1995 to 1999 were fry (Table 3). Sub-yearlings and yearlings were numerous relative to fry and represented 50.1% and 45.2% of all captures, respectively (Table 3).

Diel distributions

Juvenile chinook salmon demonstrated distinct diel patterns of emigration. Mean CPUV of chinook salmon fry was significantly greater for nocturnal periods (0.76 fish/acre-foot) than for diurnal periods (0.26 fish/acre-foot, Mann-Whitney test, $P < 0.0001$, Figure 18). However, no significant difference in mean fork lengths was observed (t-test, $P = 0.4093$). The diel pattern of emigration for pre-smolt/smolt sized chinook salmon was very similar to that of fry in that a significant difference existed between nocturnal and diurnal periods. Mean CPUV was 0.25 fish/acre-foot during nocturnal periods versus 0.10 fish/acre-foot for diurnal periods (Mann-Whitney test, $P < 0.0001$, Figure 19). Greater differences in mean fork length between nocturnal and diurnal emigrants were noted for pre-smolt/smolts than for fry-sized juveniles, but these differences were not significant (t-test, $P = 0.2032$).

Further analyses revealed that mean CPUV was always greater for nocturnal and crepuscular strata (N1, N2, N3, C1, and C2) than for any diurnal strata, for both fry and smolts (Figure 20 and 21). Significant differences in mean CPUV among strata existed for both fry (Kruskal-Wallis test, $P < 0.0001$) and pre-smolt/smolts (Kruskall Wallis test, $P < 0.0001$).

Diel patterns of emigration of juvenile rainbow trout were more pronounced than those of chinook salmon. However, capture of sub-yearlings and yearlings was low and not sufficient for statistical analyses of CPUV by length category. Therefore, fry, sub-yearlings and yearlings were combined for fork length analyses. Mean CPUV was greater for nocturnal periods (0.006 fish/acre-foot) than for diurnal periods (0.001, Mann-Whitney test using Log + 1.0 transformed values, $P < 0.0001$, Figure 22). Significant differences in mean fork lengths of rainbow trout captured during nocturnal and diurnal periods did not exist (t-test, $P < 0.0001$).

Horizontal distributions

The horizontal distribution of emigrating juvenile chinook salmon was analyzed for fry and pre-smolt/smolt sized individuals against seasonal operations at RBDD (i.e., gates raised versus gates lowered). For gates raised operations, mean CPUV of fry was slightly greater in mid-channel habitats (0.48 fish/acre-foot) than in either the west-river-margin (0.44 fish/acre-foot) or east-river-margin habitats (0.42 fish/acre-foot, Figure 23). No significant difference in fry fork lengths was detected among habitats (ANOVA, $P <= 0.7414$). Pre-smolt/smolt-sized sized juveniles were more abundant in the mid-channel habitats as well (Figure 24, Kruskall Wallis test using Log + 1.0 transformed values, $P < 0.0001$). However, mean CPUV was much less for pre-smolt/smolt-sized sized fish in all habitats than it was for fry. Mean CPUV for mid-channel habitats was 0.32 fish/acre-foot versus 0.23 fish/acre-foot for the east-river-margin and 0.16 fish/acrefoot for the west-river-margin habitats. Pre-smolt/smolt mean fork length was greater in mid-channel habitats than in either river-margin.

Discussion

The gates at RBDD were lowered shortly after construction in 1966 to regulate river flows and provide water to meet the huge agricultural demands created by California's Central Valley farmers. The precipitous decline of an already imperiled chinook salmon fishery began immediately (Williams and Williams 1991). Red Bluff Diversion Dam, on the Sacramento R. in the northern Central Valley of California, is perhaps the most important obstacle constructed in the last 40 years attributable to the dramatic decline of chinook salmon and anadromous forms of rainbow trout (Hallock 1991).

In an effort to minimize the detrimental impacts of RBDD on anadromous salmonids, the BOR explored alternative methods of delivering water to the Tehama-Colusa Canal. One alternative was construction of the RPP. Following construction, evaluations of the RPP's experimental "fish-friendly" water lifts (pumps) were made (McNabb et al. 2000, Borthwick and Corwin 2001, Weber et al. 2002). The plant's ability to deliver water to the Tehama-Colusa Canal without harming fish may allow the BOR to modify its operation of RBDD to benefit upper-Sacramento R. fishes. The experimental pumps at the RPP have been used primarily to help meet agricultural and wildlife refuge water demands occurring annually from March through mid-May and mid-September through October.

Winter chinook salmon and most fall and late-fall chinook salmon (> 70%) in the upper main stem Sacramento R. spawn upstream from RBDD (Vogel and Marine 1991). For this reason, most salmonid production in the upper river may be exposed to and potentially entrained by the RPP pumps. However, with such an abbreviated pumping schedule, the potential for entrainment of juvenile salmonids is limited. Emigration patterns for fish moving past the RPP were needed to fully evaluate its impacts on Sacramento R. fish stocks. This was critical due to the presence of species listed as threatened or endangered under the Endangered Species Act (ESA), including winter chinook salmon, spring chinook salmon and anadromous rainbow trout.

Fall chinook.— A large downstream movement of chinook fry immediately following emergence is typical of most populations (Healey 1991). Godin (1982) defined three types of fry dispersal strategies following gravel emergence. The type most closely identified with Sacramento R. fall chinook, based on the nature of the rearing habitat, is the dispersal of fry into nursery habitat located within the river or stream where they were spawned or in nursery habitat located within an adjoining tributary. Movements of newly emerged fry exhibiting this strategy typically occur downstream, although upstream movements have been documented (McCart 1967; Godin 1992).

Emergence of fall chinook fry began each December and generally peaked in January and February (Figure 8c). This represented greater than 77% of the entire run, on average. However, the RPP would not be operating during these months. Therefore, there would be no possibility of entrainment for most fall chinook juveniles.

Under current gate operations, only fall chinook emigrating past the RPP from 1 March through 15 May and from 15 September through 31 October could potentially be entrained, assuming upstream movement is negligible. This represented 21.0% of fall chinook passage (4.1 million juveniles, on average) for all years combined. However, relative abundance can vary considerably due to spatial, horizontal and diel emigration patterns. It's very likely that the proportion of fall emigrants available and exposed to potential entrainment is much less than 21.0%.

Horizontal differences in relative abundance existed below RBDD near the RPP. Mean CPUV was greater in mid-channel habitats than either river margin, especially for pre-smolt/smolt-sized sized juveniles (Figure 23 & 24). Catch per unit volume was somewhat lower in the west river-margin habitat, where intakes for the RPP pumps are located. Secondly, elevated river flows from storm events can be frequent in March and, to a lesser extent, April. Fall chinook juveniles emigrate in large numbers during these flow events. Under these conditions, water velocities in mid-channel habitats increase, and may be much higher than river-margin habitats. Therefore, rotary-screw traps in mid-channel habitats were generally sampling a much greater volume of water. Given equal fish densities (fish/acrefoot) under this scenario, there would be a much higher proportion of juveniles emigrating through the mid-channel habitat. The magnitude of that proportion, however, was not be measurable because passage estimates could not be generated for separate spatial zones.

The vertical distribution of juvenile salmon should substantially reduce the proportion exposed to entrainment. The intakes for the RPP pumps are located near the bottom of the water column at a depth of approximately 3.6 - 4.8 m, depending on river stage (Borthwick and Corwin, 2001). Studies conducted near Red Bluff have determined that while juvenile chinook emigrants utilize the entire water column, juvenile numbers were greatest 0.6 to 1.2 m below the surface and fewest at 1.2 to 1.8 m below the surface (Azevedo and Parkhurst, 1957). Borthwick and Corwin (2001) determined that 40% of fish entrained in the RPP during experimental trials were chinook salmon verses 87% (Table 1) for rotary-screw traps. Also, relative entrainment of benthic species such as prickly sculpin and lamprey ammocoetes was much greater in RPP pumps than in rotary-screw traps. Mains and Smith (1964) found chinook salmon exhibiting strong preferences for the upper water column in the Columbia River, where patterns of abundance in the upper column were nearly double those in the mid and lower column. Because rotary-screw traps and pump intakes sample different strata of the water column, we believe that differences in the relative proportion of chinook captured by rotary-screw traps versus entrained by the RPP are due to a greater proportion of chinook utilizing the upper water column. The vertical distribution of juvenile salmon may be the most important factor reducing entrainment rates of chinook salmon when pumps are in operation.

The probability of juvenile entrainment into the RPP will also be affected by diel patterns of abundance. Mains and Smith (1964) split the 24 hour day into three hour increments, a survey design similar to this study. Patterns of abundance were found to be greatest during sunrise (0300 to 0600 hours) and lowest during early morning (0600 - 0900 hours). Unwin (1986) found similar diel emigration patterns when stratifying a 24 h period into three, eight hour 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. Principal movement of emigrating juvenile chinook salmon occurred during the night on the Columbia R. system (Dauble et al. 1989). At RBDD, mean CPUV of fry during nocturnal periods was approximately three-times greater than for diurnal periods (Figure 18). For pre-smolt/smolts, it was more than two-times greater (Figure 19). Therefore, if the RPP operates during nocturnal periods, we would expect higher rates of entrainment than for diurnal periods.

Fish size, as related to swimming performance, is another factor that may influence rates of entrainment by fall chinook juveniles. If fry and pre-smolt/smolts differ in their ability to avoid entrainment, then we would expect differing entrainment rates for these two size classes. Fry-sized juveniles (< 46 mm FL) represented 73.2% of fall chinook emigrating in March, but only 10.4% in April and less than 0.1% in May. We determined that in March, 1.6 million fry emigrated past RBDD and the RPP, on average. Borthwick and Corwin (2001) determined that 81% of chinook salmon entrained in the RPP pumps were less than 40 mm FL. Therefore, March emigrants, due to the high proportion of fry, will be most at risk of entrainment by RPP pumps. However, the actual number or proportion exposed to entrainment will be much reduced due to spatial (horizontal and vertical) differences in the distribution of emigrating fall chinook.

In April overall passage dropped considerably and so did the proportion of fry. Moreover, median fork lengths increased rapidly from March to April (Figure 7). As fork lengths increase, swimming performance and ability to avoid entrainment should increase as well. This may further reduce the proportion of fall chinook susceptible to entrainment by RPP pumps.

Overall, we believe only a small fraction of annual fall chinook production occurring above RBDD will be exposed to and potentially entrained into RPP pumps. Depending on the ability of these pumps to pass fish harmlessly back to the river, the net effect of delivering water using pumps at RBDD may be negligible for fall chinook salmon in the upper-Sacramento R..

It's important to note that factors affecting fall chinook juvenile entrainment, such as the RPP pumping schedule, fish size, seasonal, diel, horizontal and vertical distributions of juveniles, will also affect entrainment of other runs of chinook salmon and rainbow trout.

Late-fall chinook.— Juvenile passage of late-fall chinook salmon past RBDD was substantially less than that of fall chinook. On average, the proportion of late-fall juveniles passing RBDD was only 1.4% of all chinook compared to 87.7% for fall chinook. However, the relative proportion of late-fall juveniles available for entrainment into RPP pumps was much greater. On average, 34.8% of late-fall juveniles had emigrated to areas below RBDD during the period 1 March to 15 May (Table 4) versus 21.0% for fall chinook (Table 2). In April alone, greater than 30% of late-fall chinook emigrated past RBDD.

The period 1 March through 15 May also coincides with potentially high demand for agricultural and wildlife refuge water, and pumps may be in operation continuously. On average, 186,502 late-fall chinook passed the RPP during this period and were available for potential entrainment. However, the actual number or proportion of late-fall juveniles exposed to entrainment during the spring season may be much less than 34.8% because of their horizontal and vertical distributions relative to pump intakes. Given that such a large proportion of fry-sized (< 46 mm FL) late-fall chinook are emigrating past the RPP during times of high water demand, there appears to be potential for entrainment of a greater proportion of late-fall juveniles than of fall chinook.

The gates at RBDD are lowered on 15 May and Lake Red Bluff is formed within 48 h. Water is then diverted into the Tehama-Colusa Canal rather than being pumped by the RPP. When RBDD gates are raised on15 September, eliminating Lake Red Bluff and returning to its run-of-the-river conditions, another 12% of annual late-fall juveniles become available for entrainment into RPP pumps. However, median fork lengths are considerably greater (> 80 mm FL) during this early fall period (Figure 10), and we expect that greater swimming performance will improve avoidance and, therefore, reduce entrainment, relative to late-fall juveniles present in March and April. Actual advantages or disadvantages will be largely dependent on size selectivity of water lifts and size-related mortality effects.

Winter chinook.— Winter chinook salmon were listed as a threatened species in 1989 and reclassified as endangered in 1994, in response to the continued decline and continued threats to the population. Production of winter chinook salmon in the Sacramento R. occurs almost exclusively upstream of RBDD (Snider et al. 1997).

Less than 1.0% of annual winter chinook emigrants are available for entrainment by RPP during the spring pumping season (1 March - 15 May). These are large individuals (100-140 mm FL) and given their horizontal, vertical, and diel distributions, we feel that very few winter chinook will be exposed to entrainment during this period. However, the fall pumping season (15 September - 31 October) will expose a greater proportion of winter chinook fry to entrainment. Overall, 38.8% of annual winter chinook emigration occurred during this period (Table 5). On average, this represented over 740,000 individuals, of which a large proportion are fry. For example, in September, 98.6% of winter chinook emigrating past the RPP are fry and 64.8% in October. Greater than 80% of fish entrained by the RPP pumps were less than 40 mm (Borthwick and Corwin 2001). The exposure to possible entrainment of such a large segment of annual winter chinook emigrants should be of particular concern. Therefore, if winter chinook entrainment, injuries and/or mortalities were to become excessive, diel patterns of emigration should be considered in scheduling plant operations. For example, winter chinook salmon had a strong affinity for crepuscular movements; three of four winter run captured during this period occurred during the two, three hour periods at sunrise and sunset. Therefore, the number of fish exposed to entrainment could be reduced 75% by modifying plant operations such that pumps are not operated during the two crepuscular periods, assuming patterns of abundance in traps are similar to patterns of entrainment by the RPP.

Spring chinook.— Spring chinook salmon are listed as threatened under ESA, and production, abundance or even presence above RBDD is questionable. Sightings of adult spring chinook above RBDD during snorkel surveys on Clear, Battle and Cottonwood/Beegum Creeks are qualified as *potential* adult spring chinook based upon date of sighting and phenotypic traits. However, Meyers et al.(1998) state that Mill and Deer Creeks, and possibly Butte Creek, are the only streams considered to have wild spring chinook salmon. These creeks are all below RBDD.

We have no data to support either argument. We did, however, capture juveniles that met the length-at-date criteria developed by Greene (1992) for spring chinook salmon.

Capture of spring chinook juveniles began in mid-October and October represented 2.2% of annual spring chinook emigrants (Table 6). These were all fry and median fork lengths ranged from 32-34 mm. Given the timing of emigration and the RPP's propensity to entrain fish less than 40 mm fork length, only a small proportion of spring chinook emigrants may be exposed to entrainment.

A much larger proportion of annual spring emigrants become available for entrainment in March, April and May. On average, 56.9% of spring chinook emigrate during this period. This protracted emigration may be advantageous in that these individuals are all pre-smolt/smolts (70-100 mm FL) who emigrate through mid-channel habitats in greater abundance than river-margin habitats (Figure 24), perhaps reducing the opportunity of entrainment substantially. As with the other races of chinook salmon, the horizontal, vertical and diel distribution of spring chinook will limit the number of fish available and exposed to entrainment.

Rainbow trout.— Along with spring chinook salmon, anadromous rainbow trout were recently listed as threatened under ESA. Therefore, entrainment of juvenile rainbow trout by RPP pumps is of concern.

There are two basic life history-types of anadromous rainbow trout; ocean-maturing (winter rainbow trout) and stream-maturing (summer rainbow trout). Although both forms inhabited the Sacramento R. system prior to dam construction in the 1940's, 50's, and 60's, it is largely felt that no summer rainbow trout remain in the Sacramento R. today (McEwan and Jackson 1996). Rainbow trout have been classified on the basis of anadromy - resident (rainbow trout) and anadromous forms (steelhead). Few morphological and genetic differences have been found (McEwan and Jackson 1996), and pre-smolt juveniles from each life-history type cannot be distinguished from each other. These factors complicate trends in rainbow trout abundance at RBDD and the following interpretations are largely speculative. For this discussion, the term rainbow trout will refer to both anadromous and non-anadromous forms of *O. mykiss*.

During each year from 1995 through 2000, two temporally distinct age-0 rainbow trout cohorts emigrated past RBDD annually (Figure 25). The first cohort was generally captured beginning in early March and continued through May, while the second cohort was captured from July through August (Figure 15). Based on the size (generally 25-40 mm) and state of development (with yolk sacs or showing sign of recent button-up) of captured fish, these fish are considered to be recently emerged from the gravels. This bimodal emergence suggests that rainbow trout populations in the upper Sacramento R. generally spawn at two different time periods. Size and capture date of the first cohort suggest a spawn timing in December and January, whereas the second cohort likely were spawned in April and May (assuming incubation requires approximately 50-days at 50° F). A biological explanation for this bimodal spawning distribution has not been shown, however, it can be speculated to result from rainbow trout spawning in different locations (e.g., main stem Sacramento R. vs. tributary spawners) or separate spawning periods for fish of different life history strategies (e.g., anadromous vs. non-anadromous rainbow trout). This phenomenon warrants further investigation as the occurrence may suggest spatial or temporal reproductive isolation between the two cohorts.

Annual production of anadromous rainbow trout and timing of emigration was such that we expect exposure to entrainment by the RPP to be minimal. Fry were only abundant from June through August when the RPP pumps typically would not be operated. Therefore, there would be no opportunity for entrainment of this most susceptible proportion of rainbow trout emigrants. Larger fish were available in March, April and May, but we feel that their size would preclude entrainment of most of these individuals. For example, in March, 89.0% were yearlings and median fork length was greater than 200 mm. Moreover, only 1.9% of all fish entrained by the RPP during this study were greater than 200 mm FL (Borthwick and Corwin 2001).

In April and May, most of rainbow trout emigrating past RBDD and the RPP were also large individuals. However, the proportion of sub-yearlings increased as the number of yearlings decreased. Therefore, median fork lengths were decreasing (Figure 17). Median fork lengths were still greater than 50 mm and given the RPP's propensity to entrain fish less than 40 mm (Borthwick and Corwin 2001), this may preclude excessive entrainment of rainbow trout.

The horizontal distribution of rainbow trout was similar to chinook salmon in that relative abundance in mid-channel habitats was greater than abundance in river-margin habitats, and was lowest in the west river-margin where RPP pump intakes were located. Therefore, the proportion of juvenile rainbow trout exposed to entrainment should be minimal.

Sources of Variability

Salmonid fry behavior is often saltatory and characterized by periods of active movement alternating with periods of residualization (Godin 1982). After the initial displacement phase, fry residualize for varying lengths of time in river-margin habitats, often while in groups (Godin 1982). Mid-sized salmonids (40-50mm) have been shown to be present in river-margin habitat, although they were infrequently captured in rotary-screw traps at RBDD (Johnson and Martin 1997). Rotary-screw traps capture fish moving downstream; therefore, fish moving upstream or in areas that can not be sampled with this gear (i.e., extreme river margin habitat), will not be captured. Both winter and fall chinook salmon fry in the Sacramento R. migrate upstream into non-natal tributaries (Murray and Rosenau 1989; Moore 1997). It is possible that size classes of juvenile salmonids that are not susceptible to capture by rotary-screw traps may be susceptible to entrainment by the RPP. If juvenile salmonids are utilizing the extreme river-margin as corridors for upstream migrations or as areas for rearing, we would expect entrainment rates by the RPP to be greater than our patterns of abundance for this size class. For example, benthic species such as prickly sculpin and lamprey ammocoetes were entrained at a much greater rate by the RPP (28 and 18%, respectively, Borthwick and Corwin 2001) than patterns of abundance from rotary-screw traps (Table 1).

Chinook salmon demonstrate a high degree of variation in life-history traits. In general, there are two basic life history strategies utilized by juvenile chinook. Ocean-type individuals migrate as fry (60-150 days post-hatching) or fingerlings in late summer or autumn of their first year (Meyers et al. 1998). The great majority of fall and winter chinook in the upper Sacramento R. exhibited ocean-type behavior. Stream-type individuals generally reside much longer in their natal streams and emigrate as yearling smolts. A component of late-fall and spring chinook populations in the upper Sacramento R. demonstrated this life history strategy. Given the extreme variability described between ocean and stream-type behaviors and that both behaviors can exist in a specific run of chinook salmon, it's probable that more subtle differences exist.

Between year variability in annual juvenile passage, fry to pre-smolt/smolt ratios, and to a lessor extent, timing of emergence was noted during the study period. Several environmental factors can affect egg to fry survival such as water temperature, dissolved oxygen content, turbidity and quality of substrate. These factors (sources of variability) may change from year to year within and among watersheds and give rise to differential variability in juvenile production and survival rates. While fry to pre-smolt/smolt survival is dependent on these same factors, the amount of suitable rearing or nursery habitat and predation also become important sources of variability.

Predation, ocean-harvest, limiting food resources, recreational angling, stray-rate, river flows and availability of spawning habitat are just a few of the many factors affecting the survival, fitness, rate of return and spawning success of adult salmon. If few adults return or if conditions are not suitable for successful spawning, then fewer juveniles will be produced.

We feel that natural variability in juvenile and adult salmonid life-history is responsible for much of the variability in our abundance data, among years.

Sources of bias

Diel, horizontal and vertical distributions.—Our investigation of diel and horizontal distributions may be affected by differences in migratory behavior for the different races of chinook. To analyze diel and horizontal patterns of emigration, all chinook, regardless of race, were combined so that appropriate sample sizes could be generated. Thus, results may not be representative of any single chinook run. Some results, however, are primarily from one race or another. For example, abundance data used to evaluate stratified diel periods within nocturnal, diurnal and crepuscular strata were gathered primarily from September through November of 1996 (Fig. 20 & 21). Thus, our results were strongly influenced by juvenile chinook emigrating during this period. These were likely winter chinook because they were numerically dominant in rotary-trap capture at this time. Therefore, our resulting diel patterns of emigration may not be representative of fall, late-fall or spring chinook.

The same was not true for our evaluation of nocturnal (all strata combined) versus diurnal (all strata combined) patterns of emigration (Figures 18, 19). We routinely conducted sunrise/sunset sampling simultaneously with the RPP entrainment trials for their determination of the fraction of emigrating chinook entrained. By checking and clearing the trap at sunrise and sunset, we also reduced mortality when juvenile chinook salmon were abundant. This method of sampling occurred in all seasons.

Although horizontal patterns of abundance were not as pronounced as diel patterns, trends were apparent at RBDD. When RBDD gates were raised and the RPP pumps were in operation, relative abundance was generally lower along the west-river-margin. However, abundance in the west-river-margin was higher when the RBDD gates were lowered and the RPP was not in operation. This may have been due to a hydraulic effect created by gate operations at RBDD. One possible conclusion is that fish were able to avoid the west-river-margin trap during the gates raised period (16 September through 15 May) when water velocities were lower in this area. Nonetheless, avoidance was not supported by our data or other published work. Roper and Scarnecchia (1996) found that capture efficiencies for naturally produced salmon did not differ for rotary-screw traps fished in low (1.4 rotations/min), moderate (2.37 rotations/min), or high (3.05 rotations/min) water velocities. The west river-margin trap sampled in areas equal to Roper and Scarnecchia's (1996) high velocity areas.

Rotary-screw traps only sampled the upper strata of the water column; therefore, passage estimates did not include juveniles emigrating at lower strata. For chinook salmon and rainbow trout captured at RBDD, this bias was believed to be small for two reasons. First, there is a large mid-channel shoal immediately below the dam and within our sampling transect. River depth in this habitat is shallow. More often than not, mid-channel traps had to be moved to other gates within this habitat or repositioned laterally within a gate to find water of suitable depth for trap operation. Secondly, the deepest habitat sampled by rotary-screw traps was the west river-margin where the RPP intakes were located (3.6 - 4.8 m deep). Relative entrainment rates of chinook salmon by the RPP (40%, Borthwick and Corwin 2001) were much less than relative capture rates of chinook salmon by rotary-screw trap (87%). This was evidence that pump intakes and rotary-screw traps sample different portions of the water column. These data also support arguments that most juvenile chinook emigrate through the upper water column. Therefore, we feel that gear bias with regard to the vertical distribution of chinook was minimal.

Incomplete sampling.— A much larger bias was due to incomplete sampling.

Irrespective of proper experimental design, samples were lost or not obtained due to river conditions. High flows restricted, impeded and, in some cases, eliminated our ability to gather some samples. High flows in combination with heavy debris loading, which was usually the case, can jeopardize personnel safety, fish health and substantially increase the risk of equipment loss. Incidental trap mortality and risk of losing samples (e.g., trap sinks or cone stops rotating) increased during high-flow events.

These limitations, in concert with strict ESA restrictions for winter chinook take and incidental mortality, led to our implementation of a sub-sampling regimen. Sub-sampling was accomplished by stratifying between day and night, and randomly sampling one of four non-overlapping periods within each strata. Estimates of passage were extrapolated to periods not fished by dividing catch by the selection probability (P=0.25) and expanding this estimate proportional to trap efficiency. This sub-sampling protocol worked extremely well for reducing capture of listed species and increased success when sampling moderate to large rises in river stage. Following our implementation of this sub-sampling protocol, our monitoring program was able to routinely fish river flows in excess of 55,000 cfs in all river channel habitats. Data on juvenile emigration could not have been obtained had we not sub-sampled during these periods.

During high flow events, it's widely speculated that substantial portions of the population may emigrate. Our data supports this belief. Passage generally increased, usually substantially, during high-flow events. These increases appeared to be linked to stage rises when accompanied by high turbidity. Estimated passage would decrease over time (usually 1 to 2-days), even if flows and turbidity remained high.

Passage estimates.— Often during high flow events, it was not possible to sample mid-channel habitats because of high water velocities and tremendous debris loading. This reduced the number of traps sampling to one or two, rather than four. Daily passage estimates were not generated using our trap efficiency model (Martin et al. 2001) when less than three traps were sampling. In these cases, passage estimates were calculated as a mean value using the estimated passage from the 24 h period preceding and immediately following the missed sample. Two months were not sampled during this study because of high sustained flows (January 1997 and February 1998). To account for juvenile passage during these months, we used a mean value derived from estimates of passage for the months immediately prior to and following these periods.

We feel that when high-flows intermittently precluded our ability to gather some samples in January, February or March, our method of estimation introduced negative bias in passage estimates of fall chinook juveniles. This was not the case for late-fall or winter chinook because their emigration occurs primarily from mid-spring through fall, when river conditions are generally stable and trapping effort is constant, resulting in more robust estimates of passage.

Trap efficiency.— Estimates of abundance using trap efficiencies of < 0.5% are very unstable (Figure 26); a slight change in efficiency (e.g., 0.1%) can result in substantial increases or decreases in passage estimates. To address this instability, we combined catch, volume sampled and trap efficiency from all traps on a given day (Equations 4 and 5).

Martin et al. (2001) developed a model that predicted trap efficiency based on the proportion of river discharge sampled (*%Q*). The data used for construction of that model were gathered from our rotary-trapping operation at RBDD. This model was used to generate our passage estimates.

The model had a moderately strong relationship (r^2=.4596) between X_d (percent river discharge sampled; %Q) and T_d (trap efficiency) for experimentally released fish. We believe with additional sampling and refining of experimental procedures, the r^2 will remain high. However, because trap efficiency and migratory behavior (distribution) were intuitively linked, environmental factors affecting migratory behavior may confound and exacerbate our attempt to model this extremely dynamic phenomena. By continuing to conduct trap efficiency trials at RBDD, we may be able to incorporate other environmental variables (e.g., water turbidity) within the model.

Experimental bias in trap efficiency trials can cause over or underestimation of chinook population numbers (Thedinga et al. 1994). For efficiency tests to be unbiased, marked fish need to be randomly mixed with unmarked fish (Van Den Avyle 1993). At RBDD, because the four traps sampled a transect, different distributions between marked and unmarked fish could lead to biased estimates of passage, when combining catch and efficiency across traps. One assumption of our trap efficiency trials was that marked fish were randomly distributed with unmarked fish. Relative frequencies did not differ significantly between expected and observed captures during trials. However, there appeared to be a general trend for recapturing fewer fish than expected in the west river-margin and greater numbers in the east river-margin (Martin et al. 2001). Other researchers have used hatchery-reared fish to estimate trap efficiencies for wild fish (Keenen et al. 1994), and some have found that emigration behaviors differ between natural and hatchery-produced salmonids (Roper and Scarneccia 1996).

Length model.— We used a length-at-date criteria developed by Greene (1992) to assign run designation to captured chinook. The criteria was developed for differentiating between runs of salmon in the upper Sacramento R. Accuracy of criteria was dependent on two assumptions: (1) timing of egg deposition and (2) rates of development and growth. Errors in one or both of these assumptions would lead to incorrect run designation which may, in turn, negatively or positively bias juvenile passage estimates (Martin et al. 2001).

The length model appeared to work reasonably well for identifying naturally produced fall and winter chinook salmon based on length distributions (Figure 27). The model does, however, break down for differentiating between naturally produced and hatchery-produced juveniles, exemplified by hatchery-released fall and late-fall chinook overlapping with spring and winter chinook, respectively (Figure 27).

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Table 1.—Fish species and number captured by rotary-screw traps at Red Bluff Diversion Dam (RK391), Sacramento River, CA., from July 1994 through June 2000.

Common name	Scientific name	Number captured	Percent
Chinook salmon	Oncorhynchus tshawytscha	744,925	87
Fall run		649,693	76
Winter run		48,408	6
Spring run		33,604	4
Late-fall run		13,220	2
Sacramento pike minnow	*Ptychocheilus grandis*	33,951	4
Sacramento sucker	*Catostomus occidentalis*	33,242	4
Prickly sculpin	*Cottus asper*	10,523	1
Pacific lamprey	*Lampetra tridentata*	5,199	1
Lampetra fry	*Lampetra spp.*[1]	4,104	*
Cypriniformes fry	Cypriniformes[2]	3,798	*
Rainbow trout/steelhead	*Oncorhynchus mykiss*	3,592	*
Sturgeon fry	*Acipenser spp.*[3]	2,605	*
Riffle Sculpin	*Cottus gulosus*	2,087	*
Bluegill sunfish	*Lepomis macrochirus*	2,013	*
Hardhead	*Mylopharodon conocephalus*	1,309	*
Cottus fry	*Cottus spp.*[4]	1,263	*
Threadfin shad	*Dorosoma petenense*	1,260	*
White catfish	*Ictalurus catus*	1,059	*
Golden shiner	*Notemigonus crysoleucas*	541	*
Threespine stickleback	*Gasterosteus aculeatus*	326	*
California roach	*Lavinia symmetricus*	275	*
Spotted bass	*Micropterus punctulatus*	188	*
Largemouth bass	*Micropterus salmoides*	185	*
Speckled dace	*Rhinichthys osculus*	175	*
Centrarchidae fry	Centrarchidae[5]	87	*
River lamprey	*Lampetra ayresi*	79	*
Tule perch	*Hysterocarpus traski*	77	*
Green sunfish	*Lepomis cyanellus*	51	*
Redear sunfish	*Lepomis microlophus*	48	*
Channel catfish	*Ictalurus punctatus*	44	*
Black crappie	*Pomoxis nigromaculatus*	41	*

Table 1.—(continued).

Common name	Scientific name	Number captured	Percent
Hitch	*Lavinia exilicauda*	41	*
Smallmouth bass	*Micropterus dolomieui*	33	*
Carp	*Cyprinus carpio*	31	*
Black bullhead	*Ictalurus melas*	17	*
Kokanee/sockeye	*Oncorhynchus nerka*	16	*
White crappie	*Pomoxis annularis*	16	*
Brown bullhead	*Ictalurus nebulosus*	8	*
American shad	*Alosa sapidissma*	4	*
Green sturgeon	*Acipenser medirostris*	3	*
Striped bass	*Morone saxatilis*	3	*
Fathead minnow	*Pimephales promelas*	2	*
Goldfish	*Carassius auratus*	2	*
Sacramento splittail	*Pogonichthys macrolepidotus*	2	*
Brown trout	*Salmo trutta*	1	*
Sacramento blackfish	*Orthodon microlepidotus*	1	*
Total		853,227	

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

[1] Fry were grouped to genus (*Lampetra tridentata, Lampetra ayresi, or Lampetra pacifica).*

[2] Fry were grouped to order (likely *Ptychocheilus grandis*, *Mylopharodon conocephalus*, or *Catostomus occidentalis*).

[3] Fry were grouped to genus (likely *Acipenser medirostris*).

[4] Fry were grouped to genus (*Cottus asper* or *Cottus gulosus*).

[5] Fry were grouped to order (*Micropterus spp.* or *Lepomis spp.*).

Table 2.— Estimated monthly passage of juvenile fall chinook salmon from capture by rotary-screw traps at Red Bluff Diversion Dam (RK391), Sacramento River, CA. Sampling was conducted from July 1994 through June 2000. Results include estimated monthly passage, number of 24-hr days sampled (*N*) and percent annual passage. Brood-years for fall chinook salmon are defined as beginning on 1 December and running through November 30. Year designation is assigned each December.

Month	*N*	Brood-year 1994	*N*	Brood-year 1995	*N*	Brood-year 1996	*N*	Brood-year 1997	*N*	Brood-year 1998	*N*	Brood-year 1999	* % annual passage
December	19	2,387,300	9	442,887	8	1,936,464	11	2,461,579	26	1,848,120	29	366,844	9.3
January	3	2,376,448	11	3,388,912	0	1,526,173	5	13,261,432	24	6,670,912	16	14,840,521	27.9
February	20	2,450,548	2	13,782,174	15	1,115,882	0	7,126,490	16	11,781,087	25	12,836,729	37.1
March	8	2,993,096	17	761,018	16	259,043	11	991,549	28	5,688,198	25	1,729,640	11.0
April	20	4,172,651	30	692,102	24	600,977	11	2,667,508	23	471,158	27	1,023,327	8.8
May	15	672,926	13	340,490	19	198,705	8	200,945	26	826,624	24	975,494	2.3
June	29	194,843	13	143,832	16	264,400	11	588,586	30	767,144	24	689,210	2.0
July	21	42,564	14	82,885	19	111,830	17	265,092	31	613,884			1.1
August	23	21,463	19	19,634	16	41,309	13	97,305	28	181,162			0.4
September	8	12,976	12	3,906	13	6,287	18	5,958	23	49,401			0.1
October	5	2,125	17	721	10	385	24	0	21	683			0.0
November	6	0	22	572	11	205	19	105	24	260			0.0

*Because brood-year 1999 was incomplete, it was excluded in calculations of percent annual passage. Only brood-years 1994 through 1998 were used.

Table 3.— Annual proportion (in percent) of chinook salmon fry (< 46 mm FL) and pre-smolt/smolts (> 45 mm FL) captured by rotary-screw traps at Red Bluff Diversion Dam (RK391), Sacramento River, CA. Sampling was conducted from July 1994 through June 2000. Data is summarized for complete brood-years only. Brood-years are defined as; (a) 1 December - November 30 for fall chinook, (b) 1 April - 31 March for late-fall chinook, (3) 1 July - June 30 for winter chinook and (4) 15 October - 14 October for spring chinook. Data is also summarized for fry, sub-yearling and yearling rainbow trout. Brood-years for rainbow trout are 1 January - 31 December.

	Fall chinook		Late-fall chinook		Winter chinook		Spring chinook		Rainbow trout		
Brood-year	Fry	Pre-smolt/ smolt	Fry	Pre-smolt/ smolt	Fry	Pre-smolt/ smolt	Fry	Pre-smolt/ smolt	Fry	Sub-yearling	Yearling
1994	62.0	38.0	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
1995	90.6	9.4	73.9	26.1	86.3	13.7	4.2	95.8	5.6	65.5	28.9
1996	79.9	20.1	20.6	79.4	68.1	31.9	30.9	69.1	4.2	62.7	33.1
1997	85.1	14.9	24.2	75.8	74.8	25.2	63.9	36.1	3.1	21.8	75.1
1998	90.3	9.7	62.0	38.0	88.1	11.9	85.6	14.4	4.0	36.4	59.6
1999	90.8	9.2	37.6	62.4	57.1	42.9	11.7	88.3	7.5	66.2	26.2

Table 4.— Estimated monthly passage of juvenile late-fall chinook salmon captured by rotary-screw traps at Red Bluff Diversion Dam (RK391), Sacramento River, CA. Sampling was conducted from July 1994 through June 2000. Results include estimated monthly passage, number of 24-hr days sampled (N) and percent annual passage. Brood-years for late-fall chinook salmon are defined as beginning on 1 April and running through March 31. Year designation is assigned each April.

		Brood-year		Brood-year		Brood-year		Brood-year		Brood-year	% annual
Month	*N*	1995	*N*	1996	*N*	1997	*N*	1998	*N*	1999	passage
April	20	65,895	30	13,698	24	19,909	11	241,824	23	131,113	30.9
May	15	15,975	13	3,450	19	8,071	8	59,444	26	63,611	7.8
June	29	1,688	13	1,283	16	14,037	11	34,077	30	16,968	4.4
July	21	1,974	14	2,390	19	29,711	17	32,281	31	56,119	8.0
August	23	5,213	19	2,762	16	47,684	13	94,981	28	110,316	17.1
September	8	10,061	12	4,445	13	32,880	18	47,958	23	79,303	11.4
October	5	7,295	17	5,133	10	12,632	24	20,998	21	49,215	6.2
November	6	4,611	22	35,525	11	28,246	19	14,088	24	38,951	7.9
December	9	1,526	8	8,621	11	3,771	26	11,826	29	20,347	3.0
January	11	280	0	4,530	5	568	24	822	16	11,421	1.2
February	2	0	15	439	0	284	16	0	25	0	0.0
March	17	0	16	0	11	0	28	0	25	0	0.0

Table 5.— Estimated monthly passage of juvenile winter chinook salmon captured by rotary-screw traps at Red Bluff Diversion Dam (RK391), Sacramento River, CA. Sampling was conducted from July 1994 through June 2000. Results include estimated monthly passage, number of 24-hr days sampled (N) and percent annual passage. Brood-years for winter chinook salmon are defined as beginning on 1 July and running through June 30. Year designation is assigned each July.

Month	*N*	Brood-year 1995	*N*	Brood-year 1996	*N*	Brood-year 1997	*N*	Brood-year 1998	*N*	Brood-year 1999	% annual passage
July	21	751	14	903	19	18,584	17	184,896	31	8,186	2.2
August	23	81,804	19	18,836	16	134,165	13	1,540,408	28	91,836	19.5
September	8	1,147,684	12	228,197	13	925,284	18	2,128,386	23	404,378	50.4
October	5	299,047	17	24,226	10	410,781	24	404,275	21	163,482	13.6
November	3	66,197	22	66,167	11	268,668	19	245,739	24	155,239	8.6
December	9	13,998	8	8,801	11	30,139	26	49,018	29	60,397	1.7
January	11	6,523	0	12,124	5	7,826	24	49,753	16	94,675	1.8
February	2	35,712	15	15,429	0	20,220	16	8,833	25	44,918	1.3
March	17	7,015	16	7,791	11	32,619	28	4,150	25	28,042	0.8
April	30	236	24	1,378	11	732	23	1,754	27	1,092	0.1
May	13	0	19	272	8	0	26	262	24	375	0.0
June	13	0	16	0	11	0	30	0	24	0	0.0

Table 6.— Estimated monthly passage of juvenile spring chinook salmon captured by rotary-screw traps at Red Bluff Diversion Dam (RK391), Sacramento River, CA. Sampling was conducted from July 1994 through June 2000. Results include estimated monthly passage, number of 24-hr days sampled (N) and percent annual passage. Brood-years for spring chinook salmon are defined as beginning on 15 October and running through 14 October. Year designation was assigned each October 15.

Month	*N*	Brood-year 1995	*N*	Brood-year 1996	*N*	Brood-year 1997	*N*	Brood-year 1998	*N*	Brood-year 1999	* % annual passage
October	5	9,056	17	491	10	1,207	26	26,394	21	20,414	2.2
November	6	22,062	22	6,505	11	9,419	19	18,057	24	6,815	2.4
December	9	3,152	8	68,052	11	307,340	26	296,856	29	30,621	27.4
January	11	3,237	0	34,913	5	7,379	24	20,974	16	113,874	7.0
February	2	4,294	15	1,775	0	35,727	16	4,199	25	37,712	3.2
March	17	753,635	16	1,091	11	64,076	28	5,847	25	58,898	34.3
April	30	49,304	24	136,766	11	70,874	23	20,608	27	281,808	21.7
May	16	6,105	19	3,889	8	10,762	26	3,004	24	19,374	1.7
June	16	0	16	404	11	482	30	110	24	466	0.1
July	14	0	19	99	17	0	31	129			0.0
August	19	0	16	0	13	0	28	0			0.0
September	12	0	13	0	18	0	23	0			0.0

* Percent annual passage was calculated using all brood years even though brood-year 1999 was incomplete.

Table 7.— Estimated monthly passage of juvenile rainbow trout captured by rotary-screw traps at Red Bluff Diversion Dam (RK391), Sacramento River, CA. Sampling was conducted from July 1994 through June 2000. Results include estimated monthly passage, number of 24-hr days sampled (N) and percent annual passage. Brood-years for rainbow trout are defined as beginning on 1 January and running through 31 December.

Month	*N*	Brood-year 1995	*N*	Brood-year 1996	*N*	Brood-year 1997	*N*	Brood-year 1998	*N*	Brood-year 1999	% annual passage
January	3	0	11	12,259	0	16,733	5	44,914	24	1,472	14.7
February	20	10,592	2	10,730	15	33,261	0	25,606	16	2,097	16.0
March	8	26,280	17	9,201	16	6,496	11	6,299	29	9,308	11.2
April	20	5,626	30	2,524	24	8,183	11	5,083	23	1,571	4.5
May	15	39,102	13	4,412	19	6,796	8	11,632	26	8,040	13.6
June	29	2,541	13	3,098	16	4,951	11	4,777	30	4,465	3.9
July	21	2,230	14	1,342	19	3,686	17	3,647	31	5,092	3.1
August	23	22,418	19	8,012	16	5,282	13	12,889	28	12,810	11.9
September	8	34,485	12	34,164	13	1,758	18	10,432	23	11,605	18.0
October	5	1,400	17	3,109	10	632	24	1,156	21	1,146	1.4
November	6	788	22	1,186	11	839	19	1,456	24	598	0.9
December	9	287	8	205	11	1,552	26	1,482	29	670	0.8

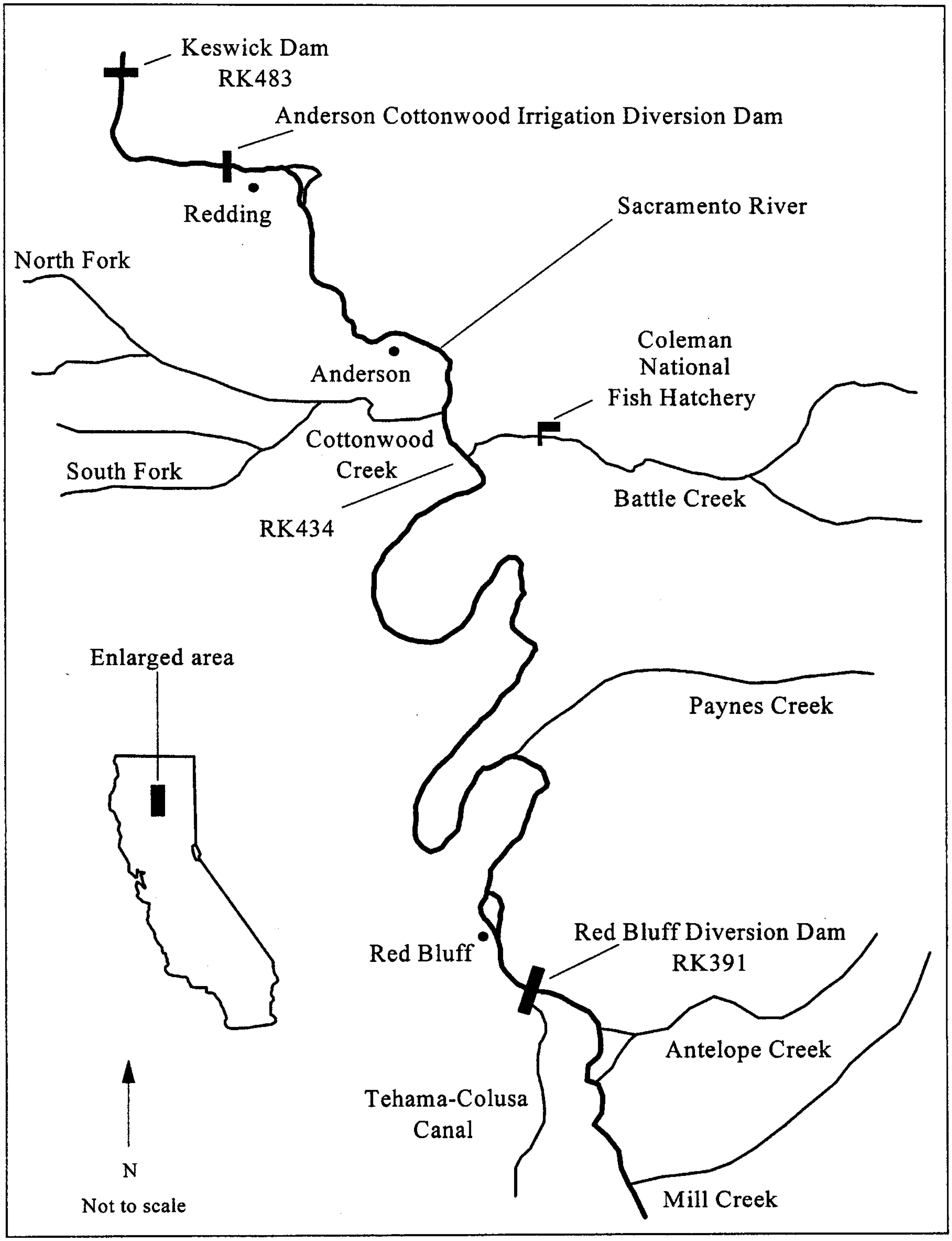

Figure 1.--Location of Red Bluff Diversion Dam on the Sacramento River at river-kilometer 391 (RK391).

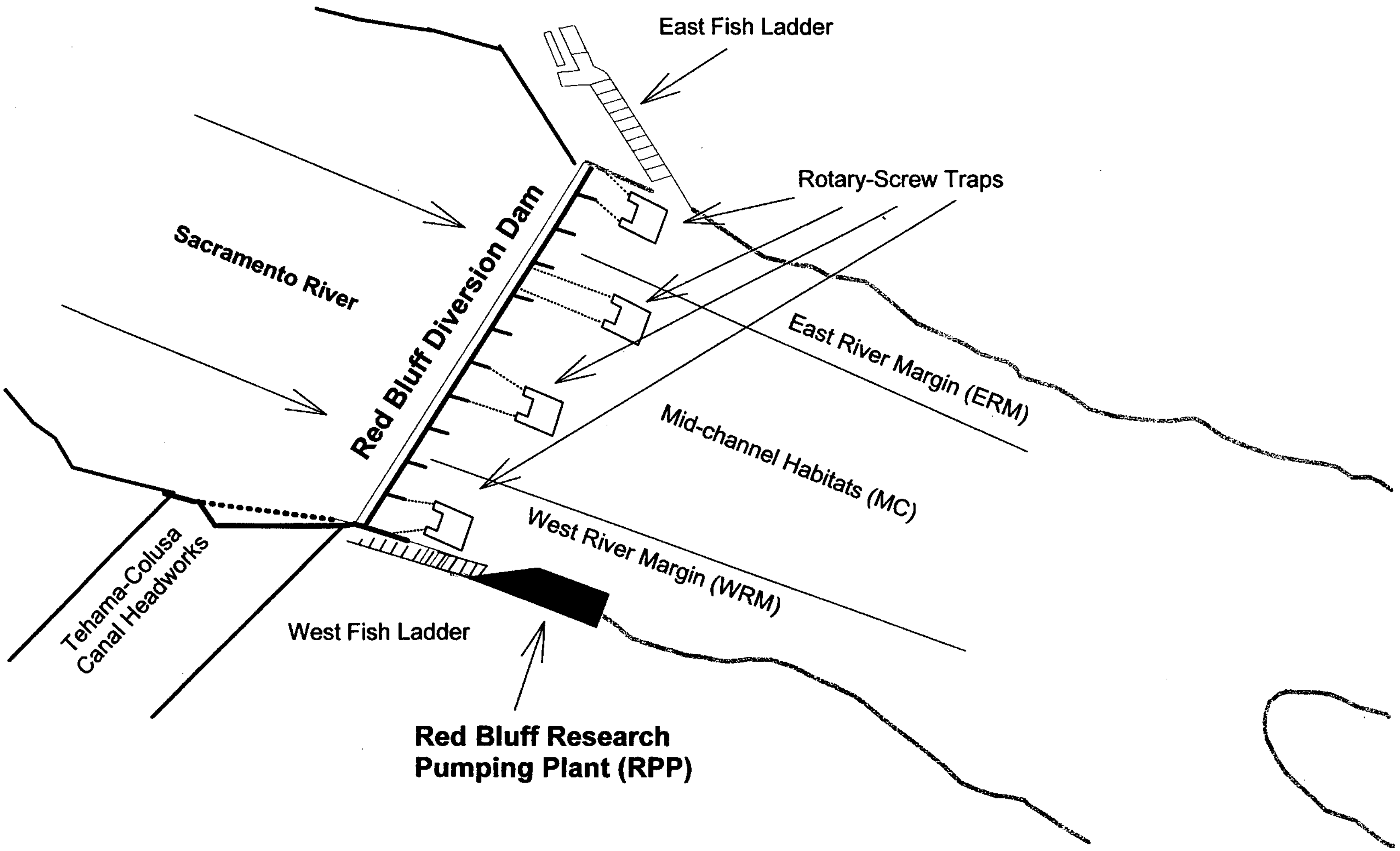

Figure 2.–Rotary-screw trap sampling transect at Red Bluff Diversion Dam (RBDD) on the Sacramento River at river kilometer 391 (RK391).

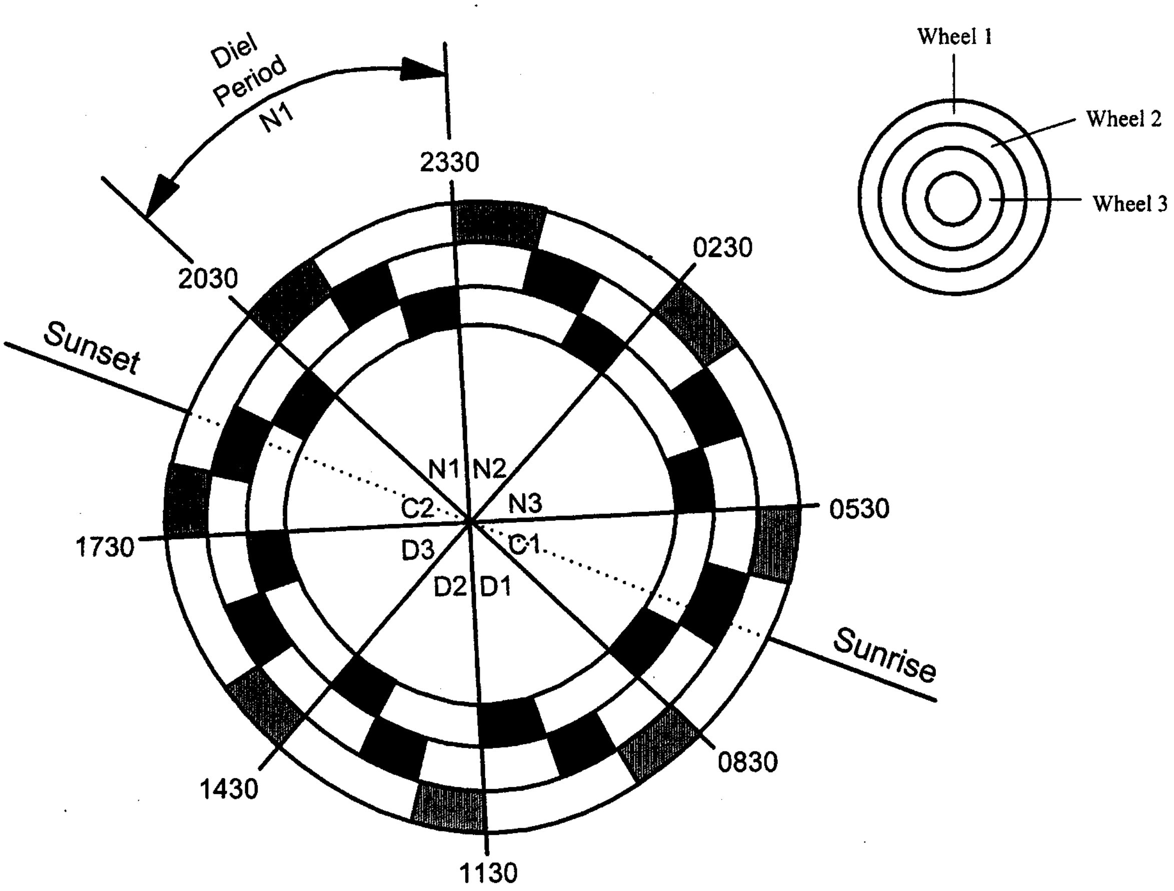

Figure 3. Diel patterns of abundance were investigated by use of a sampling wheel to randomly select strata within nocturnal and diurnal periods. This stratified random sampling design was implemented for *N* 24-h periods/month. Sampling was stratified into eight 3-h periods. Nocturnal periods included strata N1, N2 and N3. Diurnal periods included strata D1, D2 and D3. Strata remained consistent throughout the year except for 1-h adjustments for daylight savings time. Strata were not adjusted for day-length increases or decreases. However, official sunrise and sunset always occurred within crepuscular strata (C1 and C2) except for the longest days of the year. Shaded areas illustrate 1-h sampling periods within the sampling schedule.

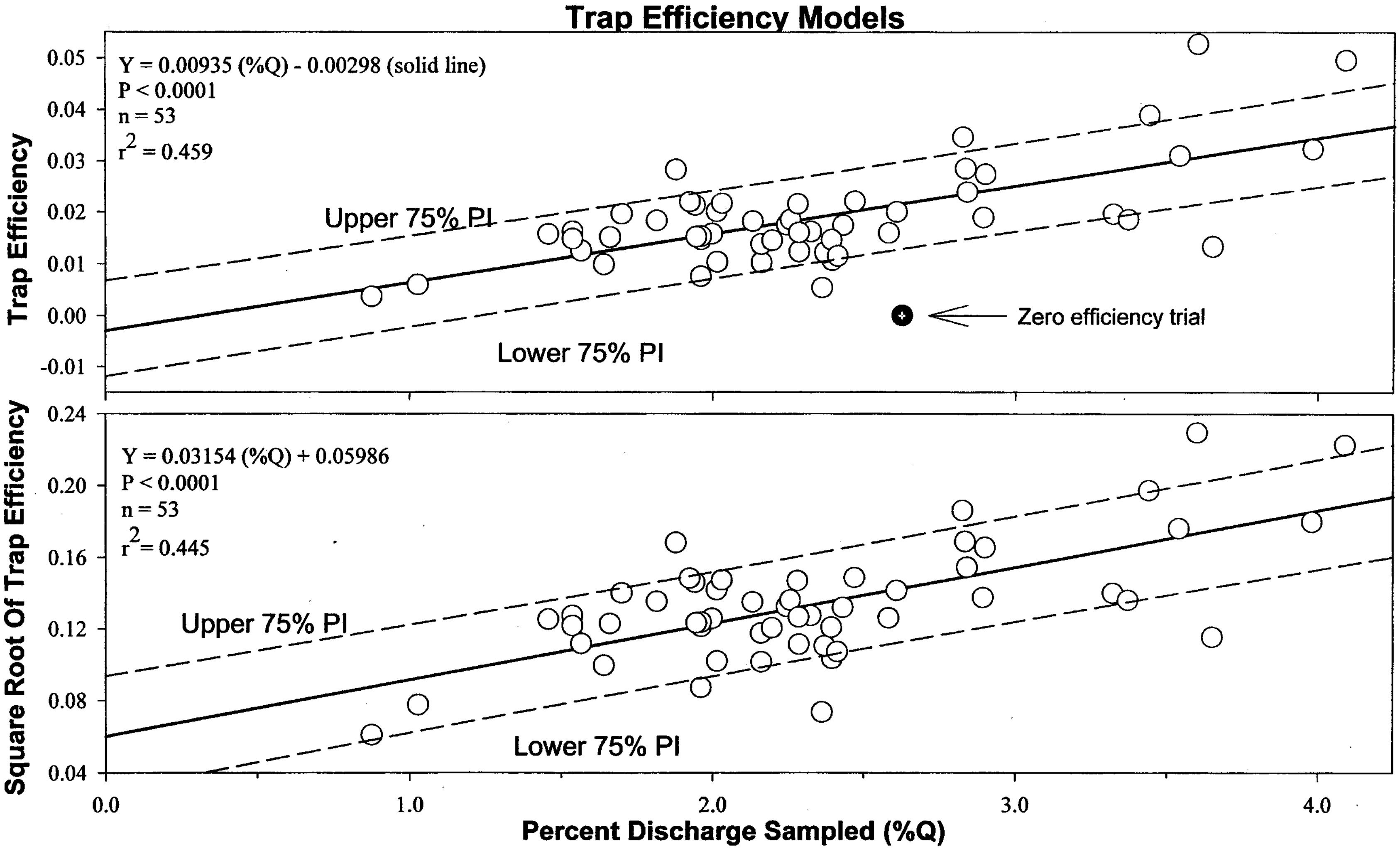

Figure 4.–Trap efficiency model for combined traps at Red Bluff Diversion Dam (RK391), Sacramento River, CA. Percent discharge sampled was linearly regressed with trap efficiency and the square root of trap efficiency. Graph includes least squares regression line with upper and lower 75% prediction intervals. Results from Box-Cox transformations indicated that square root of efficiency minimized model error. Fifty-four trap efficiency trials were conducted, although one trial resulted in zero recaptures and was not used in the regression model. Graph reproduced from Martin et al. (2001).

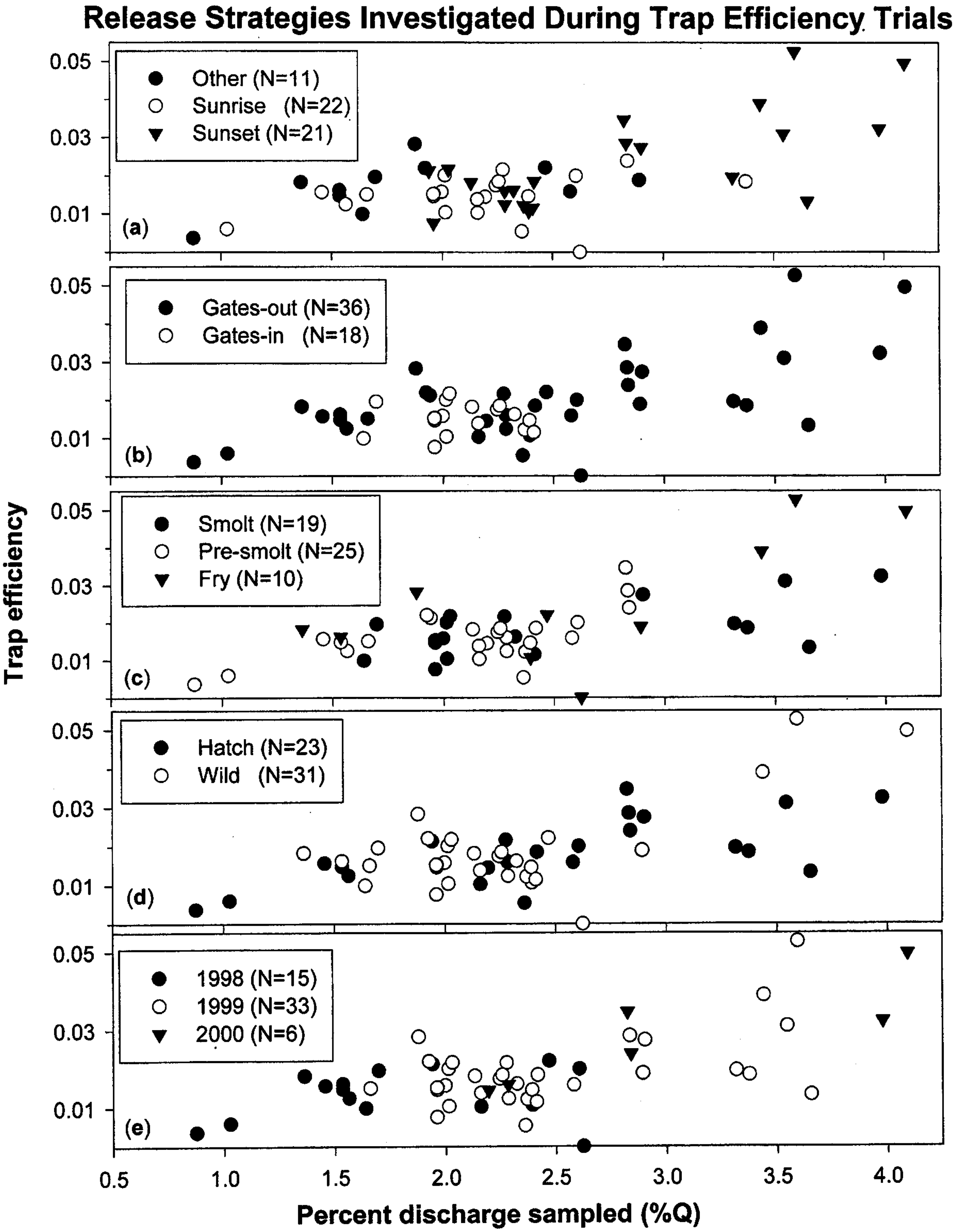

Figure 5.--Release strategies investigated during trap efficiency trials. Trials were conducted to examine components of (**a**) diel behavior, (**b**) RBDD gates raised versus lowered, (**c**) fork length at release, (**d**) hatchery versus naturally produced fish, and (**e**) year of release. Graph reproduced from Martin et al. (2001).

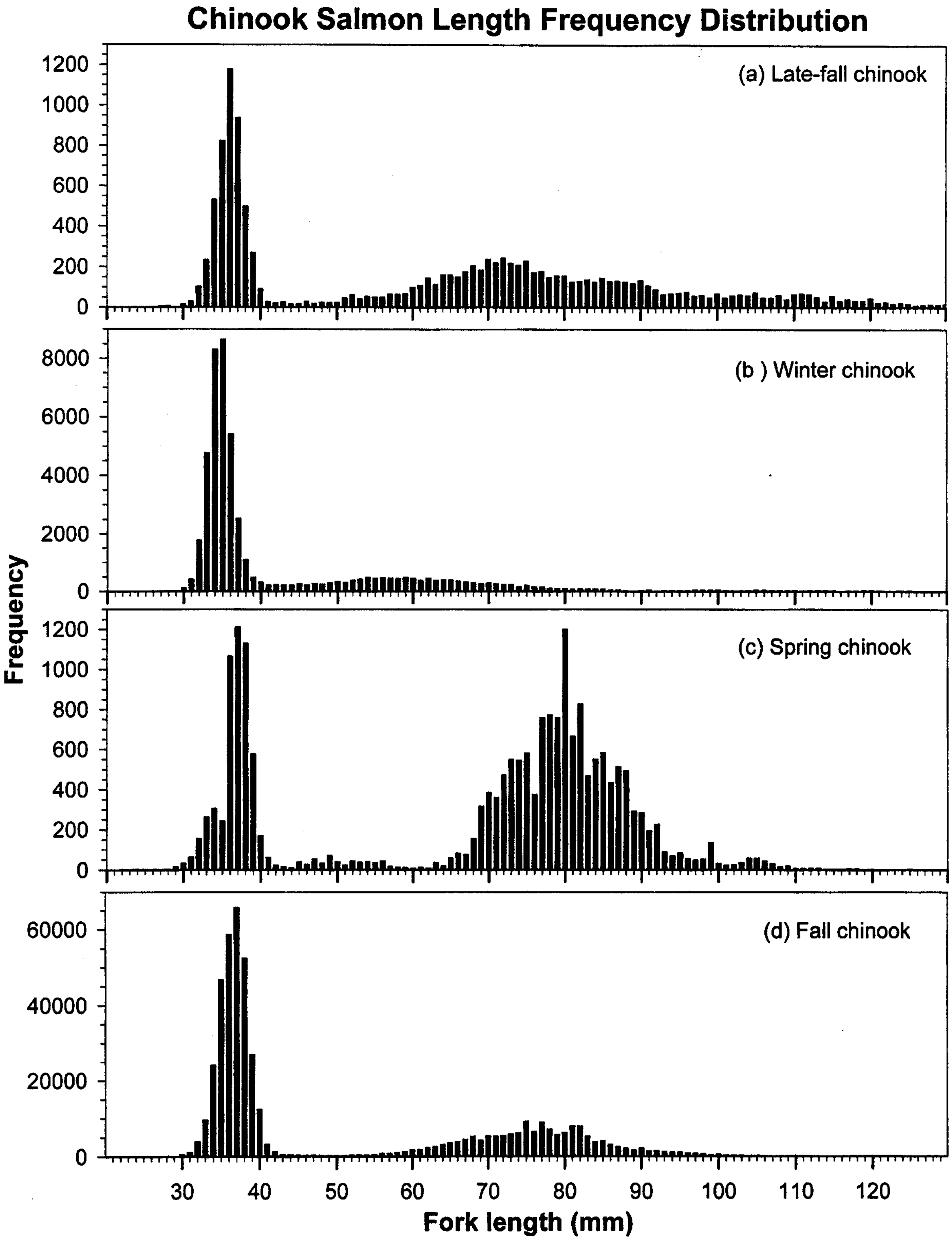

Figure 6. Length-frequency distributions for (a) late-fall, (b) winter, (c) spring and (d) fall chinook salmon captured by rotary traps below Red Bluff Diversion Dam (RK391), Sacramento River, CA. Data summarized from July 1994 through June 2000 for winter run and July 1995 through June 2000 for late-fall, spring and fall run.

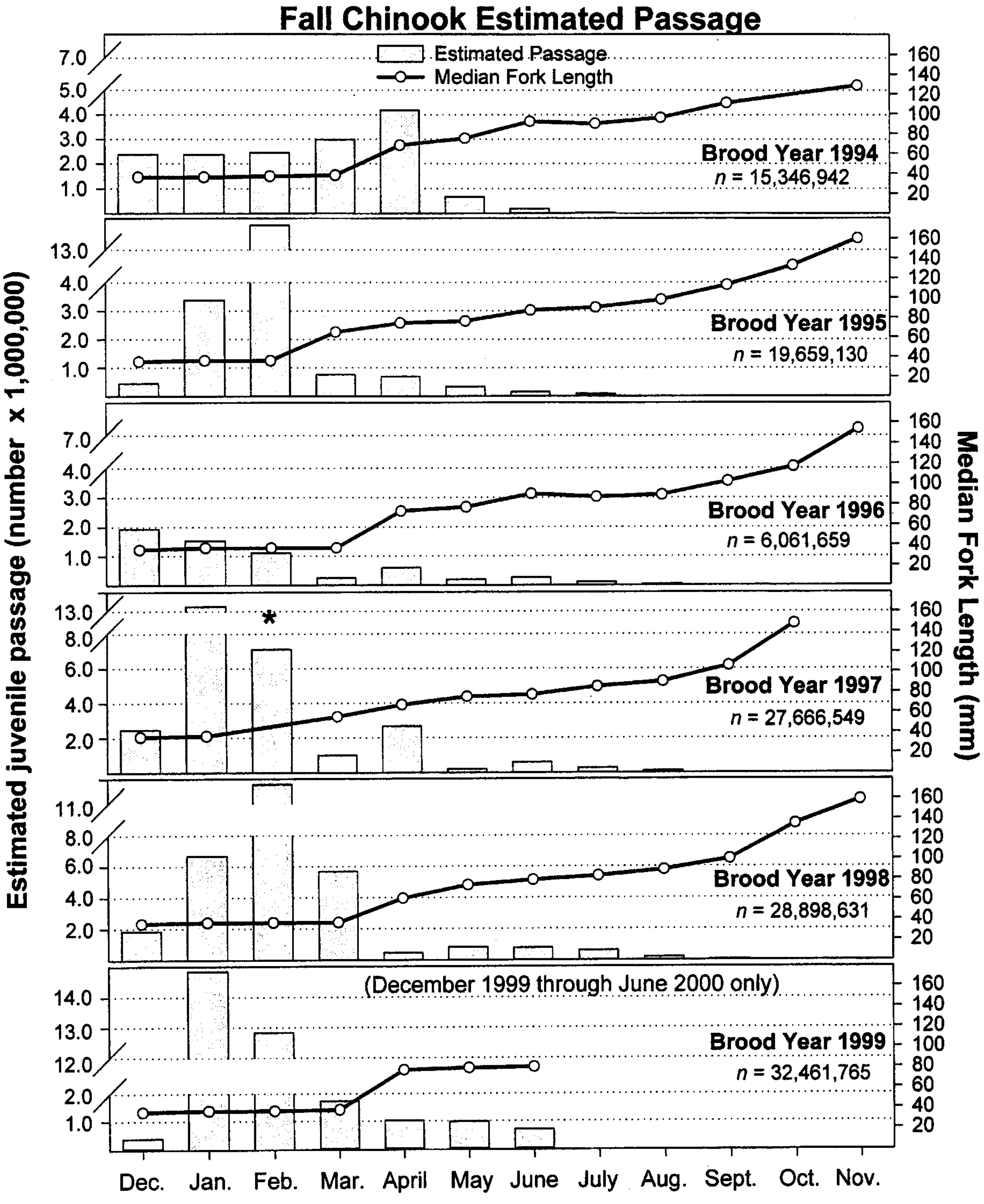

Figure 7. Juvenile passage estimates, number captured (n) and median fork lengths of naturally produced fall chinook salmon captured by rotary-screw traps below Red Bluff Diversion Dam (K391), Sacramento River, CA., for the period April 1995 through June 2000. Note that brood-year designation follows the convention of assignment of year based on first emergence of fry. For fall chinook this occurred in December of each year. Estimates have been standardized for trapping effort. Asterisk denotes that sampling was not conducted due to high river flow.

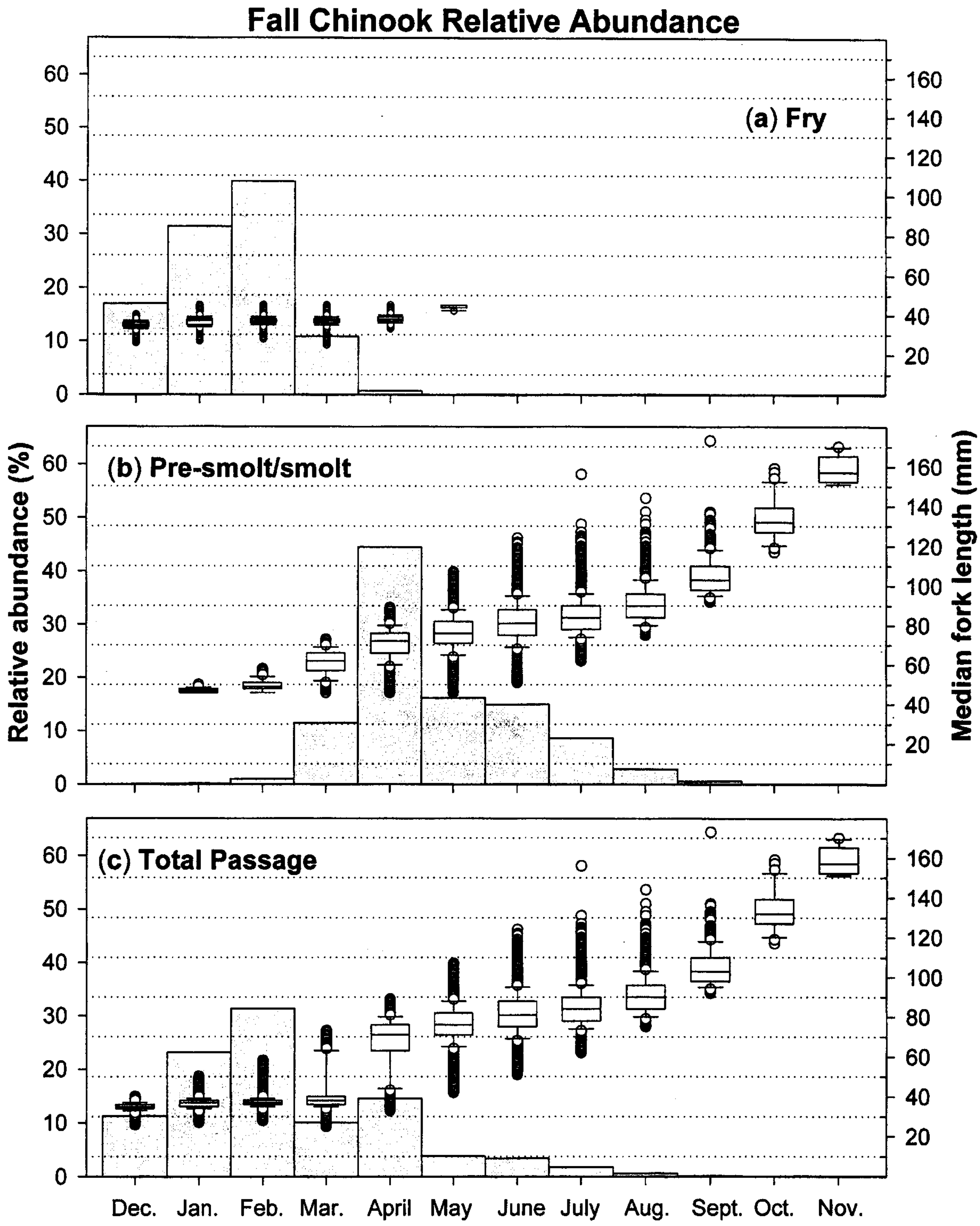

Figure 8. Relative abundance of fall chinook salmon captured by rotary-screw traps at Red Bluff Diversion Dam (RK391), Sacramento River, CA., for the period July 1994 through June 2000. Relative abundance reported for (**a**) fry (<46 mm FL), (**b**) pre-smolt/smolt (46-200 mm FL) and (**c**) total passage (fry and pre-smolt/smolts combined). Box plots display monthly median fork lengths (mm), 10th, 25th, 75th and 90th percentiles and outliers.

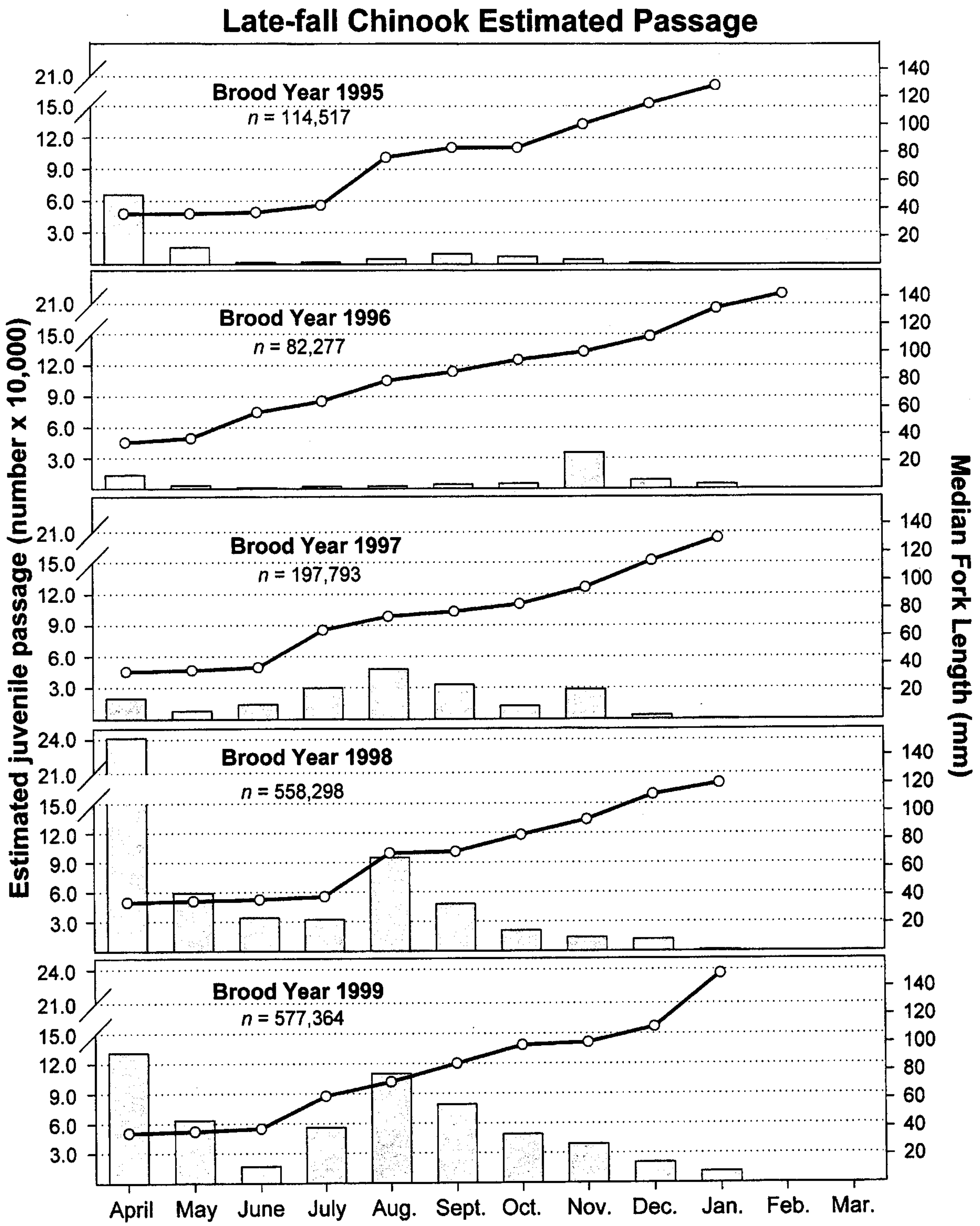

Figure 9. Juvenile passage estimates and median fork lengths of naturally produced late-fall chinook salmon captured by rotary-screw traps below Red Bluff Diversion Dam (RK391), Sacramento River, CA., for the period April 1995 through June 2000. Note that brood year designation follows the convention of assignment of year based on first emergence of fry. For late-fall chinook this occurred in April of each year. Estimates have been standardized for trapping effort.

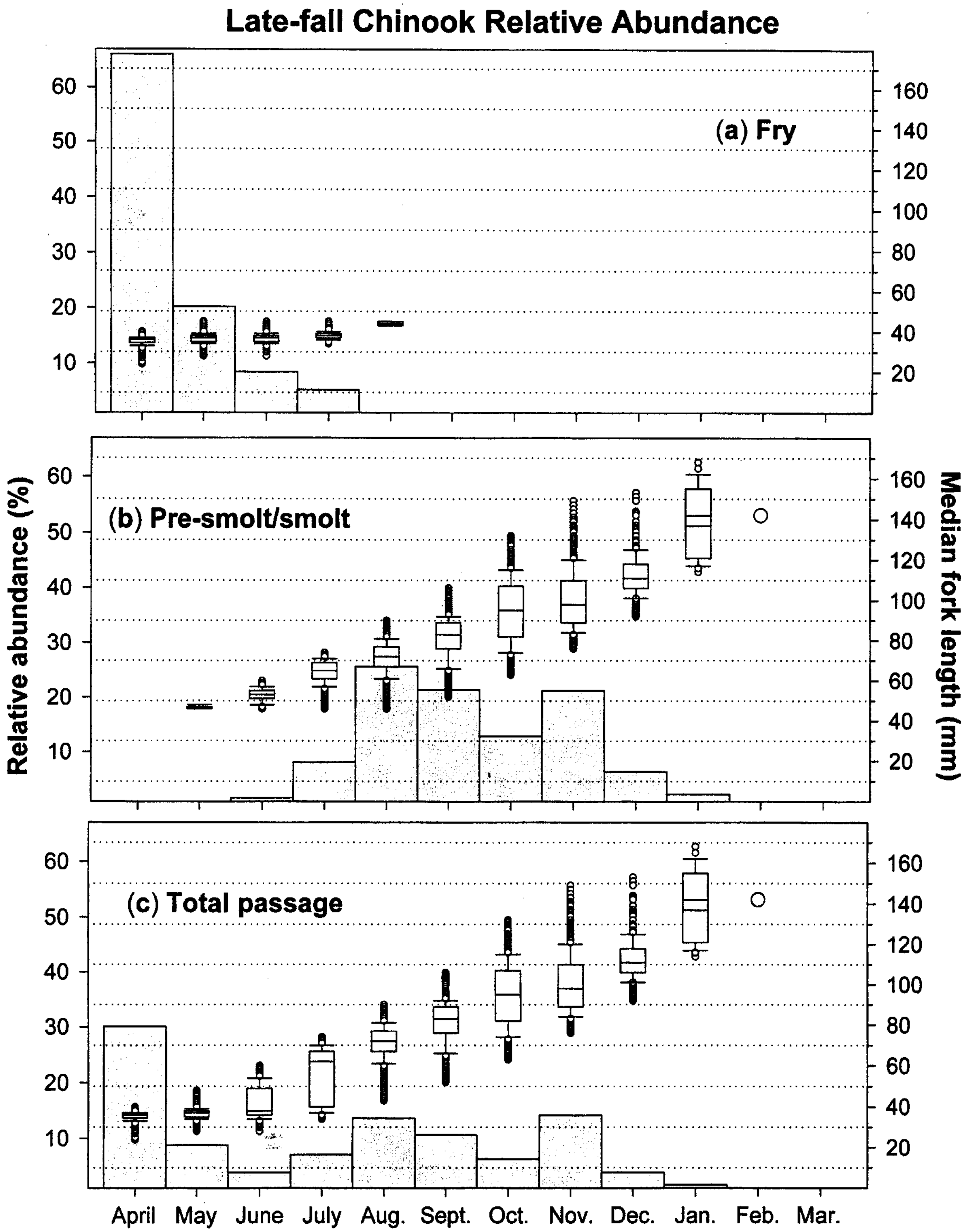

Figure 10. Relative abundance of late-fall chinook salmon captured by rotary-screw traps below Red Bluff Diversion Dam (RK391), Sacramento River, CA., for the period April 1995 through March 1999. Relative abundance reported for (a) fry (<46 mm FL), (b) pre-smolt/smolt (46-200 mm FL) and (c) total passage (fry and pre-smolt/smolts combined). Box plots display monthly median fork lengths, 10th, 25th, 75th and 90th percentiles and outliers.

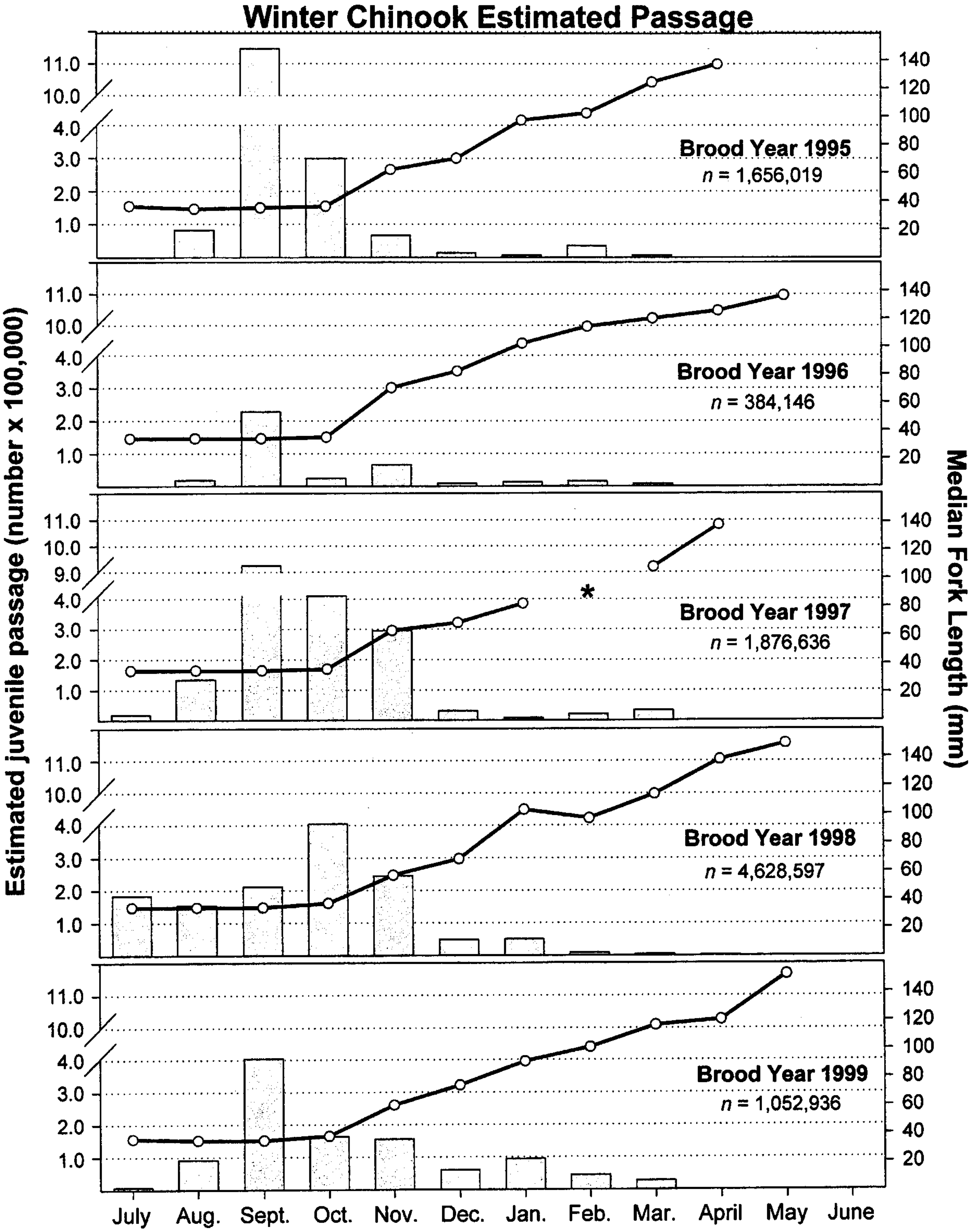

Figure 11. Juvenile passage estimates and median fork lengths of naturally produced winter chinook salmon captured by rotary-screw traps below Red Bluff Diversion Dam (RK391) for the period April 1995 through June 2000. Note that brood year designation follows the convention of assignment of year based on first emergence of fry. For winter chinook first emergence occurred in July of each year. Estimates have been standardized for trapping effort. Asterisk denotes that sampling was not conducted due to high river flow.

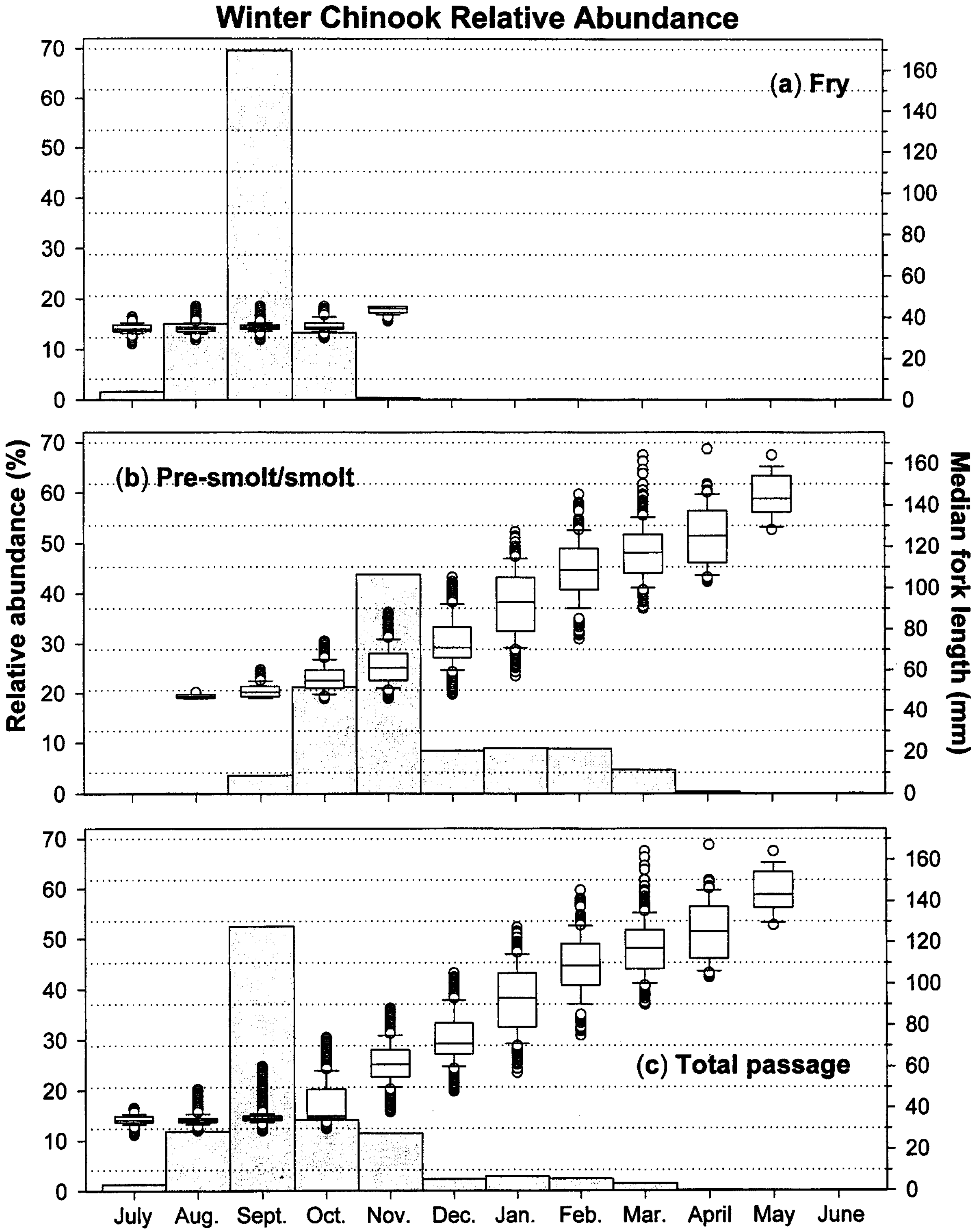

Figure 12. Relative abundance of winter chinook salmon captured by rotary-screw traps below Red Bluff Diversion Dam (RK391), Sacramento River, CA., for the period April 1995 through June 2000. Relative abundance reported for (**a**) fry (<46 mm FL), (**b**) pre-smolt/smolt (46-200 mm FL) and (**c**) total passage (fry and pre-smolt/smolts combined). Box plots display monthly median fork lengths, 10th, 25th, 75th and 90th percentiles and outliers.

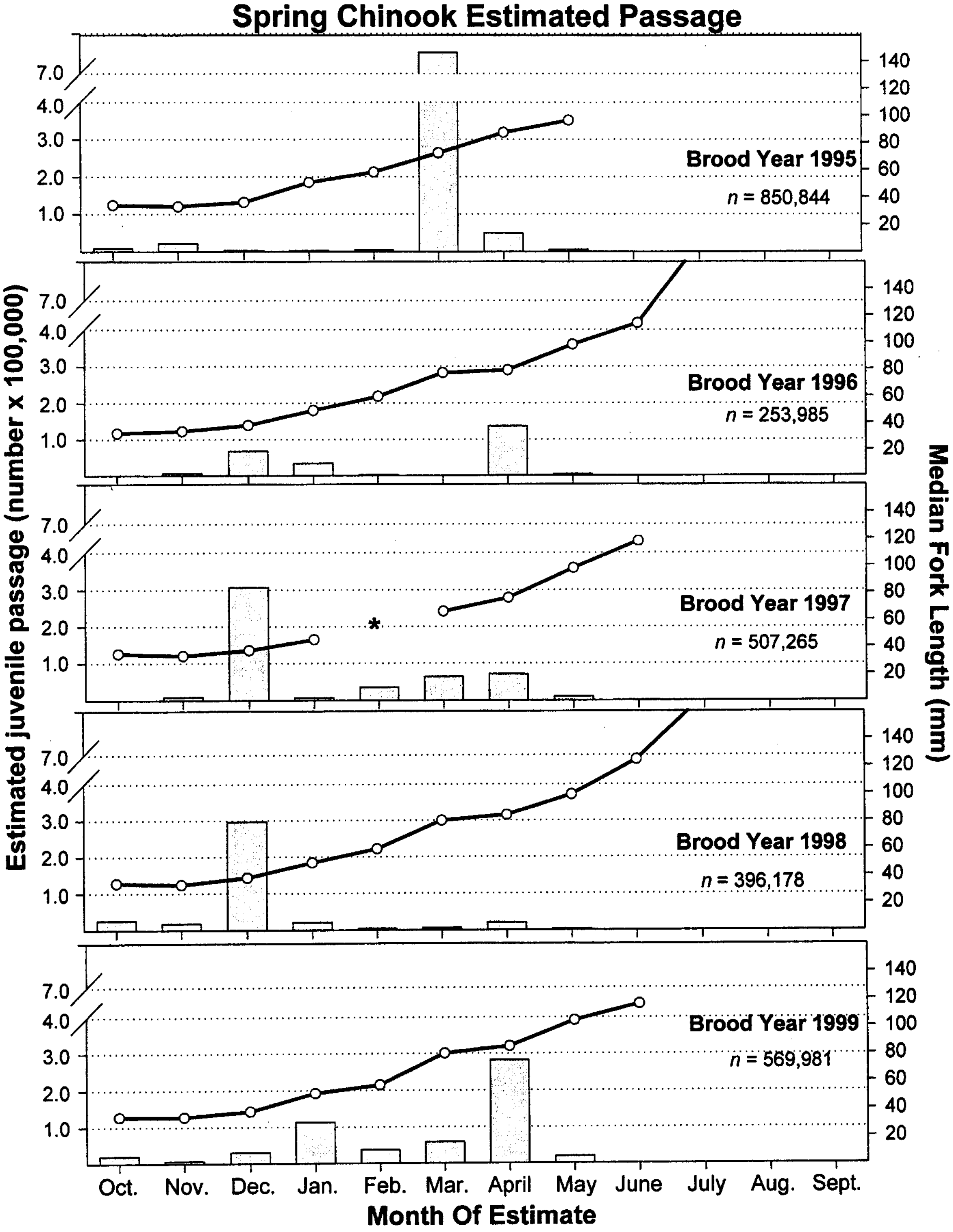

Figure 13. Juvenile passage estimates of naturally produced spring chinook salmon captured by rotary-screw traps below Red Bluff Diversion Dam (RK391) for the period April 1995 through June 2000. Note that brood year designation follows the convention of assignment of year based on first emergence of fry. For spring chinook first emergence occurred on October 15 of each year. Estimates have been standardized for trapping effort. Asterisk denotes sampling was not conducted due to high river flow.

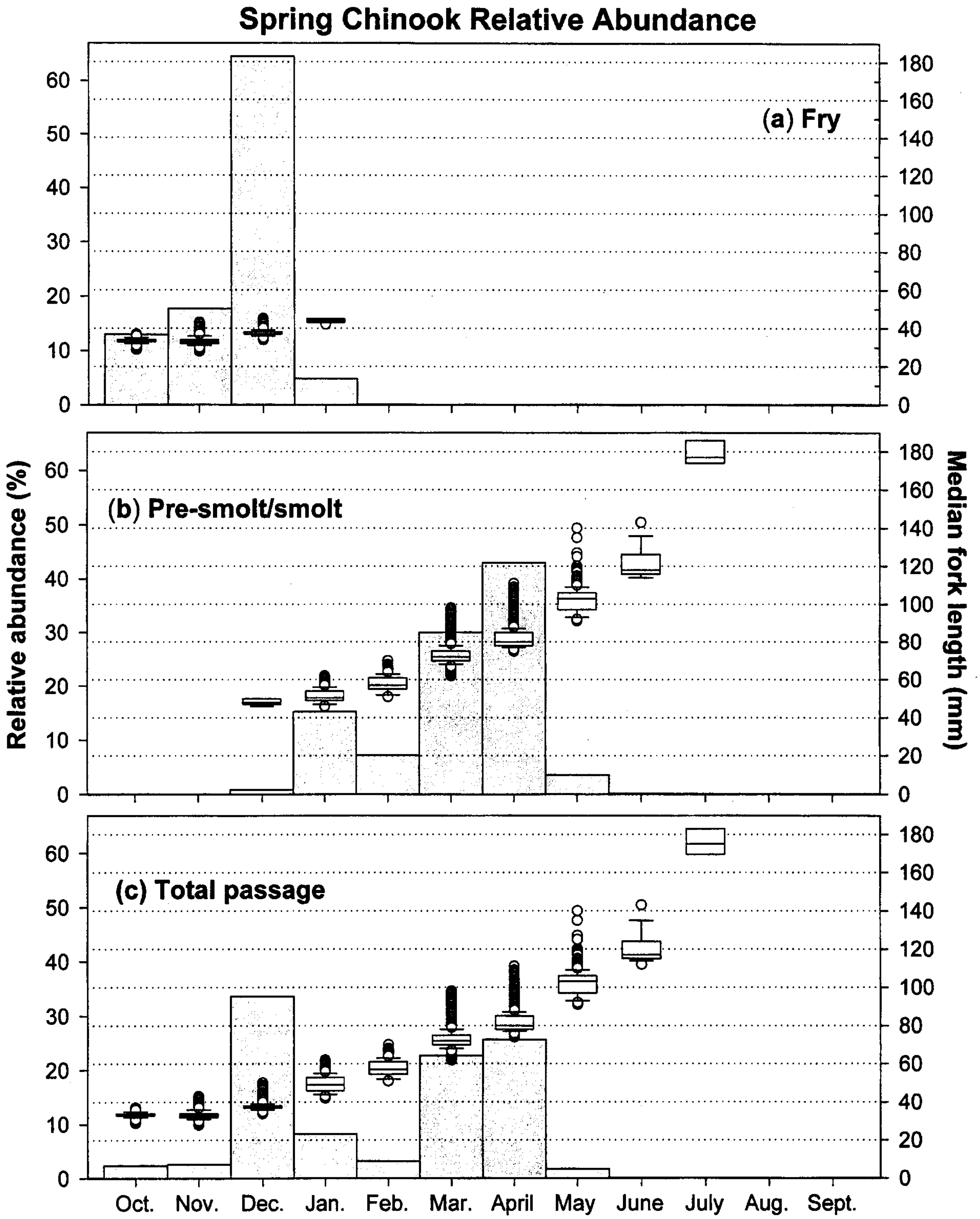

Figure 14. Relative abundance of spring chinook salmon captured by rotary-screw traps below Red Bluff Diversion Dam (RK391), Sacramento River, CA., for the period April 1995 through June 2000. Relative abundance reported for (**a**) fry (<46 mm FL), (**b**) pre-smolt/smolt (46-200 mm FL) and (**c**) total passage (fry and pre-smolt/smolts combined. Box plots display monthly median fork lengths, 10th, 25th, 75th and 90th percentiles and outliers.

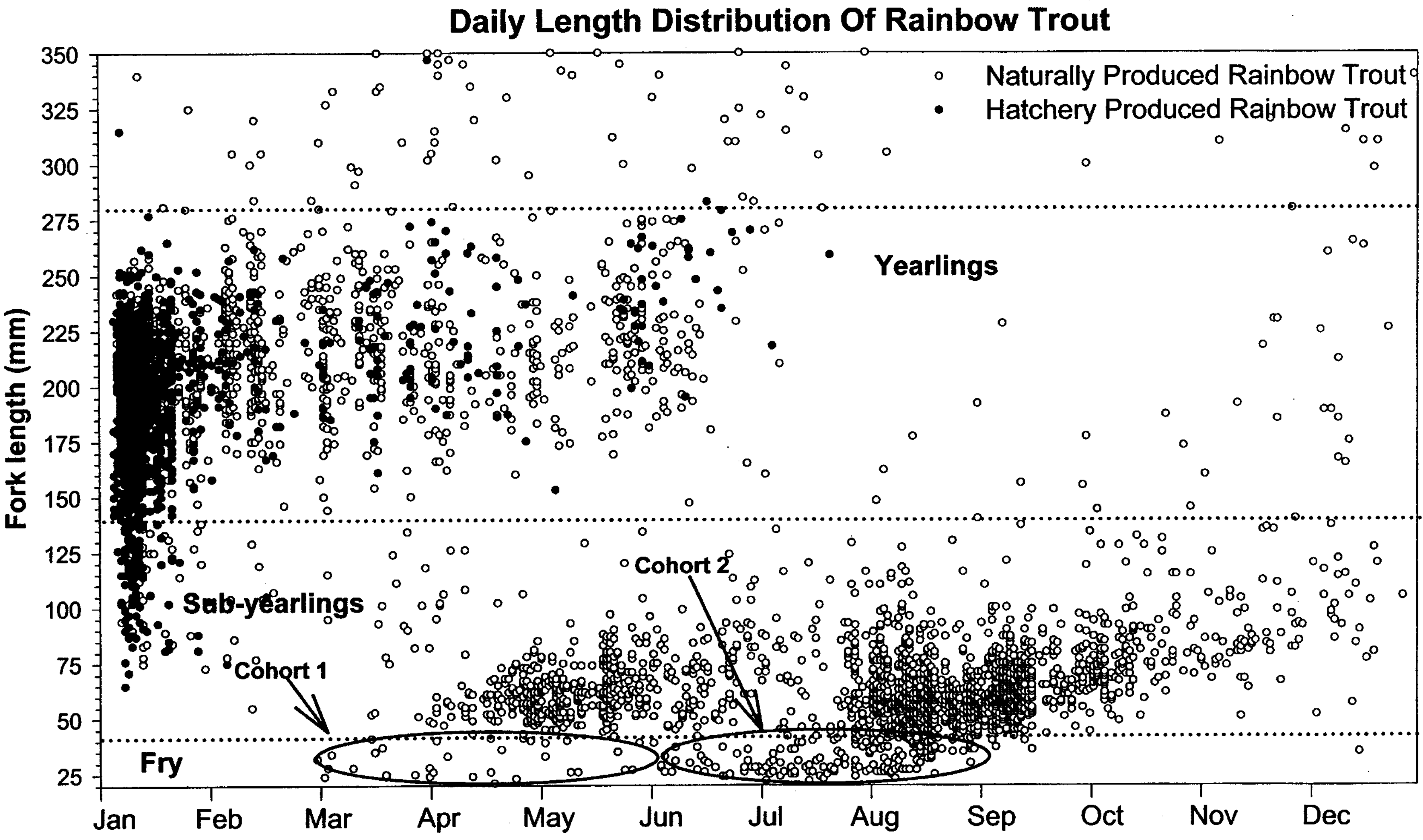

Figure 15. Within-year daily length distributions for rainbow trout captured by rotary-screw traps below Red Bluff Diversion Dam (RK391), Sacramento River, CA., for the period July 1994 through June 2000. Size criteria used for classifying fry (<41 mm FL), sub-yearling (41-138 mm FL) and yearlings (139-280 mm FL) denoted with dotted y-axis grid lines. Graph illustrates the presence of two temporally distinct cohorts. The first cohort emerges from March through May with the second emerging in June and continuing through August.

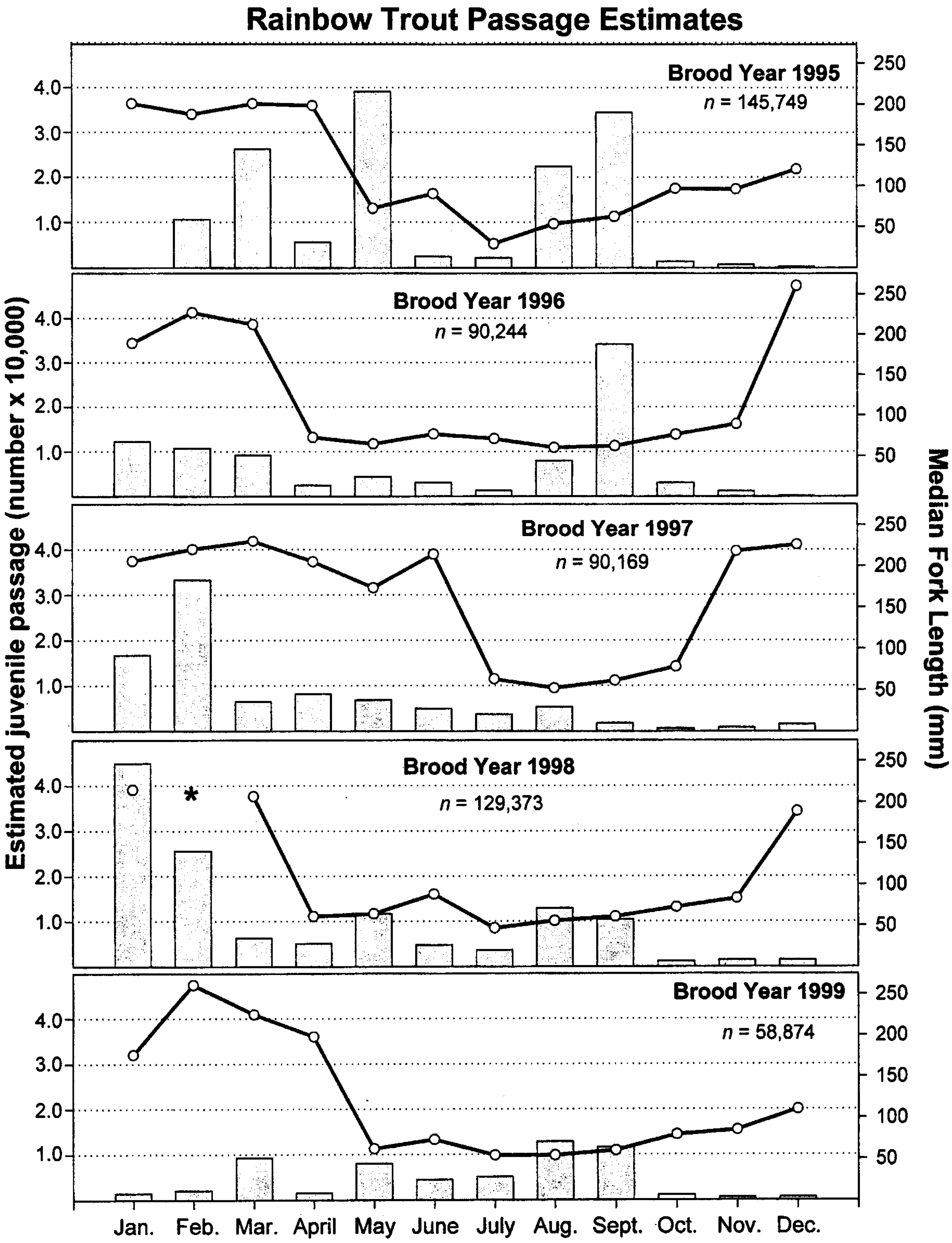

Figure 16. Juvenile passage estimates and median for lengths of naturally produced rainbow trout captured by rotary-screw traps below Red Bluff Diversion Dam (RK391), Sacramento River, CA., for the period April 1995 through June 2000. Rainbow trout brood years begin on 1 January. Estimates have been standardized for trapping effort. Asterisk denotes sampling was not conducted due to high river flow.

Rainbow Trout Relative Abundance

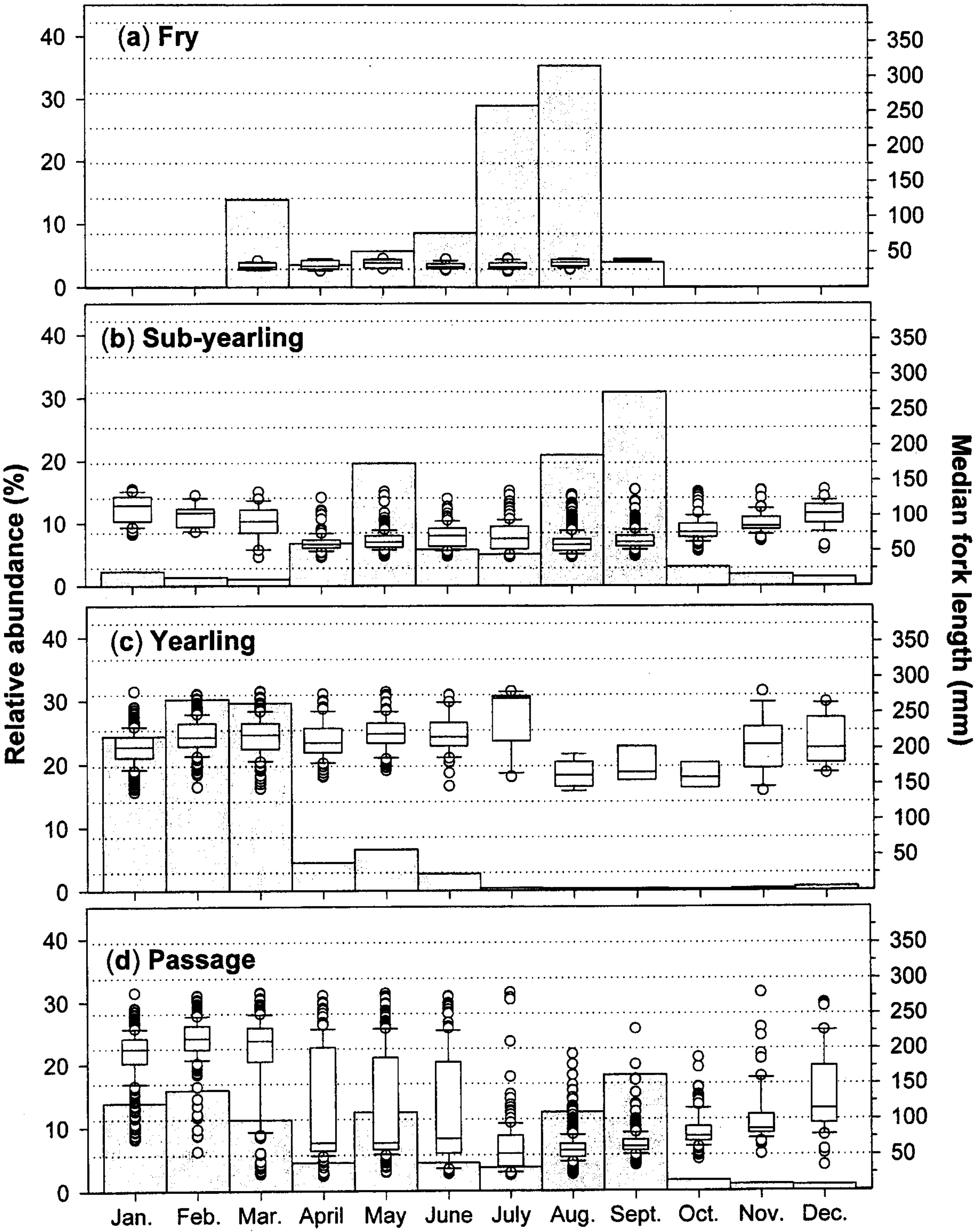

Figure 17. Relative abundance of rainbow trout captured by rotary-screw traps below Red Bluff Diversion Dam (RK391), Sacramento River, CA., for the period April 1995 through June 2000. Relative abundance reported for (a) fry (<41 mm FL), (b) sub-yearlings (46-138 mm FL), (c) yearlings (139-280 mm FL) and total passage (fry, sub-yearlings and yearlings combined). Box plots display monthly median fork lengths, 10th, 25th, 75th, and 90th percentiles and outliers.

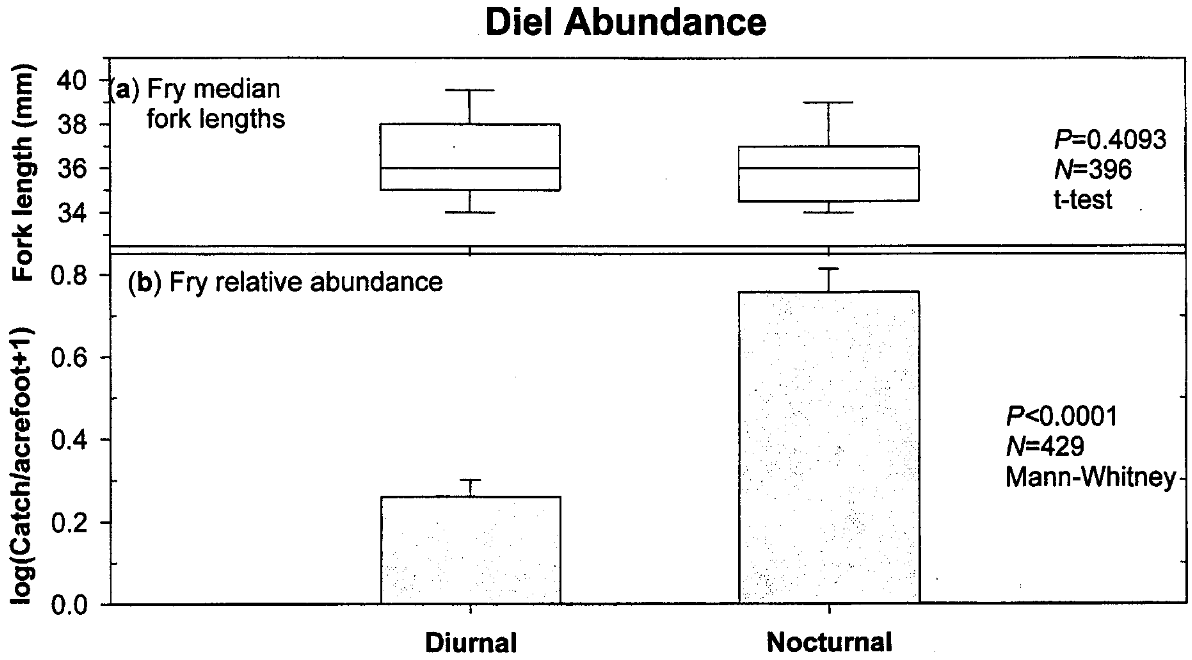

Figure 18. Relative abundance and median fork length of chinook salmon fry (all runs combined) captured by rotary-screw traps below Red Bluff Diversion Dam (RK391), Sacramento River, CA, during diurnal and nocturnal sampling. Comparisons include (a) median fork length and (b) relative abundance (CPUV). Relative abundance was significantly greater during nocturnal periods. No difference was detected in mean fork length.

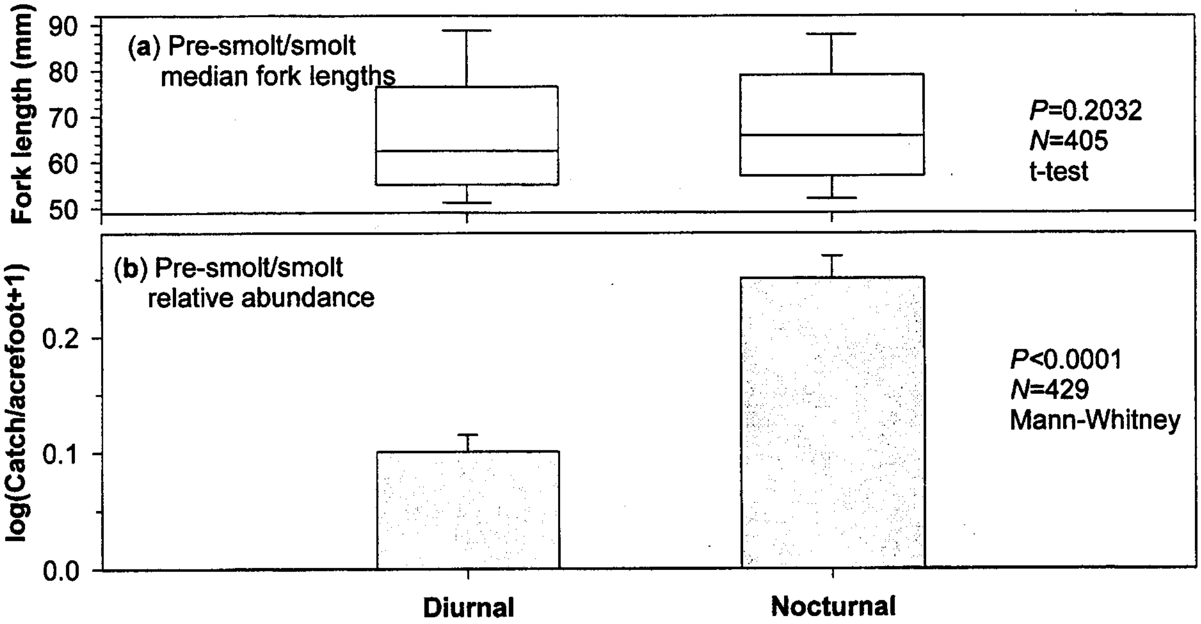

Figure 19. Relative abundance and median fork length of chinook salmon pre-smolt/smolts (all runs combined) captured by rotary-screw traps below Red Bluff Diversion Dam (RK391), Sacramento River, CA, during diurnal and nocturnal sampling. Comparisons include (a) median fork length and (b) relative abundance (CPUV). Relative abundance was significantly greater during nocturnal periods. No difference was detected in median fork length.

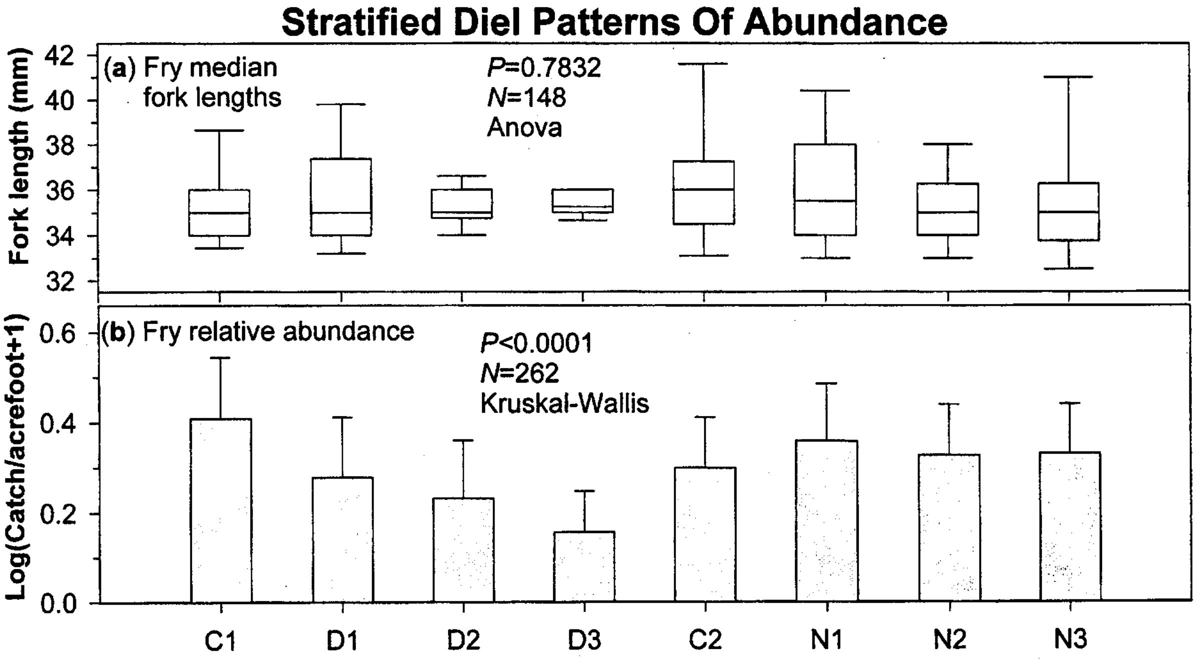

Figure 20. Relative abundance and median fork length of chinook salmon fry (all runs combined) captured by rotary-screw traps below Red Bluff Diversion Dam (RK391), Sacramento River, CA, during stratified diel sampling of 24-h periods. Comparisons include (a) median fork length and (b) relative abundance (CPUV). Note that relative abundance was always greater during nocturnal and crepuscular strata (N1, N2, N3, C1 and C2) than for diurnal strata (D1, D2 and D3). No difference was detected in median fork length.

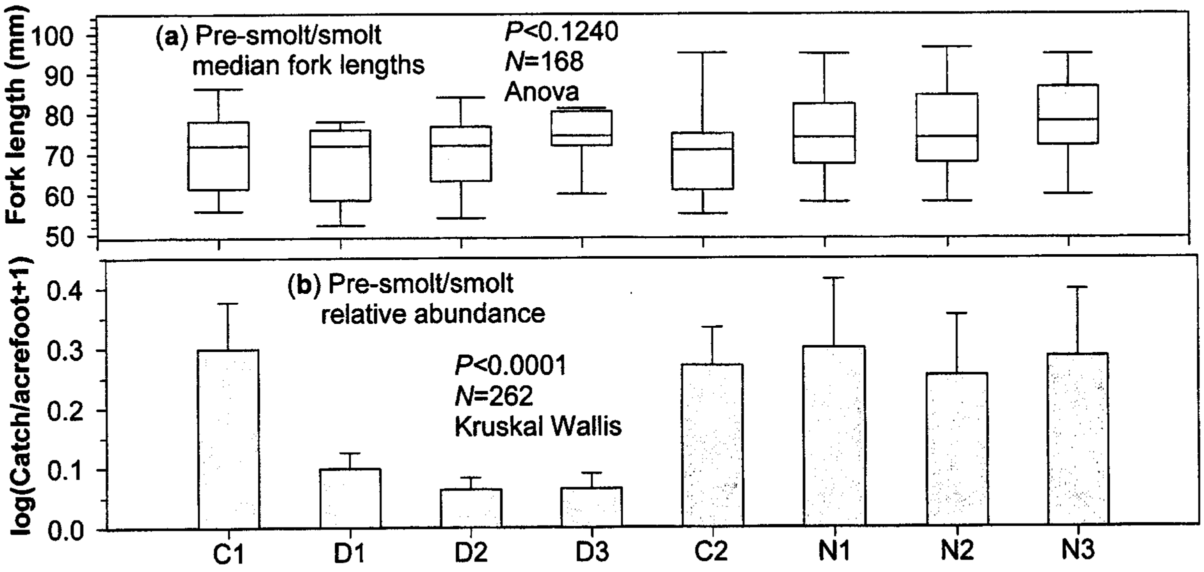

Figure 21. Relative abundance and median fork length of chinook salmon pre-smolt/smolts (all runs combined) captured by rotary-screw traps below Red Bluff Diversion Dam (RK391), Sacramento River, CA, during stratified diel sampling of 24-h periods. Comparisons include (a) median fork length and (b) relative abundance (CPUV). Note that relative abundance was always greater during nocturnal and crepuscular strata (N1, N2, N3, C1 and C2) than for diurnal strata (D1, D2 and D3). No difference was detected in median fork length.

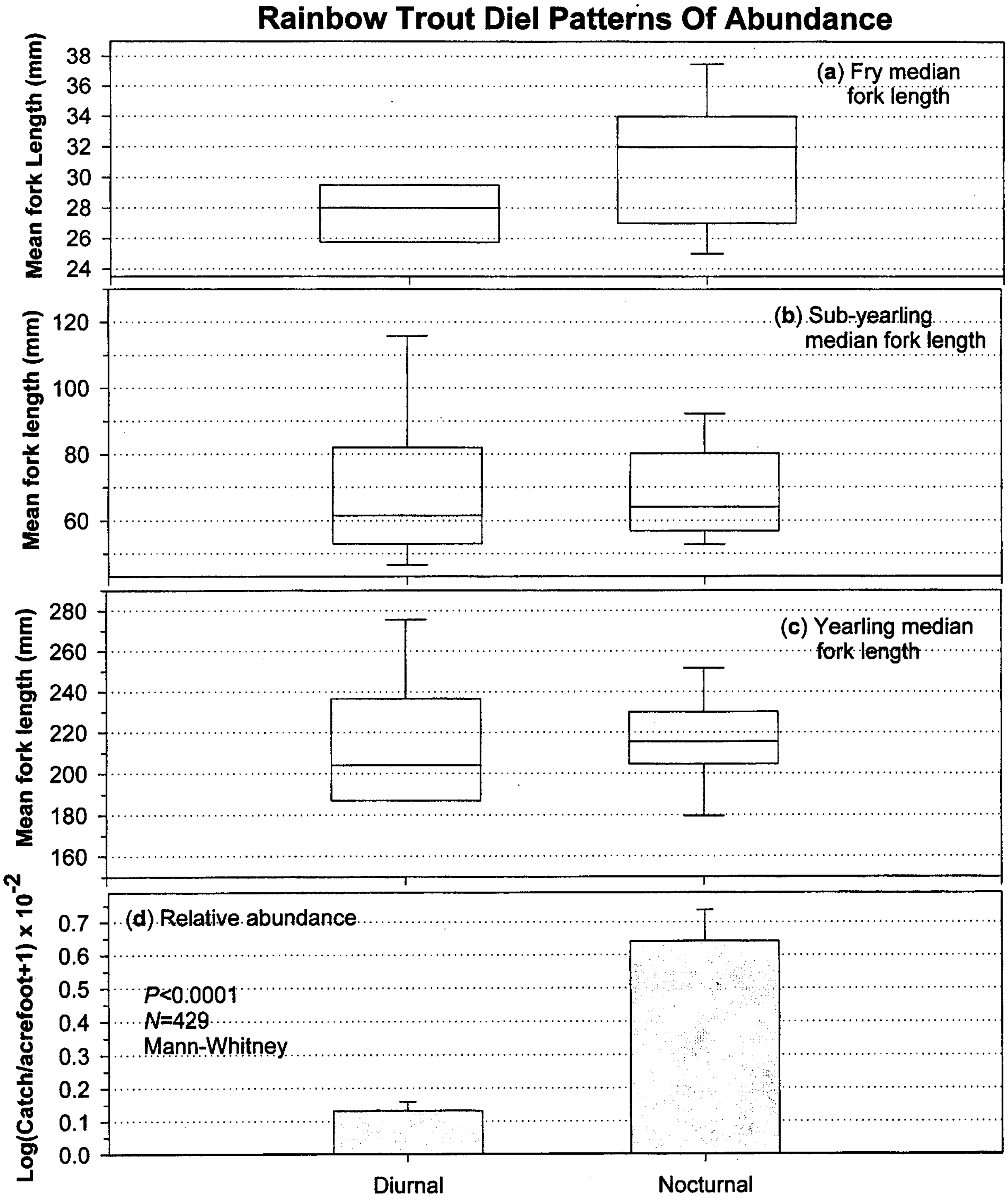

Figure 22. Relative abundance and median fork length of rainbow trout captured by rotary-screw traps below Red Bluff Diversion Dam (RK391), Sacramento River, CA, during diurnal and nocturnal sampling. Comparisons include median fork length of (a) fry, (b) sub-yearling, (c) yearling and (d) relative abundance (CPUV). Capture of rainbow trout was not sufficient to analyze relative abundance by specific length groups (fry, sub-yearlings or yearlings), separately. Therefore, all rainbow trout were combined for analysis of relative abundance. Relative abundance was significantly greater during nocturnal periods. Median fork lengths were greater for all length groups during nocturnal periods.

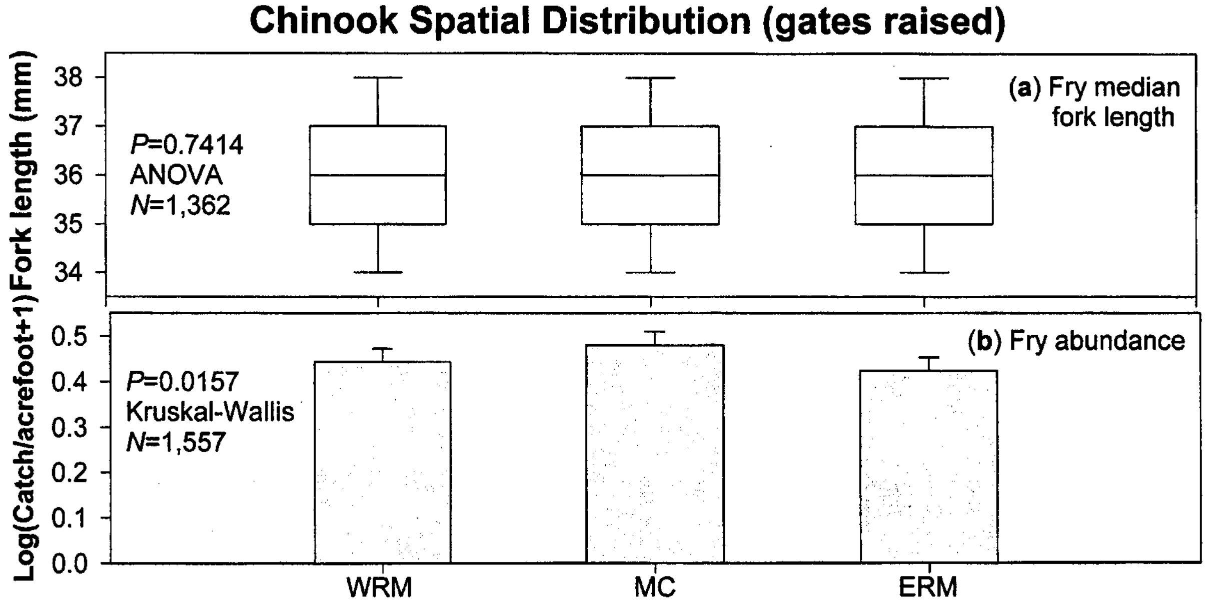

Figure 23. Relative abundance and median fork length of chinook salmon fry (all runs combined) captured by rotary-screw traps below Red Bluff Diversion Dam (RK391), Sacramento River, CA. Relative abundance and median fork length are reported for west river-margin (WRM), mid-channel (MC) and east river-margin (ERM) habitats. Comparisons include (a) median fork length and (b) relative abundance (CPUV) for traps positioned in spatially distinct habitats. Relative abundance of fry was significantly greater in mid-channel habitats. No significant difference was detected in median fork lengths.

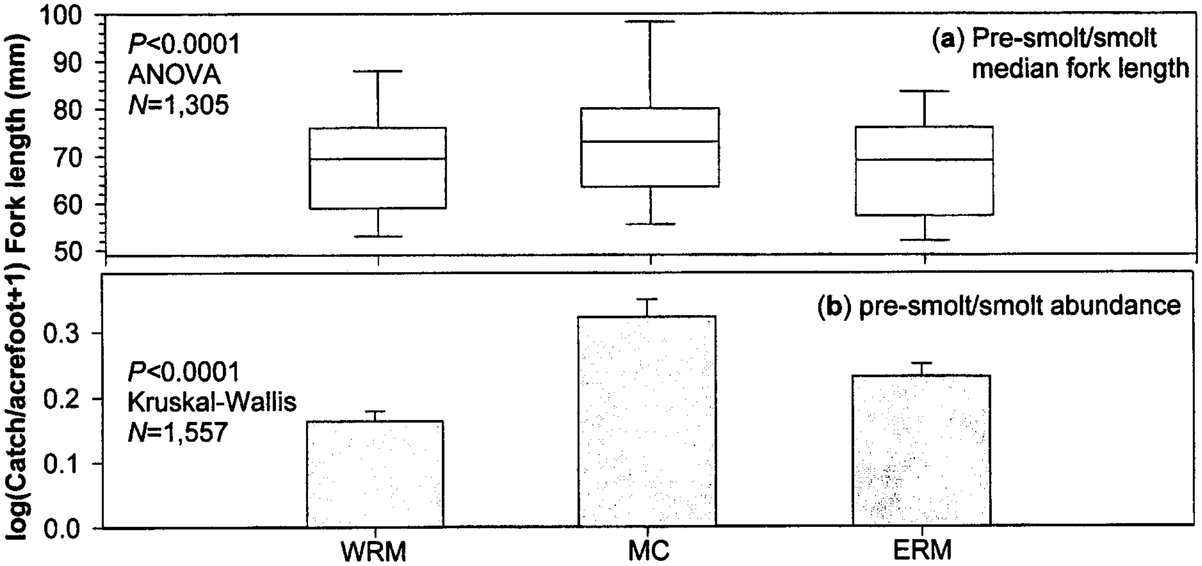

Figure 24. Relative abundance and median fork length of chinook salmon pre-smolt/smolts (all runs combined) captured by rotary-screw traps at Red Bluff Diversion Dam (RK391), Sacramento River, CA. Relative abundance and median fork lengths are reported for west river-margin (WRM), mid-channel (MC) and east river-margin (ERM) habitats. Comparisons include (a) relative abundance (CPUV) and (b) median fork length for traps positioned in spatially distinct habitats. Relative abundance and median fork length of pre-smolt/smolts was significantly greater in mid-channel habitats.

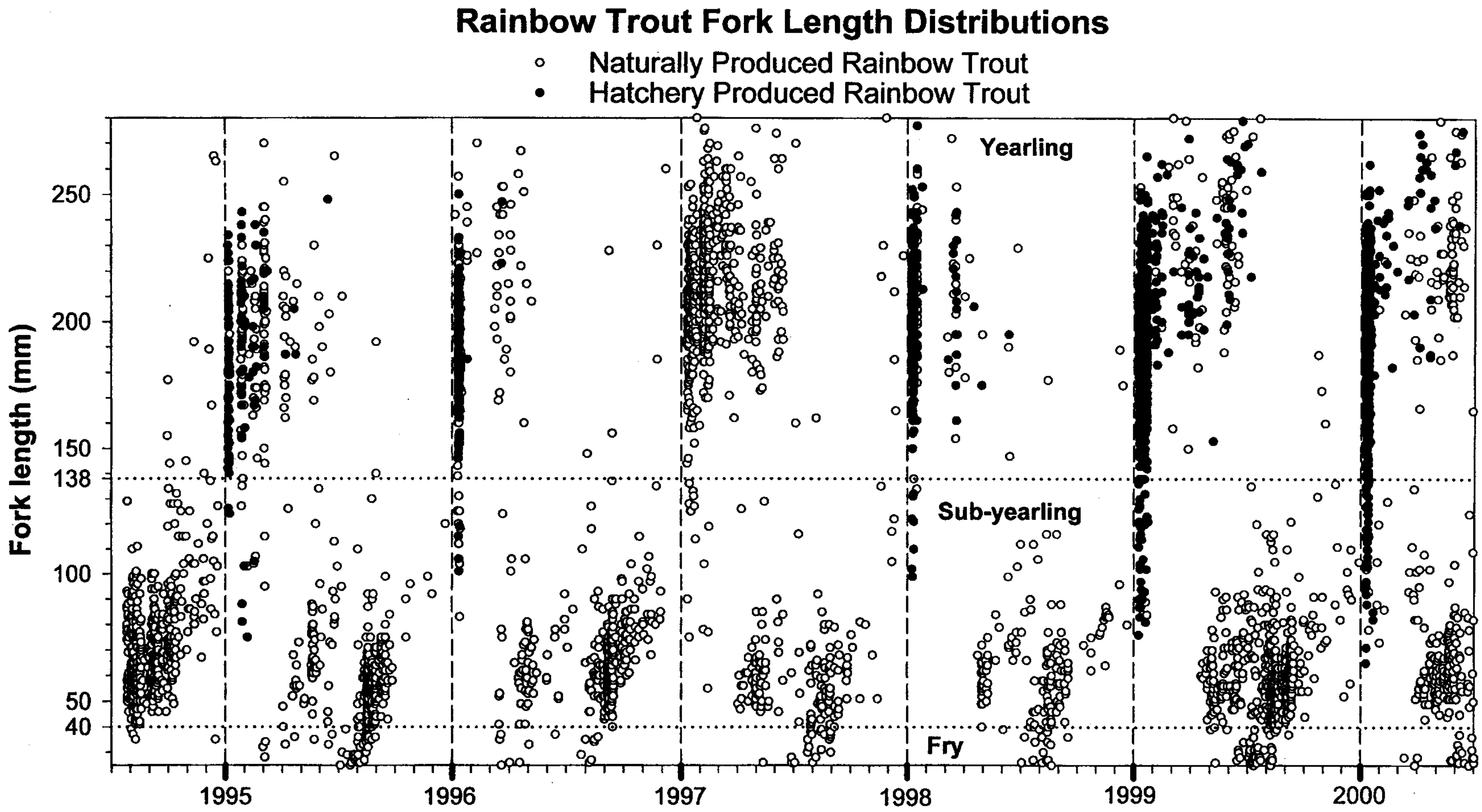

Figure 25. Between year daily length distributions for rainbow trout captured by rotary-screw traps at Red Bluff Diversion Dam (RK391), Sacramento River, CA., for the period July 1994 through June 2000. Size criteria used for classifying fry (< 41 mm FL), sub-yearling (41-138 mm FL) and yearlings (139-280 mm FL) is denoted with dotted y-axis grid lines. Graph illustrates the presence to two temporally distinct cohorts of rainbow trout. The first cohort emerges from March through May and the second emerging in June and continuing through August.

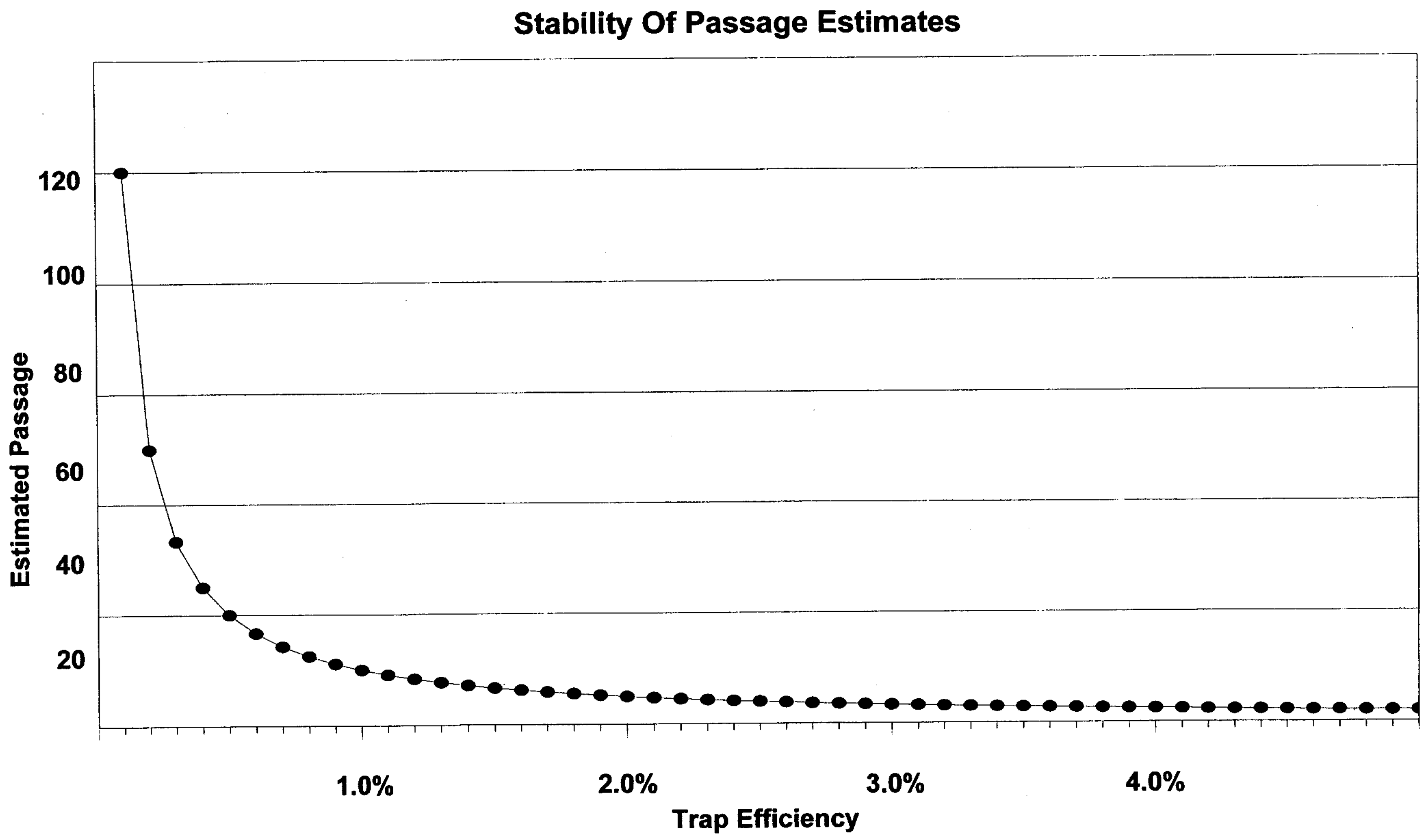

Figure 26. Relationship between trap efficiency and estimated juvenile passage at Red Bluff Diversion Dam (RK391), Sacramento River, CA.. Graph illustrates the instability of passage estimates generated from trap efficiencies less than 1.0 percent (i.e., a small change in trap efficiency results in large changes in estimated passage).

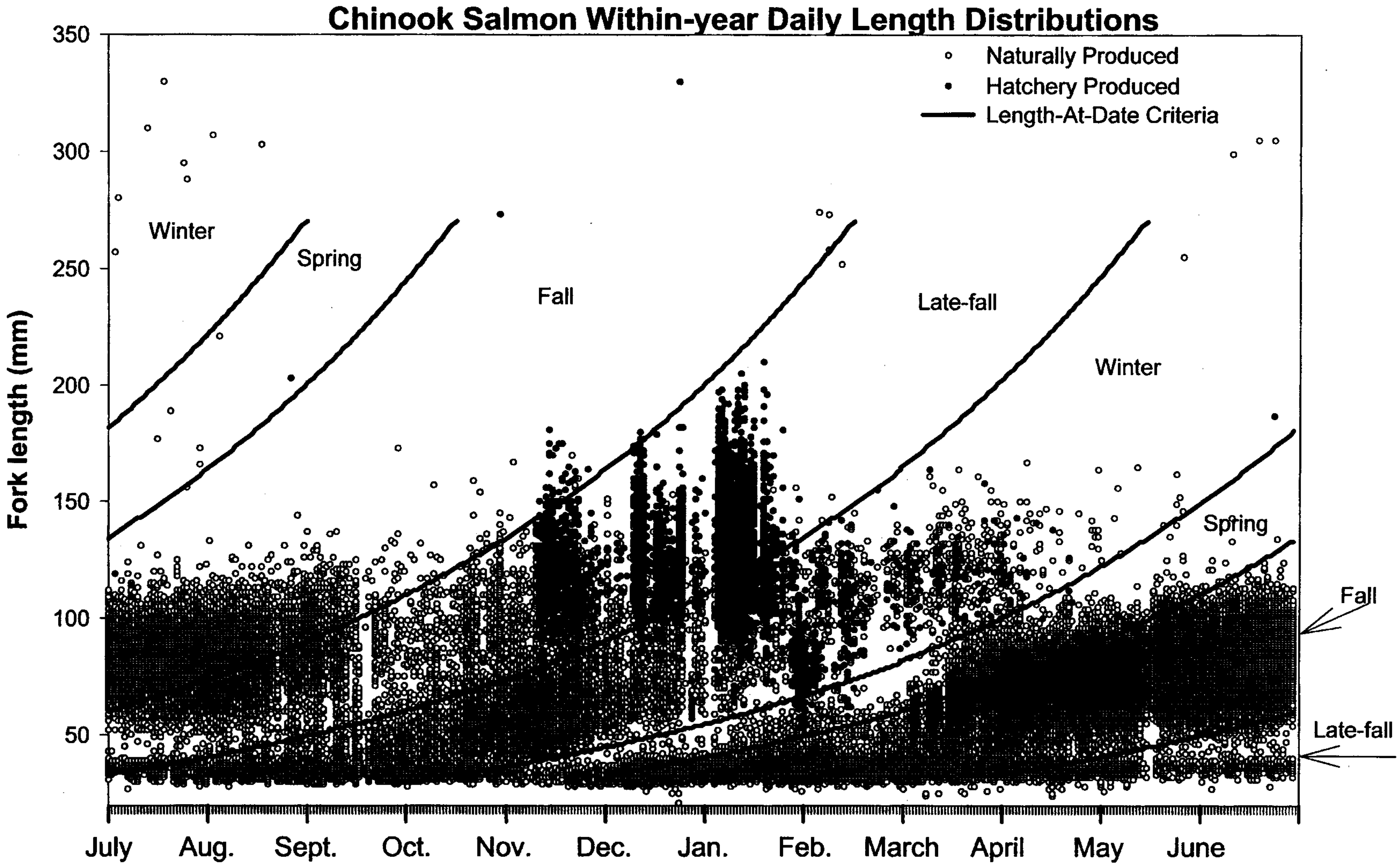

Figure 27. Within-year daily length distributions for chinook salmon captured by rotary-screw traps below Red Bluff Diversion Dam (RK391), Sacramento River, CA. Spline curves represent length-at-date criteria developed by Greene (1992).

APPENDIX I

Appendix I (list of tables)

Table **Page**

Table A1.—Monthly juvenile passage estimates (JPE) with 75% and 90% confidence intervals (C.I.), number of days sampled within the month (*N*) and median fork length (FL) for fall chinook salmon captured by rotary-screw trap at Red Bluff Diversion Dam (RK391), Sacramento River, CA.

Month	N	Median FL (mm)	JPE	75% C.I.		90% C.I.	
				Lower	Upper	Lower	Upper
			Brood-year 1995				
Dec	9	35	442,887	264,670	621,105	185,132	700,643
Jan	11	36	3,388,912	2,696,322	4,081,502	2,387,221	4,390,602
Feb	2	36	13,782,174	9,642,124	17,922,223	7,786,911	19,777,437
Mar	17	65	761,018	463,775	1,058,262	331,116	1,190,920
Apr	30	74	692,102	656,912	727,291	641,188	743,016
May	13	76	340,490	302,885	378,095	286,102	394,878
Jun	13	87	143,832	95,402	192,263	73,760	213,905
Jul	14	90	82,885	38,340	127,430	18,460	147,310
Aug	19	98	19,631	15,732	23,530	13,992	25,271
Sep	12	113	3,906	2,308	5,504	1,593	6,218
Oct	17	133	721	470	971	358	1,083
Nov	22	160	572	253	891	110	1,034
Total	179		19,659,130	14,179,192	25,139,068	11,725,943	27,592,317
			Brood-year 1996				
Dec	8	35	1,936,464	1,256,247	2,616,681	952,669	2,920,259
Jan	0	37	1,526,173	0	6,893,290	0	9,288,613
Feb	15	37	1,115,882	1,003,379	1,228,385	952,965	1,278,800
Mar	16	37	259,043	193,420	324,665	164,133	353,952
Apr	24	73	600,977	447,810	754,143	379,366	822,587
May	19	77	198,705	156,628	240,783	137,849	259,561
Jun	16	90	264,400	234,632	294,167	221,330	307,469
Jul	19	87	111,830	101,008	122,651	96,179	127,480
Aug	16	89	41,309	35,292	47,327	32,607	50,012
Sep	13	102.5	6,287	4,296	8,278	3,406	9,168
Oct	10	117	385	144	625	37	733
Nov	11	154	205	41	369	0	443
Total	167		6,061,659	3,432,898	12,531,364	2,940,541	15,419,076

Table A1.— (continued).

				75% C.I.		90% C.I.	
Month	N	Median FL (mm)	JPE	Lower	Upper	Lower	Upper
				Brood-year 1997			
Dec	11	35	2,461,579	1,792,518	3,130,639	1,493,919	3,429,238
Jan	5	36	13,261,432	3,421,452	23,101,412	0	27,492,955
Feb	0	—	7,126,490	0	32,046,100	0	43,212,926
Mar	11	55	991,549	675,106	1,307,991	533,878	1,449,219
Apr	11	67	2,667,508	775,517	4,559,499	0	5,404,955
May	8	75	200,945	132,123	269,767	101,408	300,482
Jun	11	77	588,586	459,255	717,917	401,462	775,710
Jul	17	85	265,092	227,789	302,396	211,140	319,044
Aug	13	90	97,305	77,739	116,872	69,006	125,604
Sep	18	106	5,958	3,913	8,002	3,000	8,916
Oct	24	—	0	0	0	0	0
Nov	19	148	105	0	228	0	283
Total	148		27,666,548	7,565,412	65,560,823	2,813,814	82,519,330
				Brood-year 1998			
Dec	26	36	1,848,120	1,052,746	2,643,494	697,774	2,998,466
Jan	24	37	6,670,912	1,708,119	11,633,706	0	13,848,580
Feb	16	37	11,781,087	0	25,635,219	0	31,843,448
Mar	28	37	5,688,198	1,771,622	9,604,773	23,671	11,352,724
Apr	23	61	471,158	414,475	527,840	389,146	553,169
May	26	74	826,624	733,497	919,750	691,935	961,312
Jun	30	79	767,144	666,471	867,817	621,484	912,804
Jul	31	83	613,884	562,931	664,837	540,190	687,578
Aug	28	89	181,162	165,172	197,152	158,035	204,288
Sep	23	100	49,401	38,111	60,690	33,066	65,735
Oct	21	135	683	333	1,032	177	1,188
Nov	24	159	260	97	423	25	496
Total	300		28,898,631	7,113,575	52,756,733	3,155,504	63,429,790

Table A1.— (continued).

				75% C.I.		90% C.I.	
Month	N	Median FL (mm)	JPE	Lower	Upper	Lower	Upper
			***Brood-year 1999**				
Dec	29	36	366,844	327,344	406,343	309,716	423,972
Jan	20	37	14,840,521	10,350,575	19,330,466	8,346,731	21,334,310
Feb	16	37	12,836,729	8,483,879	17,189,578	6,533,306	19,140,151
Mar	25	38	1,729,640	251,284	3,207,996	0	3,867,780
Apr	25	77	1,023,327	692,400	1,354,253	544,522	1,502,131
May	27	79	975,494	865,563	1,085,426	816,501	1,134,488
Jun	24	80	689,210	629,708	748,713	603,118	775,302
Total	166		32,461,765	21,600,753	43,322,776	17,153,894	48,178,135

*Brood-year 1999 totals do not include July through November of 2000. However, this only represents 1.6% of annual passage, on average.

Table A2.—Monthly juvenile passage estimates (JPE) with 75% and 90% confidence intervals (C.I.), number of days sampled within the month (*N*) and median fork length (FL) for late-fall chinook salmon captured by rotary-screw trap at Red Bluff Diversion Dam (RK391), Sacramento River, CA.

				75% C.I.		90% C.I.	
Month	N	Median FL (mm)	JPE	Lower	Upper	Lower	Upper
			Brood-year 1995				
Apr	20	36	65,895	50,239	81,551	43,243	88,547
May	15	36	15,975	0	58,495	0	77,471
Jun	29	37	1,688	1,153	2,223	914	2,461
Jul	21	42	1,974	1,233	2,715	902	3,046
Aug	23	76	5,213	4,054	6,371	3,537	6,888
Sep	8	83	10,061	6,563	13,559	5,000	15,122
Oct	5	83	7,295	2,610	11,981	519	14,071
Nov	6	100	4,611	3,149	6,072	2,495	6,726
Dec	9	115	1,526	1,032	2,020	811	2,240
Jan	11	128	280	0	561	0	687
Feb	2	—	0	0	0	0	0
Mar	17	—	0	0	0	0	0
Total	166		114,517	70,034	185,548	57,423	217,260
			Brood-year 1996				
Apr	30	34	13,698	12,061	15,335	11,329	16,067
May	13	37	3,450	1,666	5,234	869	6,031
Jun	13	56	1,283	239	2,328	0	2,794
Jul	14	64	2,390	999	3,782	378	4,403
Aug	19	79	2,762	1,973	3,551	1,620	3,904
Sep	12	85.5	4,445	2,643	6,247	1,838	7,052
Oct	17	94	5,133	4,362	5,904	4,018	6,248
Nov	22	100	35,525	24,229	46,821	19,181	51,869
Dec	8	111	8,621	5,625	11,617	4,288	12,954
Jan	—	131.5	4,530	0	20,258	0	27,278
Feb	15	142	439	0	880	0	1,078
Mar	16	—	0	0	0	0	0
Total	179		82,277	53,795	121,958	43,521	139,678

Table A2.— (continued).

				75% C.I.		90% C.I.	
Month	N	Median FL (mm)	JPE	Lower	Upper	Lower	Upper
			Brood-year 1997				
Apr	24	34	19,909	7,027	32,790	1,271	38,546
May	19	35	8,071	6,683	9,460	6,064	10,079
Jun	16	37	14,037	11,955	16,120	11,024	17,051
Jul	19	64	29,711	26,012	33,410	24,362	35,061
Aug	16	74	47,684	43,051	52,318	40,982	54,387
Sep	13	77.5	32,880	20,849	44,910	15,473	50,286
Oct	10	83	12,632	7,771	17,493	5,602	19,663
Nov	11	95	28,246	13,897	42,595	7,485	49,007
Dec	11	114	3,771	1,127	6,416	0	7,596
Jan	5	130	568	0	1,204	0	1,487
Feb	—	—	284	0	1,267	0	1,707
Mar	11	—	0	0	0	0	0
Total	155		197,793	138,372	257,982	112,262	284,870
			Brood-year 1998				
Apr	11	35	241,824	150,955	332,694	110,348	373,300
May	8	36	59,444	27,921	90,966	13,853	105,034
Jun	11	37	34,077	27,556	40,598	24,642	43,512
Jul	17	39	32,281	26,586	37,976	24,044	40,517
Aug	13	70	94,981	81,505	108,457	75,491	114,471
Sep	18	71	47,958	36,822	59,094	31,845	64,071
Oct	24	83	20,998	16,153	25,842	13,992	28,004
Nov	19	94	14,088	10,946	17,229	9,542	18,633
Dec	26	112	11,826	8,148	15,505	6,506	17,146
Jan	24	120	822	502	1,142	359	1,284
Feb	16	—	0	0	0	0	0
Mar	28	—	0	0	0	0	0
Total	215		558,298	387,095	729,501	310,625	805,971

Table A2.— (continued).

Month	N	Median FL (mm)	JPE	75% C.I.		90% C.I.	
				Lower	Upper	Lower	Upper
Brood-year 1999							
Apr	23	36	131,113	110,218	152,007	100,882	161,344
May	26	37	63,611	54,361	72,861	50,233	76,989
Jun	30	39	16,968	14,498	19,438	13,395	20,542
Jul	31	62	56,119	51,018	61,219	48,742	63,495
Aug	28	72	110,316	100,752	119,881	96,484	124,149
Sep	23	85	79,303	64,248	94,358	57,521	101,085
Oct	21	98	49,215	33,101	65,330	25,909	72,522
Nov	24	100	38,951	31,608	46,293	28,327	49,574
Dec	29	111	20,347	16,698	23,996	15,070	25,625
Jan	20	149	11,421	6,449	16,393	4,230	18,612
Feb	16	—	0	0	0	0	0
Mar	25	—	0	0	0	0	0
Total	296		577,364	482,953	671,776	440,791	713,937

Table A3. Monthly juvenile passage estimates (JPE) with 75% and 90% confidence intervals (C.I.), number of days sampled within the month (*N*) and median fork length (FL) for winter chinook salmon captured by rotary-screw trap at Red Bluff Diversion Dam (RK391), Sacramento River, CA.

Month	N	Median FL (mm)	JPE	75% C.I.		90% C.I.	
				Lower	Upper	Lower	Upper
			Brood-year 1995				
Jul	21	36	751	326	1,176	136	1,366
Aug	23	34	81,804	63,302	100,306	55,045	108,563
Sep	8	35	1,147,684	866,780	1,428,589	741,255	1,554,114
Oct	5	36	299,047	139,559	458,535	68,380	529,714
Nov	6	62	66,197	55,335	77,060	50,481	81,914
Dec	9	70	13,998	9,856	18,140	8,007	19,988
Jan	11	97	6,523	4,084	8,962	2,996	10,050
Feb	2	102	35,712	34	76,184	34	94,320
Mar	17	124	7,015	2,998	11,032	1,205	12,825
Apr	30	137	236	111	361	55	417
May	13	—	0	0	0	0	0
Jun	13	—	0	0	0	0	0
Total	158		1,658,968	1,142,384	2,180,345	927,594	2,413,271
			Brood-year 1996				
Jul	14	34	903	272	1,533	3	1,815
Aug	19	34	18,836	15,246	22,426	13,644	24,028
Sep	12	34	228,197	138,782	317,613	98,826	357,569
Oct	17	35	24,226	20,870	27,583	19,372	29,081
Nov	22	70	66,167	45,814	86,521	36,719	95,616
Dec	8	82	8,801	5,743	11,859	4,379	13,223
Jan	0	102	12,124	0	83,192	0	114,909
Feb	15	114	15,429	12,065	18,792	10,558	20,300
Mar	16	120	7,791	5,880	9,701	5,028	10,553
Apr	24	125.5	1,378	907	1,848	697	2,058
May	19	136.5	272	38	506	4	610
Jun	16	—	0	0	0	0	0
Total	182		384,124	245,620	581,573	189,230	669,762

Table A3.— (continued).

Month	N	Median FL (mm)	JPE	75% C.I.		90% C.I.	
				Lower	Upper	Lower	Upper
			Brood-year 1997				
Jul	19	35	18,584	15,273	21,895	13,796	23,373
Aug	16	35	134,165	115,609	152,720	107,328	161,001
Sep	13	35	925,284	658,568	1,192,005	539,375	1,311,193
Oct	10	36	410,781	264,621	556,940	199,391	622,171
Nov	11	63	295,668	169,095	422,241	112,535	478,801
Dec	11	68.5	30,139	17,609	42,669	12,017	48,261
Jan	5	82	7,826	4,732	10,920	3,352	12,301
Feb	0	—	20,220	0	138,977	0	192,194
Mar	11	108	32,619	13,157	52,081	4,471	60,767
Apr	11	138	732	172	1,292	3	1,574
May	8	—	0	0	0	0	0
Jun	11	—	0	0	0	0	0
Total	126		1,876,017	1,258,831	2,591,740	992,267	2,911,602
			Brood-year 1998				
Jul	17	34	184,896	144,015	225,778	125,770	244,023
Aug	13	34	1,540,408	1,291,595	1,789,220	1,180,551	1,900,264
Sep	18	34	2,128,386	1,816,504	2,440,268	1,677,136	2,579,636
Oct	24	37	404,275	295,296	513,294	246,602	561,949
Nov	19	57	245,739	202,655	288,823	183,403	308,075
Dec	26	68.5	49,018	18,284	79,751	4,568	93,468
Jan	24	103	49,753	18,311	81,195	4,279	95,227
Feb	16	97	8,833	4,012	13,653	1,852	15,813
Mar	28	114	4,150	3,045	5,254	2,552	5,747
Apr	23	138	1,754	1,122	2,385	840	2,667
May	26	149.5	262	100	425	27	497
Jun	30	—	0	0	0	0	0
Total	264		4,617,473	3,794,900	5,440,046	3,427,579	5,807,366

Table A3.— (continued).

Month	N	Median FL (mm)	JPE	75% C.I. Lower	75% C.I. Upper	90% C.I. Lower	90% C.I. Upper
			Brood-year 1999				
Jul	31	36	8,186	7,109	9,262	6,629	9,742
Aug	28	35	91,836	83,503	100,168	79,785	103,887
Sep	23	35	404,378	331,139	477,616	298,412	510,344
Oct	21	38	163,482	144,157	182,807	135,532	191,431
Nov	24	60	155,239	125,579	184,899	112,325	198,153
Dec	29	74	60,397	51,510	69,285	47,544	73,251
Jan	20	91	94,675	53,893	135,456	35,693	153,656
Feb	16	101	44,918	18,378	71,458	6,485	83,352
Mar	25	116.5	28,042	9,636	46,448	1,421	54,663
Apr	25	120.5	1,092	788	1,396	652	1,532
May	27	152	375	180	570	92	657
Jun	24	—	0	0	0	0	0
Total	293		1,052,619	825,872	1,279,365	724,570	1,380,668

Table A4.—Monthly juvenile passage estimates (JPE) with 75% and 90% confidence intervals (C.I.), number of days sampled within the month (*N*) and median fork length (FL) for spring chinook salmon captured by rotary-screw trap at Red Bluff Diversion Dam (RK391), Sacramento River, CA.

				75% C.I.		90% C.I.	
Month	N	Median FL (mm)	JPE	Lower	Upper	Lower	Upper
			Brood-year 1995				
Oct	11	34	9,056	7,495	10,616	825	17,286
Nov	6	33	22,062	19,414	24,709	8,090	36,033
Dec	9	36	3,152	2,874	3,430	1,687	4,617
Jan	11	51	3,237	2,679	3,794	296	6,178
Feb	2	58	4,294	2,950	5,638	0	11,398
Mar	17	72	753,635	663,718	843,552	279,412	1,227,859
Apr	30	87	49,304	48,414	50,194	44,608	54,000
May	13	96	6,105	5,755	6,454	4,262	7,947
Jun	13	—	0	0	0	0	0
Jul	14	—	0	0	0	0	0
Aug	19	—	0	0	0	0	0
Sep	12	—	0	0	0	0	0
Total	157		850,844	753,301	948,387	339,180	1,365,318
			Brood-year 1996				
Oct	13	32	491	427	555	155	827
Nov	22	33.5	6,505	5,790	7,220	2,732	10,279
Dec	8	38	68,052	60,235	75,868	26,828	109,275
Jan	—	—	34,913	0	100,562	0	381,148
Feb	15	59.5	1,775	1,534	2,016	501	3,048
Mar	16	77	1,091	991	1,191	564	1,618
Apr	24	79	136,766	127,086	146,446	85,676	187,856
May	19	98	3,889	3,521	4,258	1,946	5,833
Jun	16	114	404	326	482	0	816
Jul	19	177	99	67	130	0	265
Aug	16	—	0	0	0	0	0
Sep	13	—	0	0	0	0	0
Total	181		253,985	199,977	338,728	118,401	700,966

Table A4.— (continued).

				75% C.I.		90% C.I.	
Month	N	Median FL (mm)	JPE	Lower	Upper	Lower	Upper
Brood-year 1997							
Oct	15	34.5	1,207	1,045	1,370	352	2,063
Nov	11	33	9,419	7,759	11,079	657	18,181
Dec	11	37	307,340	268,467	346,213	102,322	512,358
Jan	5	45	7,379	6,288	8,469	1,627	13,131
Feb	—	—	35,727	1,219	70,235	0	218,153
Mar	11	66	64,076	54,521	73,631	13,683	114,468
Apr	11	76	70,874	56,460	85,288	0	146,948
May	8	98	10,762	9,596	11,927	4,616	16,907
Jun	11	118	482	327	637	0	1,300
Jul	17	—	0	0	0	0	0
Aug	13	—	0	0	0	0	0
Sep	18	—	0	0	0	0	0
Total	131		507,265	405,682	608,849	123,257	1,043,509
Brood-year 1998							
Oct	26	34	26,394	23,916	28,871	13,330	39,457
Nov	19	33	18,057	17,011	19,103	12,535	23,579
Dec	26	38	296,856	225,529	368,184	0	673,037
Jan	24	49	20,974	17,058	24,890	323	41,625
Feb	16	59	4,199	3,514	4,884	577	7,821
Mar	28	80	5,847	5,475	6,218	3,887	7,807
Apr	23	84	20,608	19,942	21,275	17,091	24,126
May	26	99	3,004	2,806	3,203	1,959	4,050
Jun	30	124.5	110	85	134	0	240
Jul	31	169.5	129	100	158	0	283
Aug	28	—	0	0	0	0	0
Sep	23	—	0	0	0	0	0
Total	300		396,178	315,437	476,920	49,701	822,026

Table A4.— (continued).

				75% C.I.		90% C.I.	
Month	N	Median FL (mm)	JPE	Lower	Upper	Lower	Upper
			Brood-year 1999				
Oct	21	34	20,414	18,943	21,885	12,655	28,173
Nov	24	34	6,815	6,547	7,083	5,400	8,231
Dec	29	38	30,621	29,877	31,364	26,701	34,541
Jan	20	51	113,874	103,765	123,982	60,563	167,184
Feb	16	57	37,712	34,278	41,145	19,562	55,862
Mar	25	80	58,898	53,987	63,810	32,996	84,801
Apr	25	85	281,808	248,047	315,570	103,619	459,997
May	27	104	19,374	18,686	20,062	15,743	23,005
Jun	24	116	466	409	522	169	762
Jul	0	—	0	0	0	0	0
Aug	0	—	0	0	0	0	0
Sep	0	—	0	0	0	0	0
Total	211		569,981	514,540	625,423	277,408	862,555

Table A5. Monthly juvenile passage estimates (JPE) with 75% and 90% confidence intervals (C.I.), number of days sampled within the month (*N*) and median fork length (FL) for rainbow trout captured by rotary-screw trap at Red Bluff Diversion Dam (RK391), Sacramento River, CA.

				75% C.I.		90% C.I.	
Month	N	Median FL (mm)	JPE	Lower	Upper	Lower	Upper
				Brood-year 1995			
Jan	3	200	0	0	0	0	0
Feb	20	187	10,592	0	37,187	0	49,104
Mar	8	200	26,280	2,641	49,918	0	60,468
Apr	20	198	5,626	3,528	7,724	2,590	8,662
May	15	72	39,102	0	107,177	0	137,558
Jun	29	90	2,541	1,782	3,299	1,443	3,638
Jul	21	29	2,230	1,311	3,148	901	3,558
Aug	23	53	22,418	18,543	26,293	16,813	28,023
Sep	8	62	34,485	21,832	47,138	16,178	52,793
Oct	5	96	1,400	381	2,419	0	2,874
Nov	6	95.5	788	238	1,337	0	1,582
Dec	9	120	287	0	590	0	725
Total	167		145,749	50,256	286,231	37,925	348,986
				Brood-year 1996			
Jan	11	189	12,259	8,655	15,864	7,046	17,472
Feb	2	227	10,730	0	48,431	0	65,325
Mar	17	212	9,201	4,974	13,429	3,087	15,316
Apr	30	72.5	2,524	1,990	3,058	1,751	3,297
May	13	64.5	4,412	1,908	6,917	790	8,035
Jun	13	76.5	3,098	1,355	4,842	575	5,621
Jul	14	71	1,342	495	2,189	117	2,566
Aug	19	60	8,012	6,194	9,829	5,383	10,640
Sep	12	62	34,164	24,737	43,591	20,524	47,804
Oct	17	76	3,109	2,439	3,779	2,140	4,078
Nov	22	89	1,186	844	1,529	691	1,682
Dec	8	260	205	0	444	0	551
Total	178		90,243	53,590	153,903	42,105	182,389

Table A5.— (continued).

Month	N	Median FL (mm)	JPE	75% C.I. Lower	75% C.I. Upper	90% C.I. Lower	90% C.I. Upper
			Brood-year 1997				
Jan	—	—	16,733	0	75,349	0	101,509
Feb	15	220	33,261	25,177	41,344	21,555	44,967
Mar	16	230	6,496	4,935	8,058	4,238	8,755
Apr	24	205	8,183	5,368	10,998	4,111	12,255
May	19	173.5	6,796	5,387	8,204	4,758	8,833
Jun	16	214	4,951	3,384	6,519	2,684	7,219
Jul	19	63	3,686	2,730	4,642	2,304	5,068
Aug	16	52	5,282	4,467	6,097	4,104	6,461
Sep	13	61	1,758	1,141	2,374	866	2,650
Oct	10	78	632	350	913	225	1,038
Nov	11	218	839	468	1,210	303	1,376
Dec	11	226	1,552	701	2,404	320	2,784
Total	170		90,170	54,110	168,112	45,467	202,916
			Brood-year 1998				
Jan	5	215	44,914	4,493	85,336	0	103,375
Feb	—	—	25,606	0	115,070	0	155,160
Mar	11	207	6,299	2,312	10,285	533	12,064
Apr	11	61	5,083	2,937	7,228	1,979	8,187
May	8	64	11,632	4,453	18,811	1,249	22,014
Jun	11	88	4,777	3,167	6,387	2,448	7,107
Jul	17	46.5	3,647	2,724	4,569	2,312	4,981
Aug	13	55.5	12,889	10,048	15,730	8,780	16,998
Sep	18	60.5	10,432	6,790	14,074	5,163	15,702
Oct	24	72	1,156	362	1,951	7	2,305
Nov	19	83	1,456	922	1,990	683	2,228
Dec	26	392.5	1,482	468	2,496	15	2,949
Total	163		129,372	38,676	283,926	23,169	353,070

Table A5.— (continued).

				75% C.I.		90% C.I.	
Month	N	Median FL (mm)	JPE	Lower	Upper	Lower	Upper
Brood-year 1999							
Jan	24	176	1,472	279	2,665	0	3,197
Feb	16	261	2,097	329	3,865	0	4,657
Mar	28	225	9,308	2,216	16,400	0	19,565
Apr	23	198	1,571	1,133	2,008	937	2,204
May	26	62	8,040	5,746	10,334	4,723	11,358
Jun	30	73	4,465	3,167	5,762	2,588	6,341
Jul	31	54	5,092	4,305	5,879	3,954	6,230
Aug	28	54	12,810	11,395	14,225	10,763	14,857
Sep	23	60	11,605	8,869	14,342	7,646	15,565
Oct	21	79	1,146	814	1,479	665	1,627
Nov	24	85	598	352	845	242	955
Dec	29	110	670	448	892	349	991
Total	303		58,874	39,053	78,695	31,867	87,547
Brood-year 2000							
Jan	20	198	3,097	1,539	4,655	844	5,350
Feb	16	177	2,515	501	4,528	0	5,431
Mar	25	111	8,300	181	16,418	0	20,041
Apr	25	68	4,881	3,050	6,711	2,232	7,529
May	27	74	10,131	8,805	11,458	8,213	12,050
Jun	24	66	3,815	3,141	4,490	2,839	4,792
Total	137		32,739	17,217	48,260	14,128	55,193

APPENDIX II

APPENDIX II (list of figures)

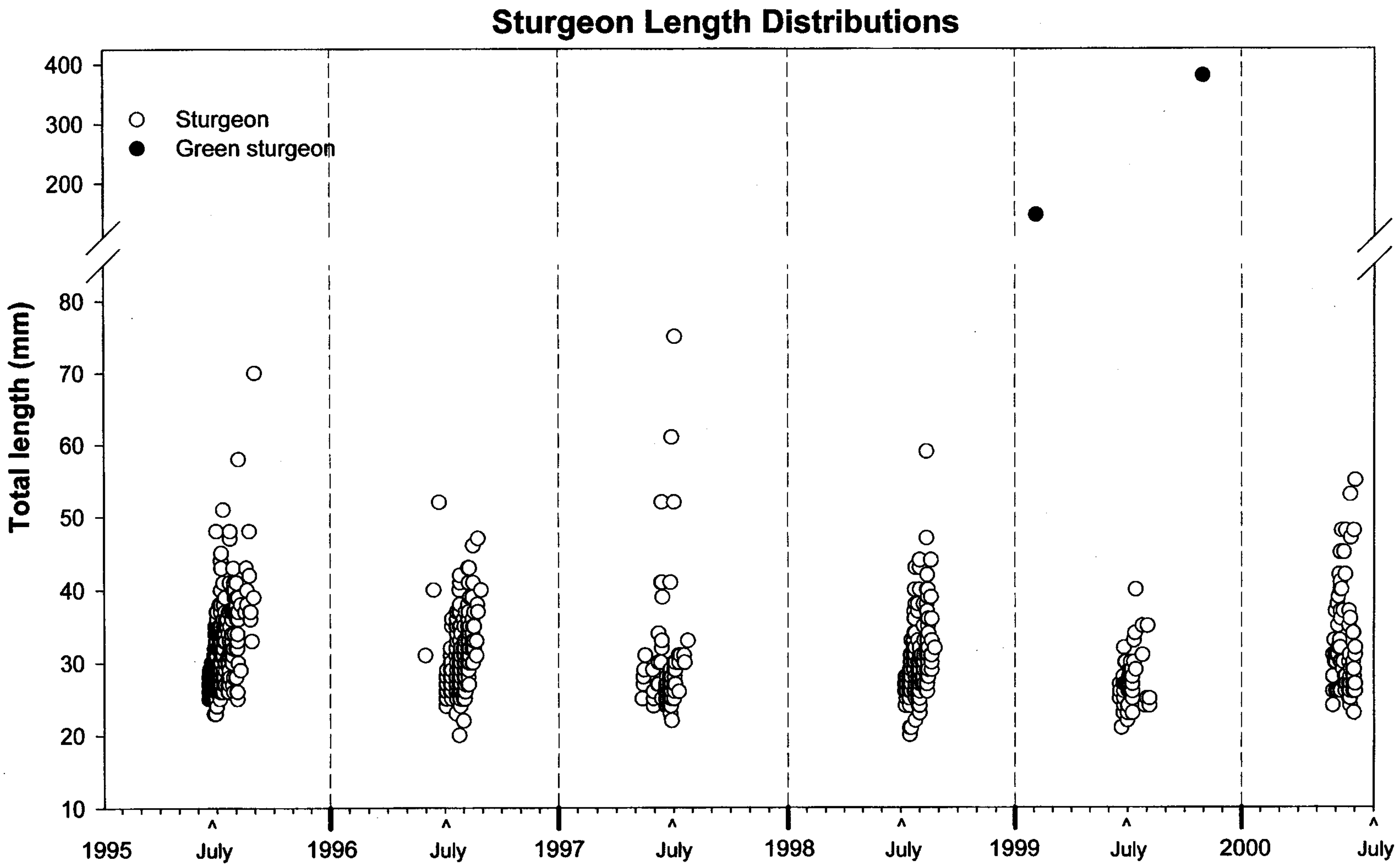

Figure A1. Among-year length distributions for juvenile sturgeon (*Acipenser spp.*) captured by rotary-screw traps at Red Bluff Diversion Dam (RK391), Sacramento River, CA. Data summarized from July 1994 through June 2000. In 1996 and 1997, a total of 124 juvenile sturgeon were grown out and positively identified as green sturgeon (*A. medirostris*).

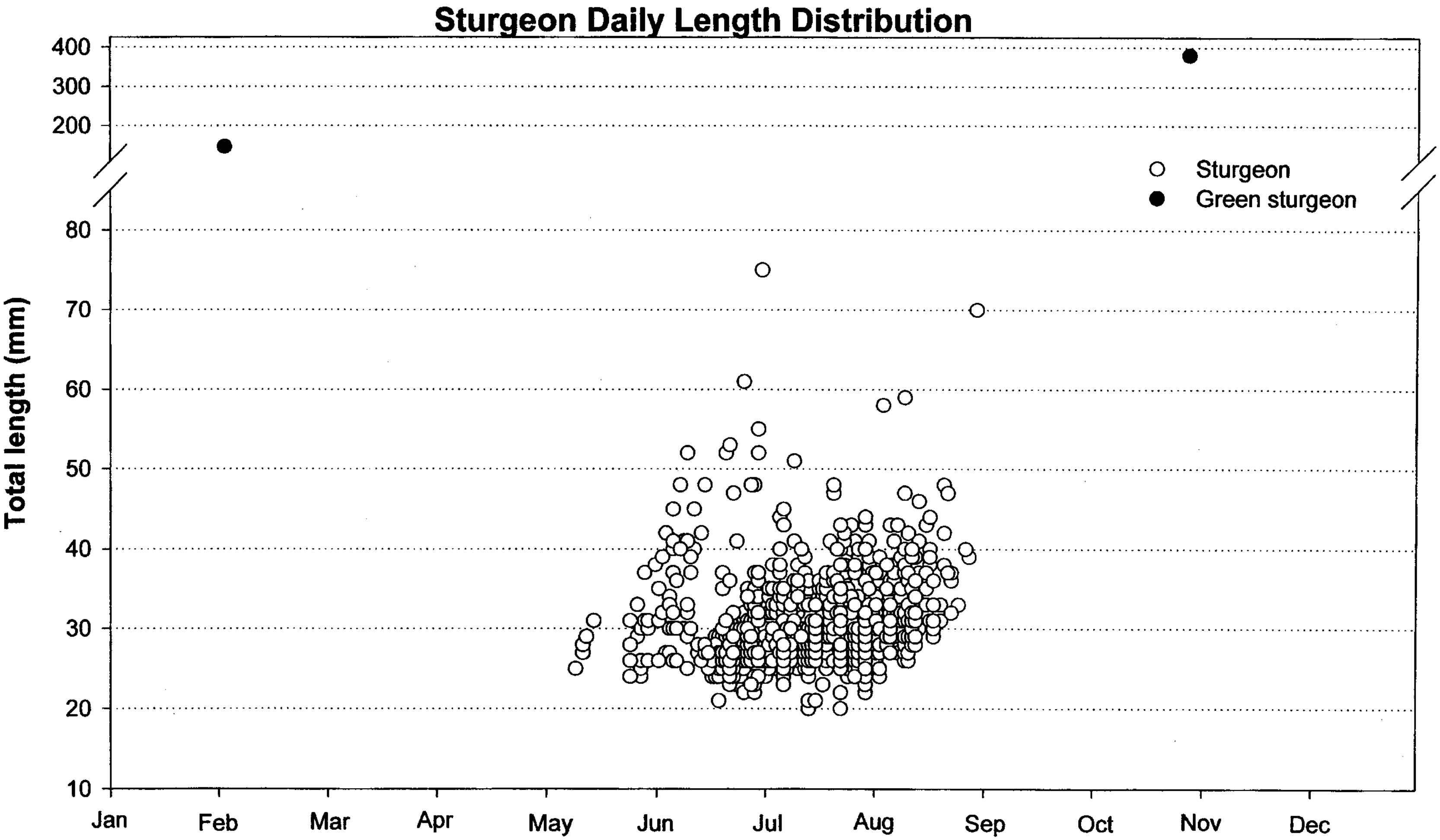

Figure A2. Within-year length distribution for juvenile sturgeon (*Acipenser spp.*) captured by rotary-screw traps at Red Bluff Diversion Dam (RK391), Sacramento River, CA. Data summarized from July 1994 through June 2000. In 1996 and 1997, a total of 124 juvenile sturgeon were grown out and positively identified as green sturgeon (*A. medirostris*).

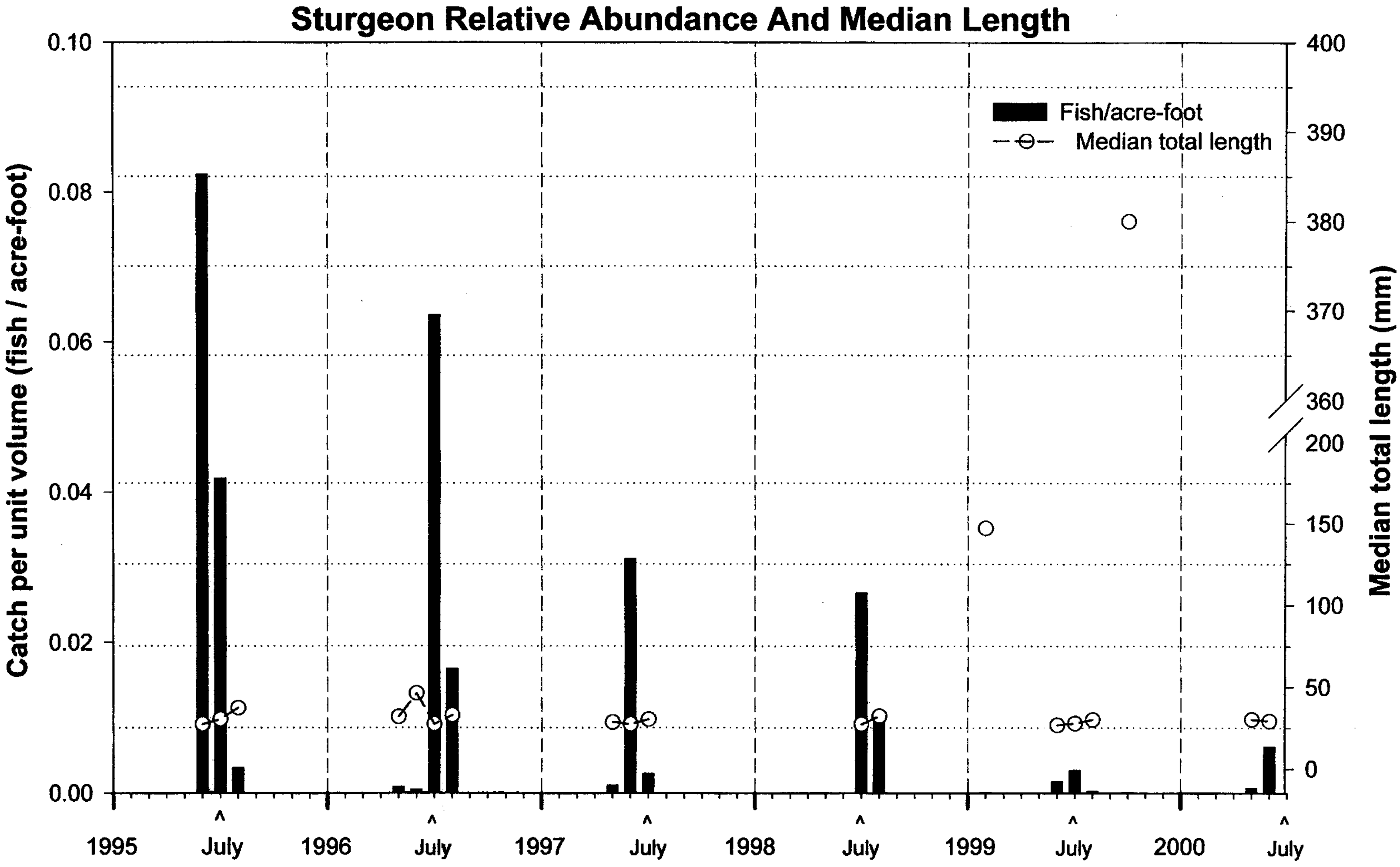

Figure A3. Relative abundance (fish/acre-foot) and median length for juvenile sturgeon (*Acipenser spp.*) captured by rotary-screw traps at Red Bluff Diversion Dam (RK 391), Sacramento River, CA. Data summarized from January 1995 through June 2000. In 1996 and 1997, a total of 124 juvenile sturgeon (*Acipenser spp.*) were grown out and positively identified as green sturgeon (*Acipenser medirostris*).

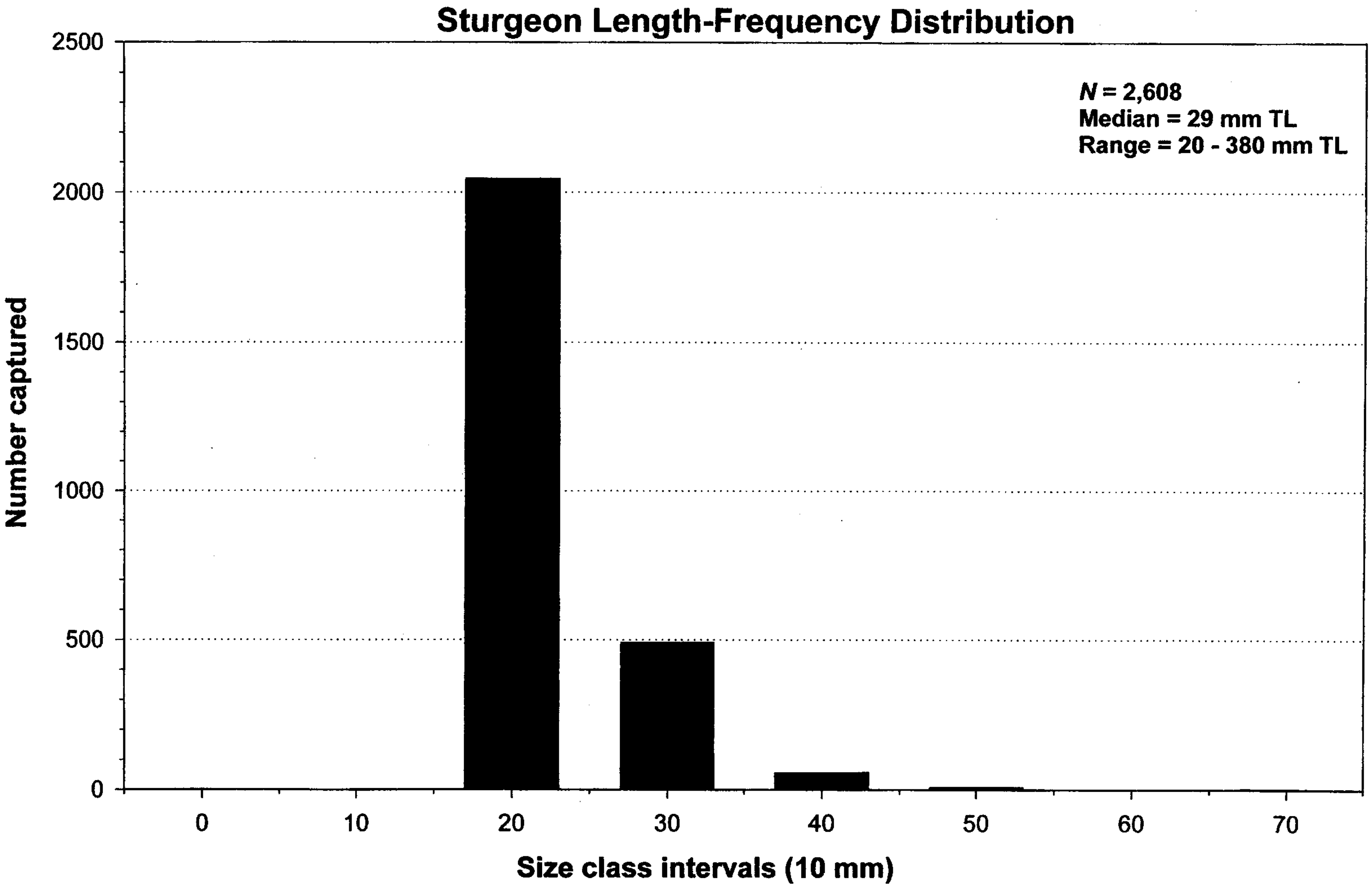

Figure A4. Length-frequency distribution for juvenile sturgeon (*Acipenser spp.*) captured by rotary-screw traps at Red Bluff Diversion Dam (RK 391), Sacramento River, CA. Size class intervals are reported in 10 mm increments. Data summarized from July 1994 through June 2000. In 1996 and 1997, a total of 124 juvenile sturgeon were grown out and positively identified as green sturgeon (*Acipenser medirostris*).

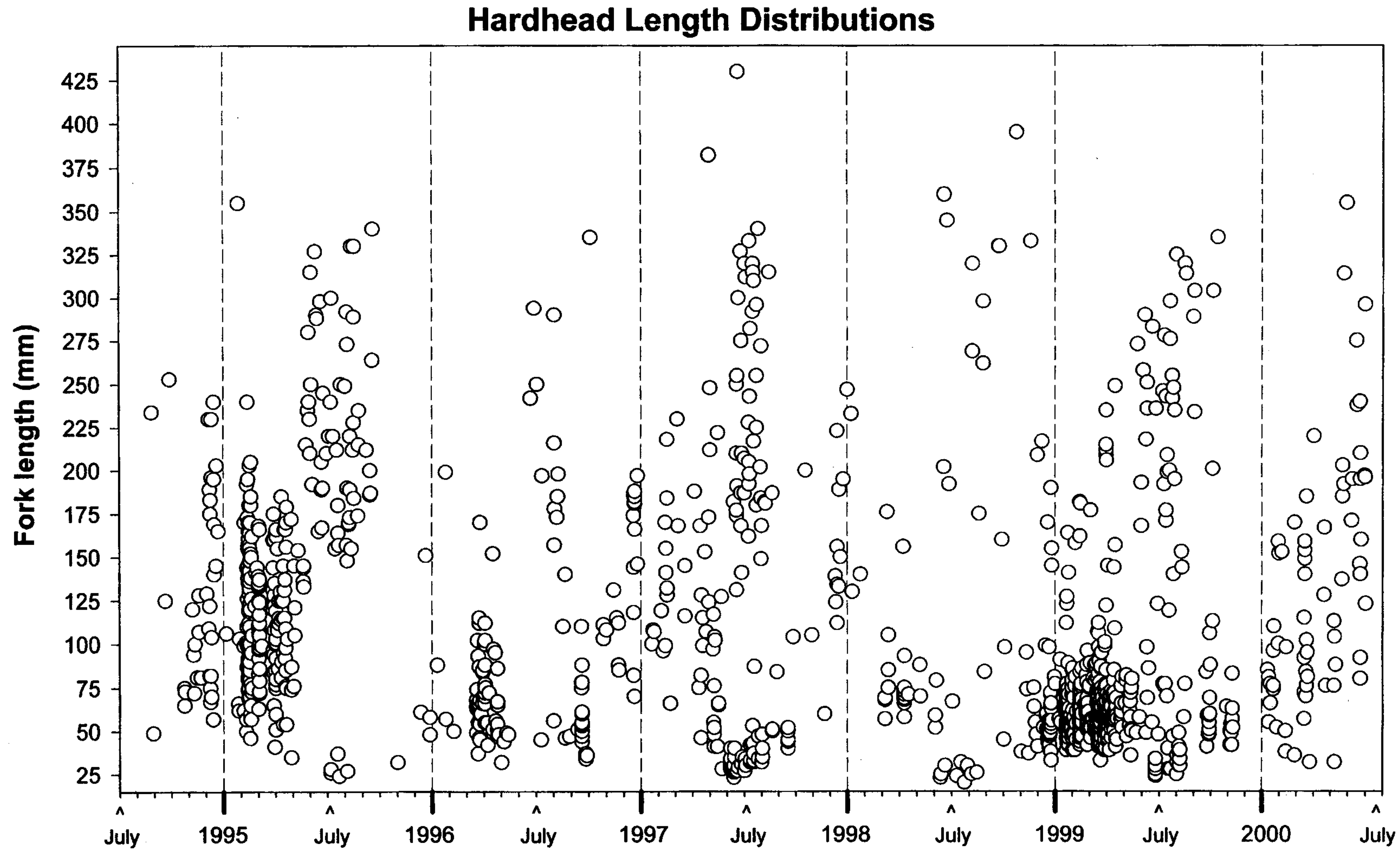

Figure A5. Among-year length distributions for juvenile hardhead (*Mylopharodon conocephalus*) captured by rotary-screw traps at Red Bluff Diversion Dam (RK 391), Sacramento River, CA. Data summarized from July 1994 through June 2000.

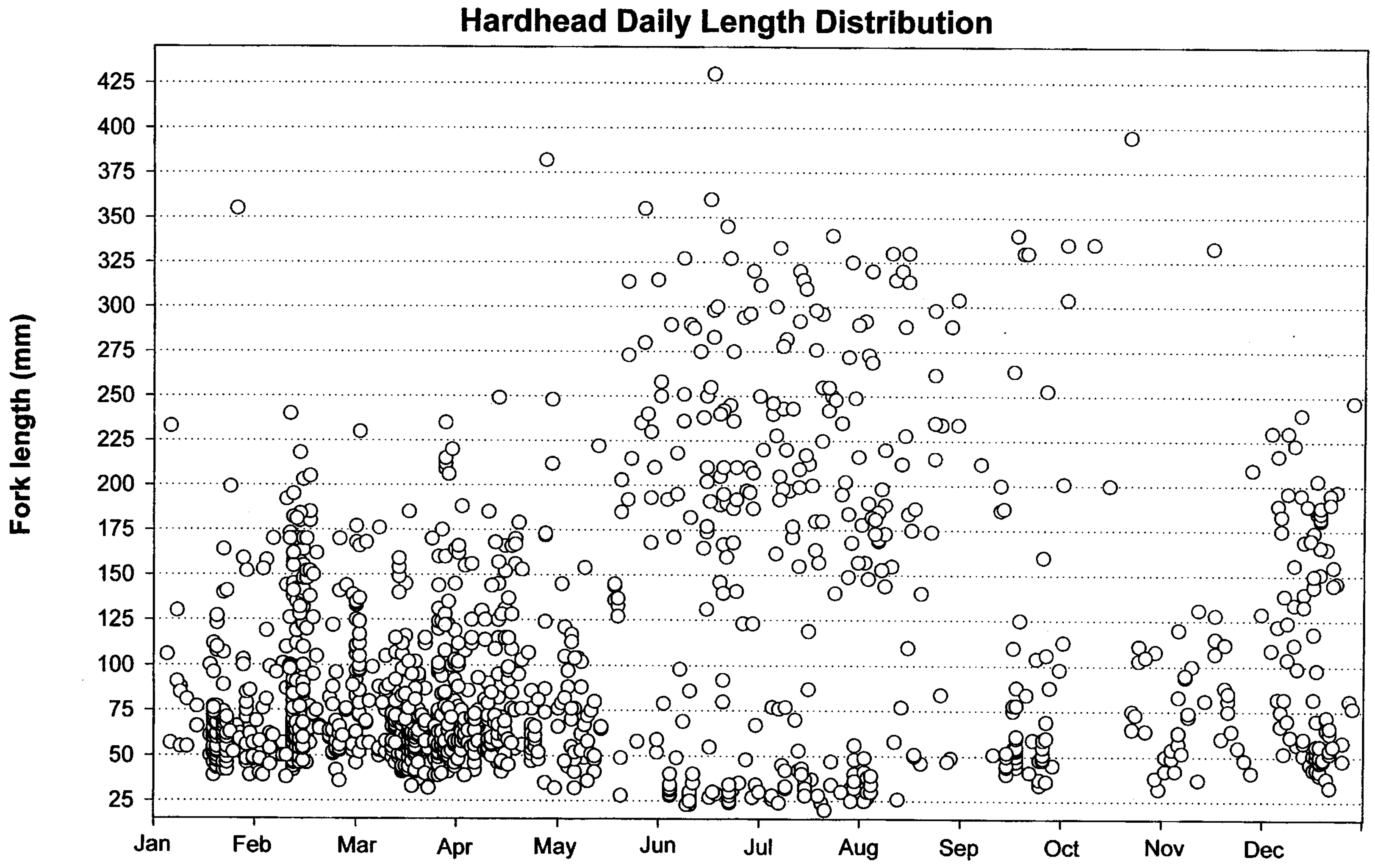

Figure A6. Within-year length distribution for hardhead (*Mylopharodon conocephalus*) captured by rotary-screw traps at Red Bluff Diversion Dam (RK 391), Sacramento River, CA. Data summarized from July 1994 through June 2000.

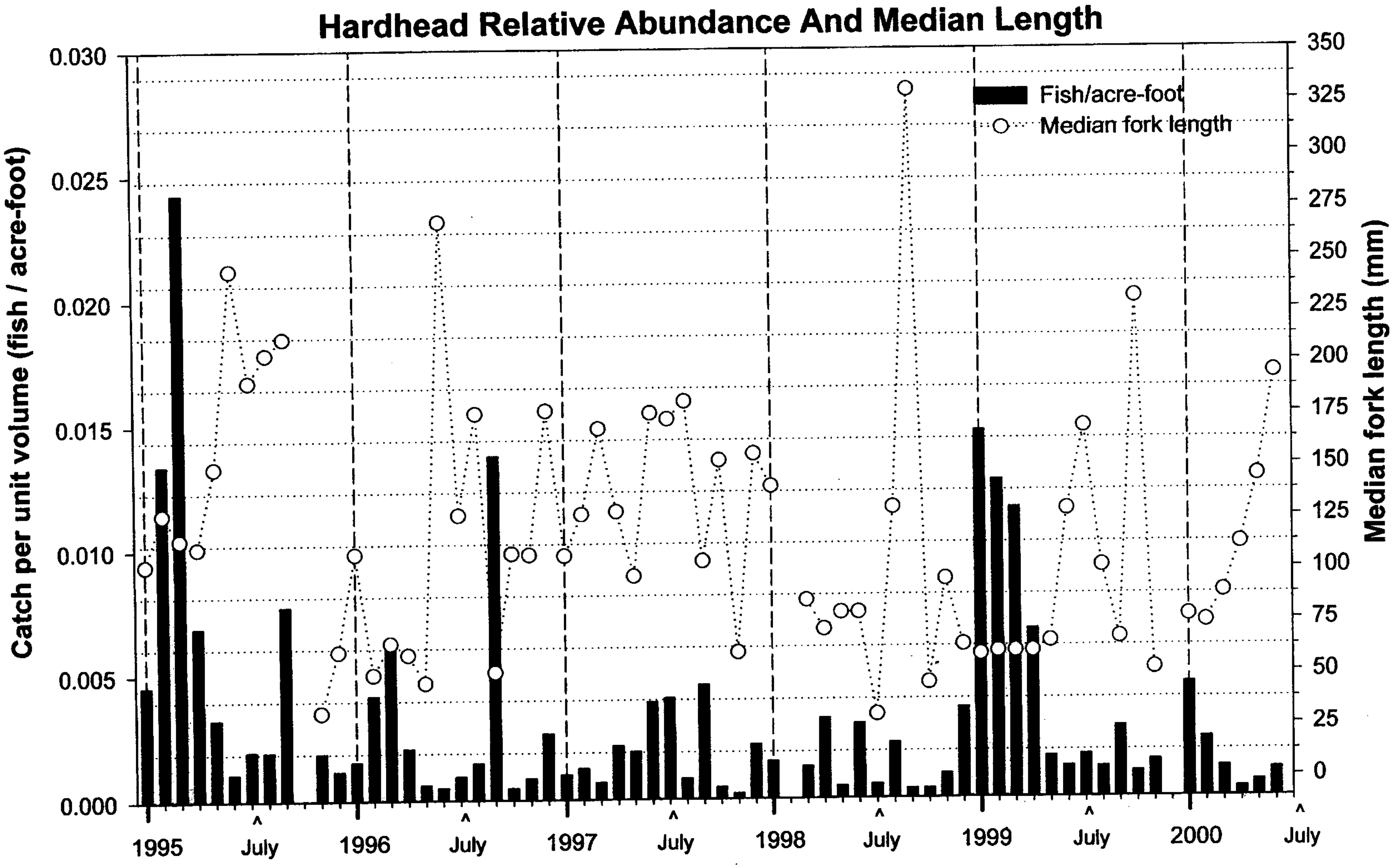

Figure A7. Relative abundance (fish/acrefoot) and median fork length for juvenile hardhead (*Mylopharodon conocephalus*) captured by rotary-screw traps at Red Bluff Diversion Dam (RK 391), Sacramento River, CA. Data summarized from January 1995 through June 2000.

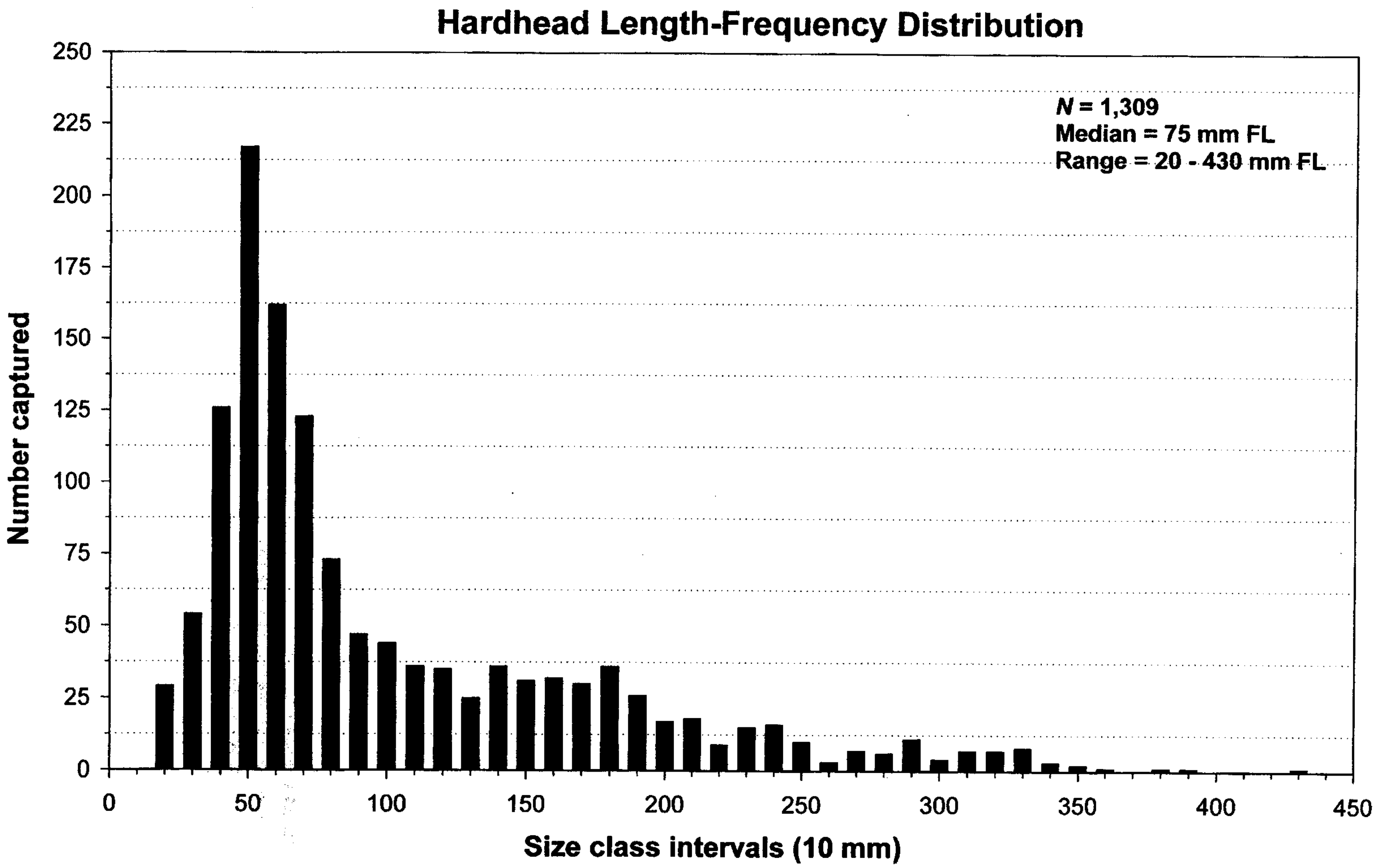

Figure A8. Length-frequency distribution for juvenile hardhead (*Mylopharodon conocephalus*) captured by rotary-screw traps at Red Bluff Diversion Dam (RK 391), Sacramento River, CA. Size class intervals are reported in 10 mm increments. Data summarized from July 1994 through June 2000.

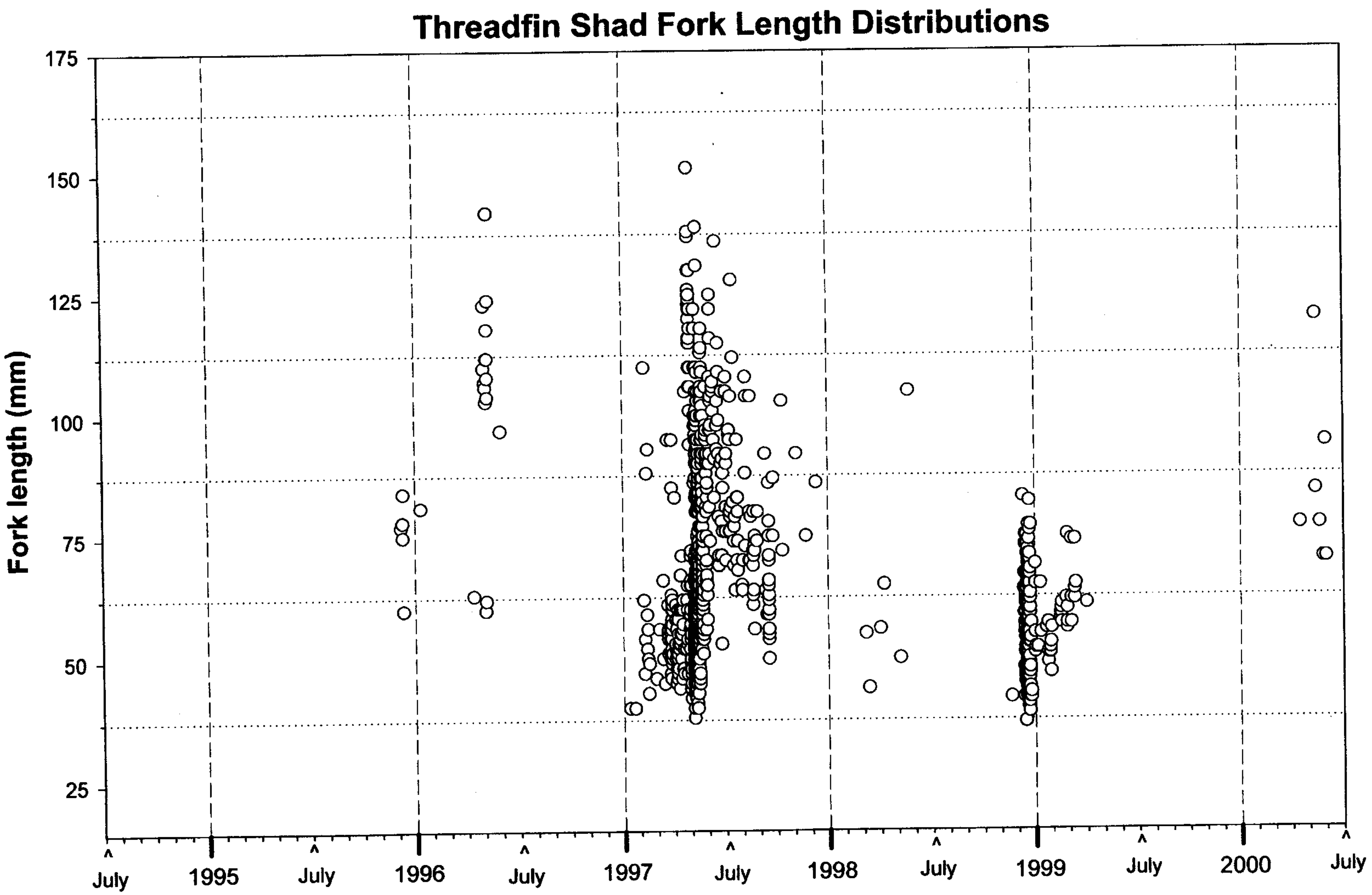

Figure A9. Among-year fork length distributions for threadfin shad (*Dorosoma petenense*) captured by rotary-screw traps at Red Bluff Diversion Dam (RK 391), Sacramento River, CA. Data summarized from July 1994 through June 2000.

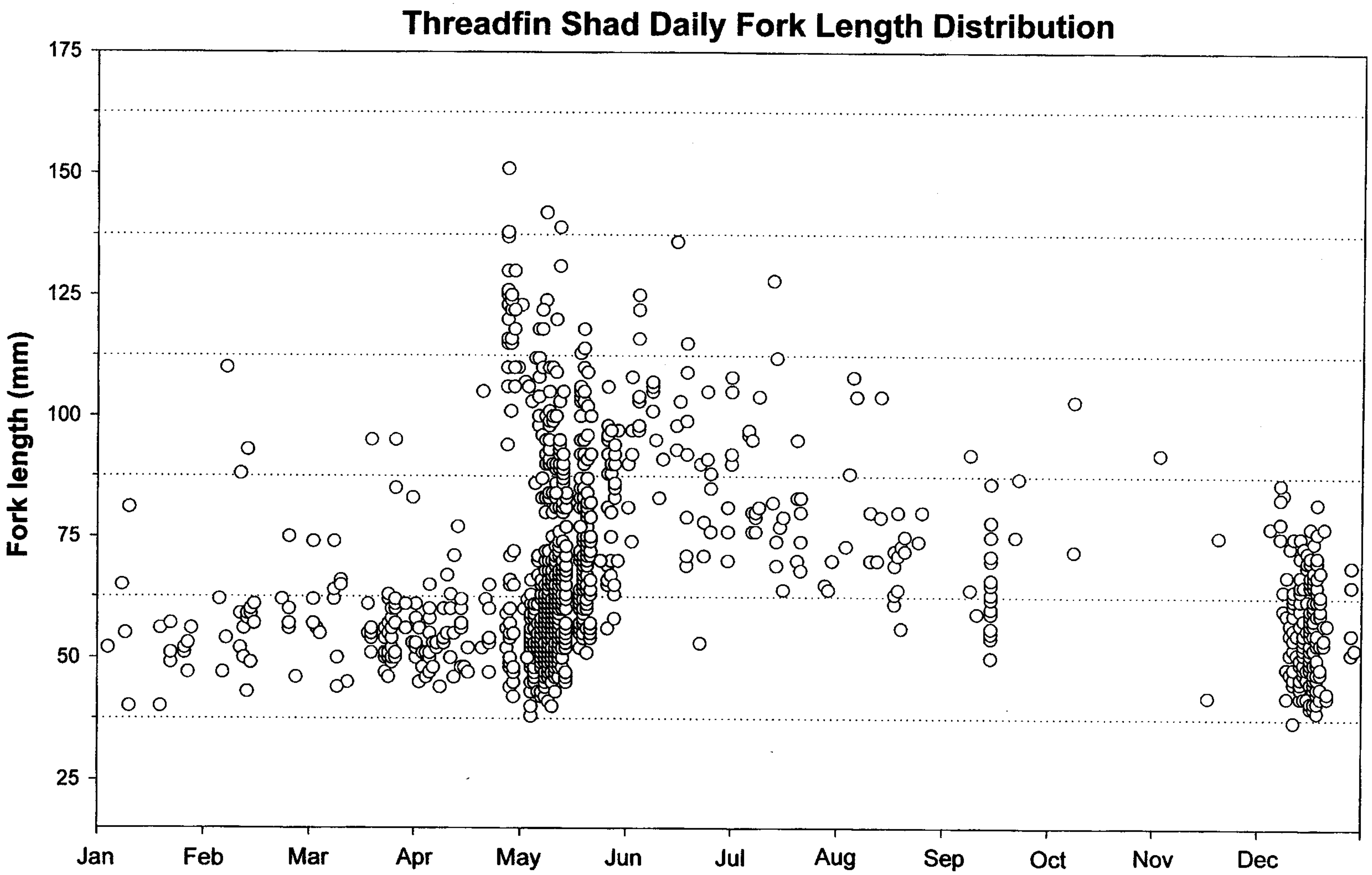

Figure A10. Within-year fork length distribution for threadfin shad (*Dorosoma petenense*) captured by rotary-screw traps at Red Bluff Diversion Dam (RK 391), Sacramento River, CA. Data summarized from July 1994 through June 2000.

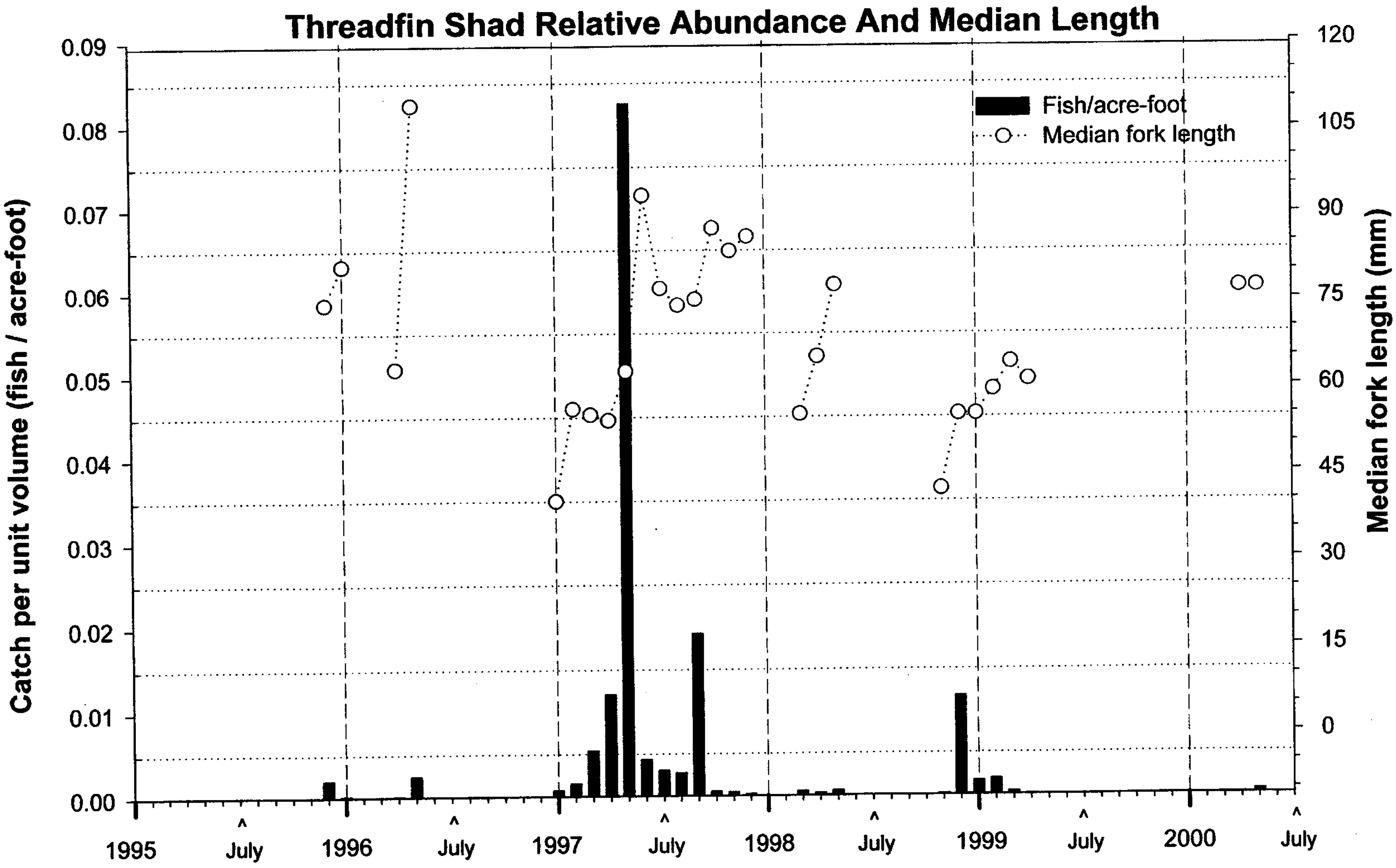

Figure A11. Relative abundance (fish/acrefoot) and median fork length for threadfin shad (*Dorosoma petenense*) captured by rotary-screw traps at Red Bluff Diversion Dam (RK 391), Sacramento River, CA. Data summarized from January 1995 through June 2000.

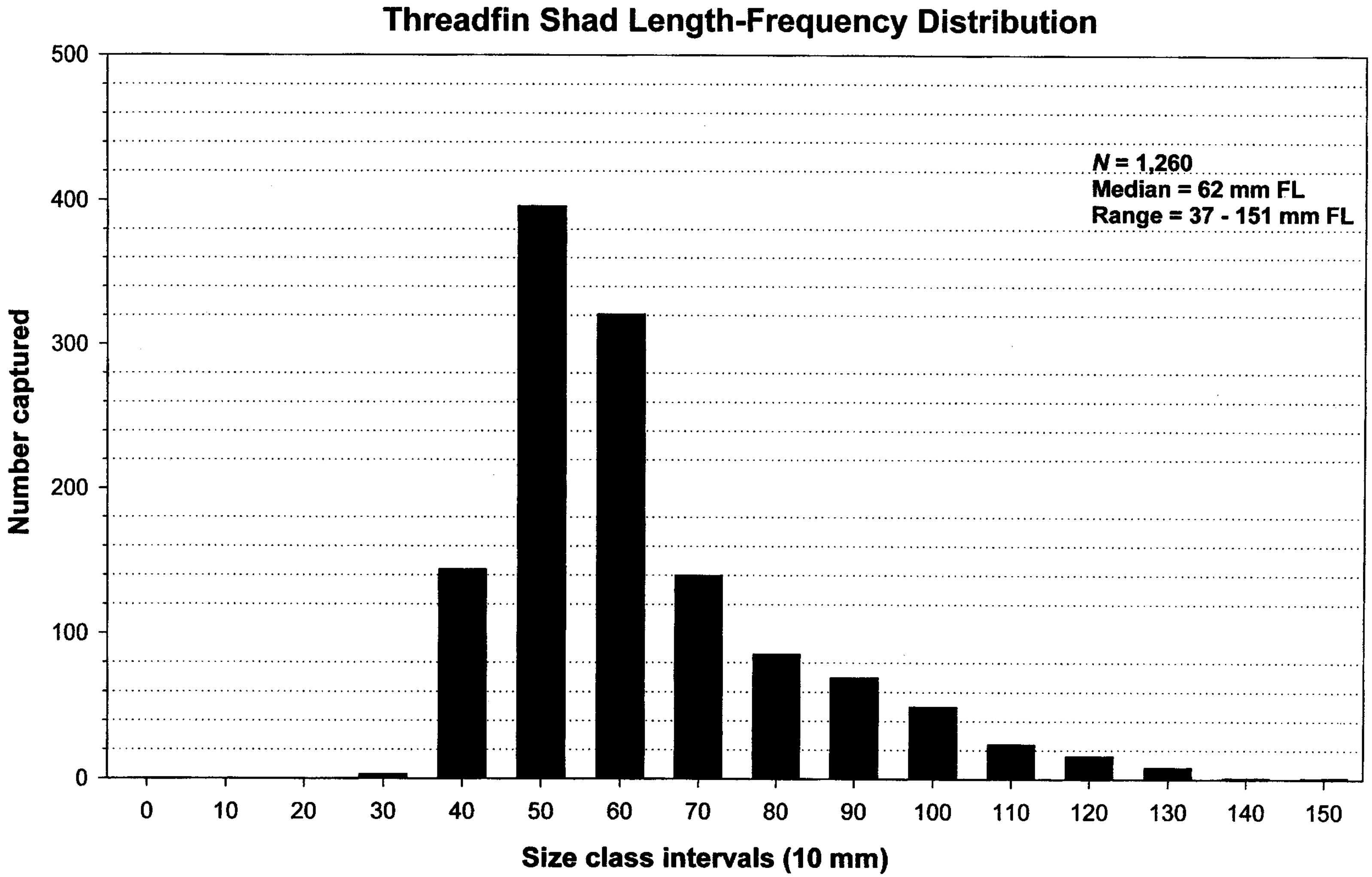

Figure A12. Length-frequency distribution for threadfin shad (*Dorosoma petenense*) captured by rotary-screw traps at Red Bluff Diversion Dam (RK 391), Sacramento River, CA. Size class intervals are reported in 10 mm increments. Data summarized from July 1994 through June 2000.

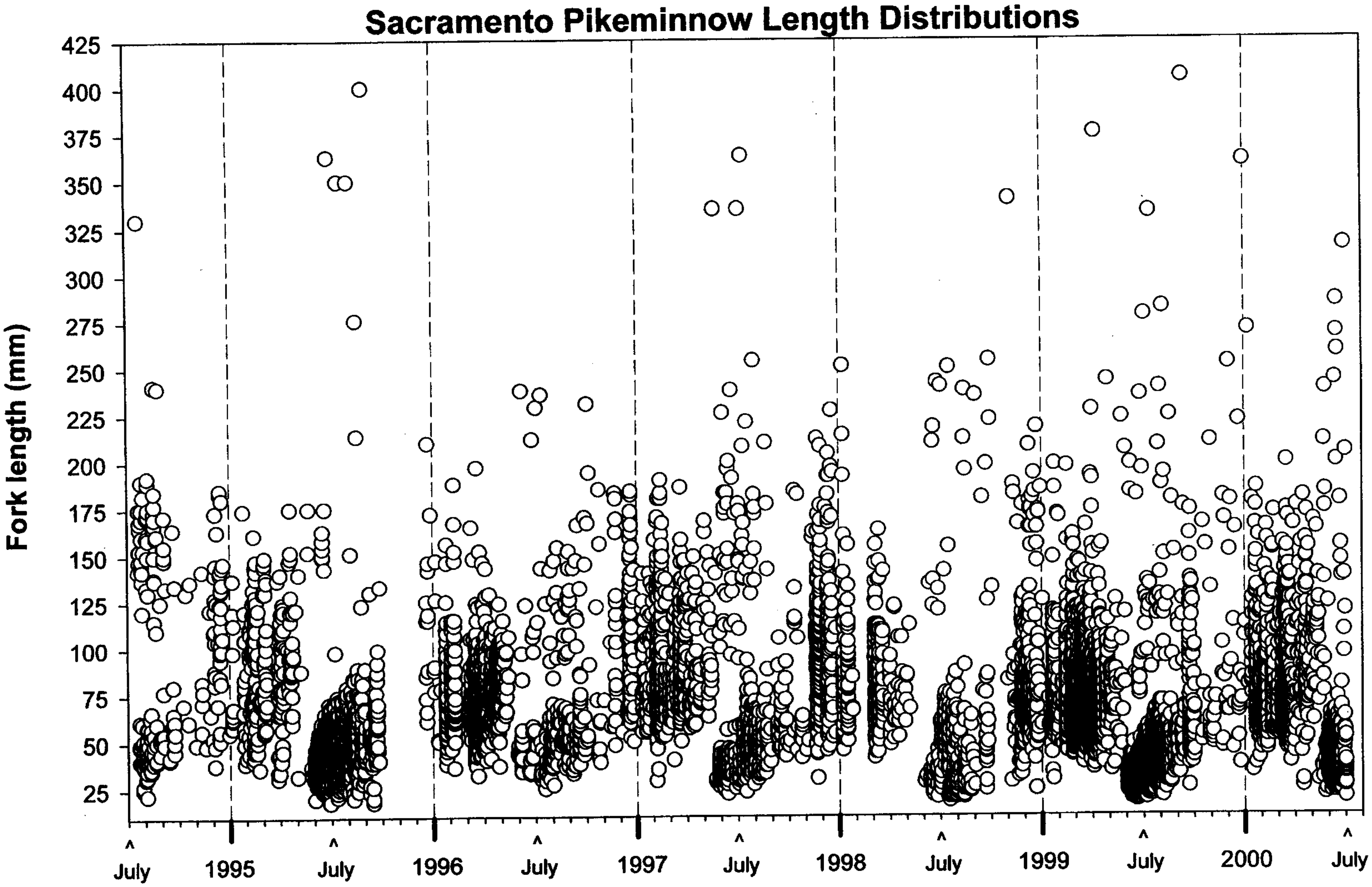

Figure A13. Among-year length distributions for Sacramento pikeminnow (*Ptychocheilus grandis*) captured by rotary-screw traps at Red Bluff Diversion Dam (RK 391), Sacramento River, CA. Data summarized from July 1994 through June 2000.

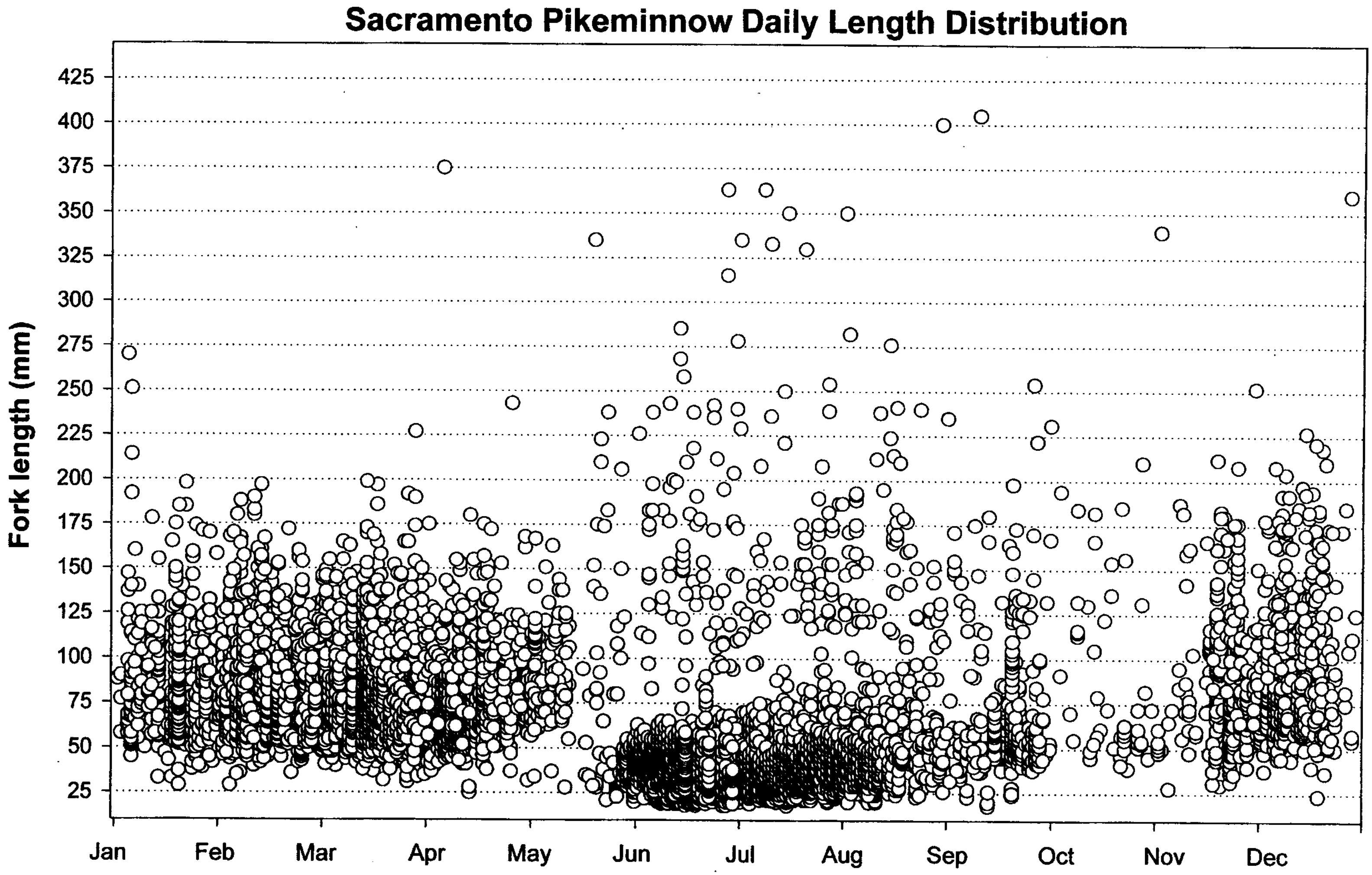

Figure A14. Within-year fork length distribution for Sacramento pikeminnow (*Ptychocheilus grandis*) captured by rotary-screw traps at Red Bluff Diversion Dam (RK 391), Sacramento River, CA. Data summarized from July 1994 through June 2000.

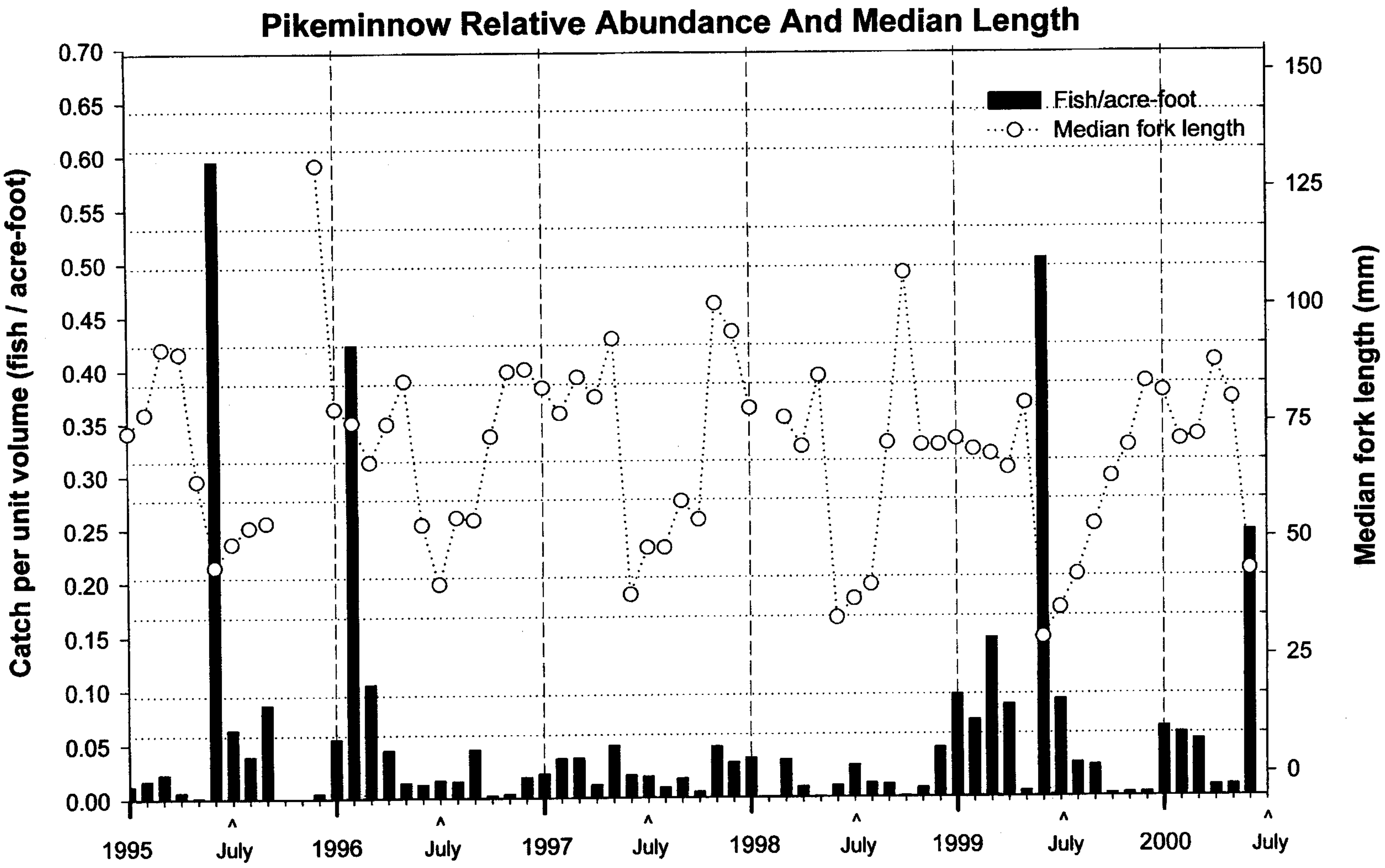

Figure A15. Relative abundance (fish/acrefoot) and median fork length for Sacramento pikeminnow (*Ptychocheilus grandis*) captured by rotary-screw traps at Red Bluff Diversion Dam (RK 391), Sacramento River, CA. Data summarized from January 1995 through June 2000.

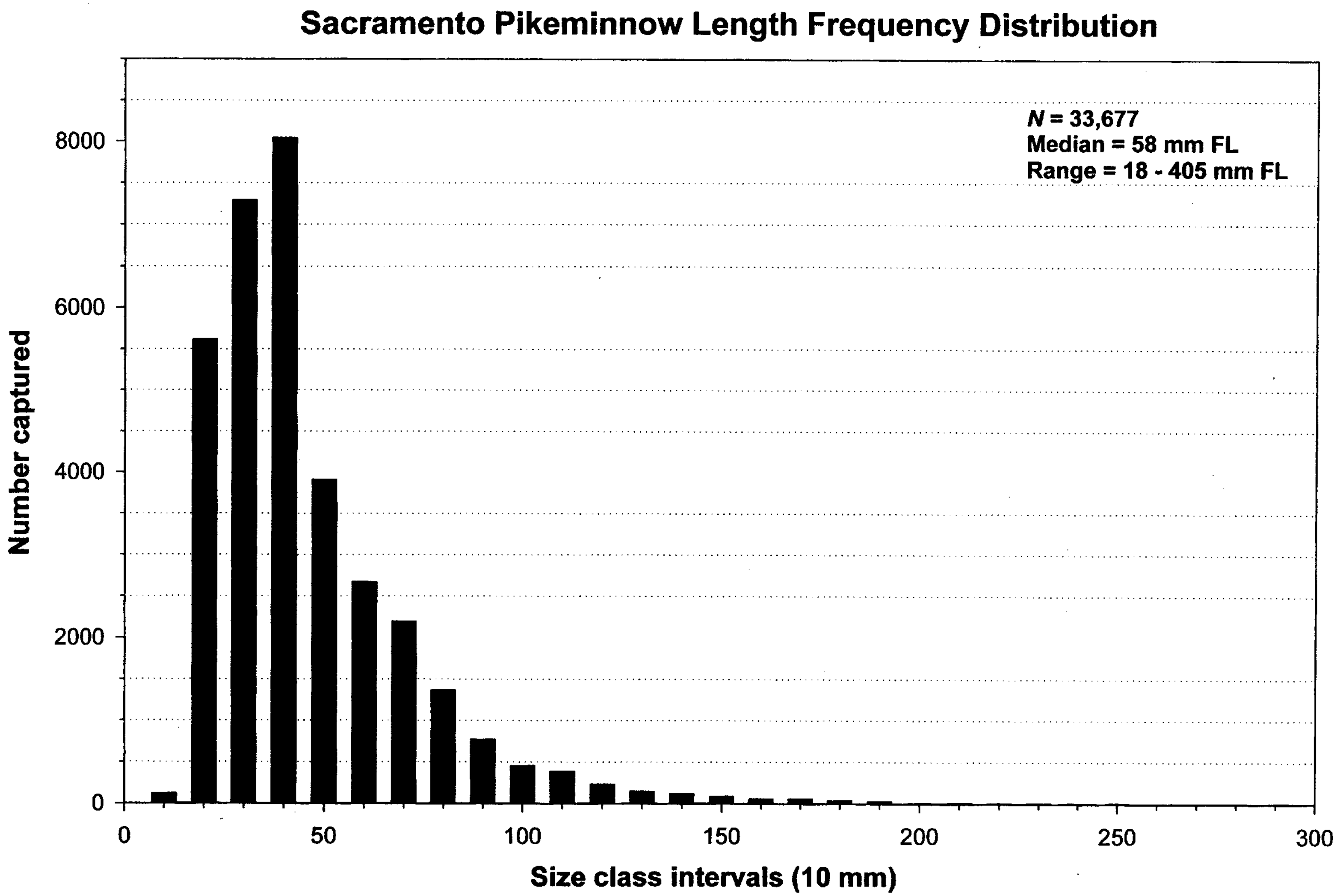

Figure A16. Length-frequency distribution for Sacramento pikeminnow (*Ptychocheilus grandis*) captured by rotary-screw traps at Red Bluff Diversion Dam (RK 391), Sacramento River, CA. Size class intervals are reported in 10 mm increments. Data summarized from July 1994 through June 2000.

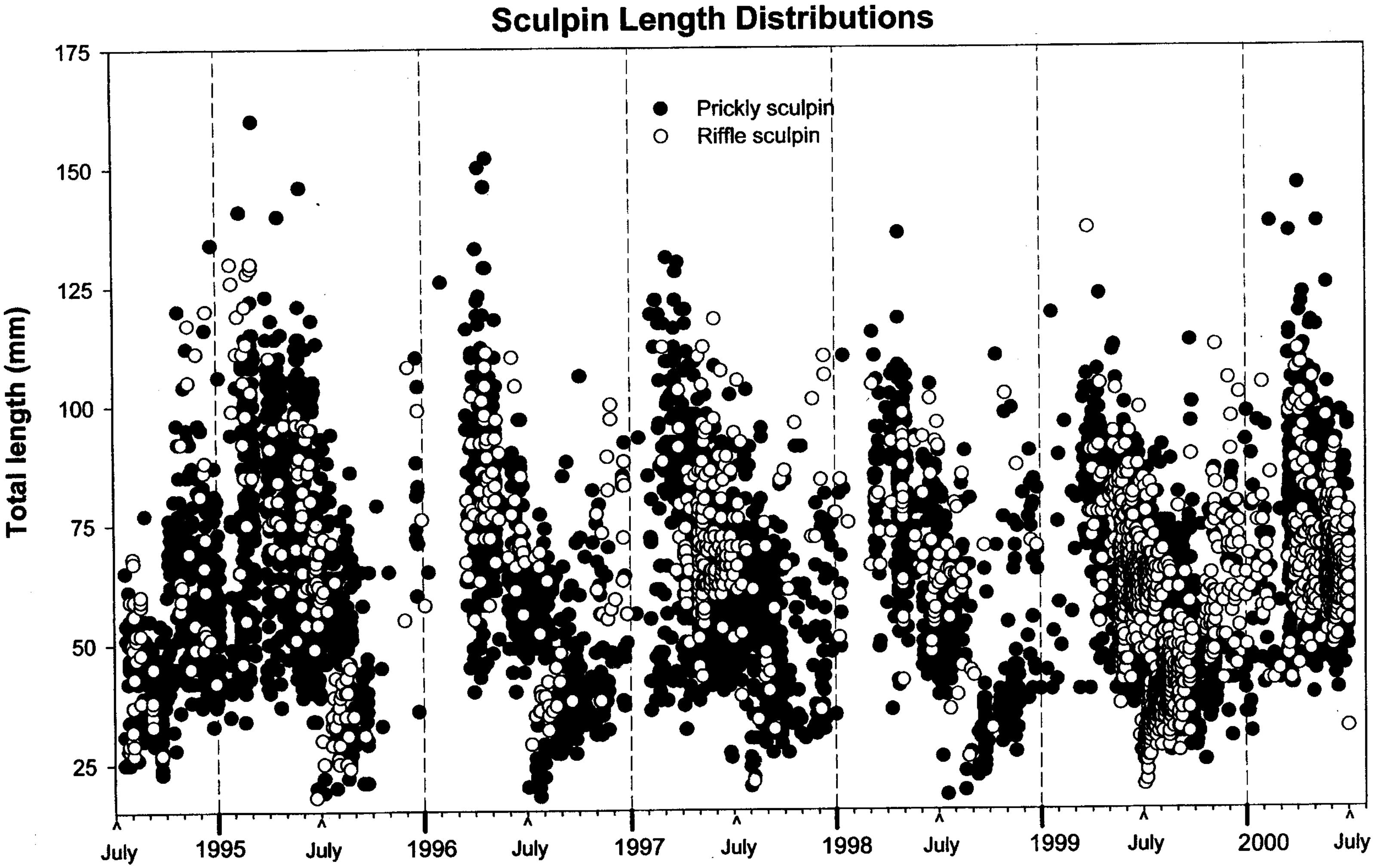

Figure A17. Among-year length distributions for prickly sculpin (*Cottus asper*) and riffle sculpin (*C. gulosus*) captured by rotary-screw traps at Red Bluff Diversion Dam (RK 391), Sacramento River, CA. Data summarized from July 1994 through June 2000.

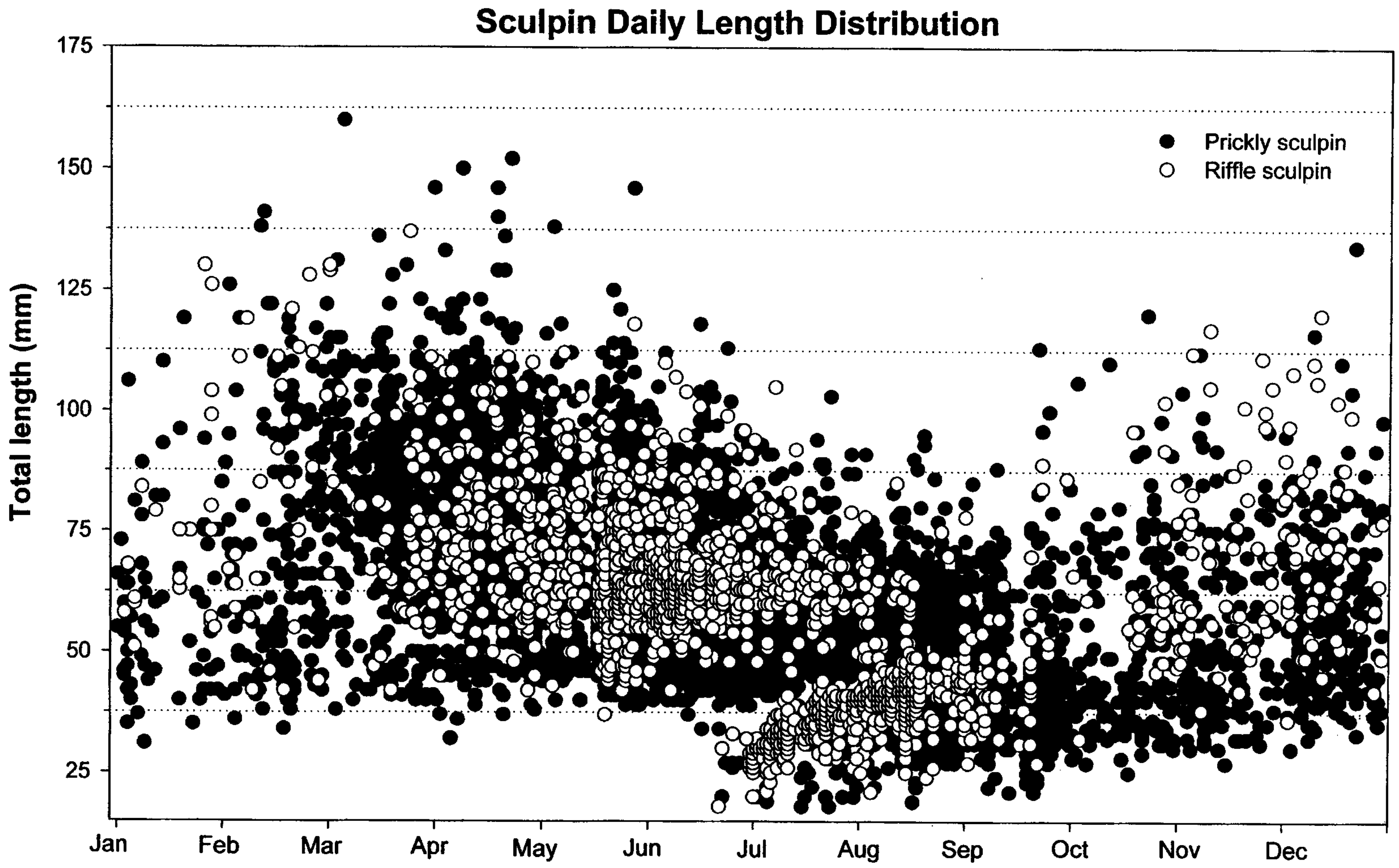

Figure A18. Within-year length distributions for prickly sculpin (*Cottus asper*) and riffle sculpin (*C. gulosus*) captured by rotary-screw traps at Red Bluff Diversion Dam (RK 391), Sacramento River, CA. Data summarized from July 1994 through June 2000.

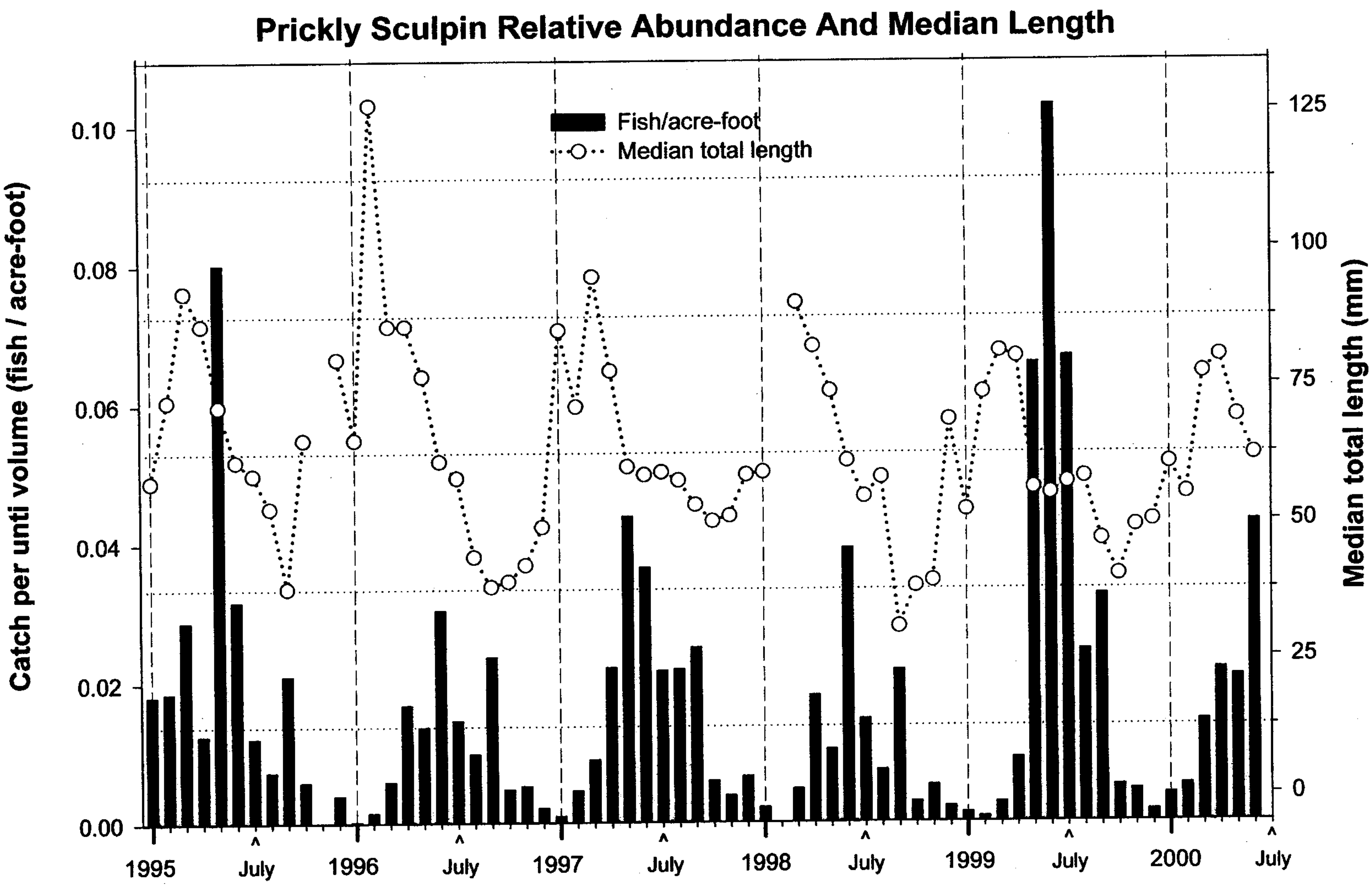

Figure A19. Relative abundance (fish/acre-foot) and median length for prickly sculpin (*Cottus asper*) captured by rotary-screw traps at Red Bluff Diversion Dam (RK391), Sacramento River, CA. Data summarized from January 1995 through June 2000.

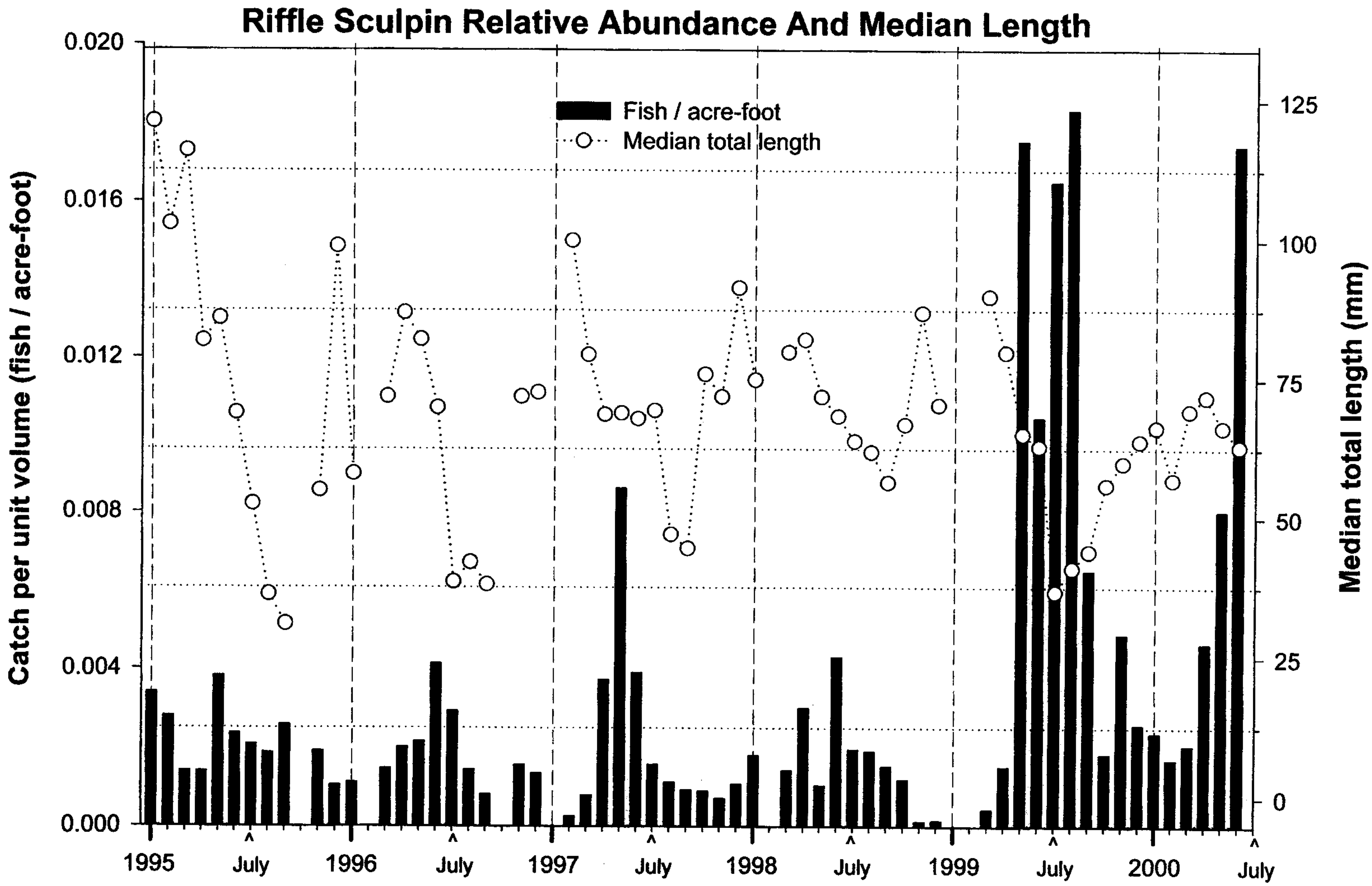

Figure A20. Relative abundance (fish/acrefoot) and median total length for riffle sculpin (*Cottus gulosus*) captured by rotary-screw traps at Red Bluff Diversion Dam (RK 391), Sacramento River, CA. Data summarized from January 1995 through June 2000.

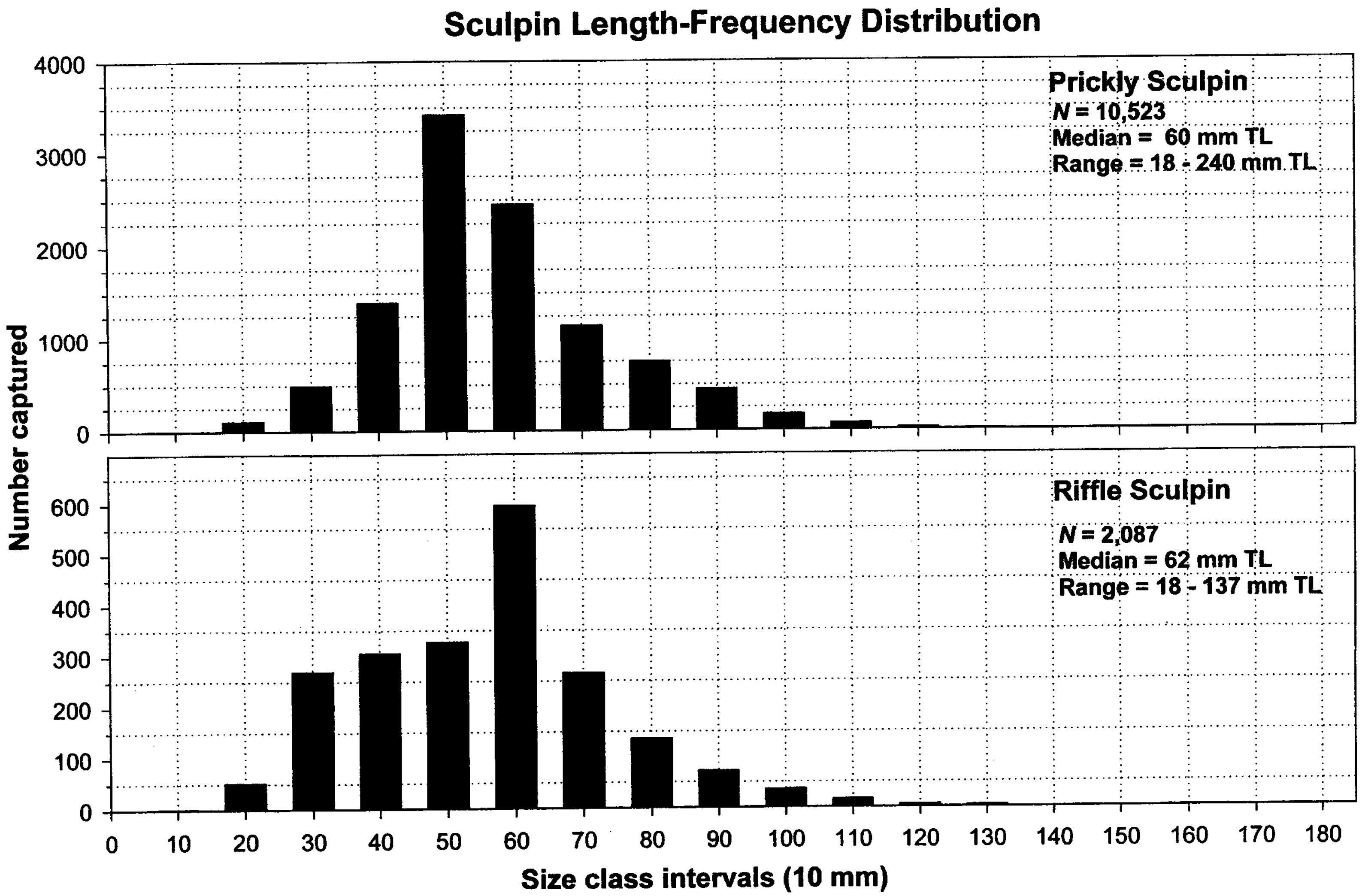

Figure A21. Length-frequency distribution for prickly sculpin (*Cottus asper*) and riffle sculpin (*Cottus gulosus*) captured by rotary-screw traps at Red Bluff Diversion Dam (RK 391), Sacramento River, CA. Size class intervals are reported in 10 mm increments. Data summarized from July 1994 through June 2000.

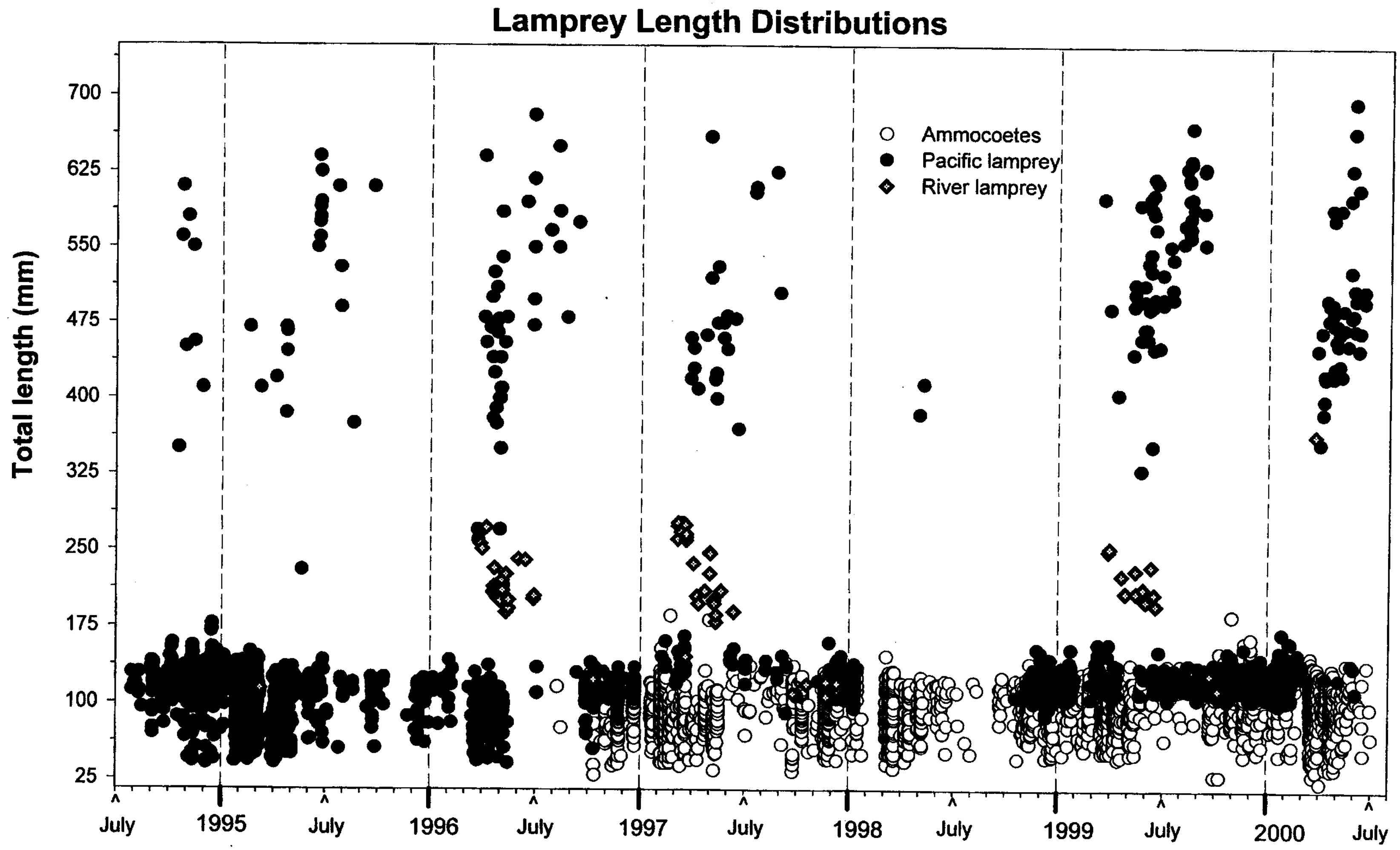

Figure A22. Among-year length distributions for lamprey ammocoetes (*Lampetra spp.*), Pacific lamprey (*L. pacifica*) and river lamprey (*L. tridentata*) captured by rotary-screw traps at Red Bluff Diversion Dam (RK391), Sacramento River, CA. Prior to 1996, all ammocoetes were classified as Pacific lamprey. Data summarized from July 1994 through June 2000.

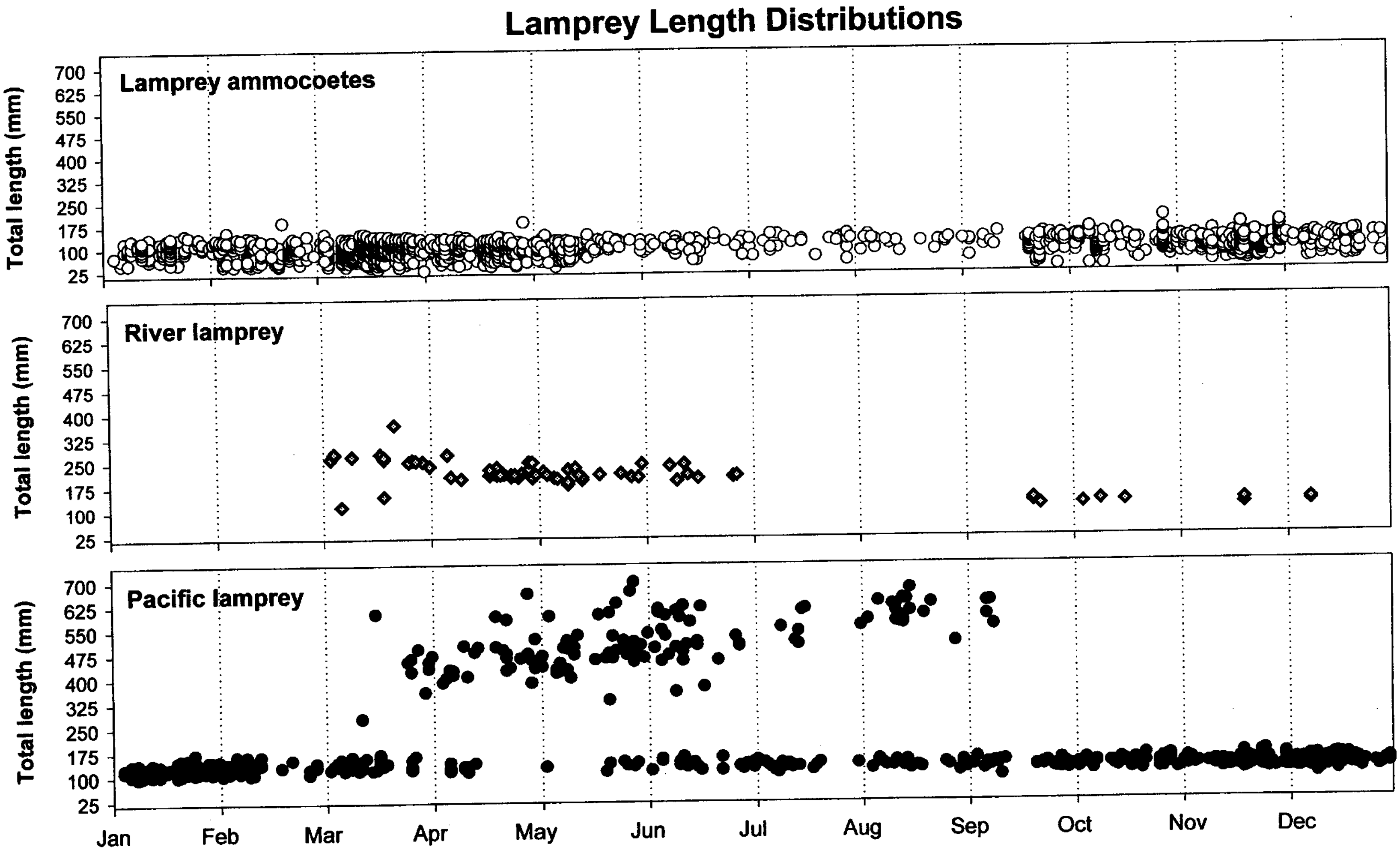

Figure A23. Within-year length distributions for lamprey ammocoetes (*Lampetra spp.*), Pacific lamprey (*L. pacifica*) and river lamprey (*L. tridentata*) captured by rotary-screw traps at Red Bluff Diversion Dam (RK391), Sacramento River, CA. Prior to 1996, all ammocoetes were classified as Pacific lamprey. Data summarized from July 1994 through June 2000.

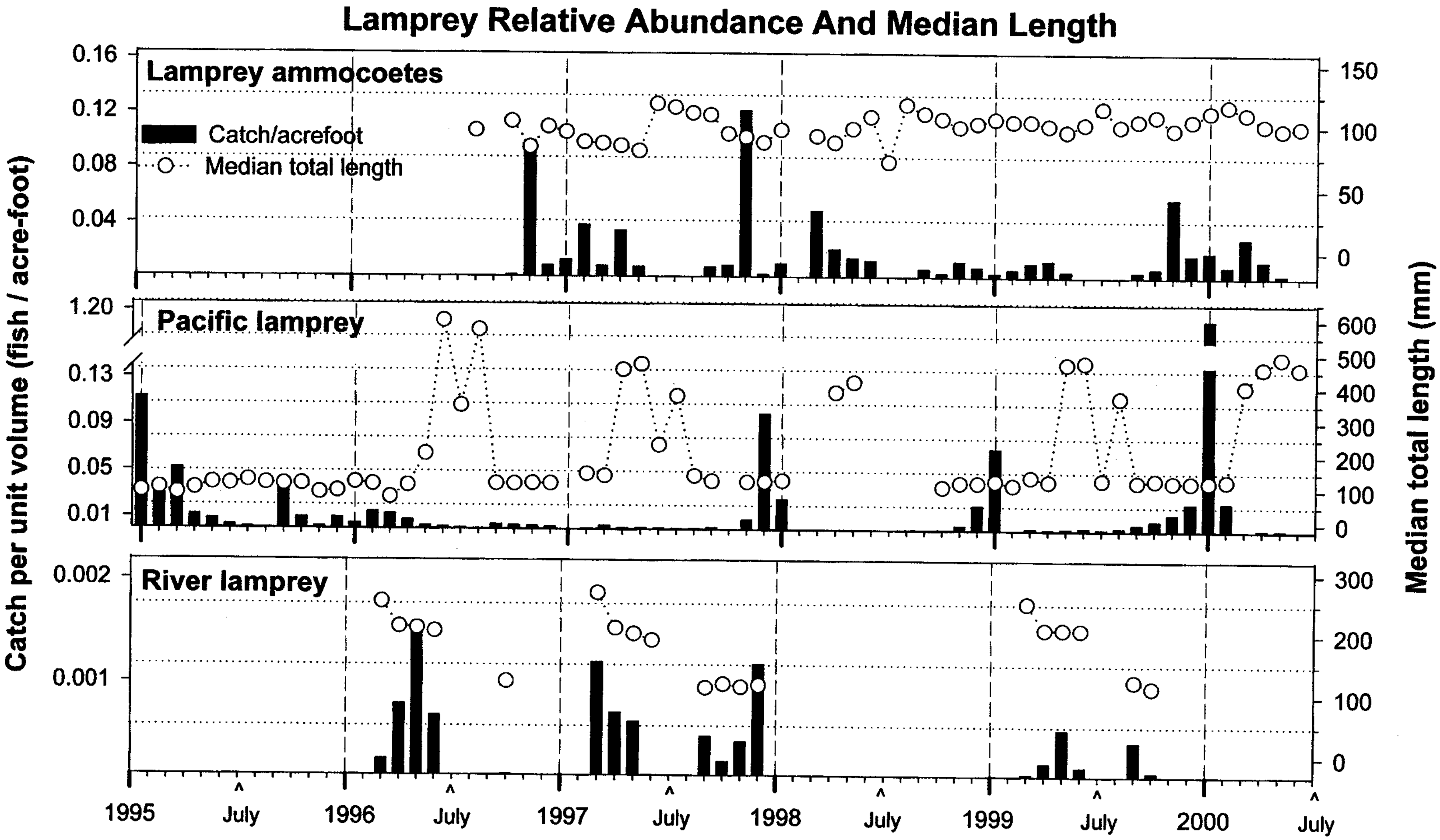

Figure A24. Relative abundance (fish/acre-foot) and median length for lamprey ammocoetes (*Lampetra spp.*), Pacific lamprey (*L. pacifica*) and river lamprey (*L. tridentata*) captured by rotary-screw traps at Red Bluff Diversion Dam (RK391),Sacramento River, CA. Data summarized from January 1995 through June 2000. Prior to 1996, all ammocoetes were classified as Pacific lamprey.

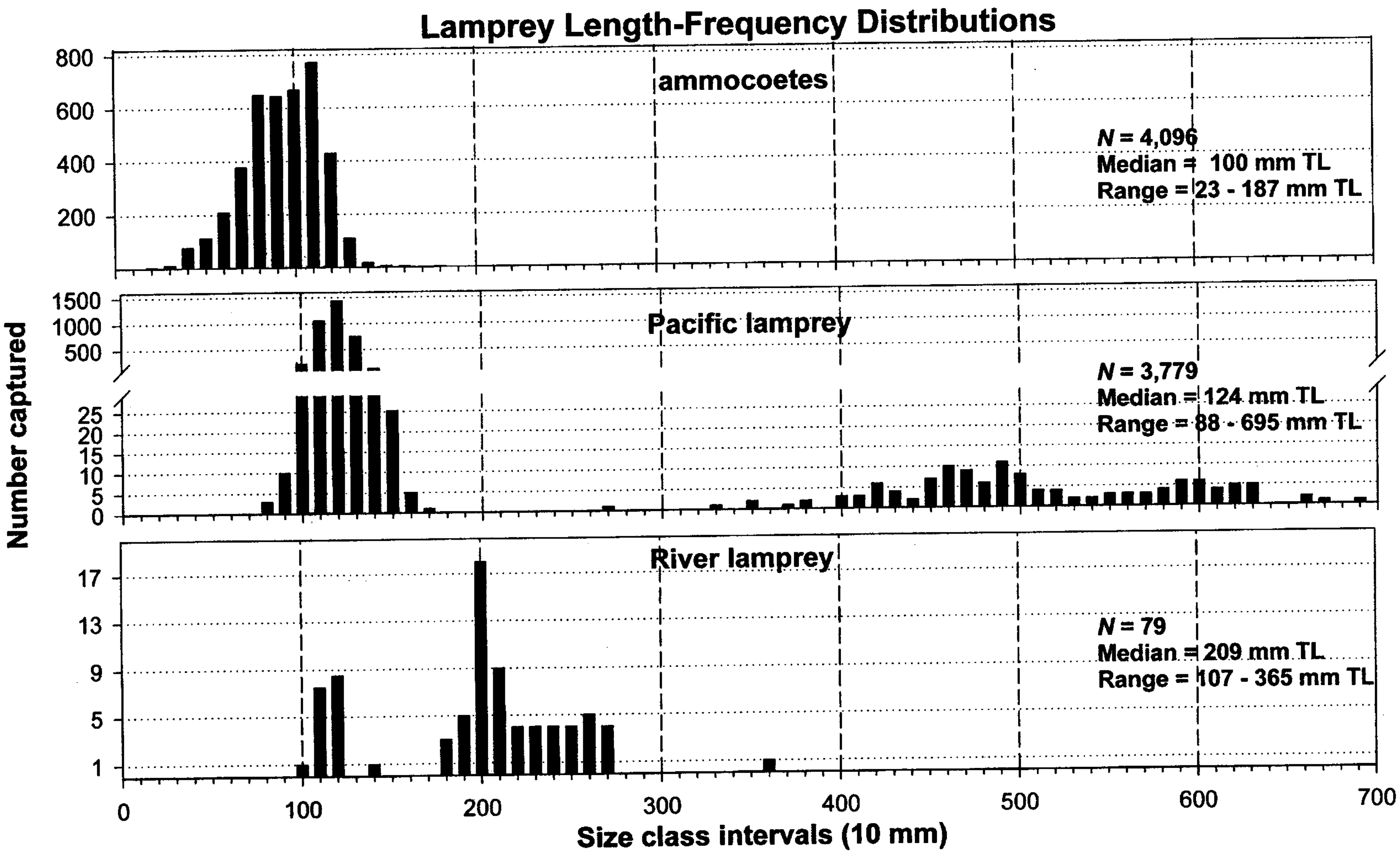

Figure A25. Length-frequency distribution for lamprey ammocoetes (*Lampetra spp*), Pacific lamprey (*L. pacifica*) and river lamprey (*L. tridentata*) captured by rotary-screw traps at Red Bluff Diversion Dam (RK 391), Sacramento River,CA. Size class intervals are reported in 10 mm increments. Data summarized from July 1994 through June 2000. Prior to 1996, all ammocoetes were classified as Pacific lamprey.

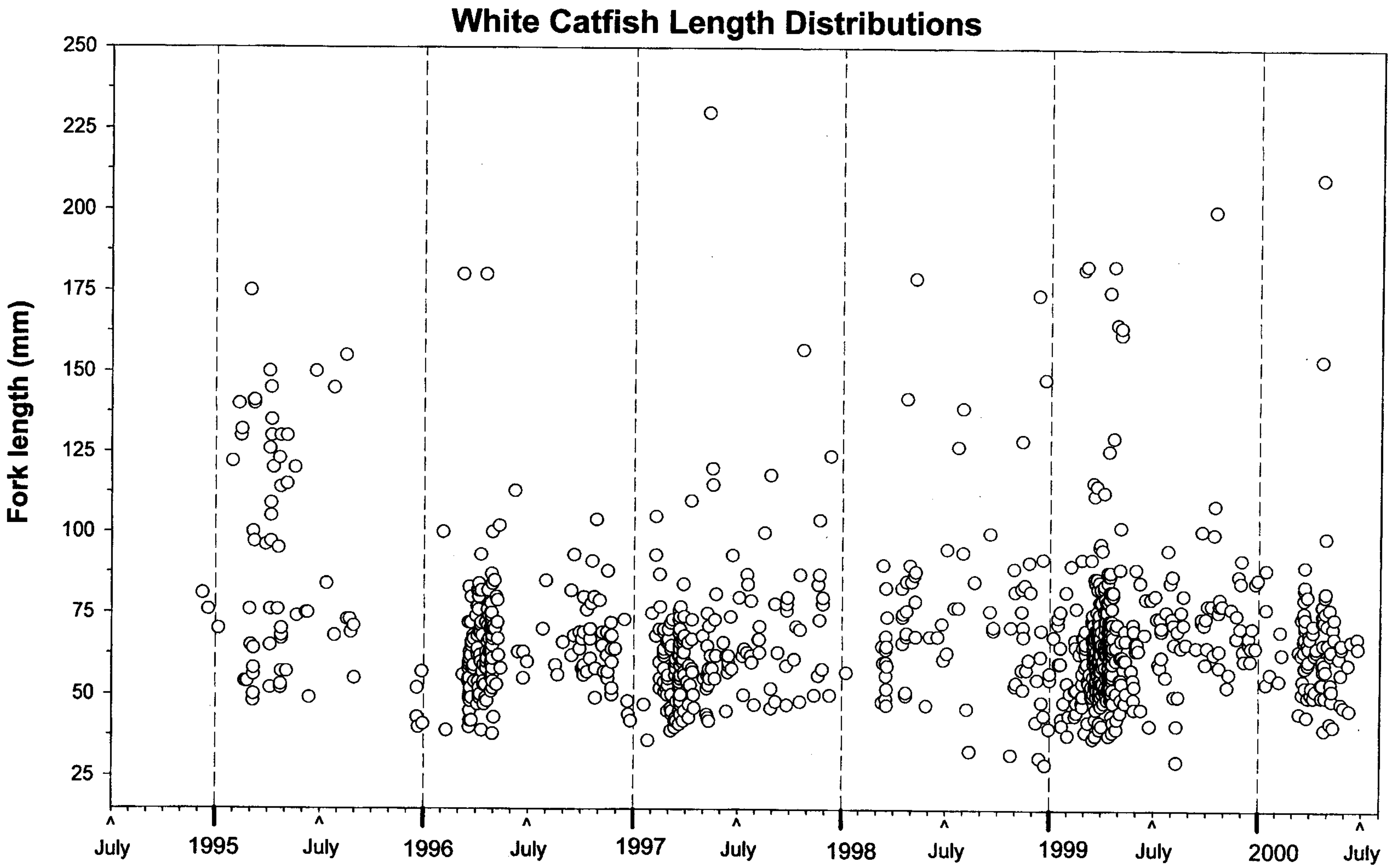
White Catfish Length Distributions

Figure A26. Among-year fork length distributions for white catfish (*Ictalurus catus*) captured by rotary-screw traps at Red Bluff Diversion Dam (RK 391), Sacramento River, CA. Data summarized from July 1994 through June 2000.

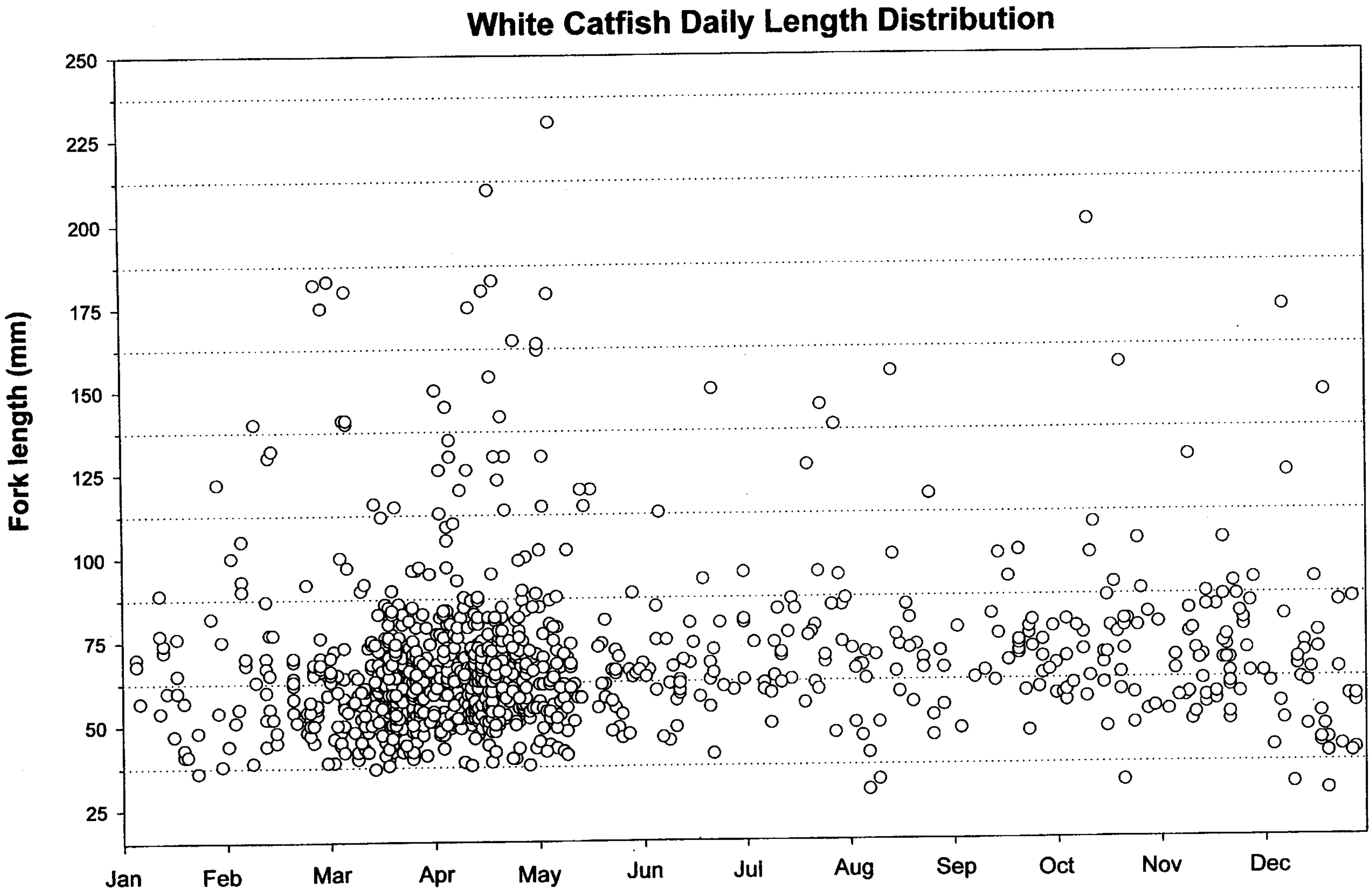

Figure A27. Within-year fork length distribution for white catfish (*Ictalurus catus*) captured by rotary-screw traps at the Red Bluff Diversion Dam (RK 391), Sacramento River, CA. Data summarized from July 1994 through June 2000.

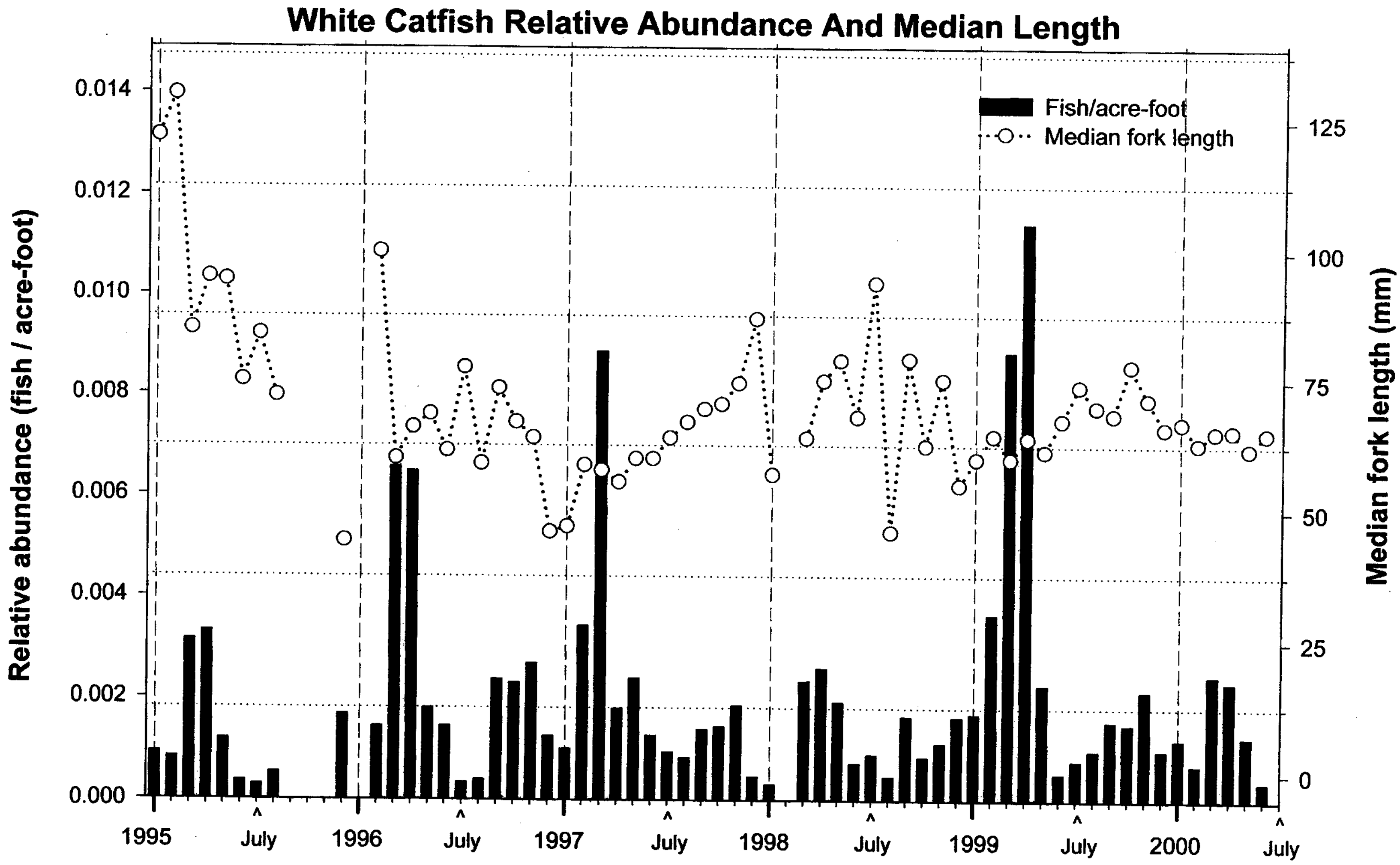
White Catfish Relative Abundance And Median Length

Figure A28. Relative abundance (fish/acrefoot) and median fork length for white catfish (*Ictalurus catus*) captured by rotary-screw traps at Red Bluff Diversion Dam (RK 391), Sacramento River, CA. Data summarized from January 1995 through June 2000.

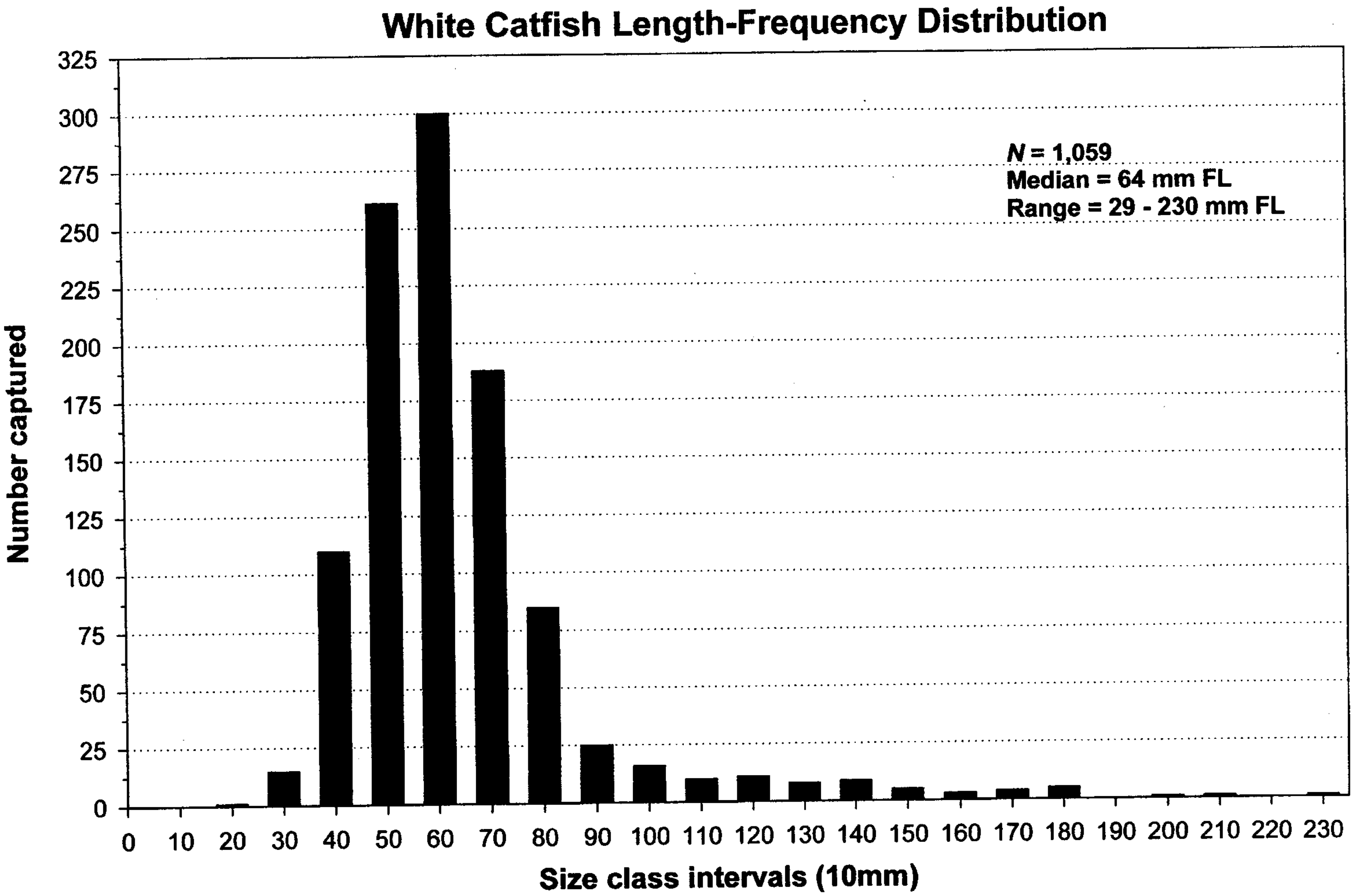

Figure A29. Length-frequency distribution for white catfish (*Ictalarus catus*) captured by rotary-screw traps at Red Bluff Diversion Dam (RK 391), Sacramento River, CA. Size class intervals are reported in 10 mm increments. Data summarized from July 1994 through June 2000.

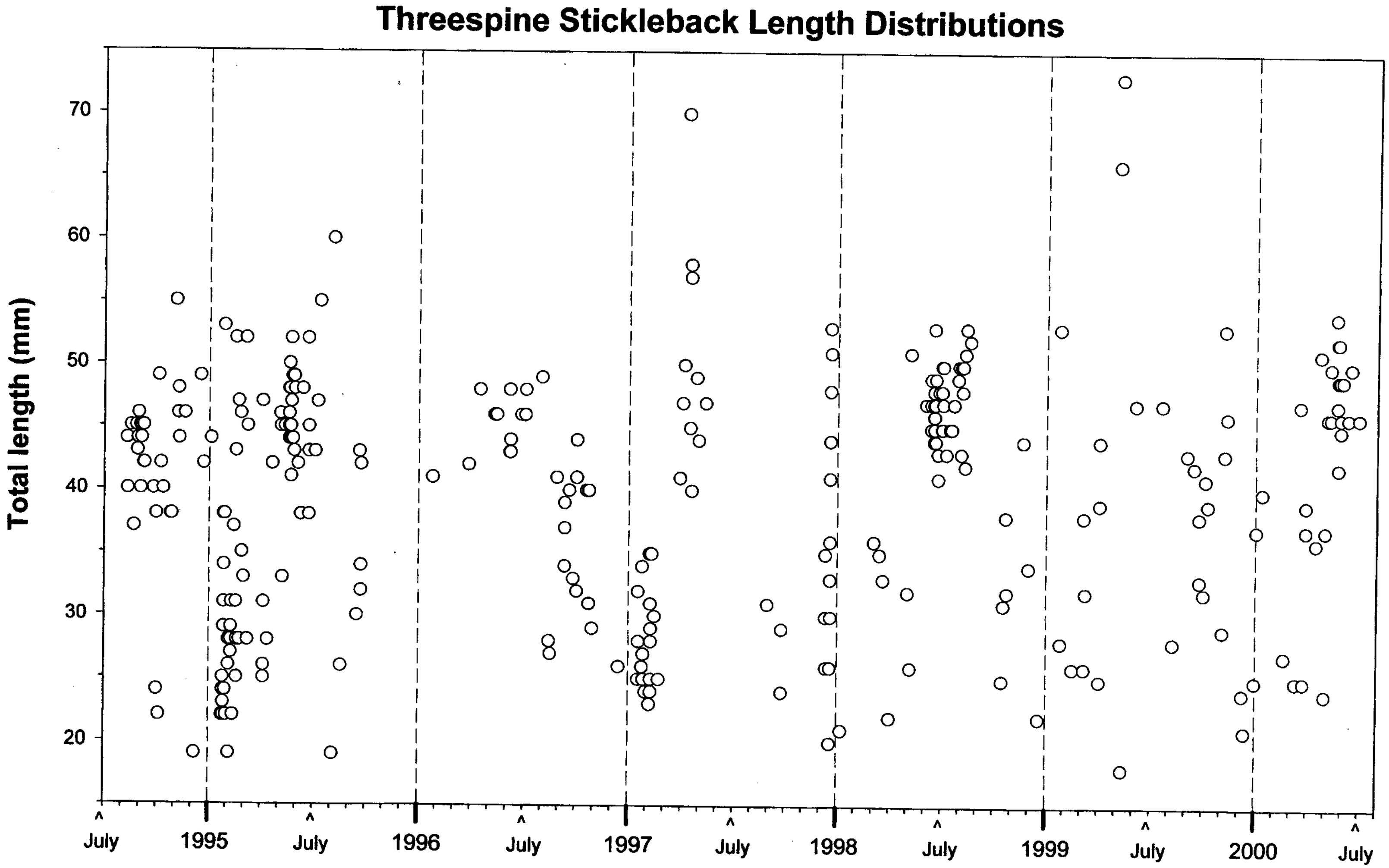

Figure A30. Among-year length distributions for threespine stickleback (*Gasterosteus aculeatus*) captured by rotary-screw traps at Red Bluff Diversion Dam (RK 391), Sacramento River, CA. Data summarized from July 1994 through June 2000.

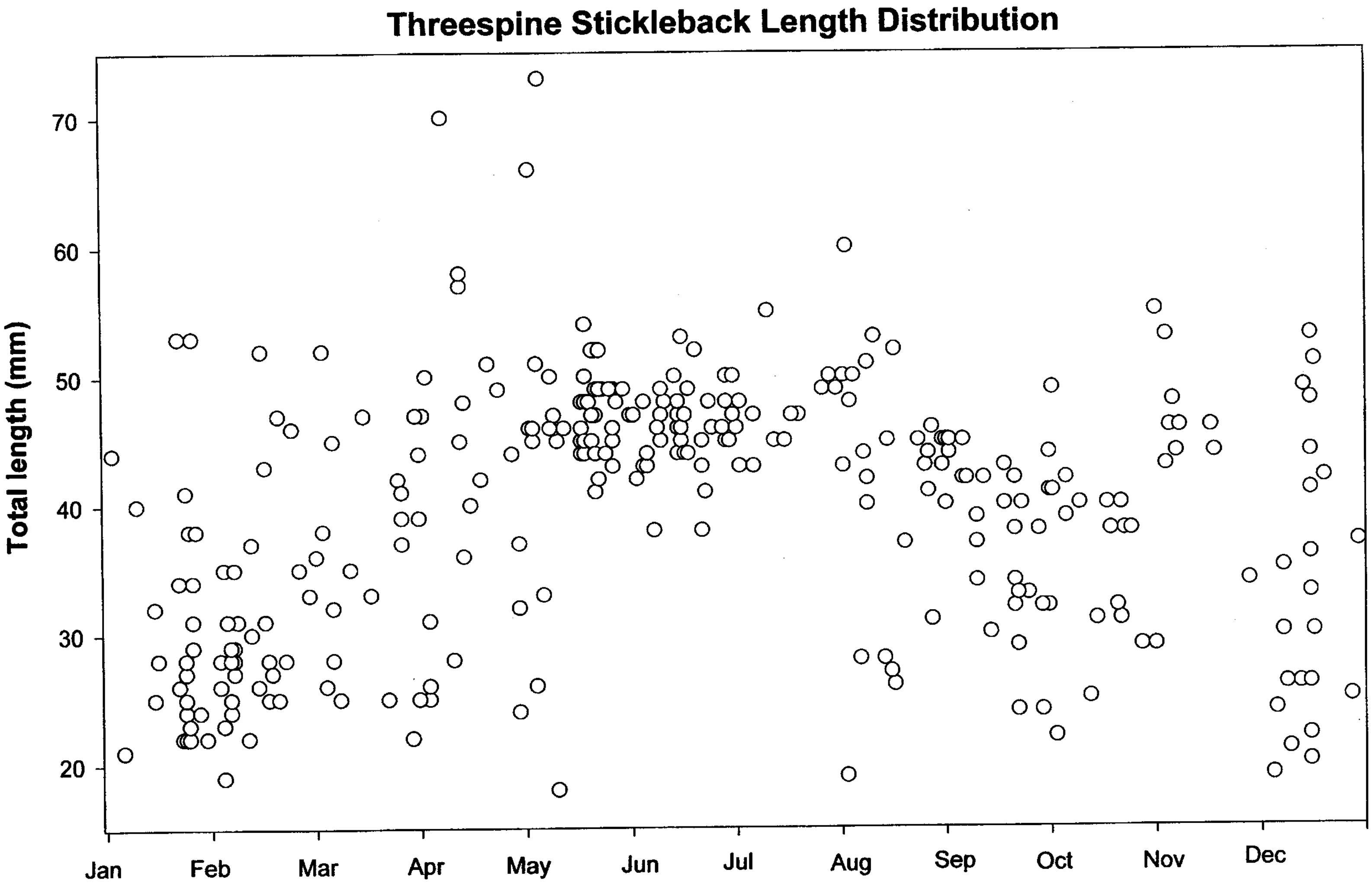

Figure A31. Within-year length distribution for threespine stickleback (*Gasterosteus aculeatus*) captured by rotary-screw traps at Red Bluff Diversion Dam (RK 391), Sacramento River, CA. Data summarized from July 1994 through June 2000.

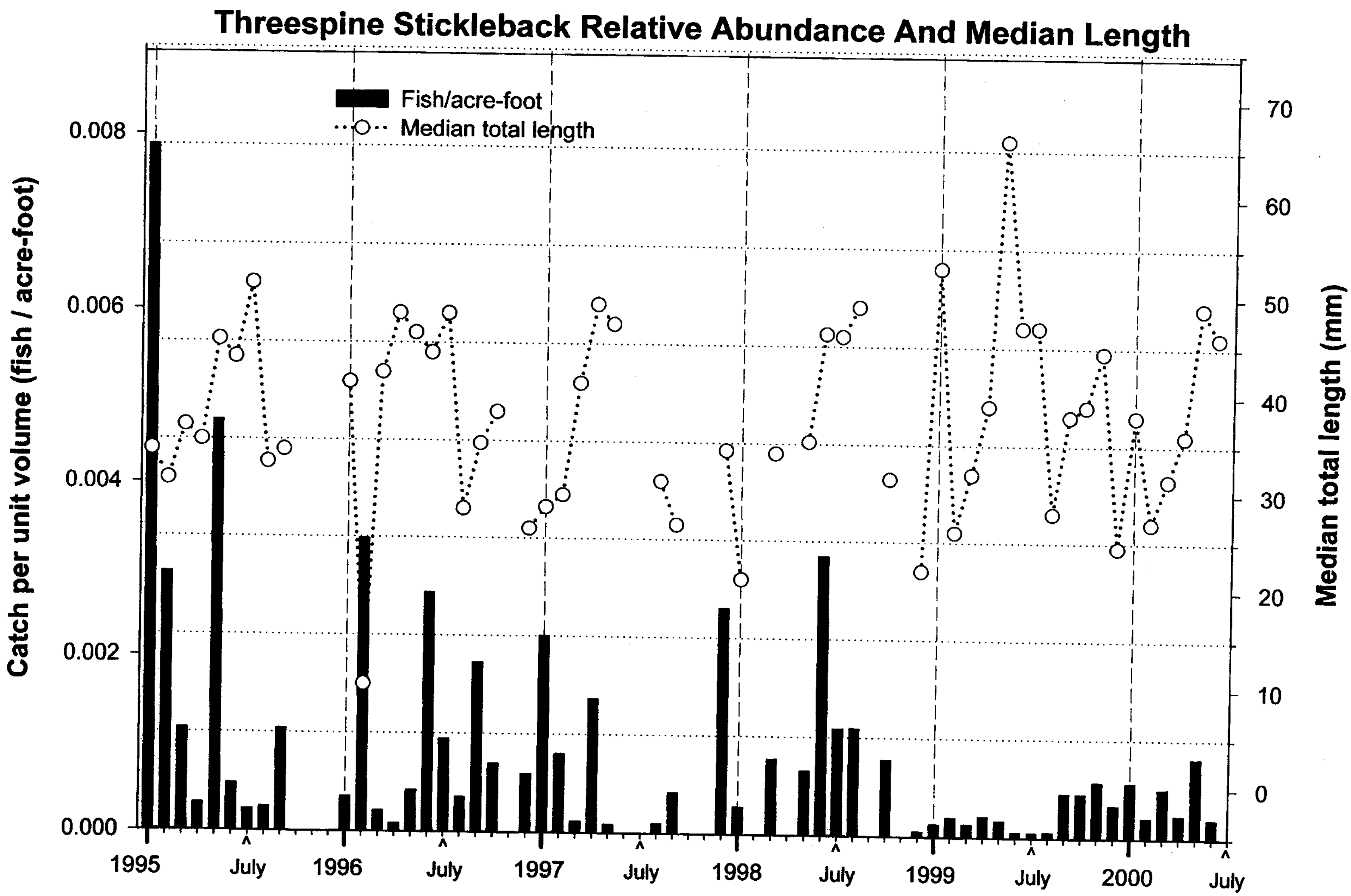

Figure A32. Relative abundance (fish/acrefoot) and median length for threespine stickleback (*Gasterosteus aculeatus*) captured by rotary-screw traps at Red Bluff Diversion Dam (RK 391), Sacramento River, CA. Data summarized from January 1995 through June 2000.

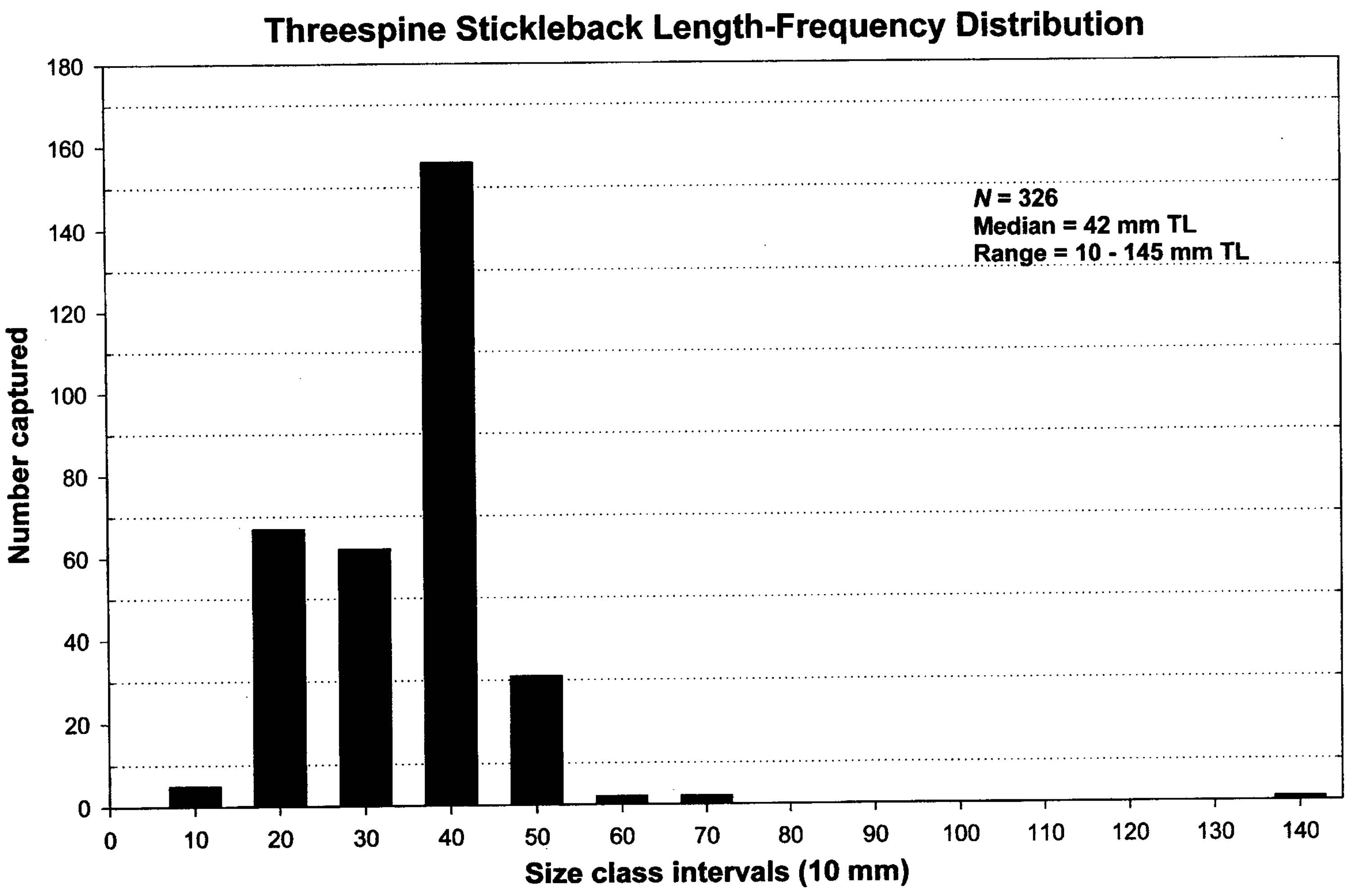

Figure A33. Length-frequency distribution for threespine stickleback (*Gasterosteus aculeatus*) captured by rotary-screw traps at Red Bluff Diversion Dam (RK 391), Sacramento River, CA. Size class intervals are reported in 10 mm increments. Data summarized from July 1994 through June 2000.

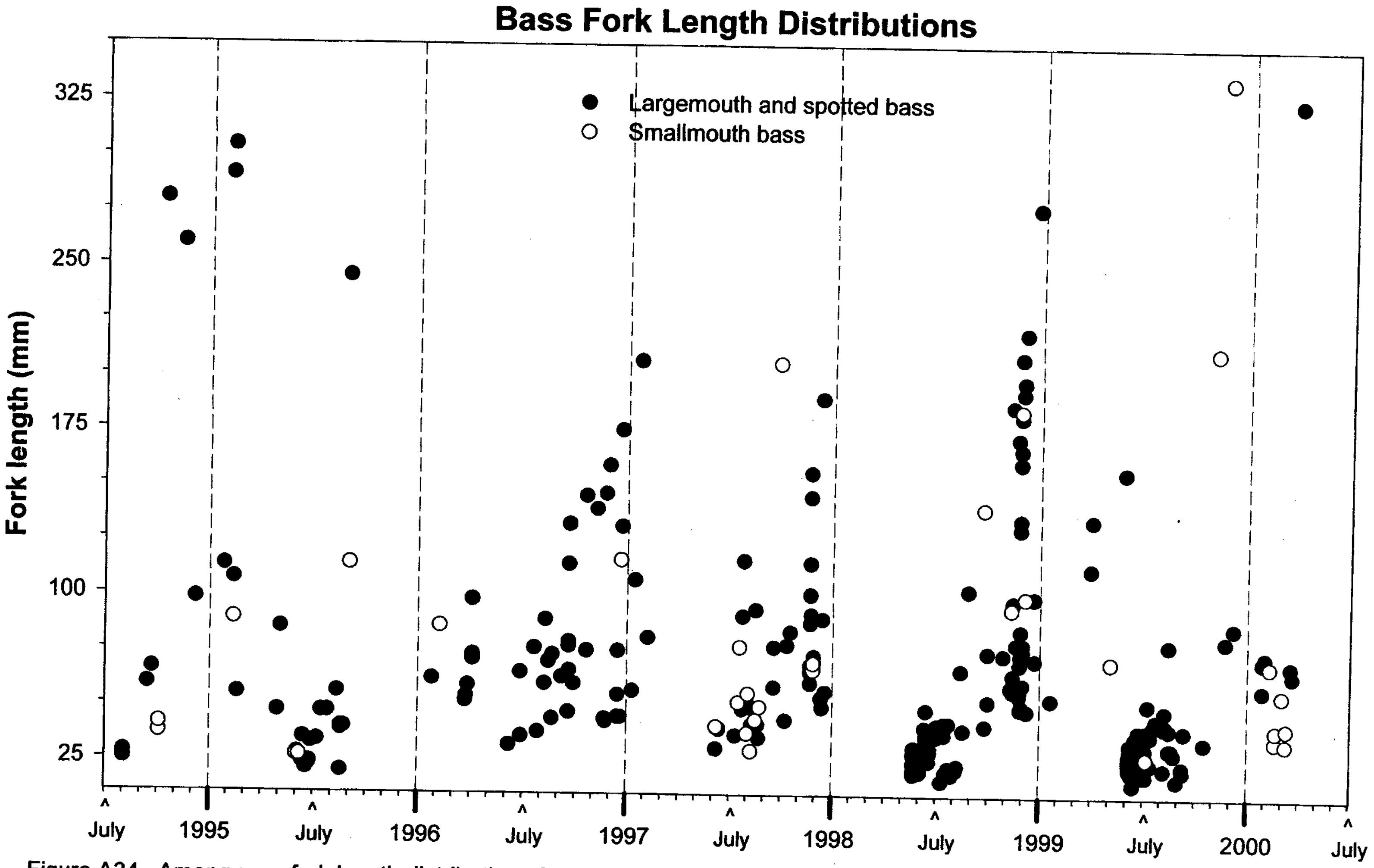

Figure A34. Among-year fork length distributions for smallmouth bass (*Micropterus dolomieui*), spotted bass (*M. punctulatus*), and largemouth bass (*M. salmoides*) captured by rotary-screw traps at the Red Bluff Diversion Dam (RK 391), Sacramento River, CA. Identification of spotted bass prior to 1998 was uncertain, therefore, spotted bass and largemouth bass have been combined. Data summarized from July 1994 through June 2000.

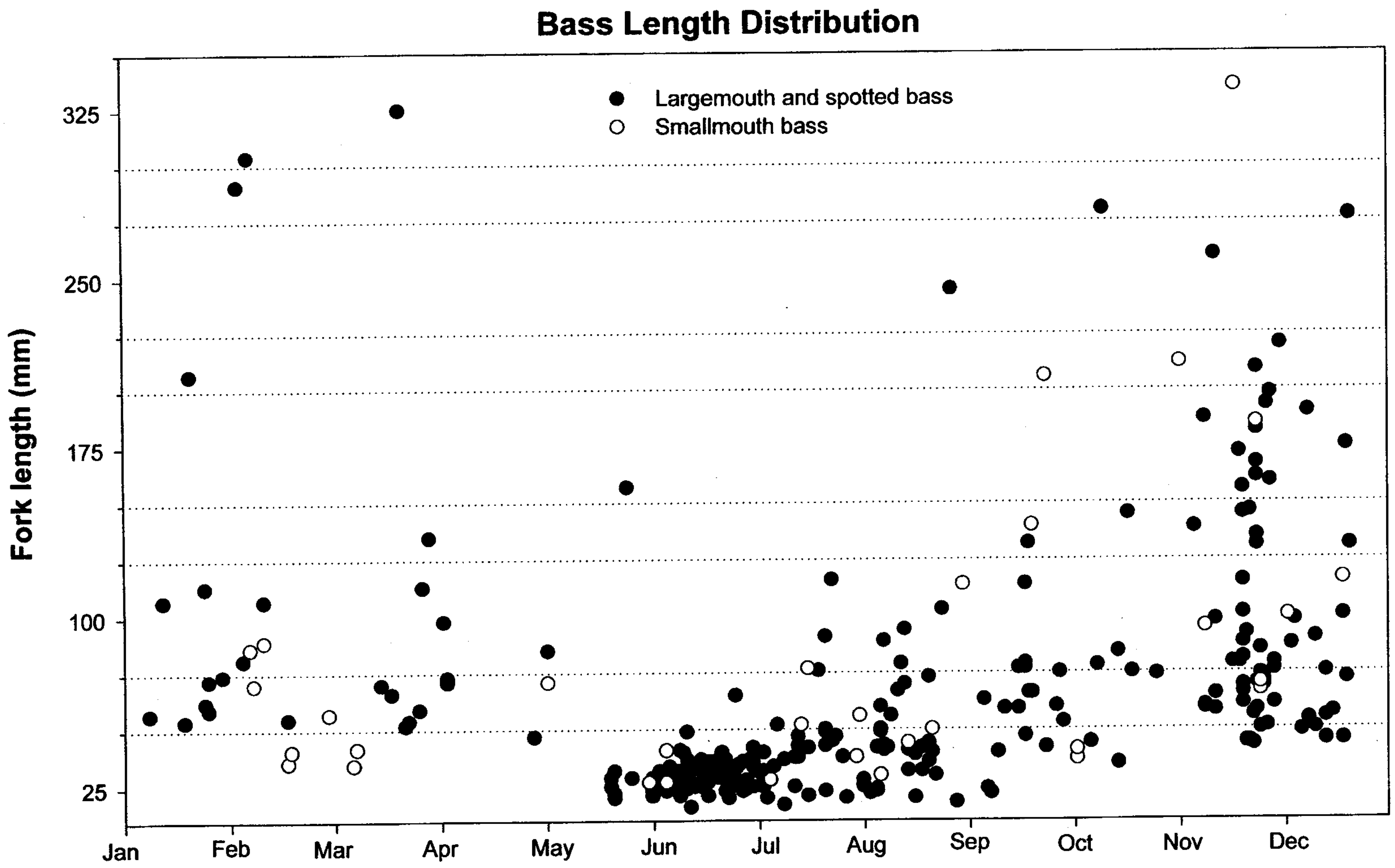

Figure A35. Within-year fork length distributions for smallmouth bass (*Micropterus dolomieui)*, spotted bass (*M. punctulatus*), and largemouth bass (*M. salmoides*) captured by rotary-screw traps at the Red Bluff Diversion Dam (RK 391), Sacramento River, CA. Identification of spotted bass prior to 1998 was uncertain, therefore, spotted bass and largemouth bass have been combined. Data summarized from July 1994 through June 2000.

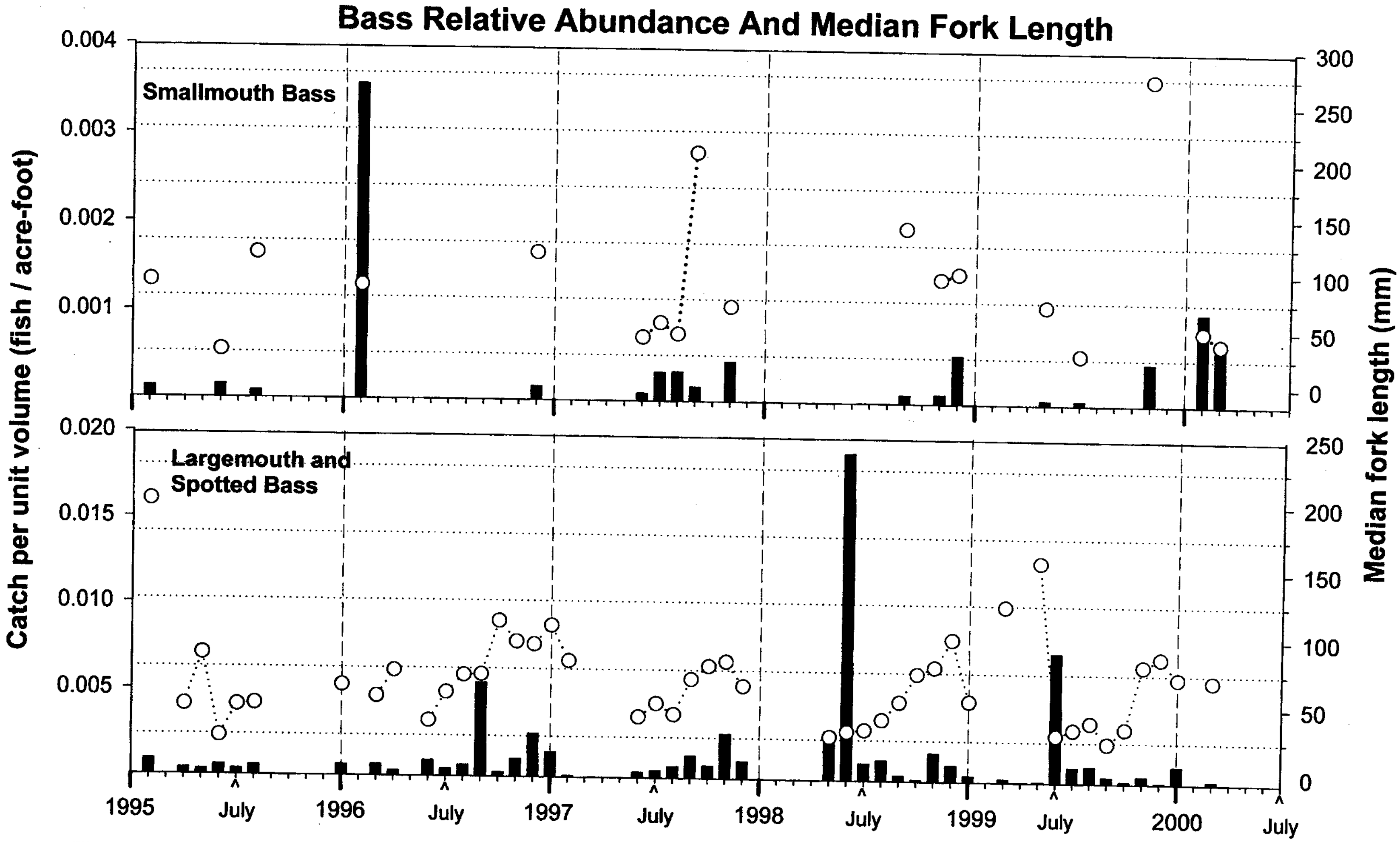

Figure A36. Relative abundance (fish/acre-foot) and median length for smallmouth bass (*Micropterus dolomieui*), spotted bass (*M. punctulatus*), and largemouth bass (*M. salmoides*) captured by rotary-screw traps at the Red Bluff Diversion Dam (RK 391), Sacramento River, CA. Identification of spotted bass prior to 1998 was uncertain, therefore, spotted bass and largemouth bass have been combined. Data summarized from January 1995 through June 2000.

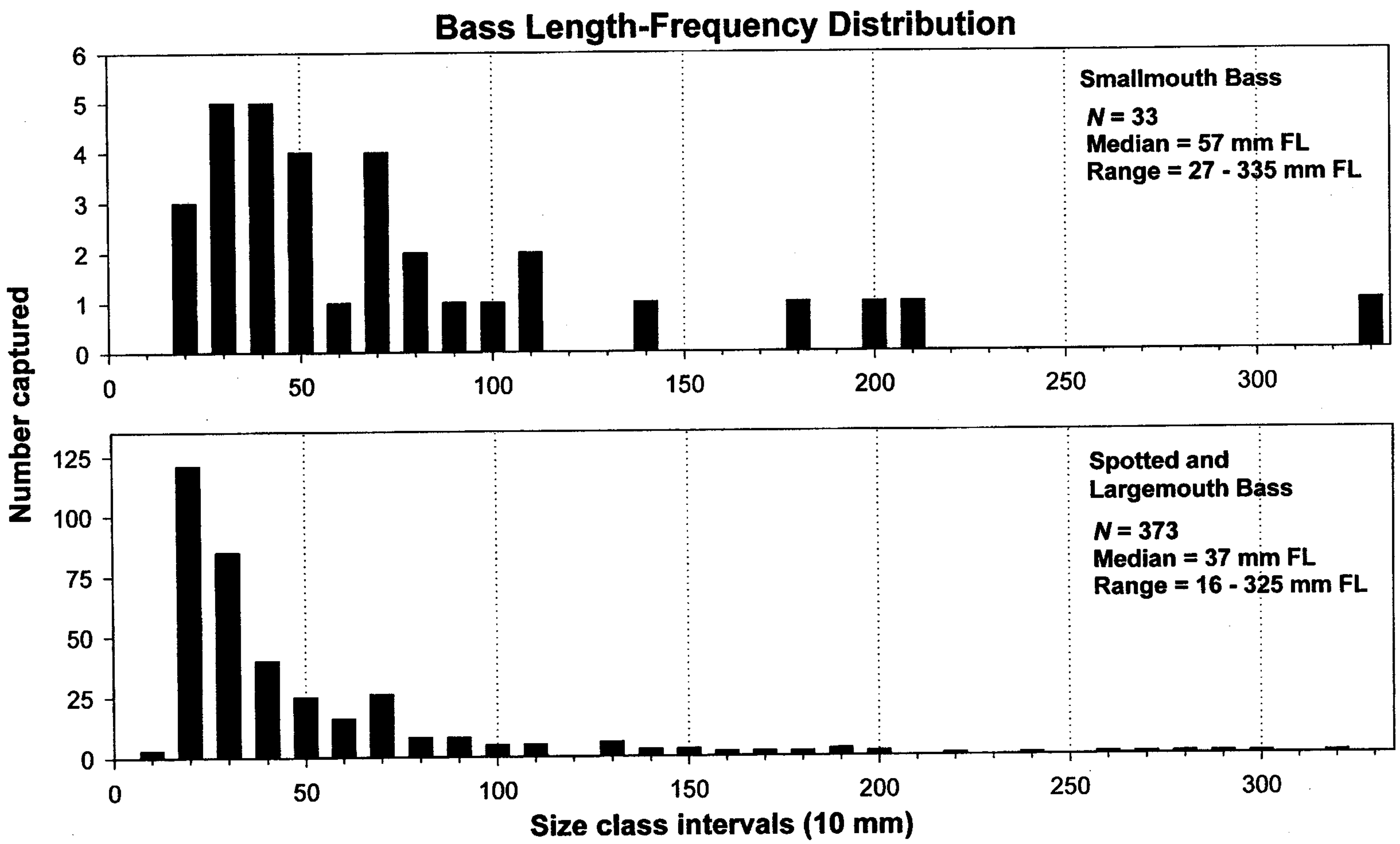

Figure A37. Length-frequency distribution for smallmouth bass (*Micropterus dolomieui*), spotted bass (*M. punctulatus*), and largemouth bass (*M. salmoides*) captured by rotary-screw traps at the Red Bluff Diversion Dam (RK 391), Sacramento River, CA. Identification of spotted bass prior to 1998 was uncertain, therefore, spotted bass and largemouth bass have been combined. Size class intervals are reported in 10 mm increments. Data summarized from July 1994 through June 2000.

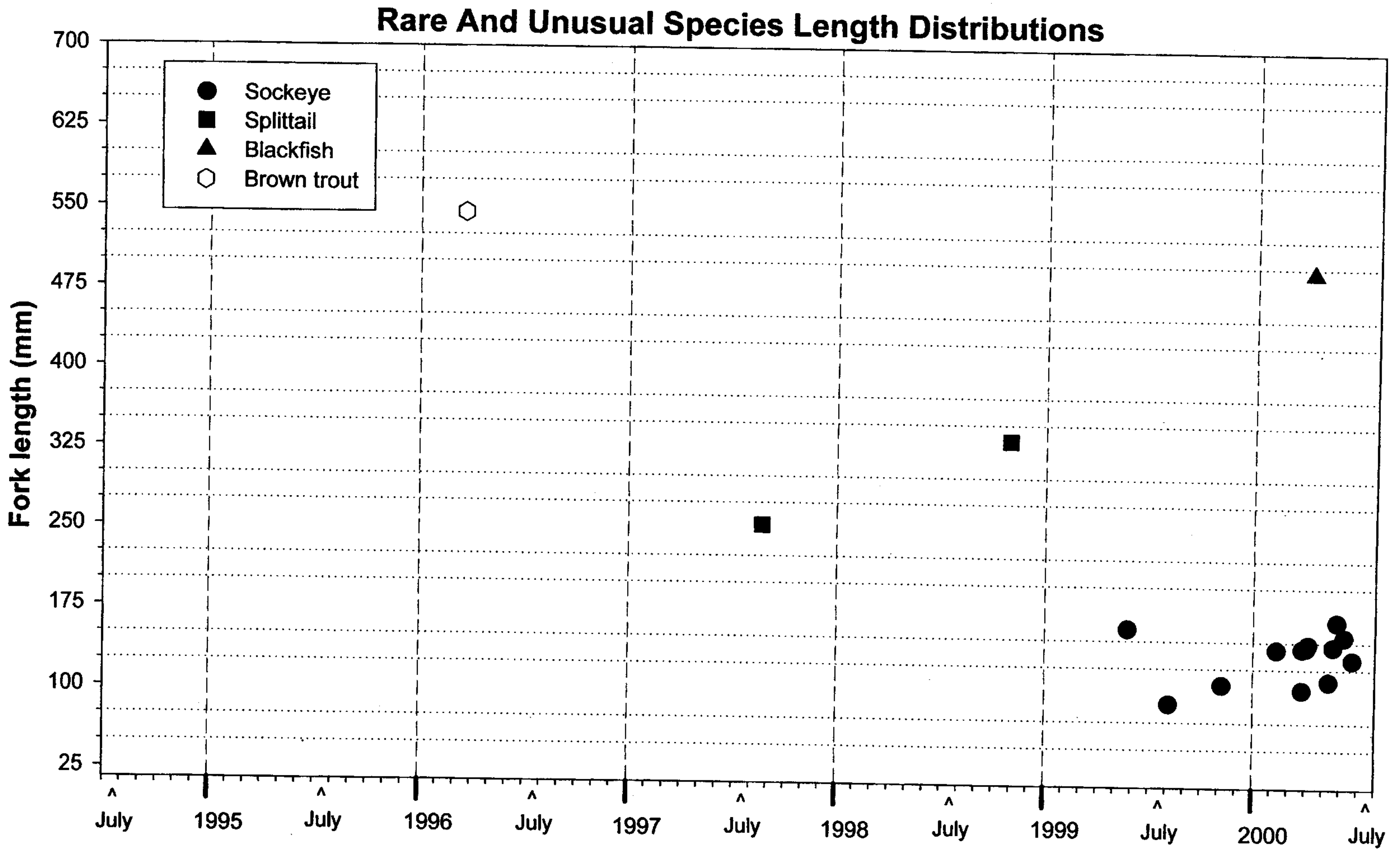

Figure A38. Among-year fork length distributions for rare and unusual species captured by rotary-screw traps at Red Bluff Diversion Dam (RK 391), Sacramento River, CA. Captures of sockeye salmon (*Oncorhynchus nerka*), Sacramento splittail (*Pogonichthys macrolepidotus*), Sacramento blackfish (*Orthodon microlepidotus*) and brown trout (*salmo trutta*) summarized from July 1994 through June 2000.

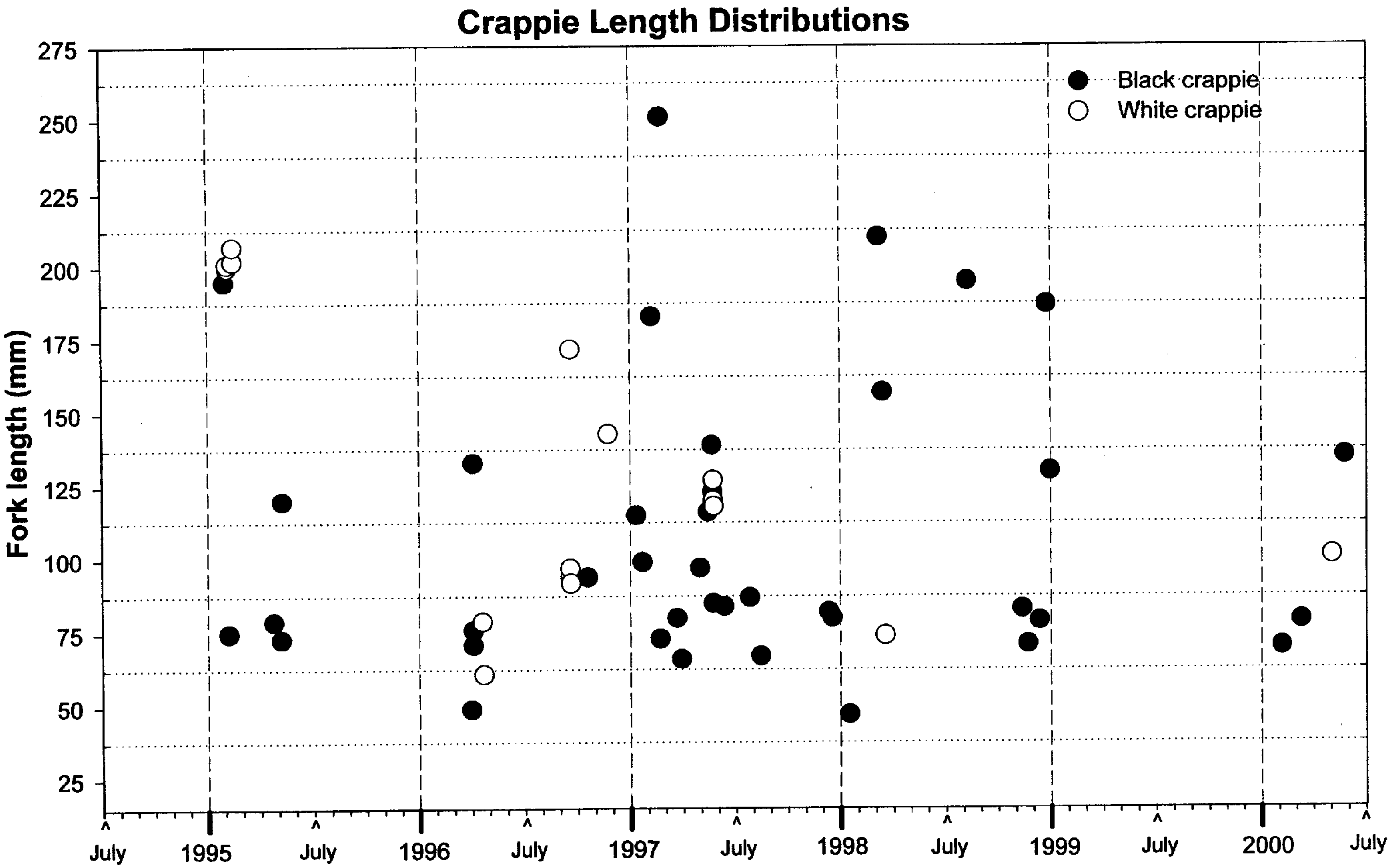

Figure A39. Among-year fork length distributions for black crappie (*Pomoxis nigromaculatus*) and white crappie (*Pomoxis annularis*) captured by rotary-screw traps at Red Bluff Diversion Dam (RK 391), Sacramento River, CA. Data summarized from July 1994 through June 2000.

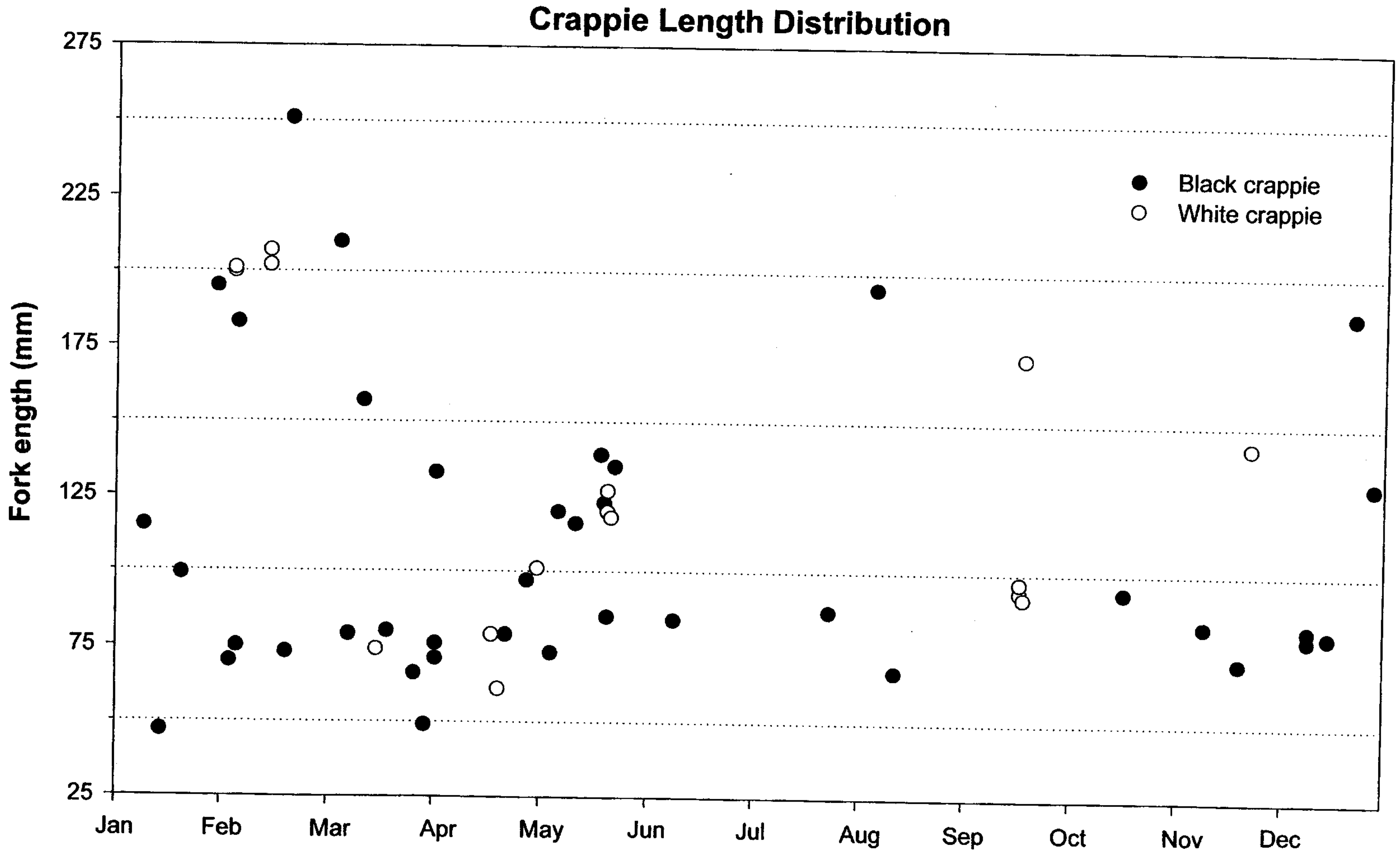

Figure A40. Within-year fork length distributions for black crappie (*Pomoxis nigromaculatus*) and white crappie (*Pomoxis annularis*) captured by rotary-screw traps at Red Bluff Diversion Dam (RK 391), Sacramento River, CA. Data summarized from July 1994 through June 2000.

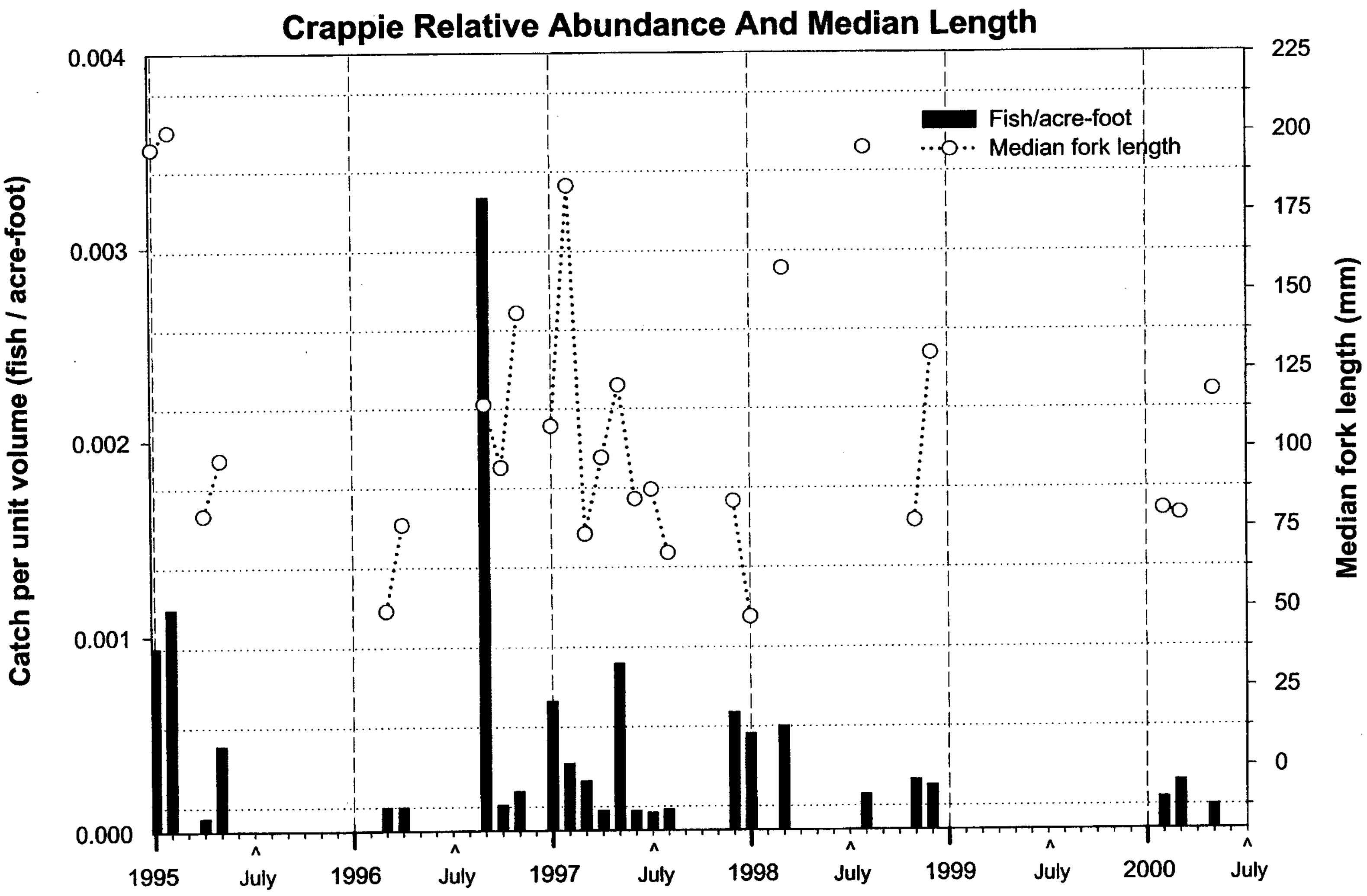

Figure A41. Combined relative abundance (fish/acrefoot) and median length for black crappie (*Pomoxis nigromaculatus*) and white crappie (*P. annularis*) captured by rotary-screw traps at Red Bluff Diversion Dam (RK 391), Sacramento River, CA. Data summarized from January 1995 through June 2000.

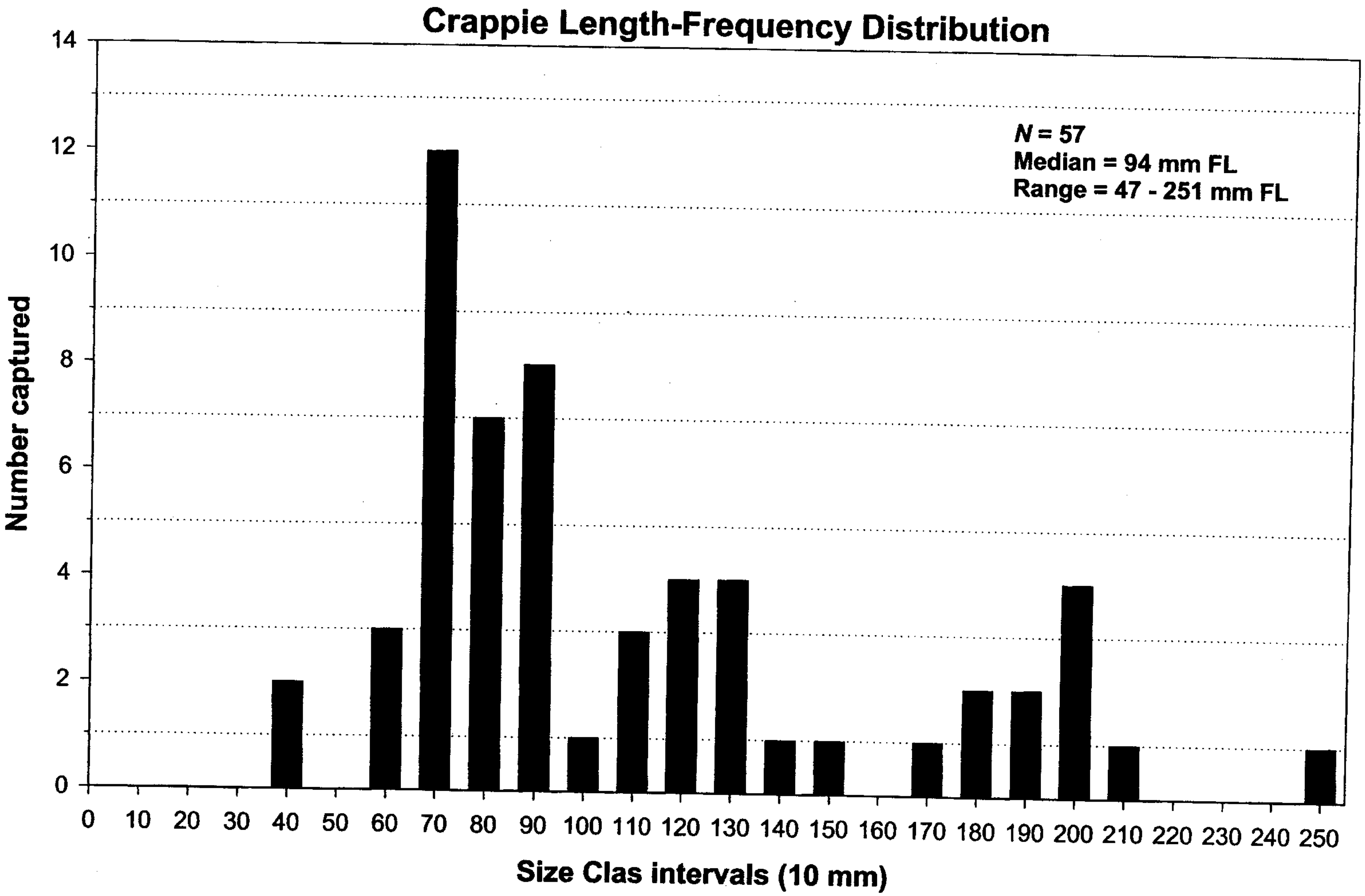

Figure A42. Combined length-frequency distribution for black crappie (*Pomoxis nigromaculatus*) and white crappie (*P. annularis*) captured by rotary-screw traps at Red Bluff Diversion Dam (RK 391), Sacramento River, CA. Size class intervals are reported in 10 mm increments. Data summarized from July 1994 through June 2000.

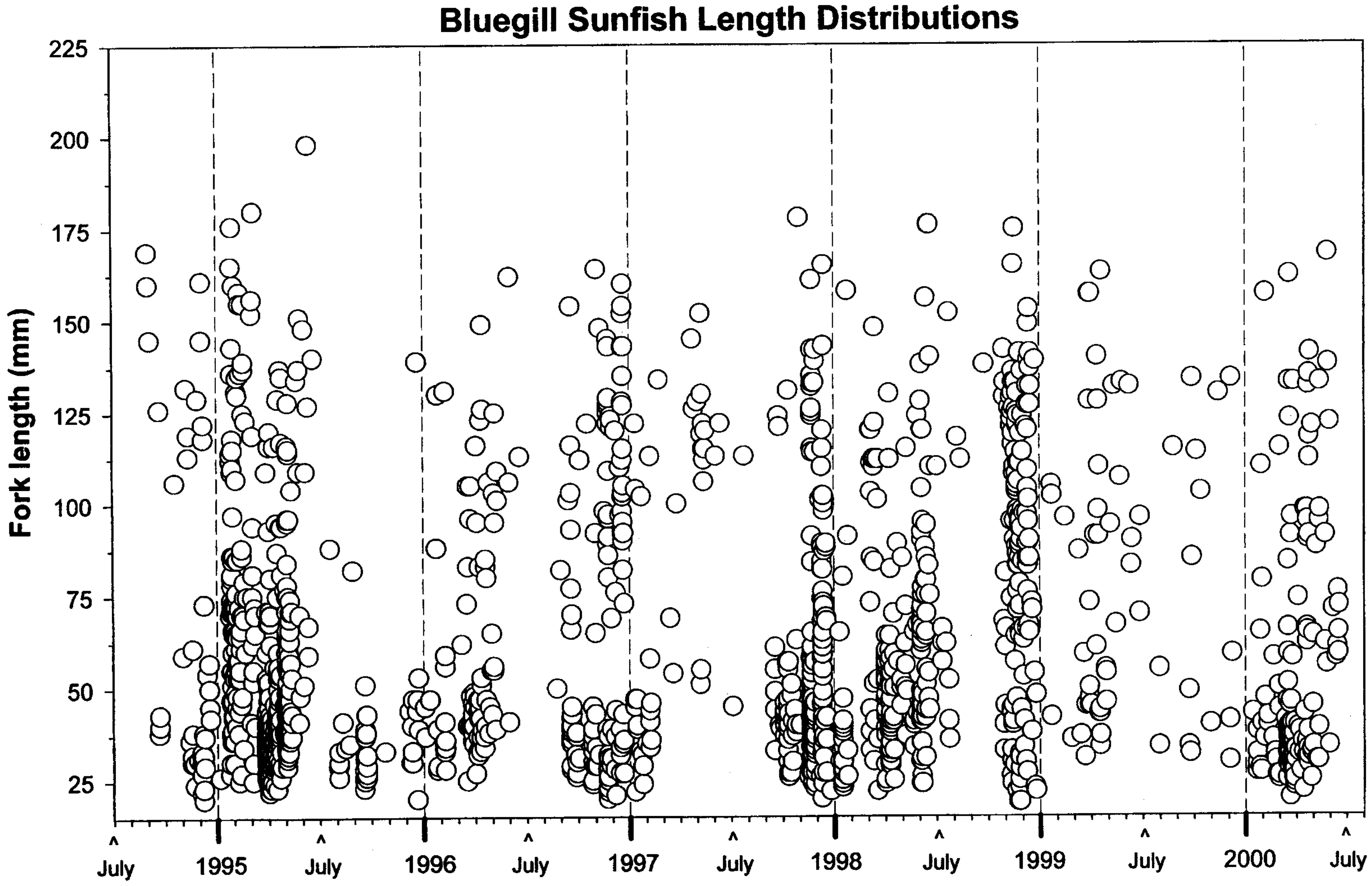

Figure A43. Among-year fork length distributions for bluegill sunfish (*Lepomis macrochirus*) captured by rotary-screw traps at Red Bluff Diversion Dam (RK 391), Sacramento River, CA. Data summarized from July 1994 through June 2000.

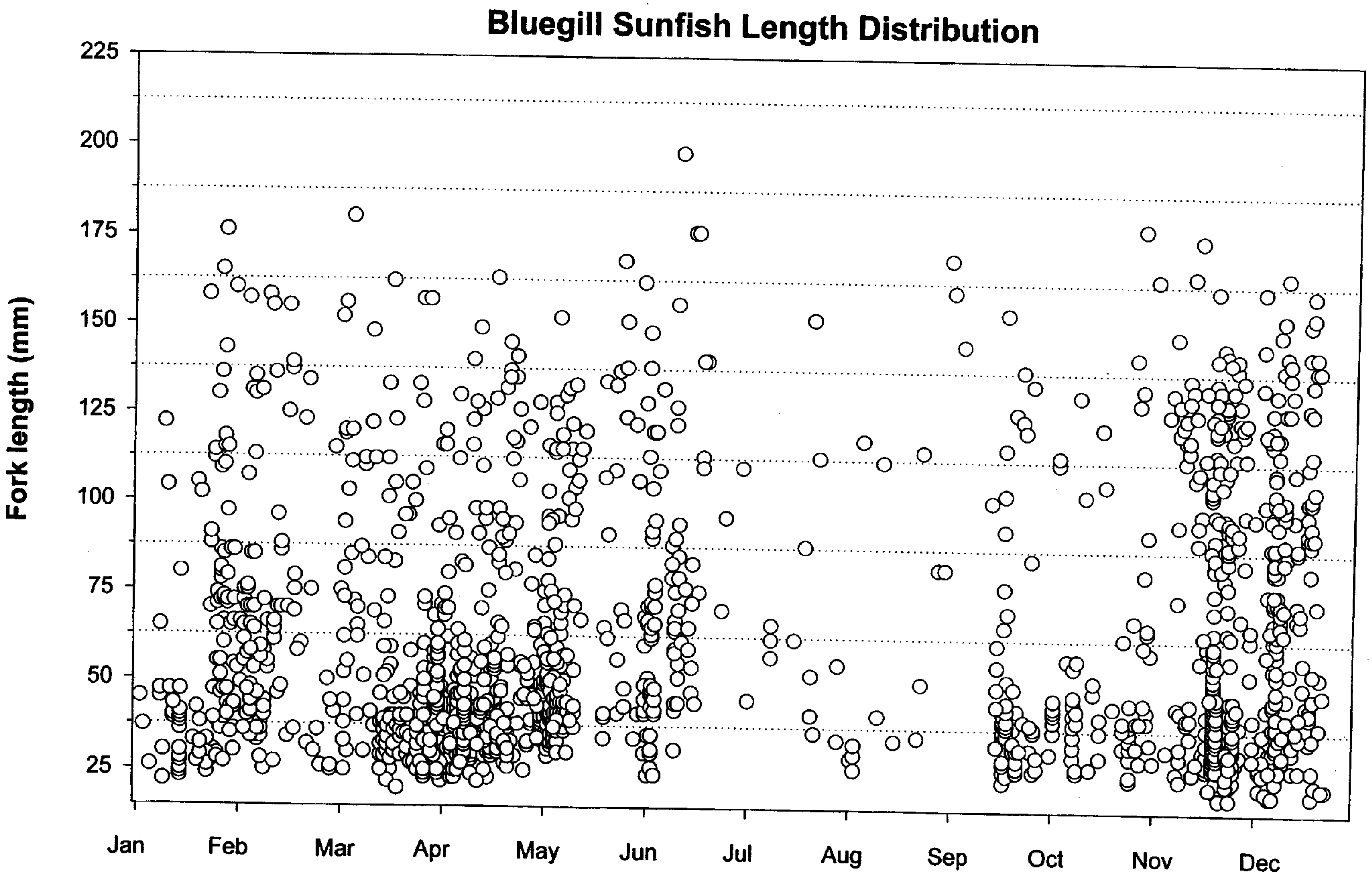

Figure A44. Within-year fork length distributions for bluegill sunfish (*Lepomis macrochirus*) captured by rotary-screw traps at Red Bluff Diversion Dam (RK 391), Sacramento River, CA. Data summarized from July 1994 through June 2000.

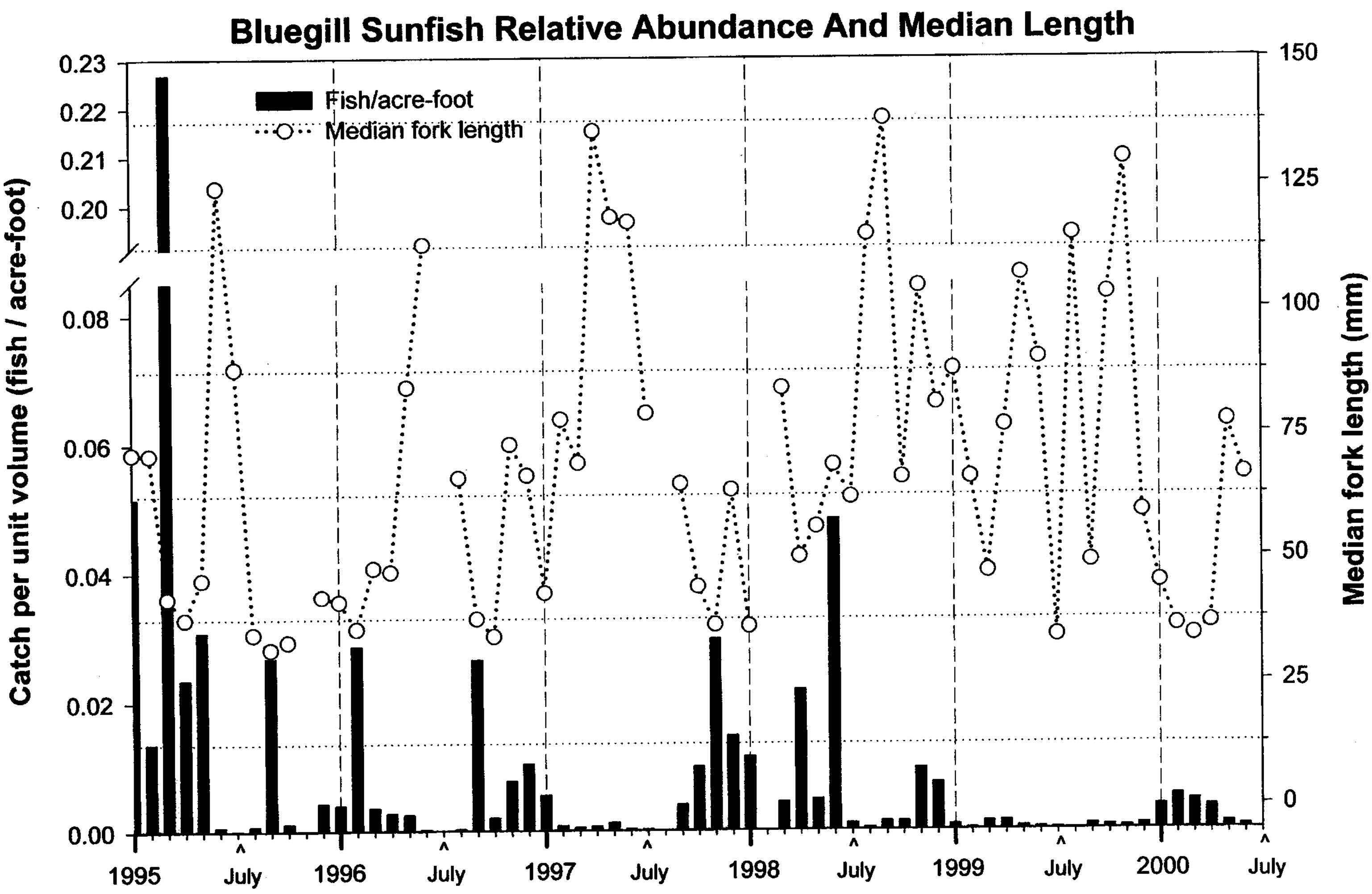

Figure A45. Relative abundance (fish/acrefoot) and median length for bluegill sunfish (*Lepomis macrochirus*) captured by rotary-screw traps at Red Bluff Diversion Dam (RK 391), Sacramento River, CA. Data summarized from January 1995 through June 2000.

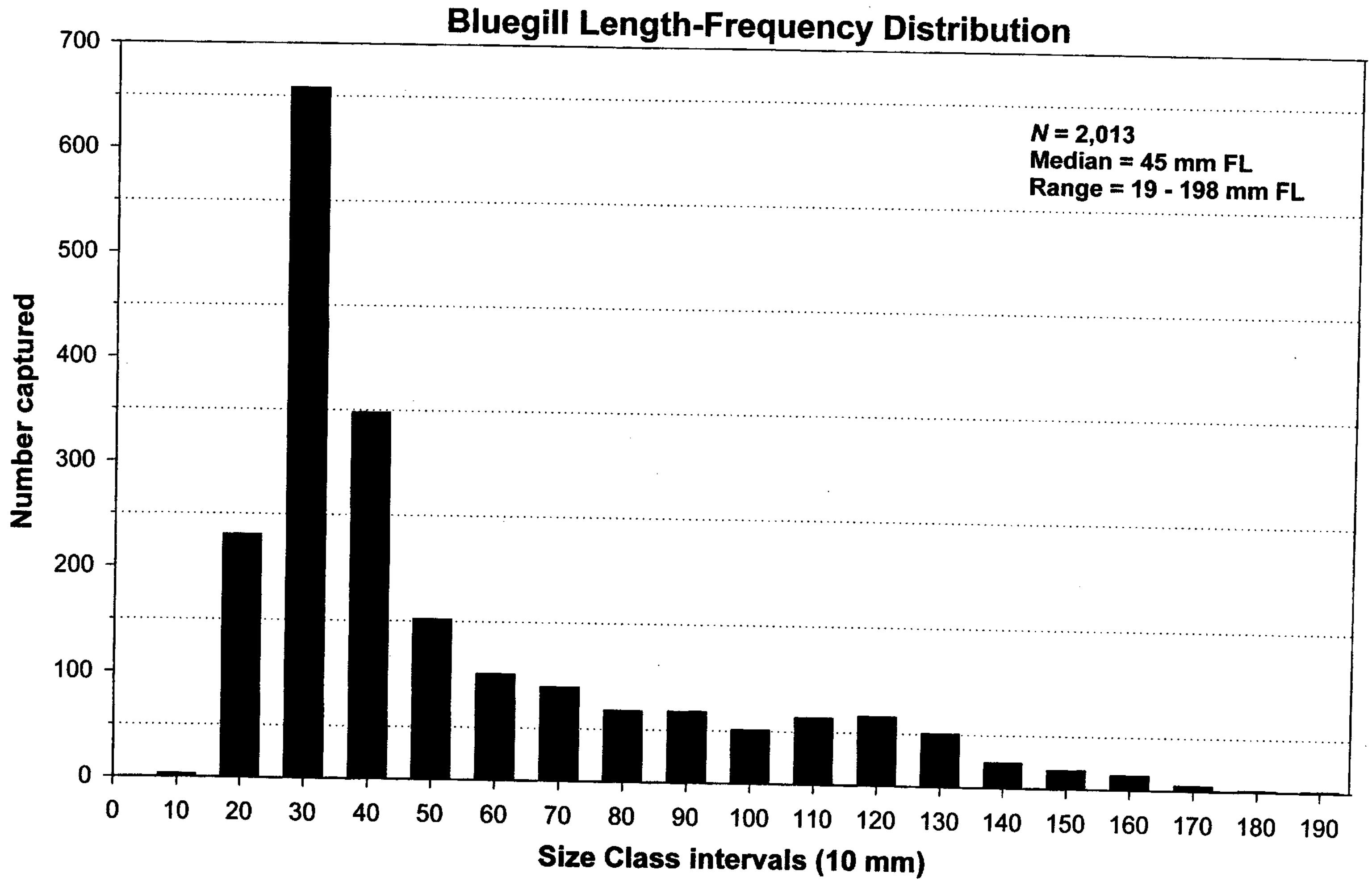

Figure A46. Length-frequency distribution for bluegill sunfish (*Lepomis macrochirus*) captured by rotary-screw traps at Red Bluff Diversion Dam (RK 391), Sacramento River, CA. Size class intervals reported in 10 mm increments. Data summarized from July 1994 through June 2000.

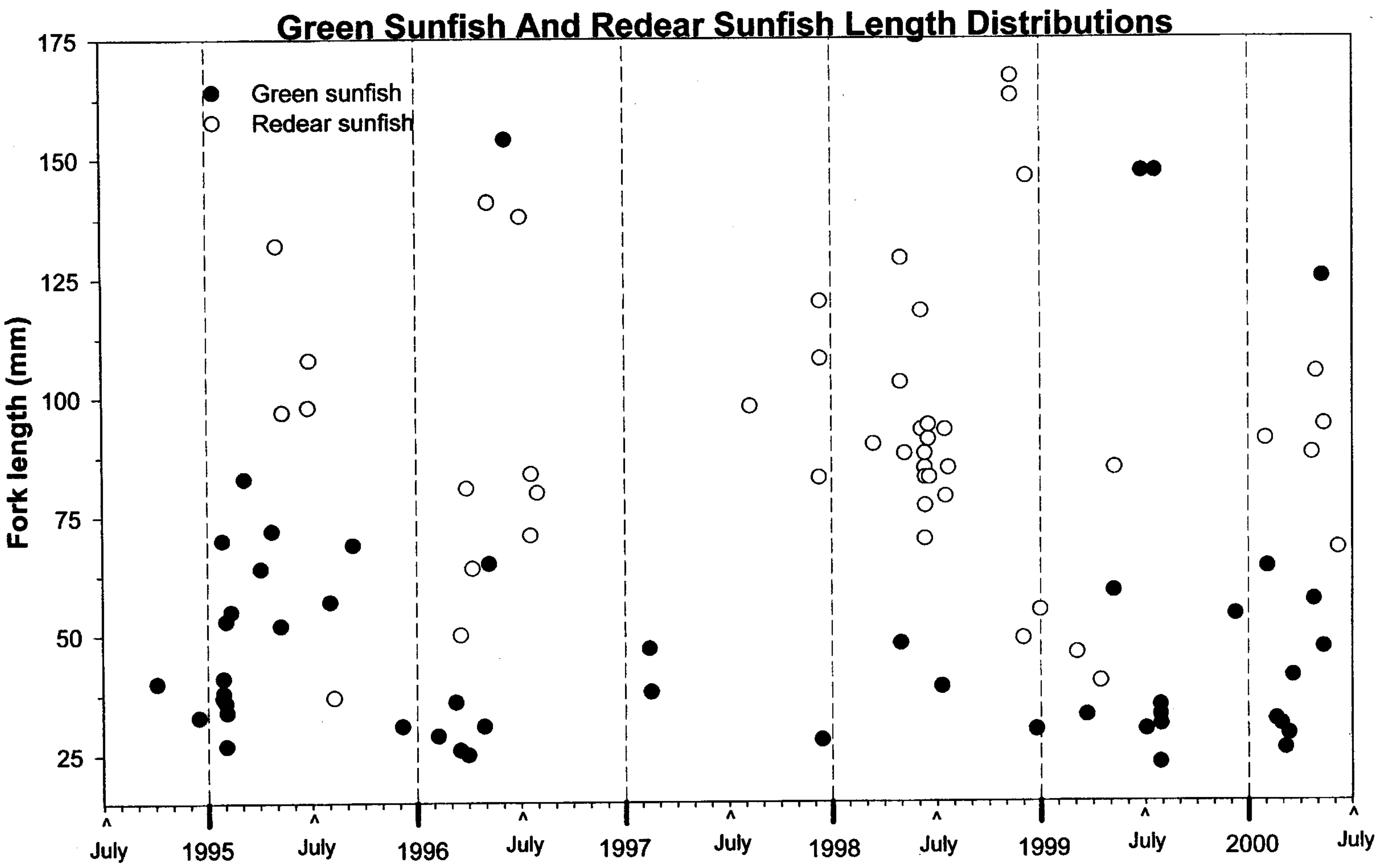

Figure A47. Among-year fork length distributions for green sunfish (*Lepomis cyanellus*) and redear sunfish (*L. microlophus*) captured by rotary-screw traps at Red Bluff Diversion Dam (RK 391), Sacramento River, CA. Data summarized from July 1994 through June 2000.

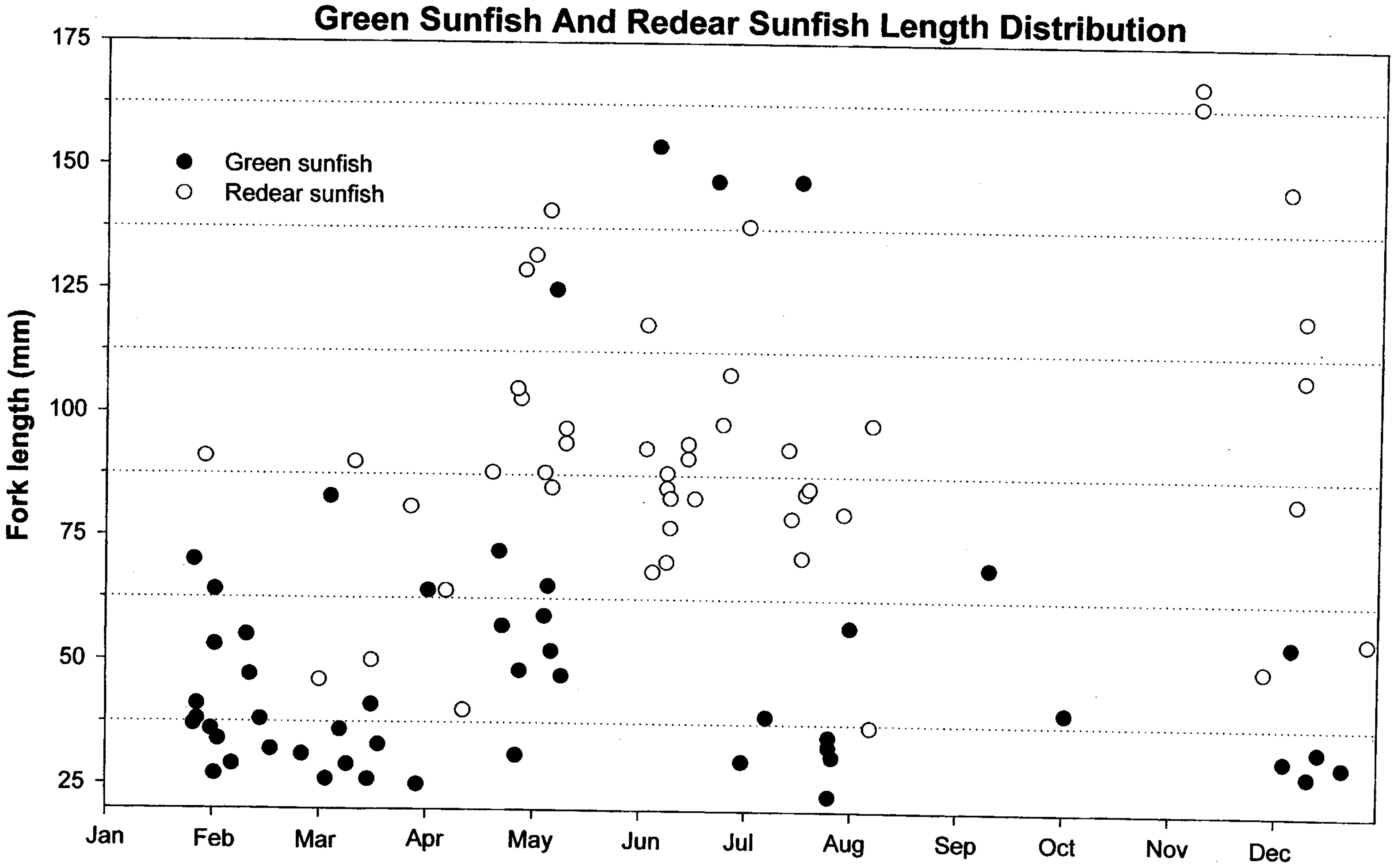

Figure A48. Within-year fork length distributions for green sunfish (*Lepomis cyanellus*) and redear sunfish (*L. microlophus*) captured by rotary-screw traps at Red Bluff Diversion Dam (RK 391), Sacramento River, CA. Data summarized from July 1994 through June 2000.

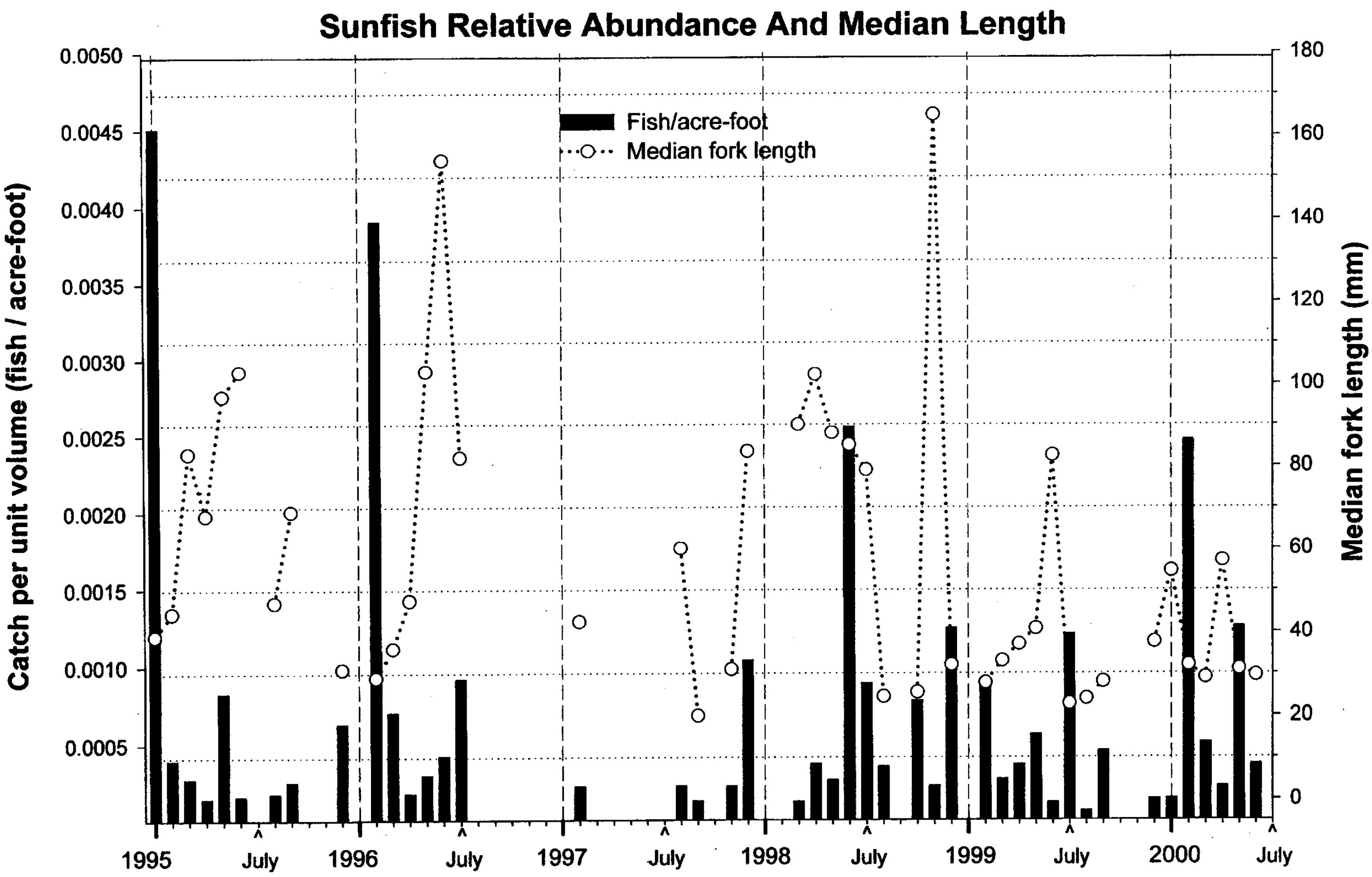

Figure A49. Combined relative abundance (fish/acrefoot) and median length for green sunfish (*Lepomis cyanellus)* and redear sunfish (*L. microlophus*) captured by rotary-screw traps at Red Bluff Diversion Dam (RK 391), Sacramento River, CA. Data summarized from January 1995 through June 2000.

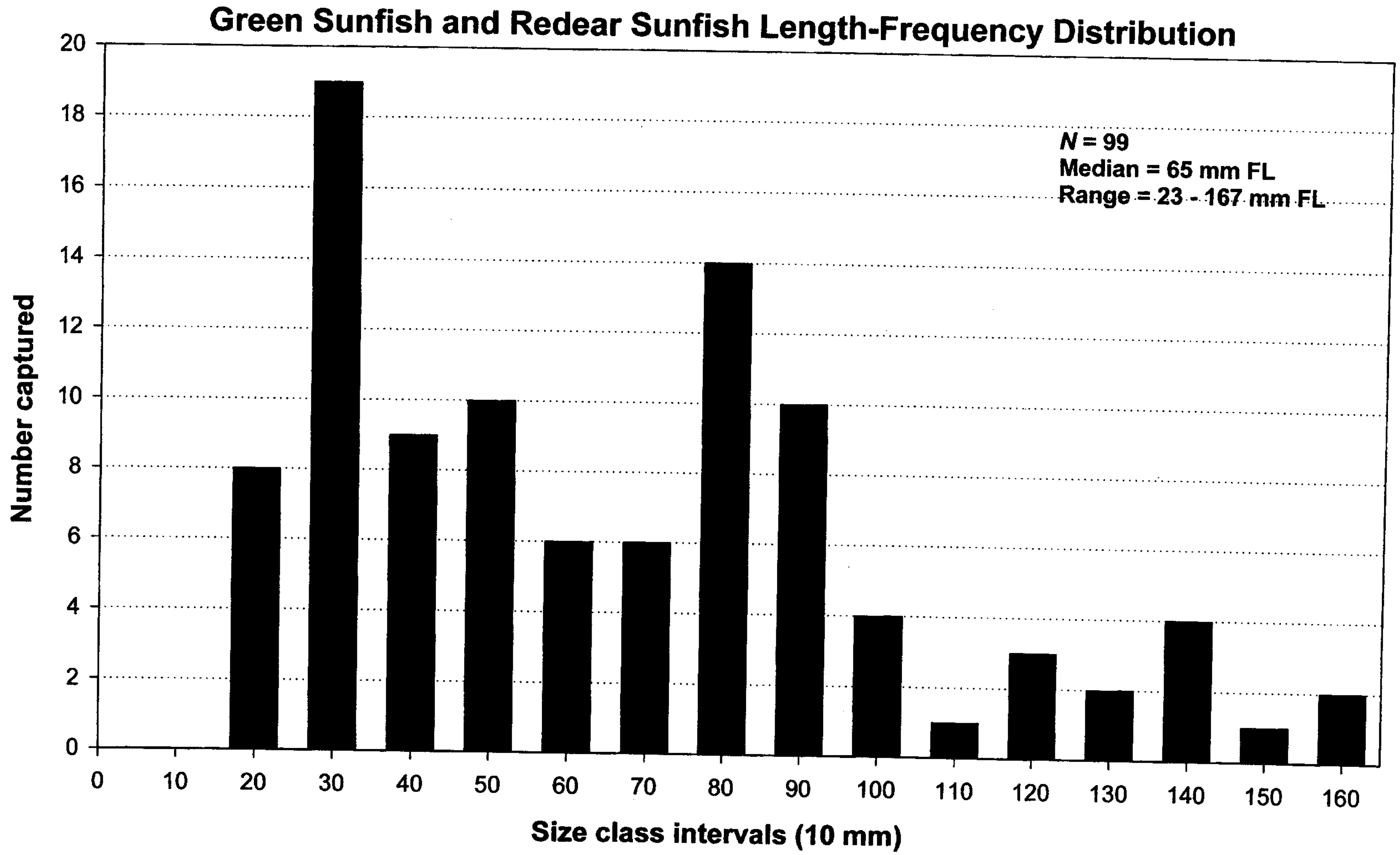

Figure A50. Combined length-frequency distribution for green sunfish (*Lepomis cyanellus*) and redear sunfish (*L. microlophus*) sunfish captured by rotary-screw traps at Red Bluff Diversion Dam (RK 391), Sacramento River, CA. Size class intervals are reported in 10 mm increments. Data summarized from July 1994 through June 2000.

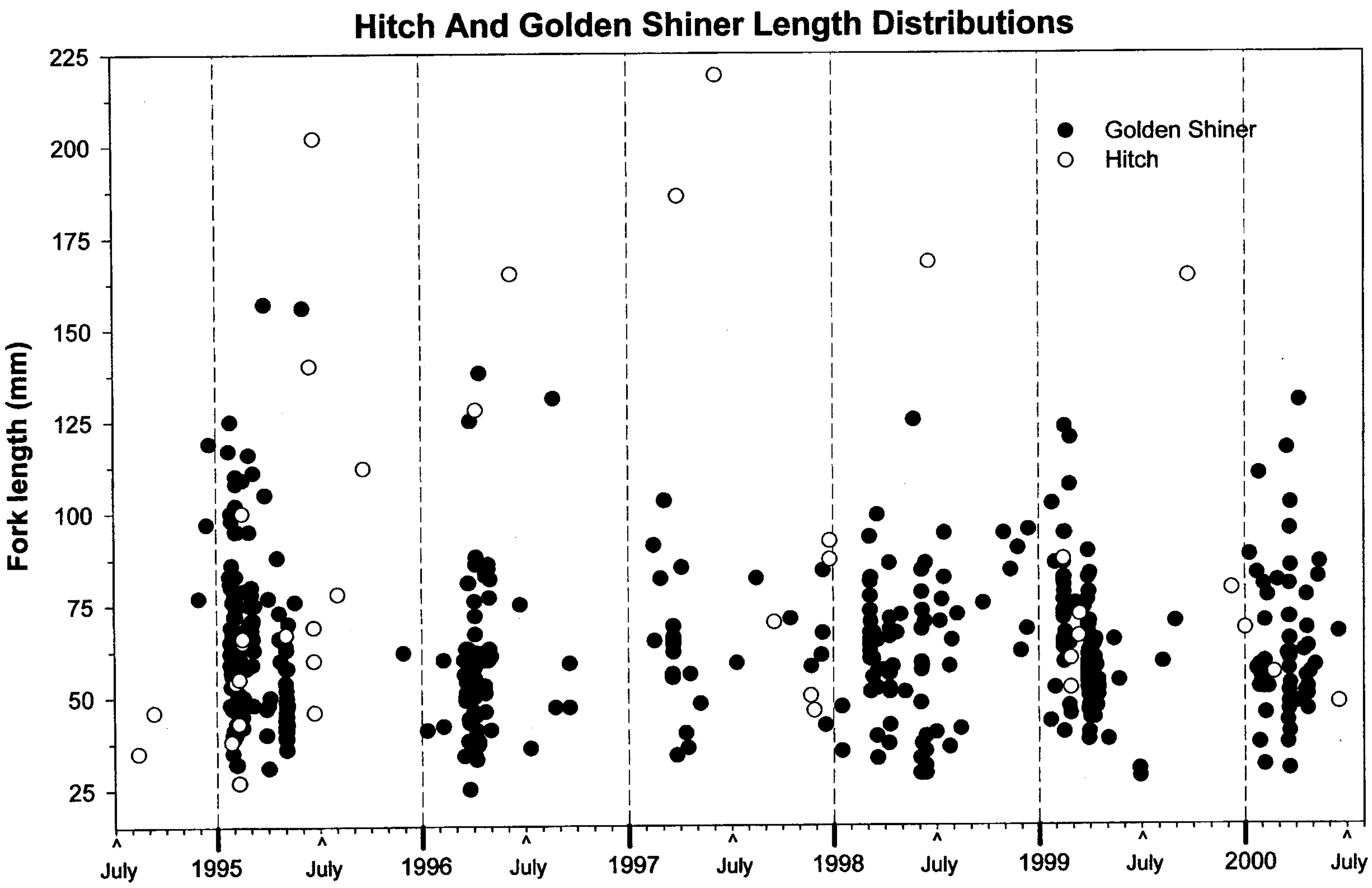

Figure A51. Among-year fork length distributions for golden shiner (*Notemigonus crysoleucas*) and hitch (*Lavinia exilicauda*) captured by rotary-screw traps at Red Bluff Diversion Dam (RK 391), Sacramento River, CA. Data summarized from July 1994 through June 2000.

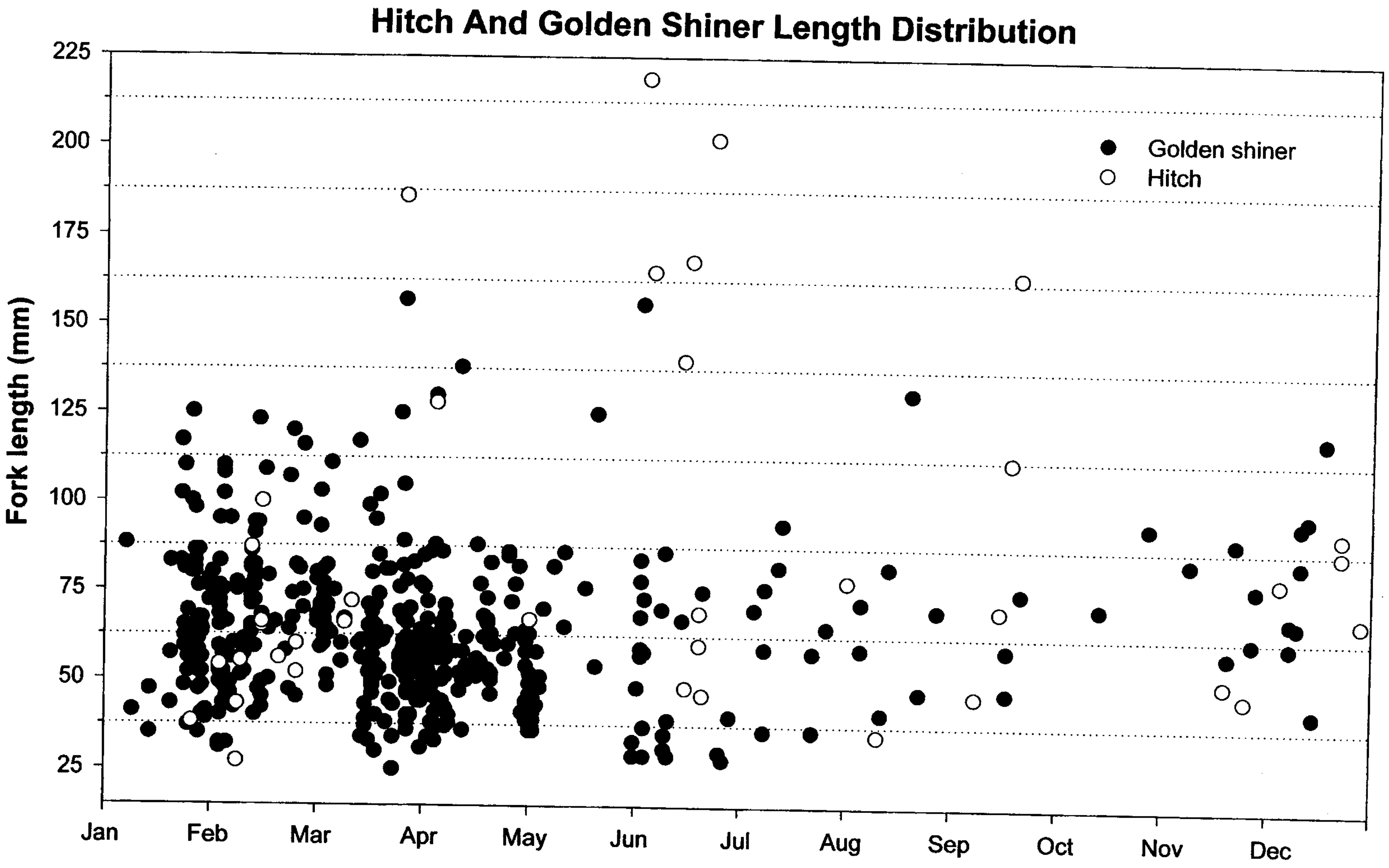

Figure A52. Within-year fork length distributions for golden shiner (*Notemigonus crysoleucas*) and hitch (*Lavinia exilicauda*) captured by rotary-screw traps at Red Bluff Diversion Dam (RK 391), Sacramento River, CA. Data summarized from July 1994 through June 2000.

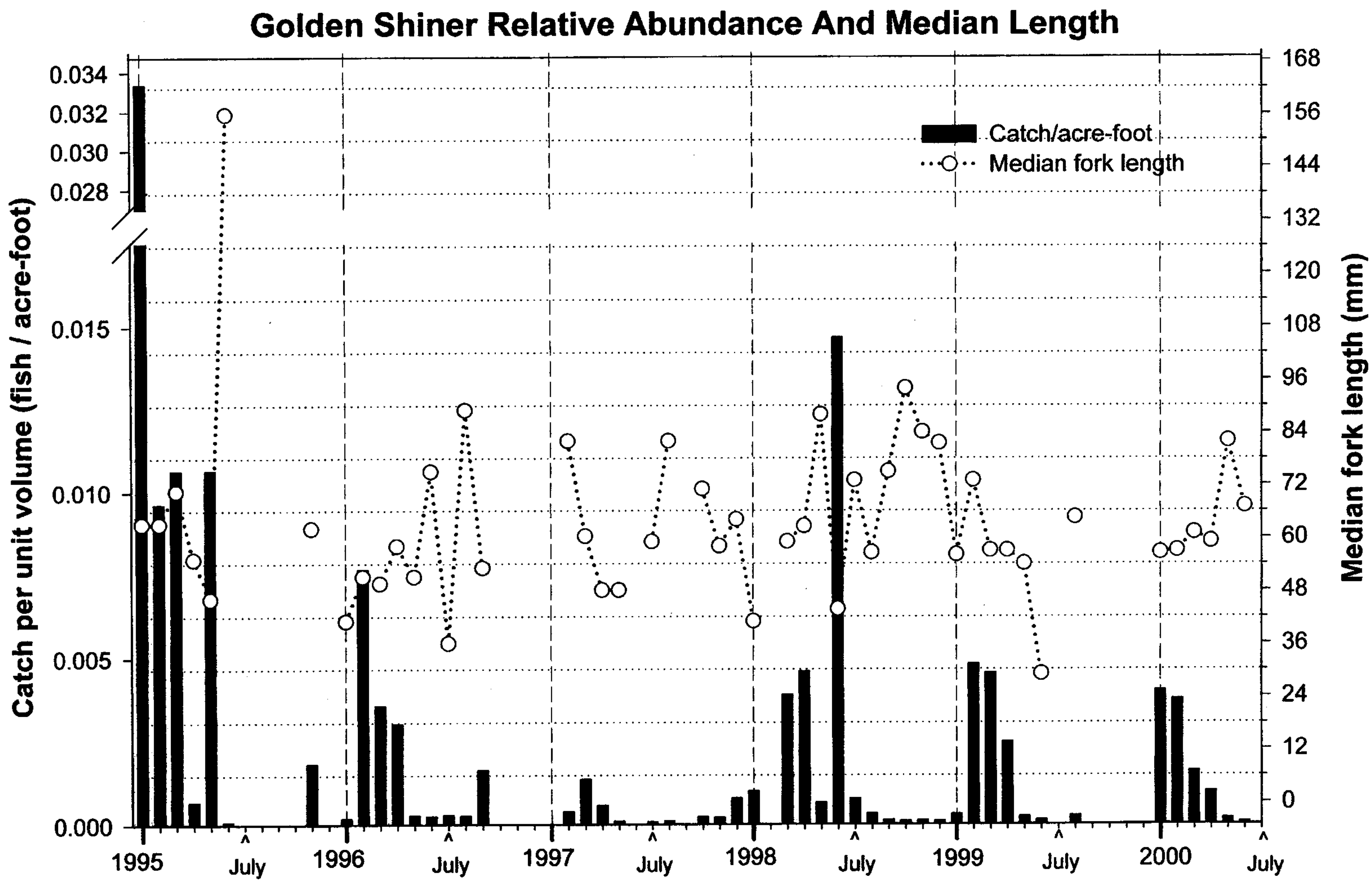

Figure A53. Relative abundance (fish/acrefoot) and median length for golden shiner (*Notemigonus crysoleucas*) captured by rotary-screw traps at Red Bluff Diversion Dam (RK 391), Sacramento River, CA. Data summarized from January 1995 through June 2000.

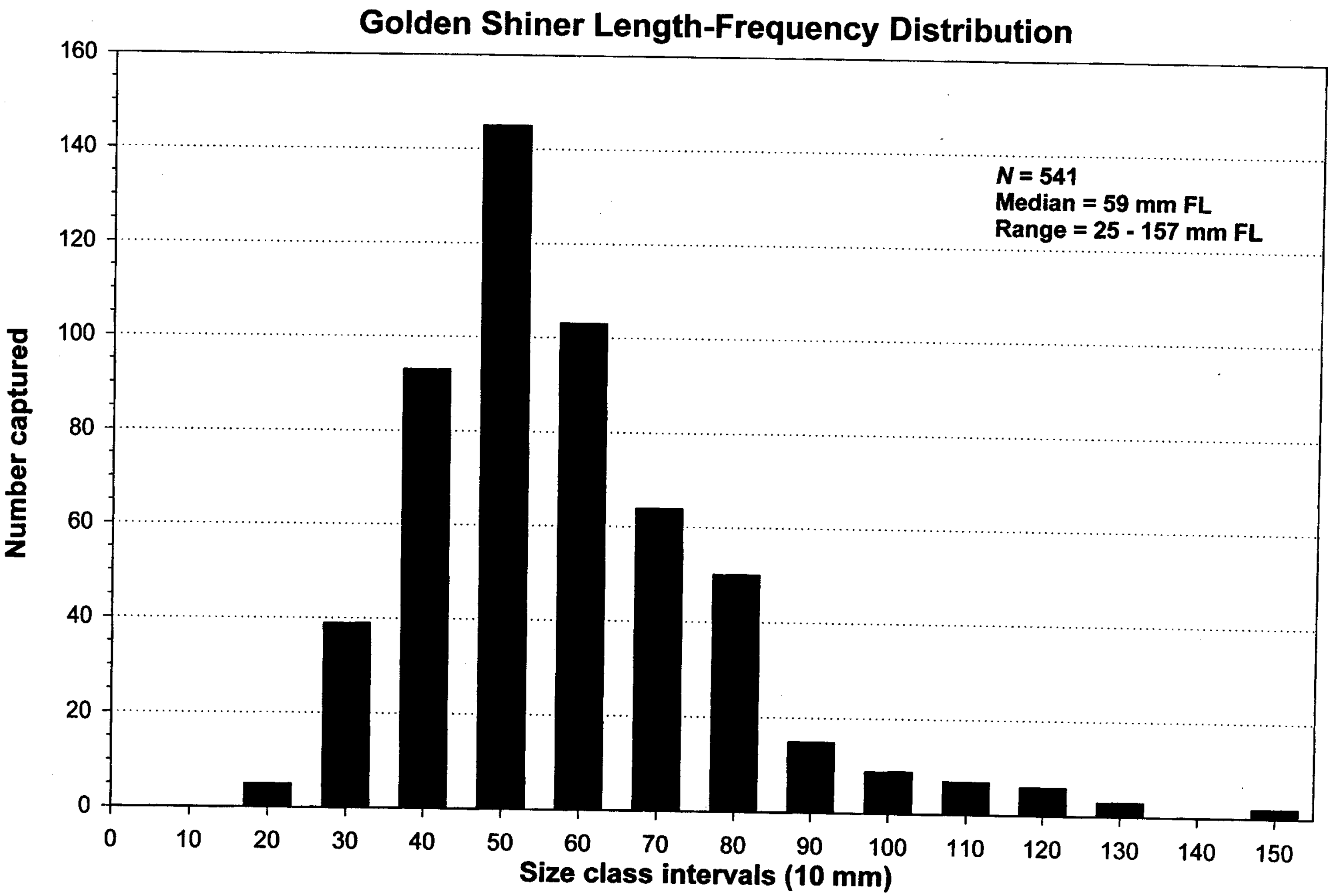

Figure A54. Length-frequency distribution for golden shiner (*Notemigonous crysoleucas*) captured by rotary-screw traps at Red Bluff Diversion Dam (RK 391), Sacramento River, CA. Size class intervals reported in 10mm increments. Data summarized from July 1994 through June 2000.

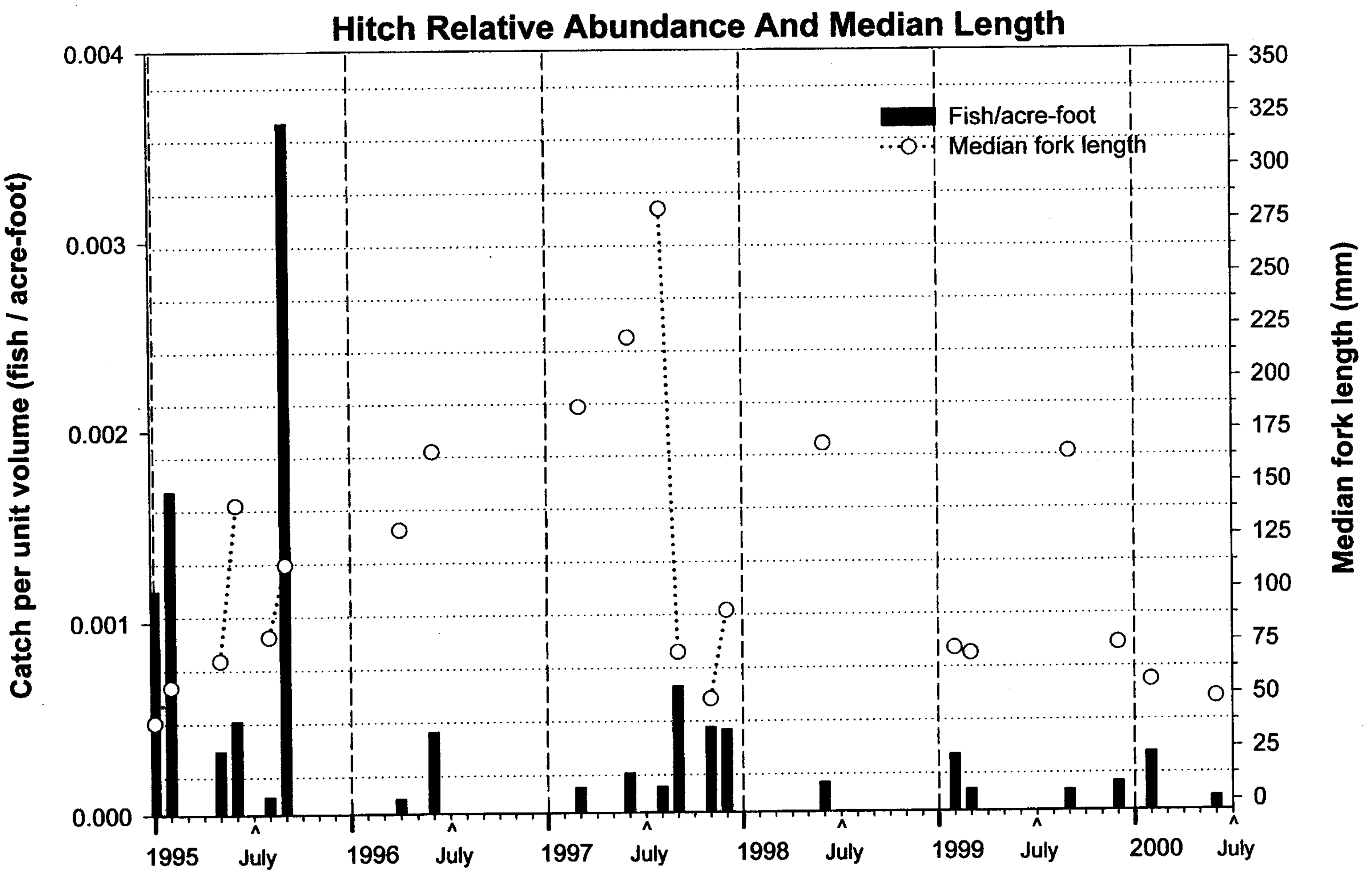

Figure A55. Relative abundance (fish/acre-foot) and median fork length for hitch (*Lavinia exilicauda*) captured by rotary-screw traps at Red Bluff Diversion Dam (RK 391), Sacramento River, CA. Data summarized from January 1995 through June 2000.

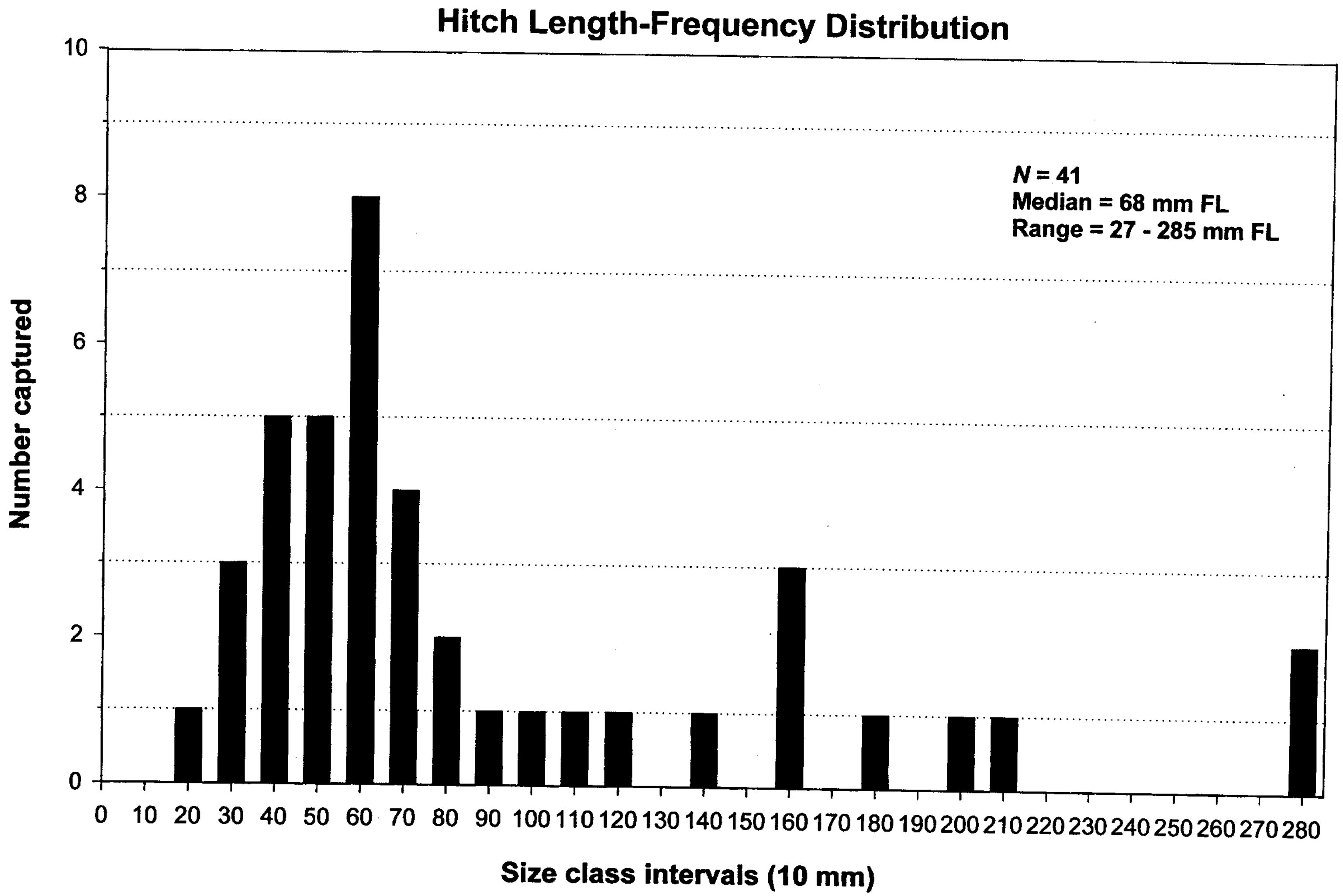

Figure A56. Length-frequency distribution for hitch (*Lavinia exilicauda*) captured by rotary-screw traps at the Red Bluff Diversion Dam (RK 391), Sacramento River, CA. Size class intervals reported in 10 mm increments. Data summarized from January 1995 through June 2000.

Tule Perch Length Distributions

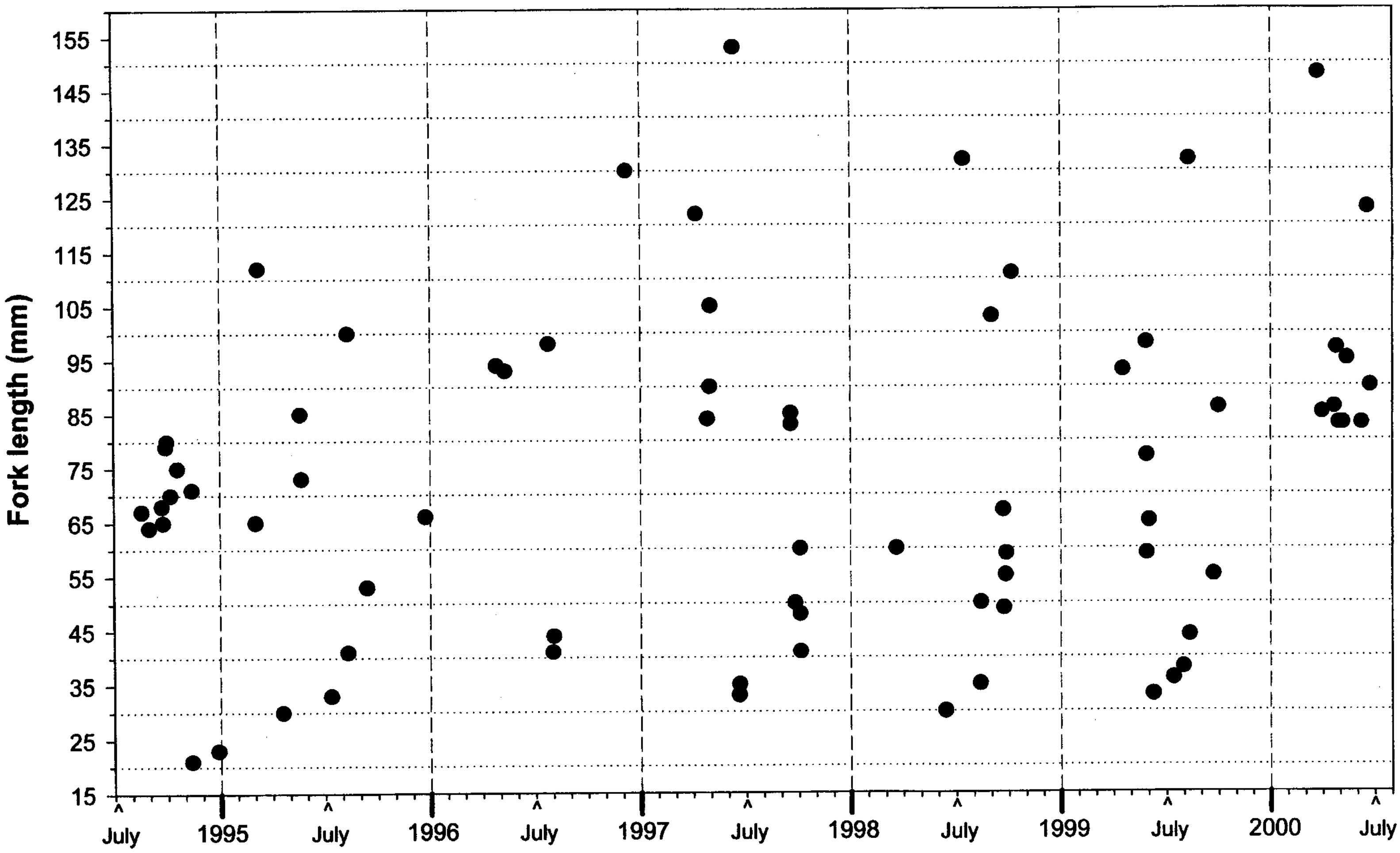

Figure A57. Among-year fork length distributions for Tule perch (*Hysterocarpus traski*) captured by rotary-screw traps at Red Bluff Diversion Dam (RK 391), Sacramento River, CA. Data summarized from July 1994 through June 2000.

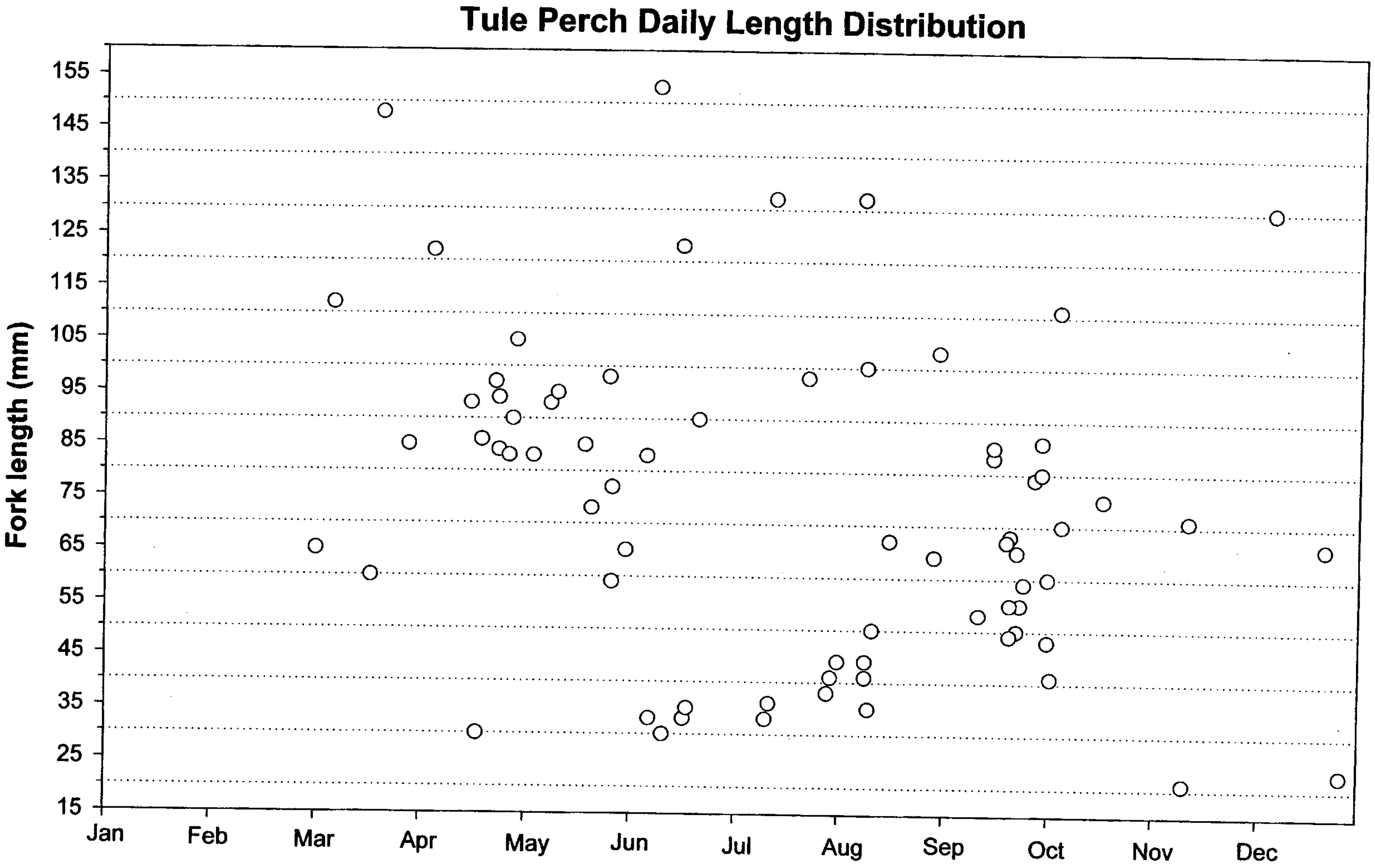

Figure A58. Within-year fork length distribution for Tule perch (*Hysterocarpus traski*) captured by rotary-screw traps at Red Bluff Diversion Dam (RK 391), Sacramento River, CA. Data summarized from July 1994 through June 2000.

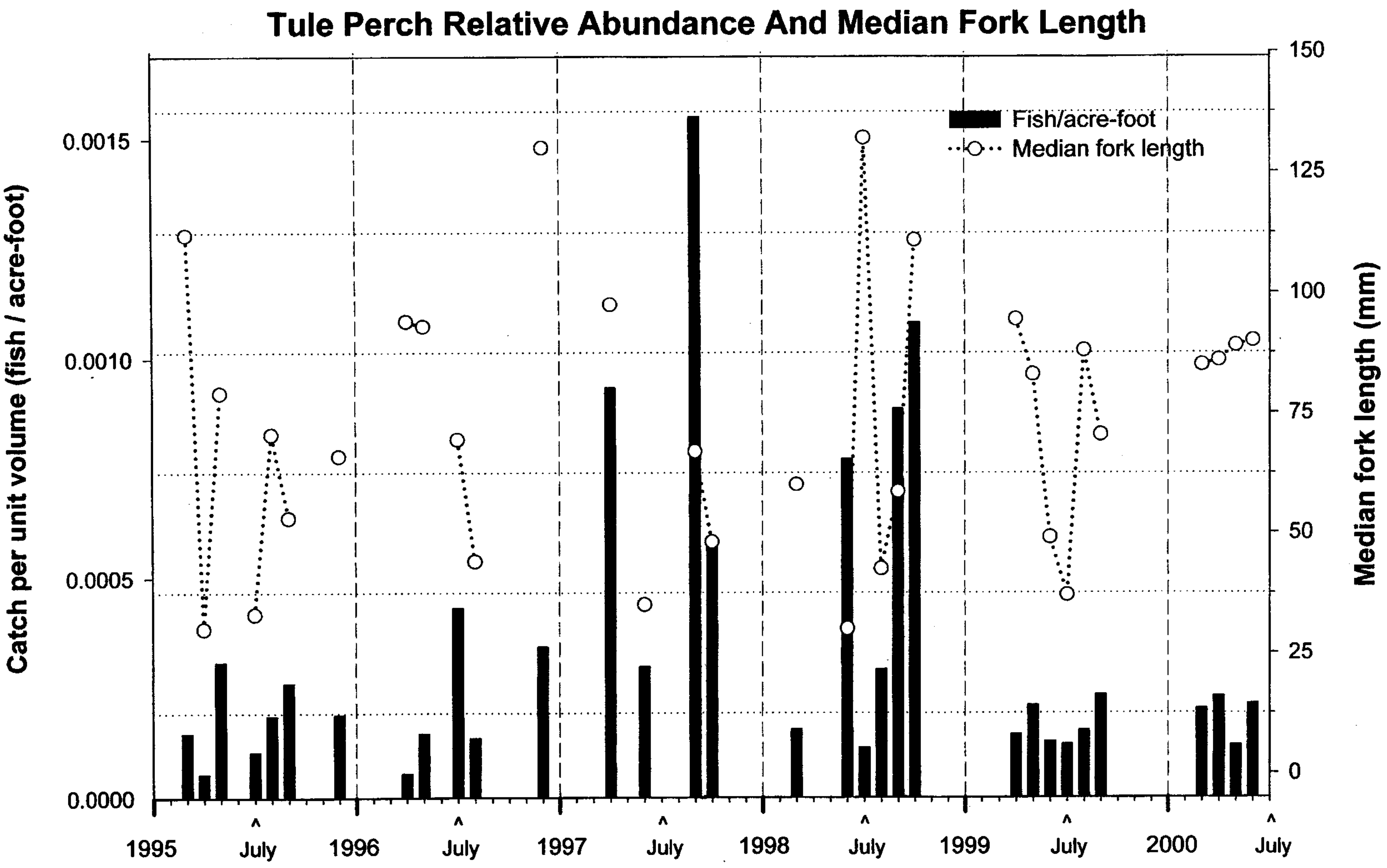

Figure A59. Relative abundance (fish/acre-foot) and median fork length for Tule perch (*Hysterocarpus traski*) captured by rotary-screw traps at Red Bluff Diversion Dam (RK 391), Sacramento River, CA. Data summarized from January 1995 through June 2000.

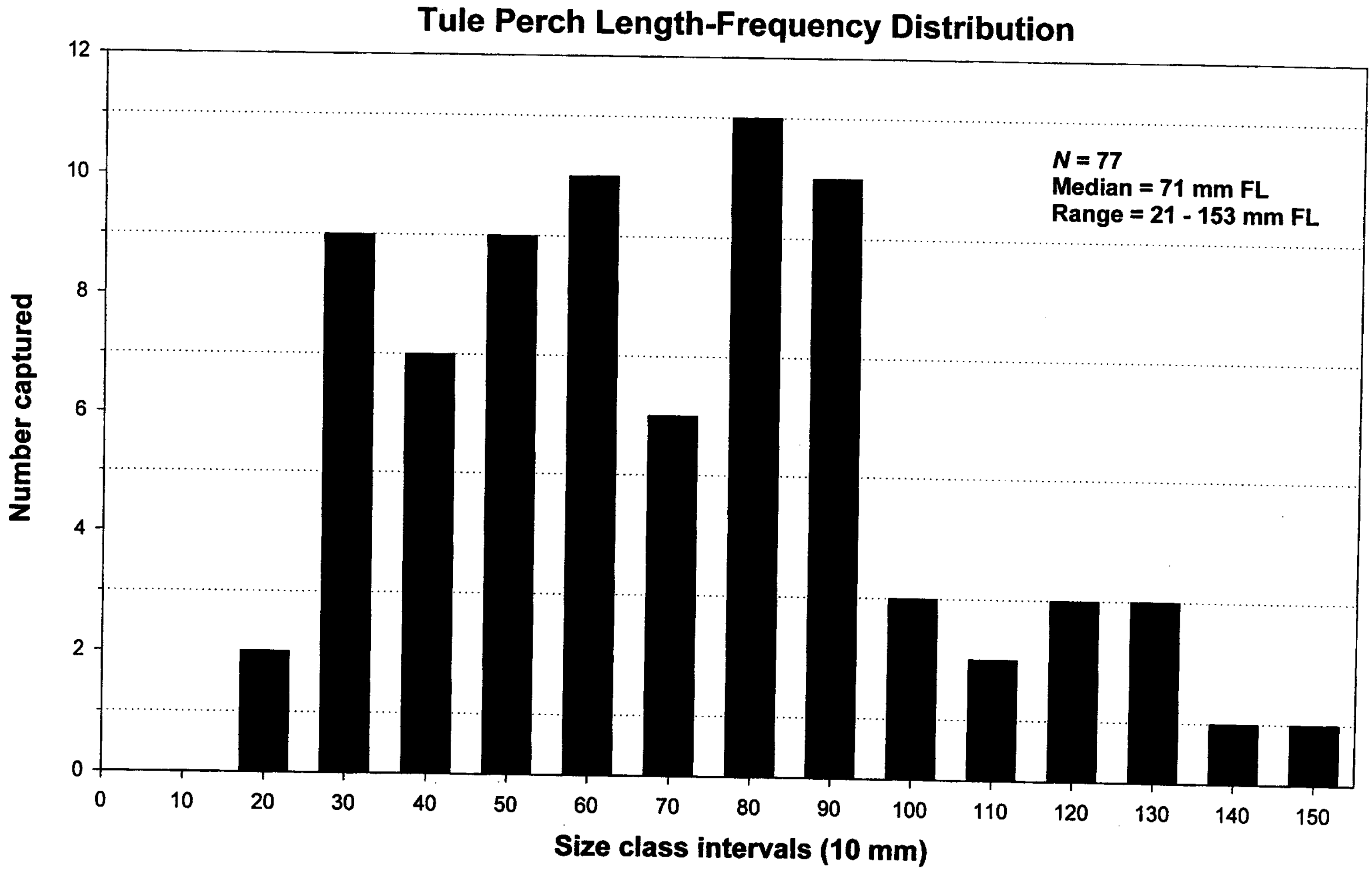

Figure A60. Length-frequency distribution for Tule perch (*Hysterocarpus traski*) captured by rotary-screw traps at Red Bluff Diversion Dam (RK 391), Sacramento River, CA. Size class intervals are reported in 10 mm increments. Data summarized from July 1994 through June 2000.

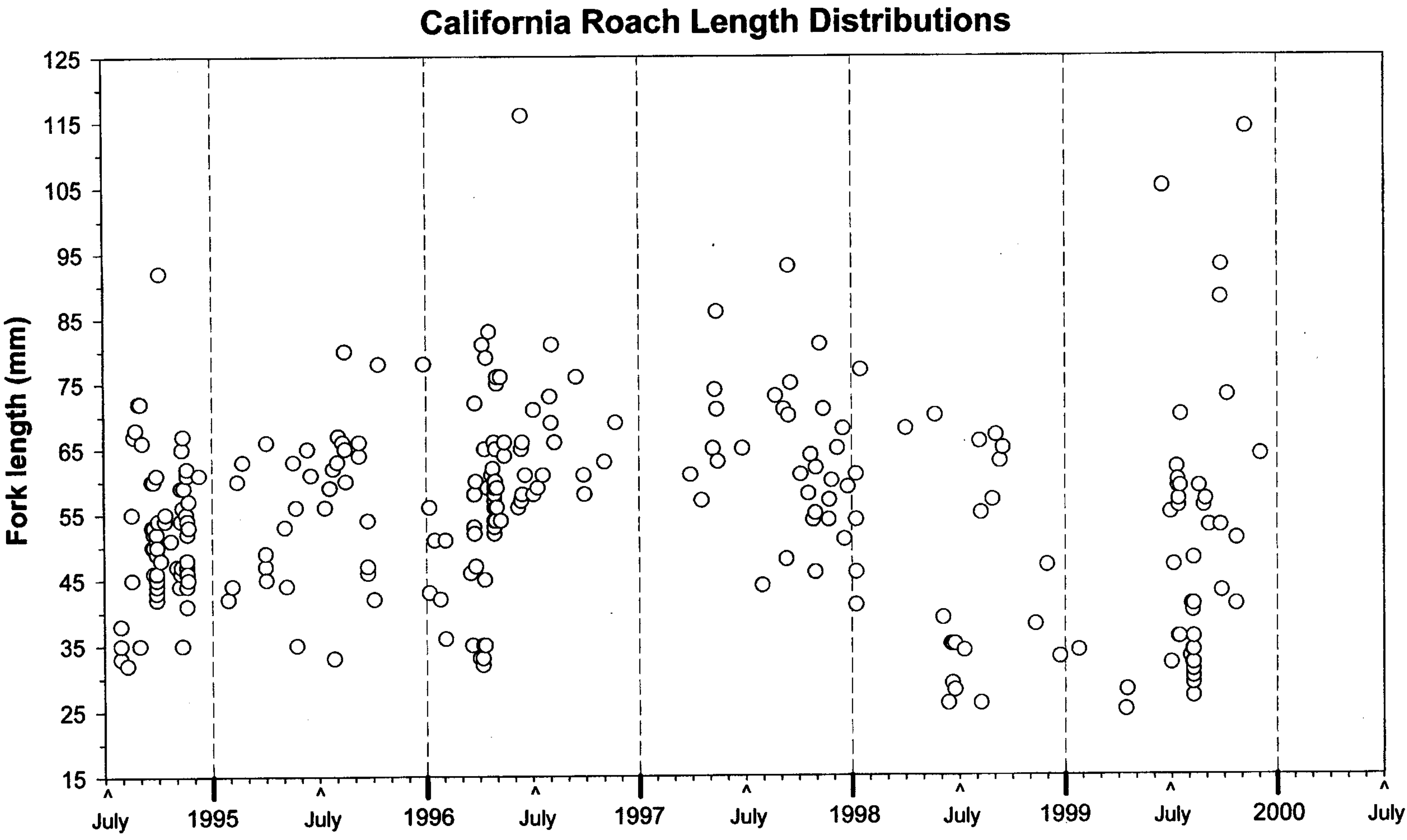

Figure A61. Among-year fork length distributions for California roach (*Hesperoleucus symmetricus*) captured by rotary-screw traps at Red Bluff Diversion Dam (RK 391), Sacramento River, CA. Data summarized from July 1994 through June 2000.

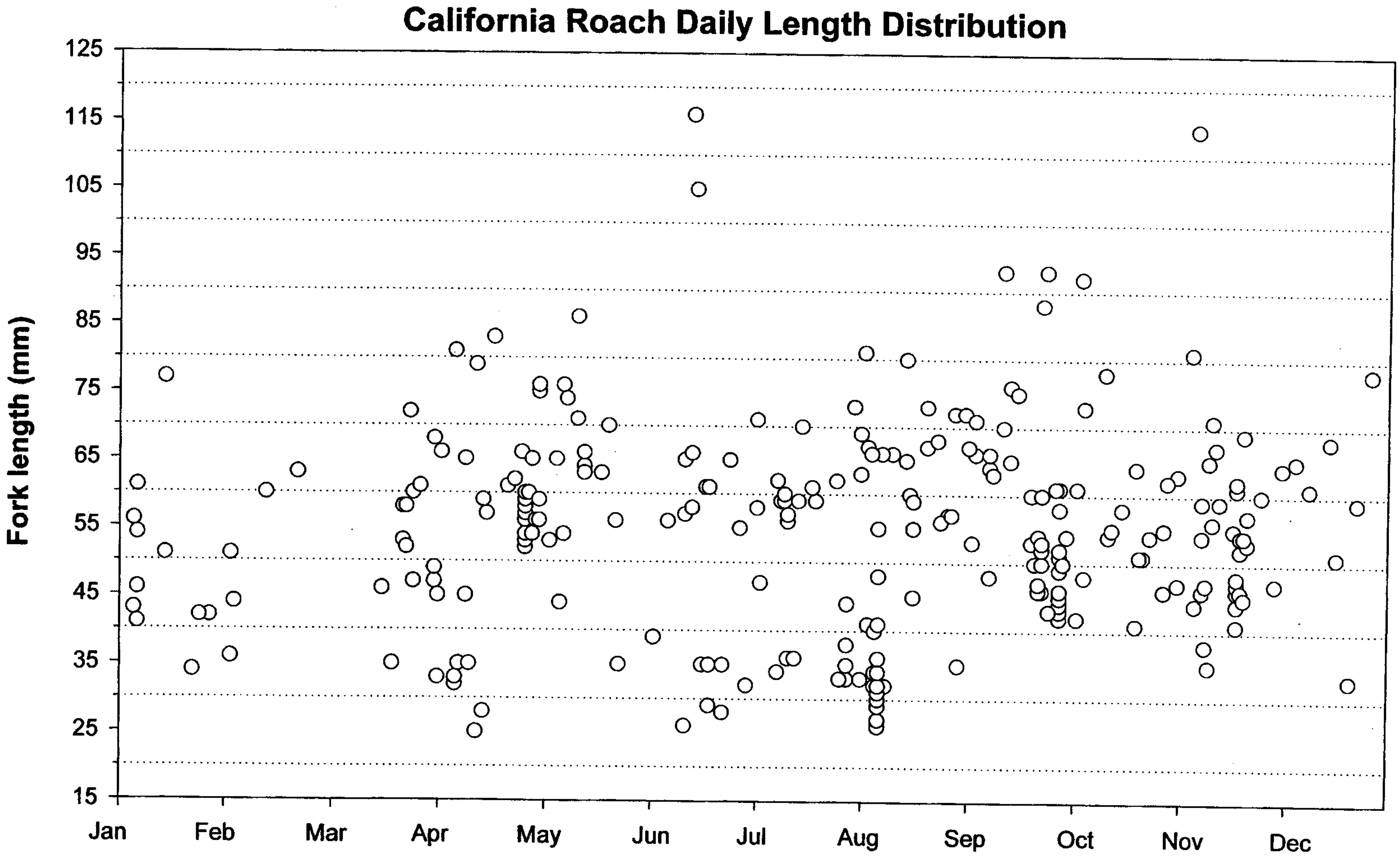

Figure A62. Within-year fork length distribution for California roach (*Hesperoleucus symmetricus*) captured by rotary-screw traps at Red Bluff Diversion Dam (RK 391), Sacramento River, CA. Data summarized from July 1994 through June 2000.

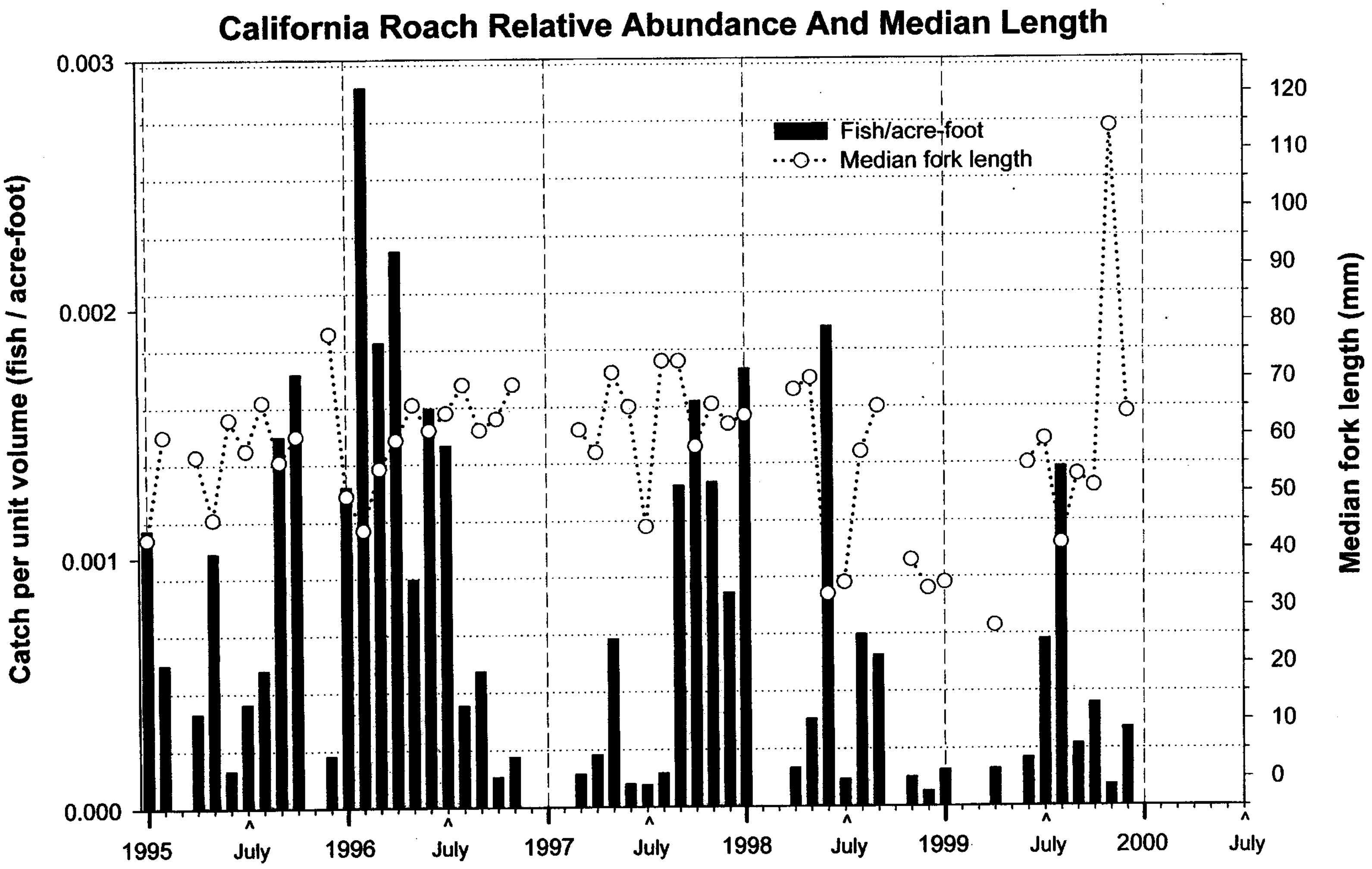

Figure A63. Relative abundance (fish/acre-foot) and median fork length for California roach (*Hesperoleucus symmetricus*) captured by rotary-screw traps at Red Bluff Diversion Dam (RK 391), Sacramento River, CA. Data summarized from January 1995 through June 2000.

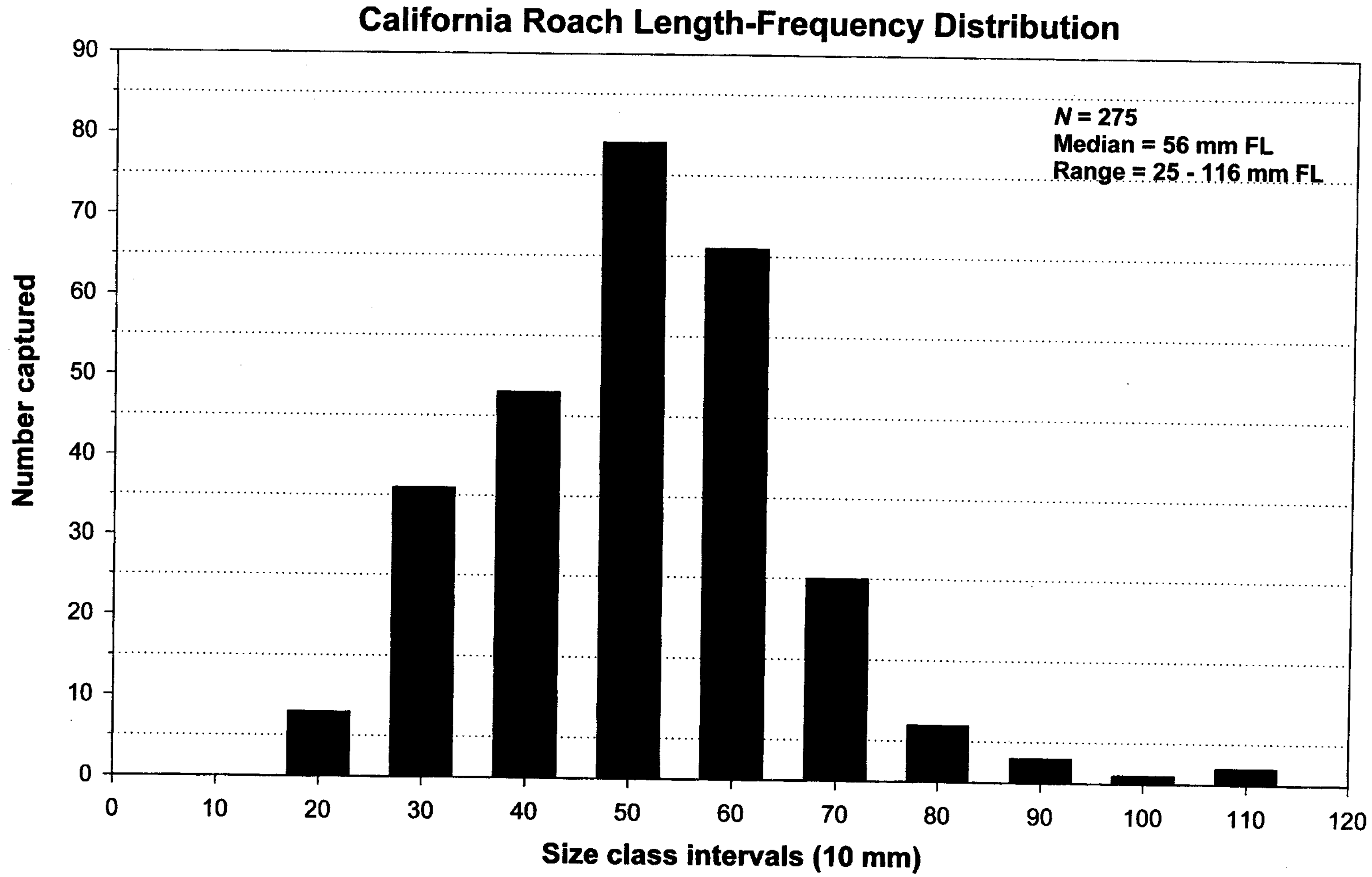

Figure A64. Length-frequency distribution for California roach (*Hesperoleucus symmetricus*) captured by rotary-screw traps at Red Bluff Diversion Dam (RK 391), Sacramento River, CA. Size class intervals reported in 10 mm increments. Data summarized from July 1994 through June 2000.

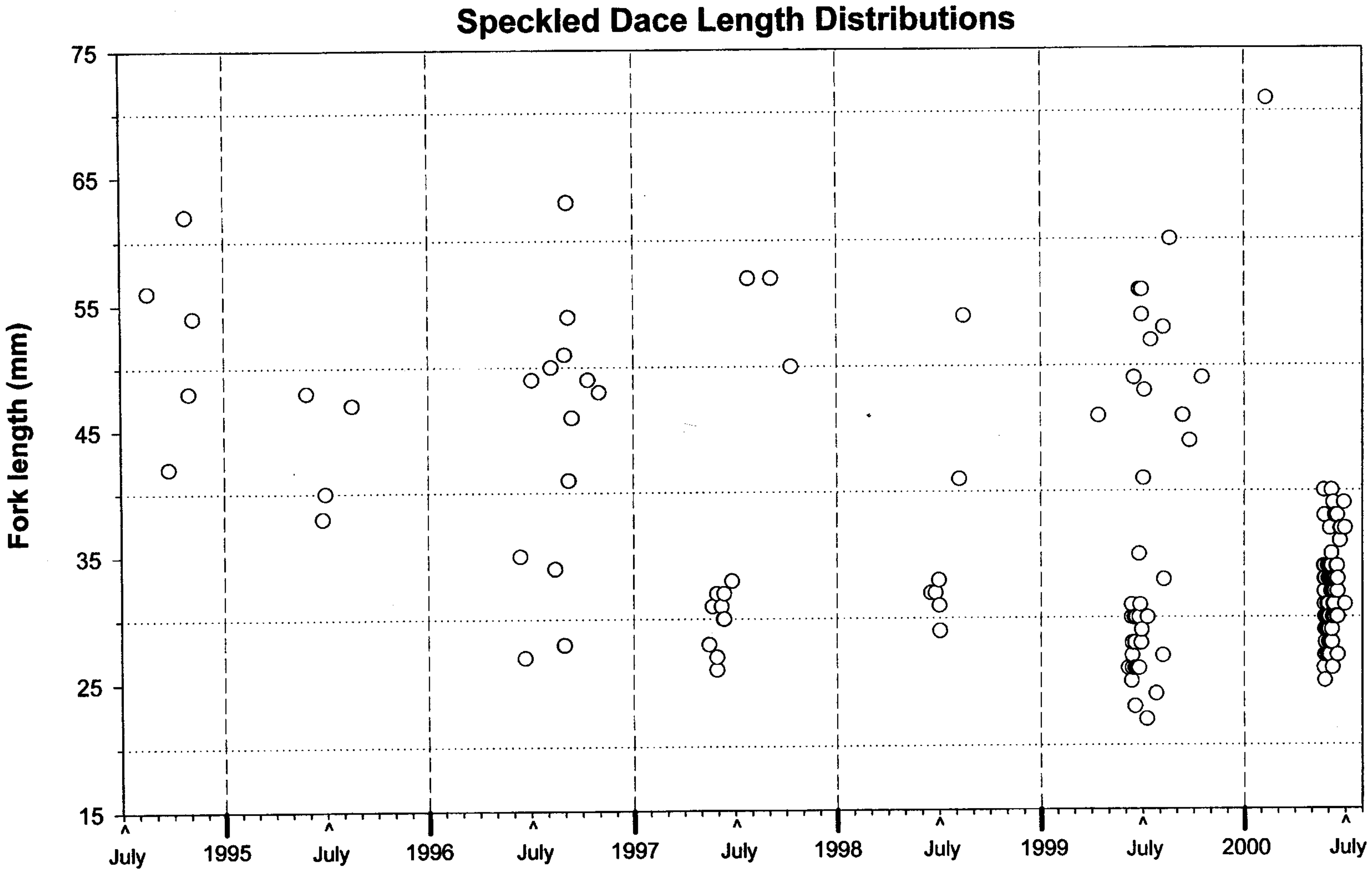

Figure A65. Among-year fork length distributions for speckled dace (*Rhinichthys osculus*) captured by rotary-screw traps at Red Bluff Diversion Dam (RK 391), Sacramento River, CA. Data summarized from July 1994 through June 2000.

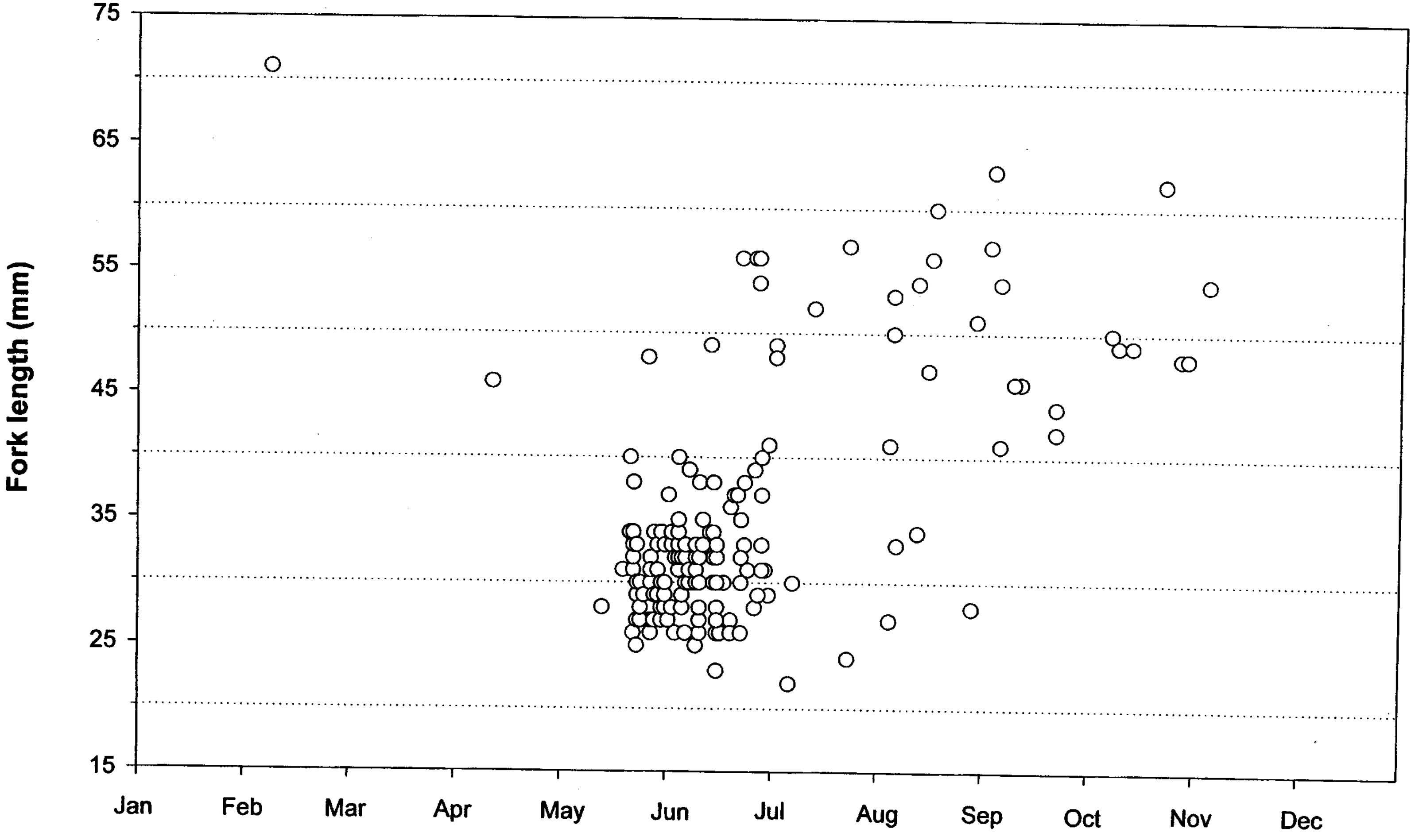
Speckled Dace Daily Length Distribution

Figure A66. Within-year fork length distribution for speckled dace (*Rhinichthys osculus*) captured by rotary-screw traps at Red Bluff Diversion Dam (RK 391), Sacramento River, CA. Data summarized from July 1994 through June 2000.

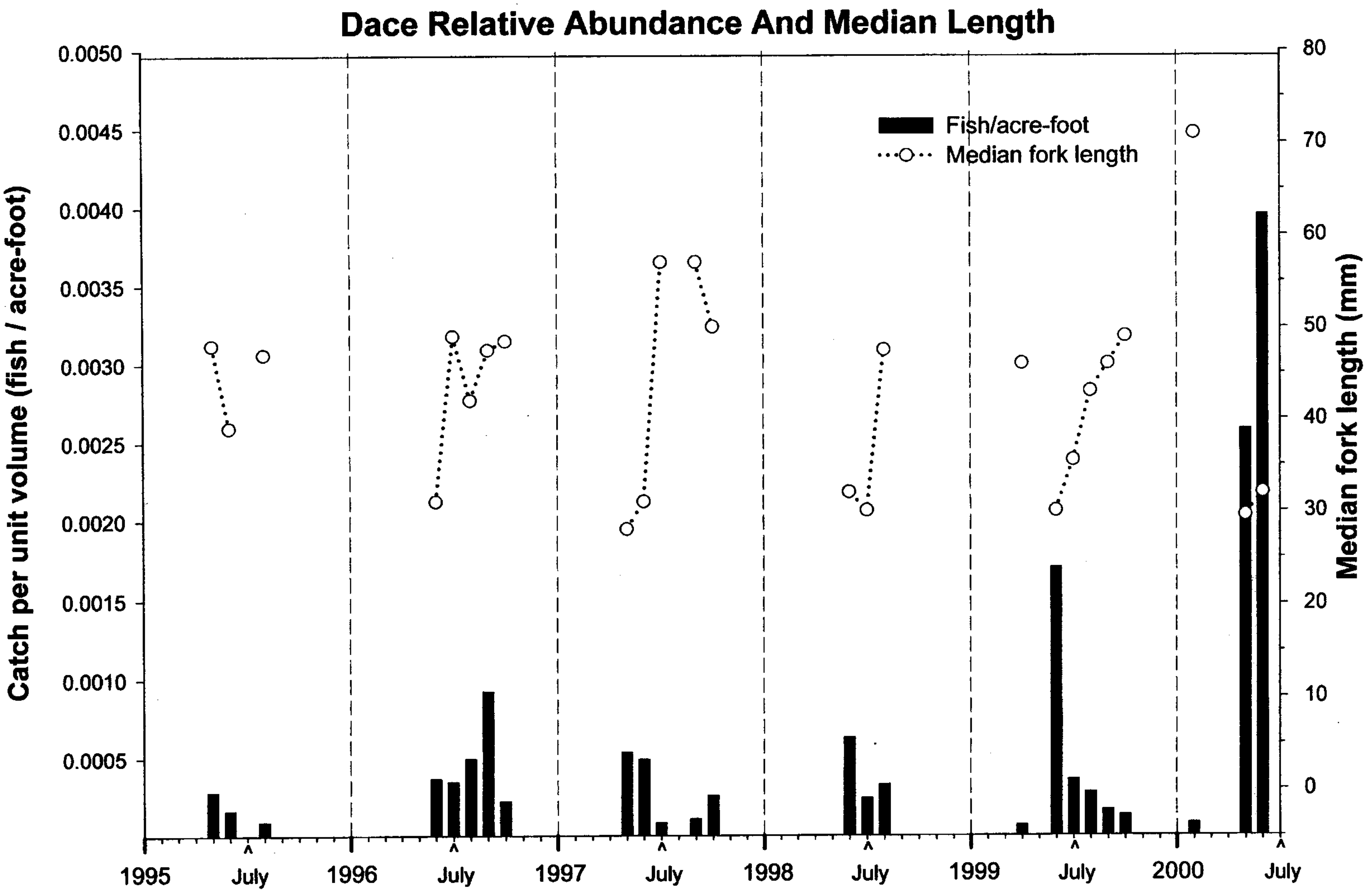

Figure A67. Relative abundance (fish/acre-foot) and median fork length for speckled dace (*Rhinichthysosculus*) captured by rotary-screw traps at Red Bluff Diversion Dam (RK 391), Sacramento River, CA. Data summarized from January 1995 through June 2000.

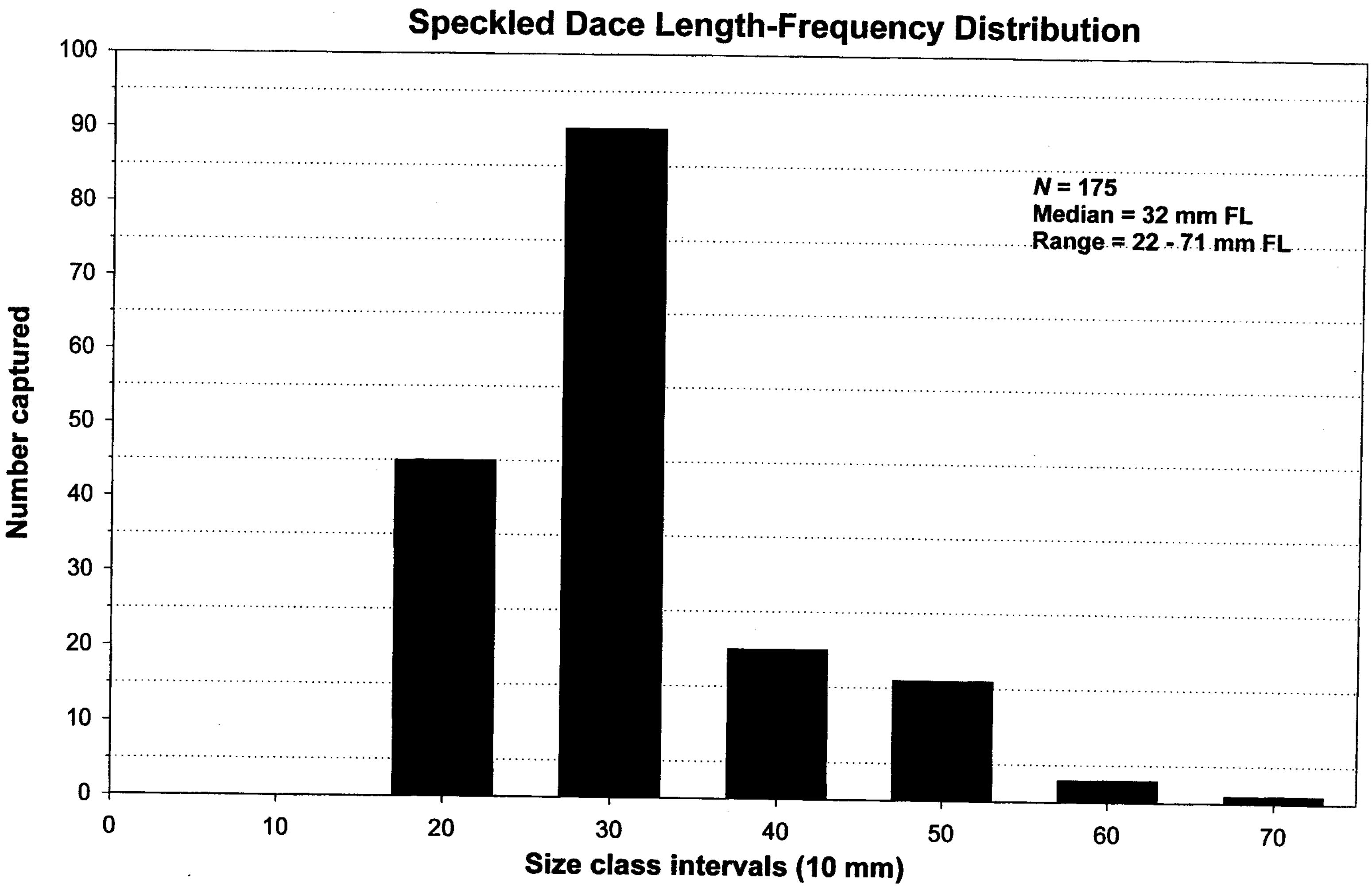

Figure A68. Length-frequency distribution for speckled dace (*Rhinichthys osculus*) captured by rotary-screw traps at Red Bluff Diversion Dam(RK 391), Sacramento River, CA. Size class intervals are reported in 10 mm increments. Data summarized from July 1994 through June 2000.

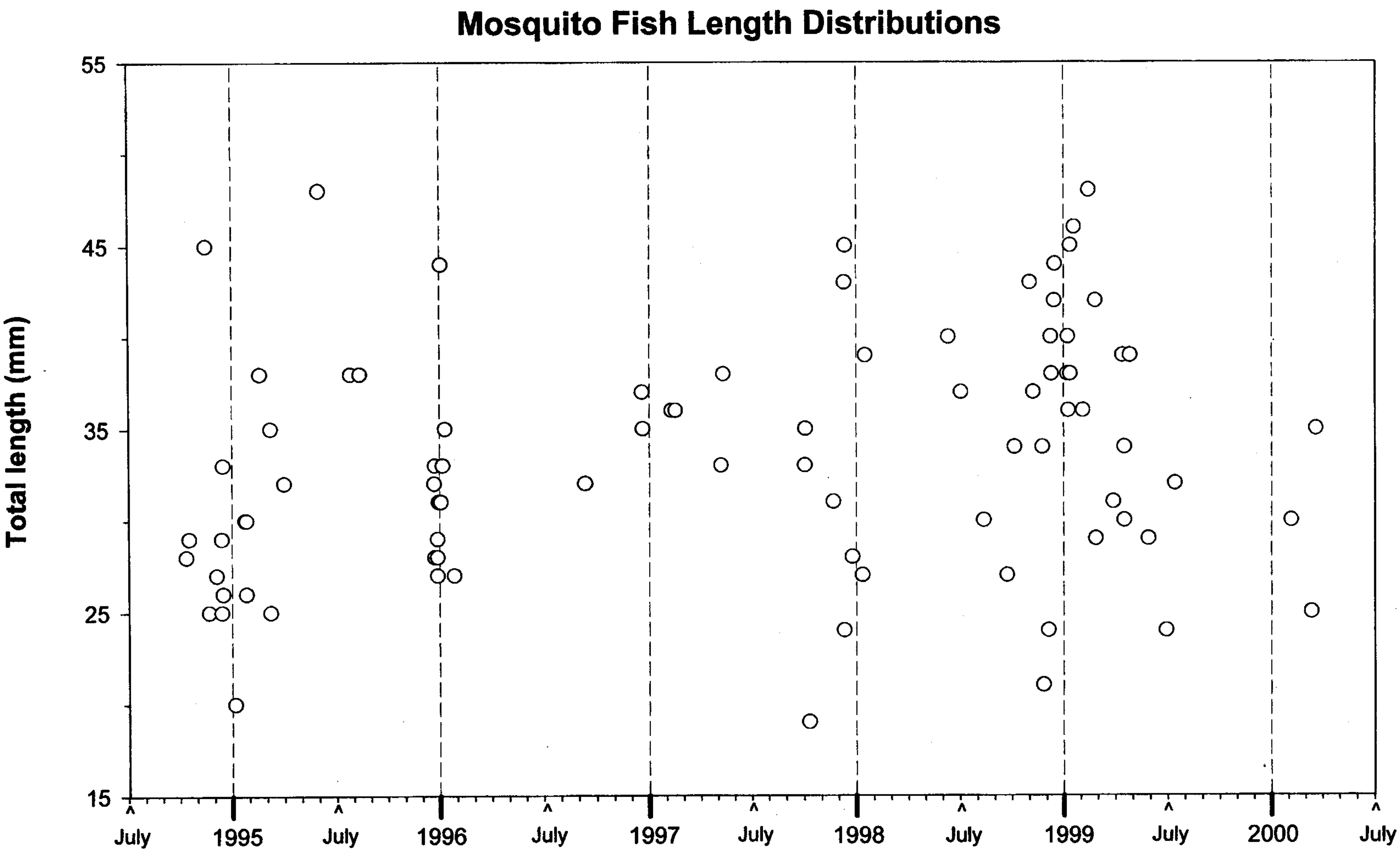

Figure A69. Among-year length distribution for mosquito fish (*Gambusia affinis)* captured by rotary-screw traps at Red Bluff Diversion Dam (RK 391), Sacramento River, CA. Data summarized from July 1994 through June 2000.

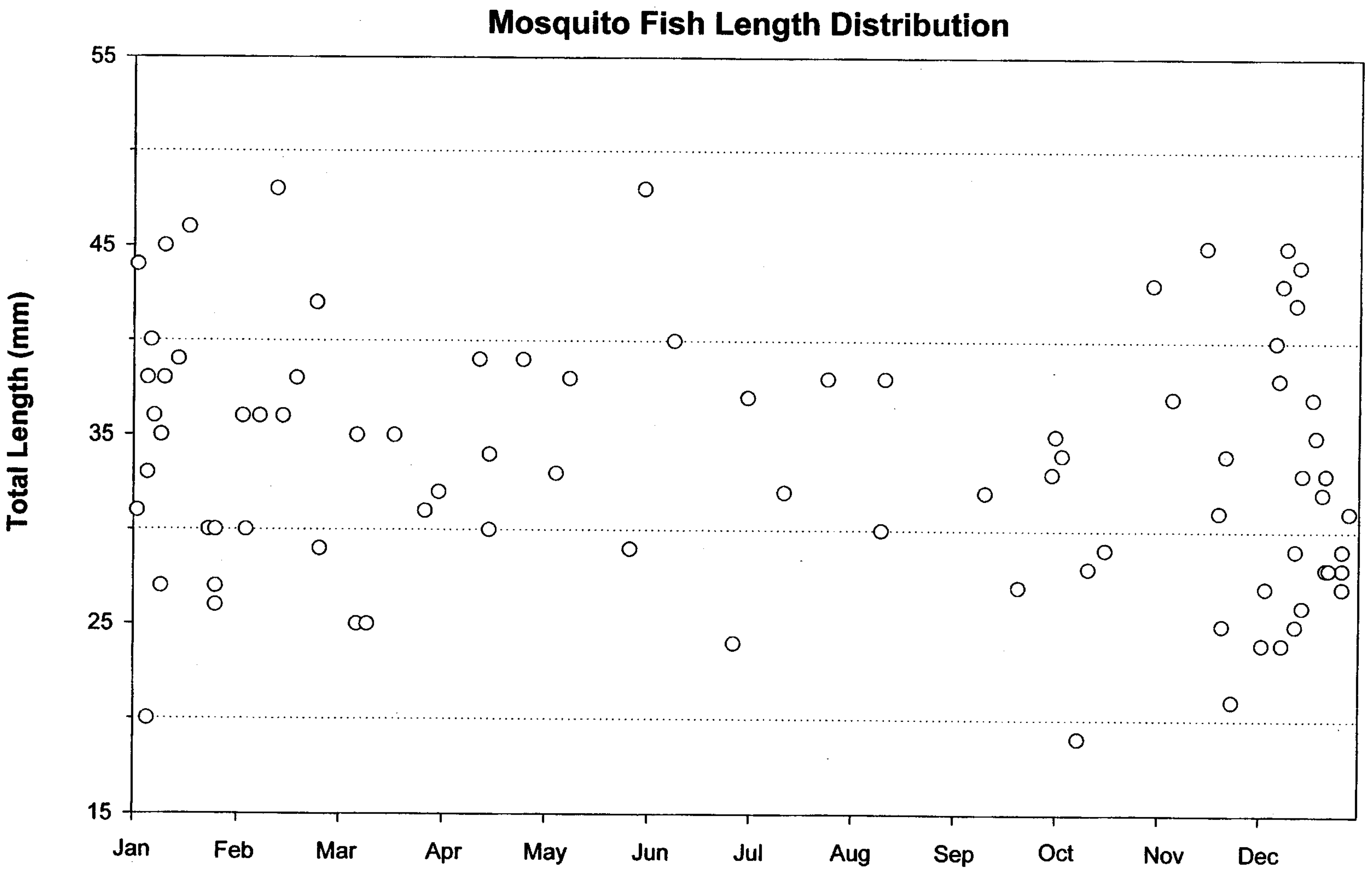

Figure A70. Within-year length distribution for mosquito fish (*Gambusia affinis*) captured by rotary-screw traps at Red Bluff Diversion Dam (RK 391), Sacramento River, CA. Data summarized from July 1994 through June 2000.

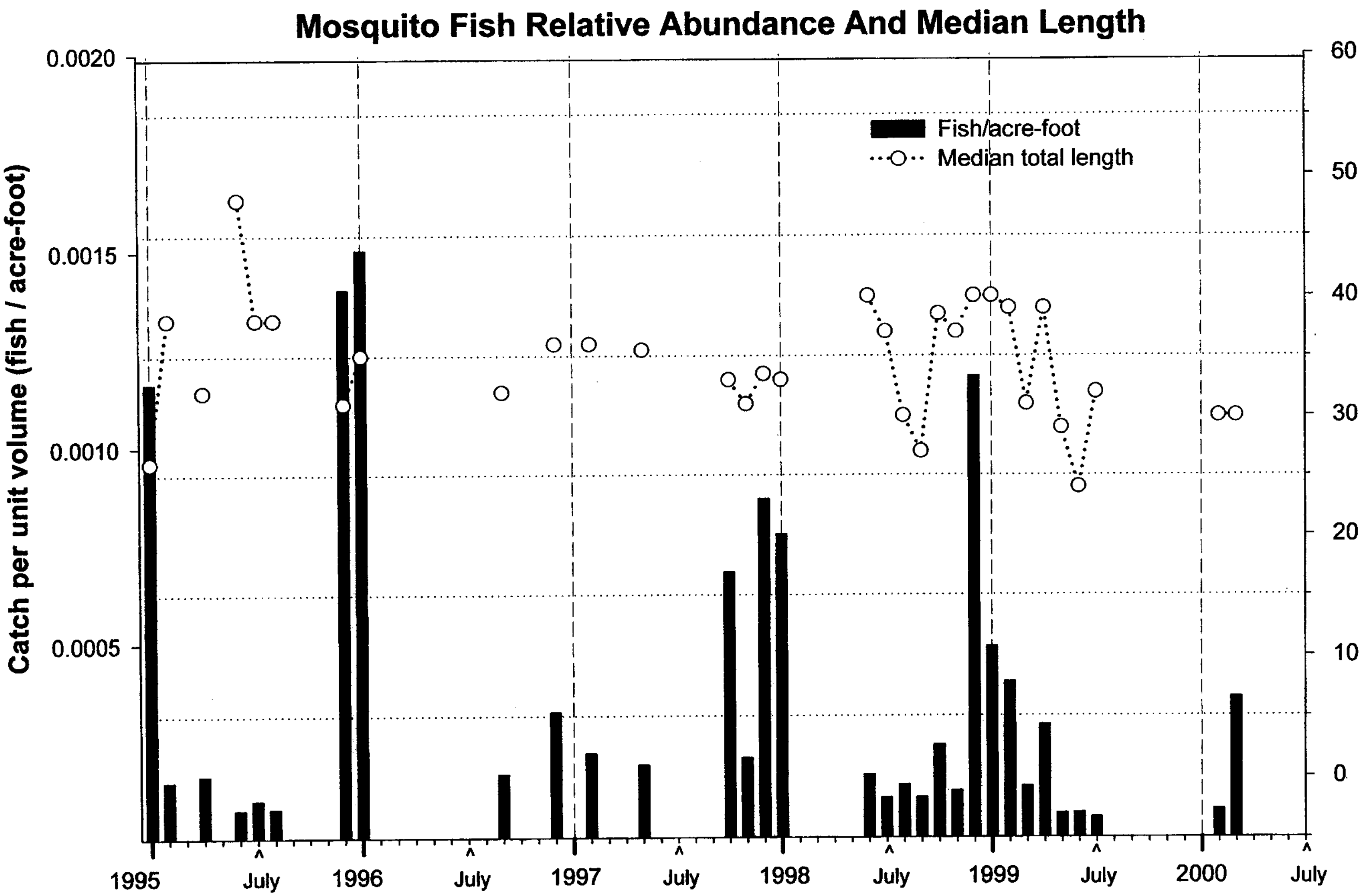

Figure A71. Relative abundance (fish/acre-foot) and median length for mosquito fish (*Gambusia affinis*) captured by rotary-screw traps at Red Bluff Diversion Dam (RK 391), Sacramento River, CA. Data summarized from January 1995 through June 2000.

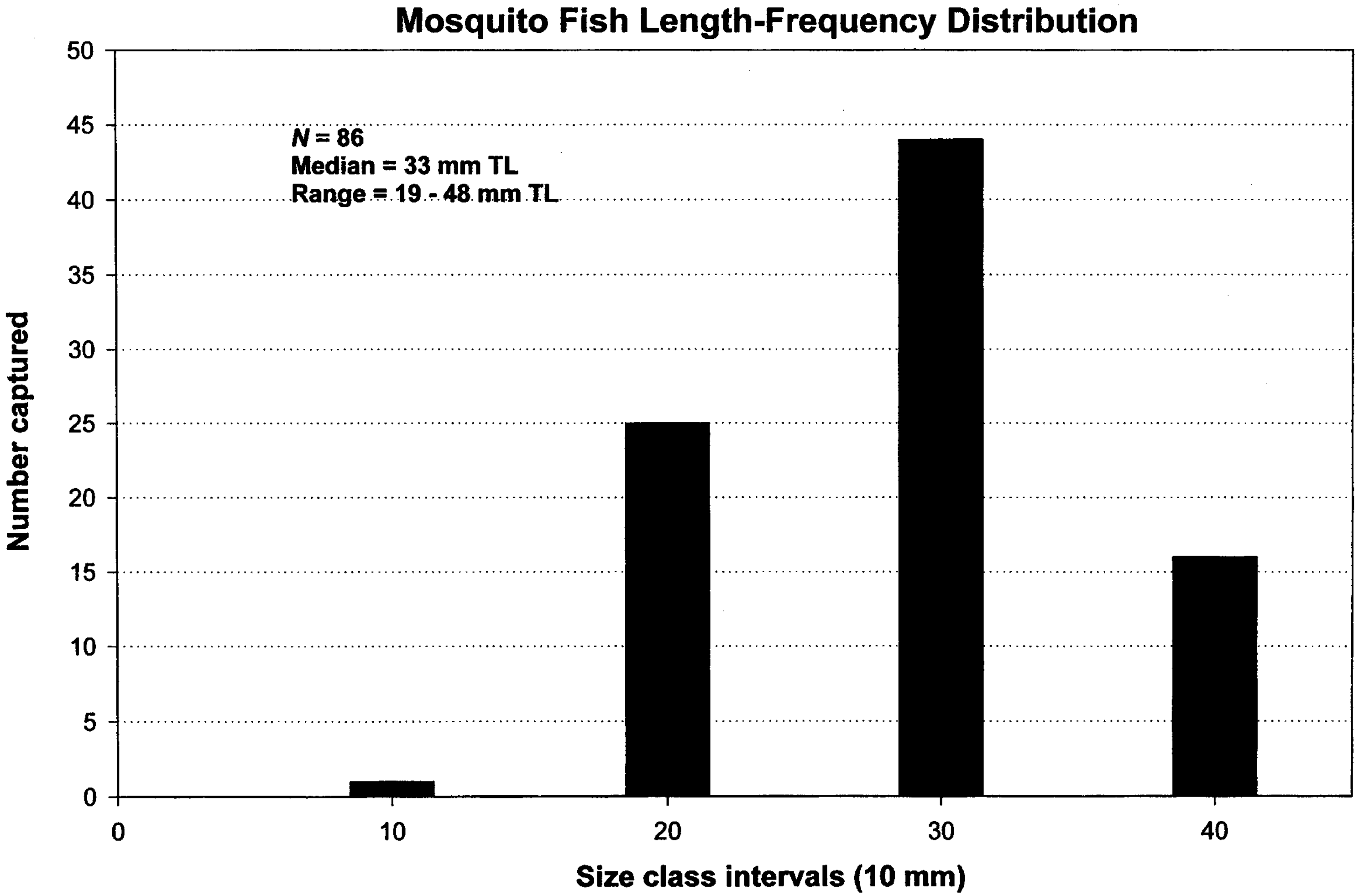

Figure A72. Length-frequency distribution for mosquito fish (*Gambusia affinis*) captured by rotary-screw traps at Red Bluff Diversion Dam (RK 391), Sacramento River, CA. Size class intervals reported in 10 mm increments. Data summarized from July 1994 through June 2000.

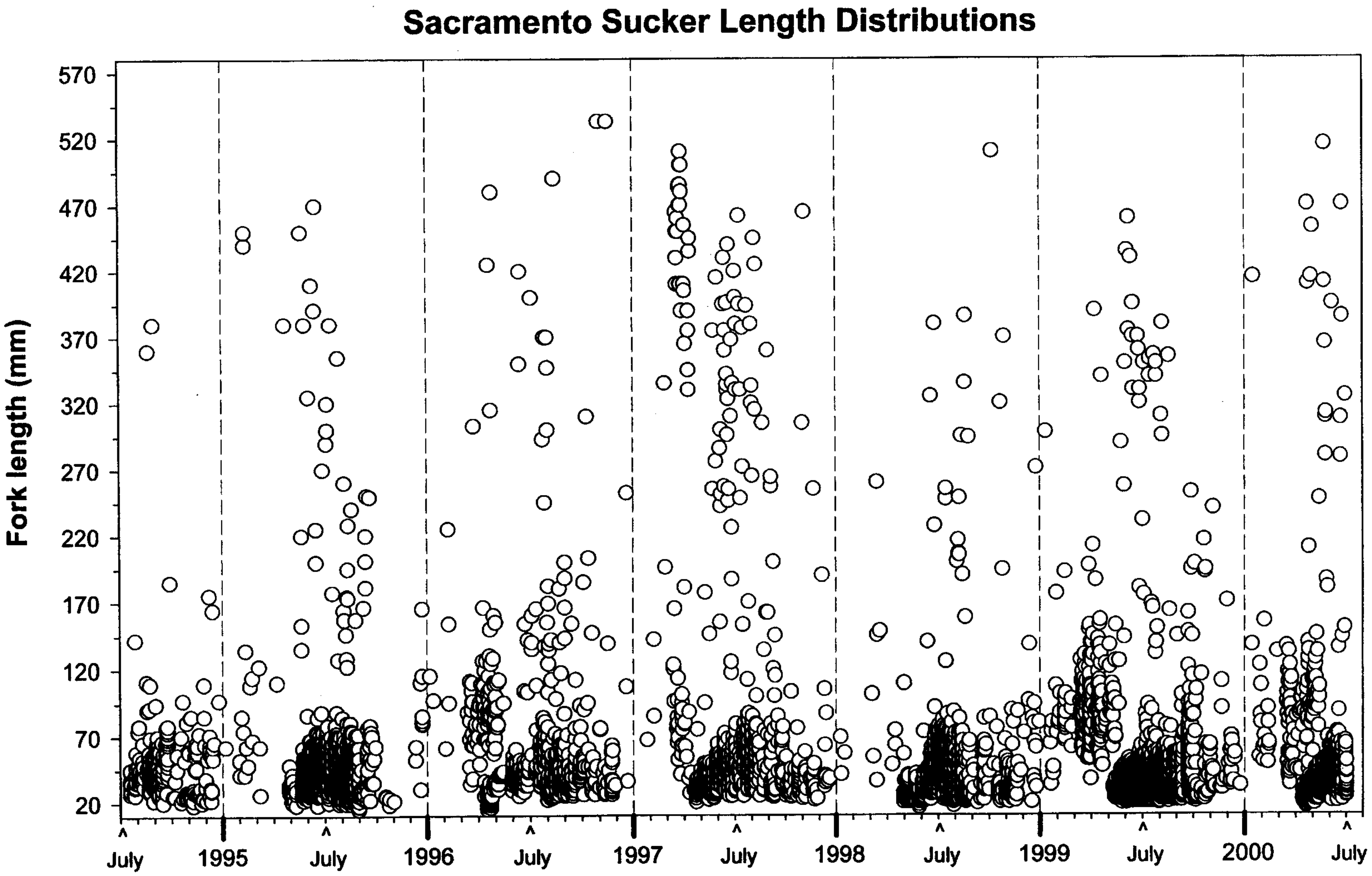

Figure A73. Among-year fork length distributions for Sacramento sucker (*Catostomus occidentalis*) captured by rotary-screw traps at Red Bluff Diversion Dam (RK 391), Sacramento River, CA. Data summarized from July 1994 through June 2000.

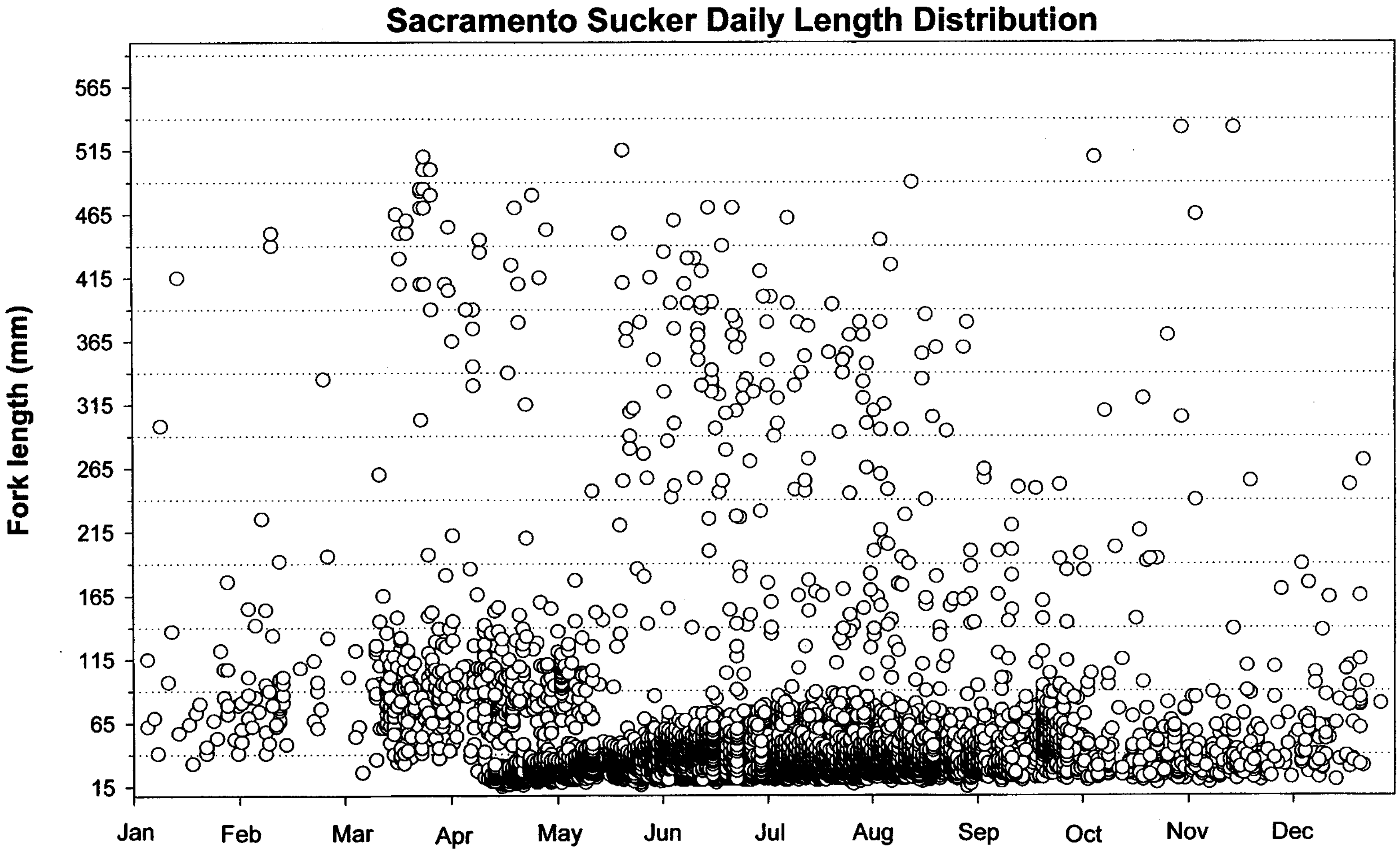

Figure A74. Within-year fork length distribution for Sacramento sucker (*Catostomus occidentalis*) captured by rotary-screw traps at Red Bluff Diversion Dam (RK 391), Sacramento River, CA. Data summarized from July 1994 through June 2000.

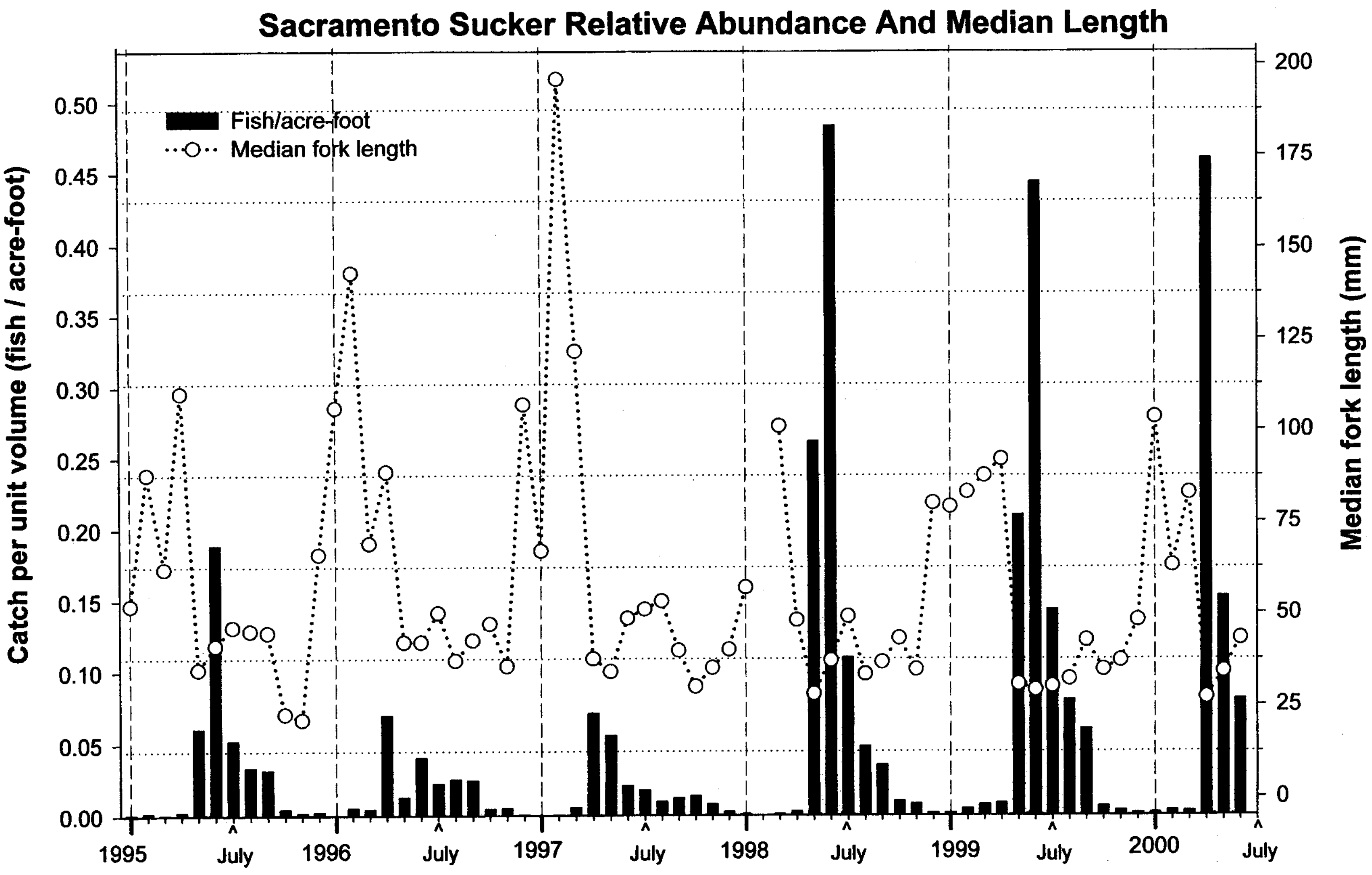

Figure A75. Relative abundance (fish/acre-foot) and median fork length for Sacramento sucker (*Catostomus occidentalis*) captured by rotary-screw traps at Red Bluff Diversion Dam (RK 391), Sacramento River, CA. Data summarized from January 1995 through June 2000.

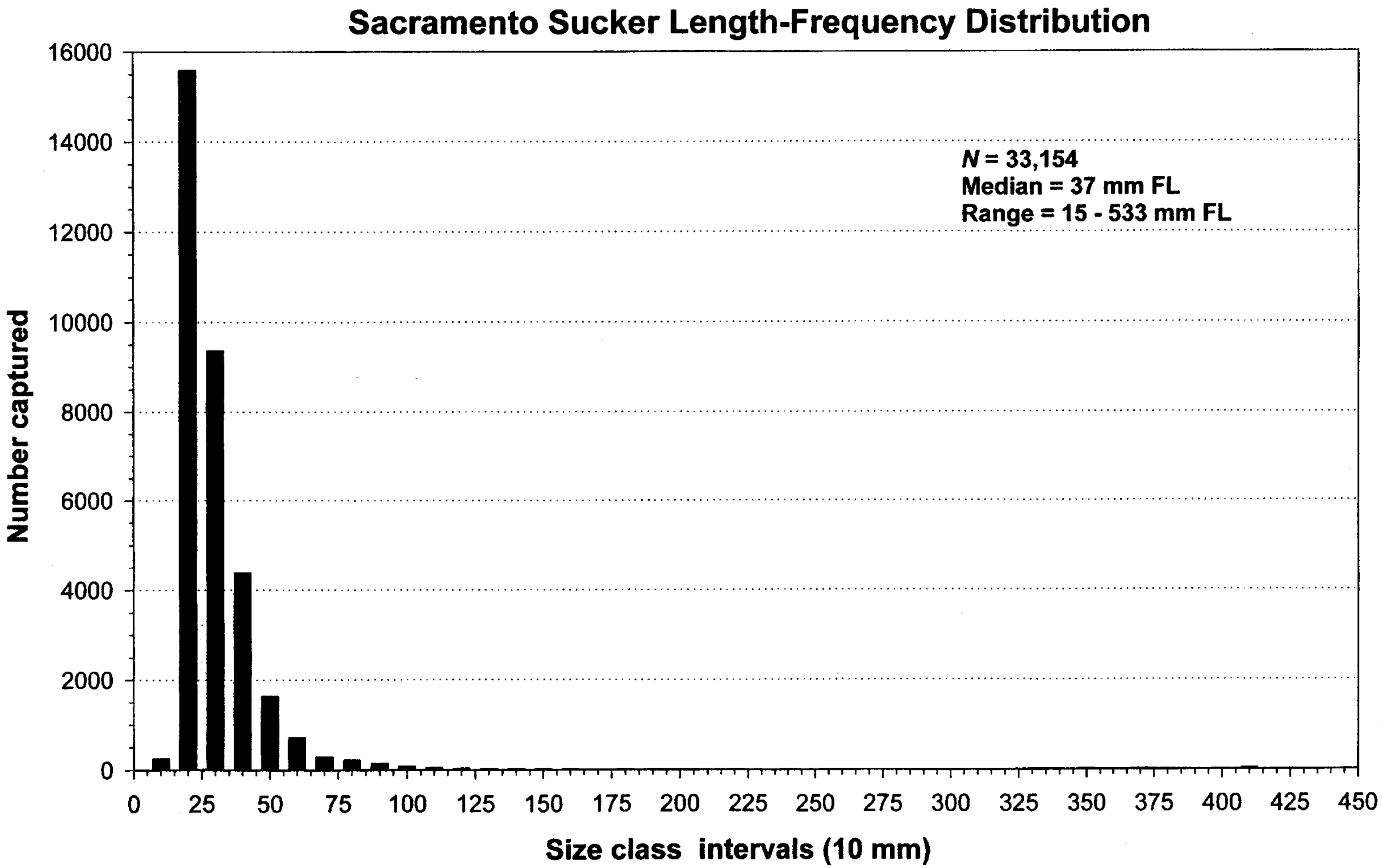

Figure A76. Length-frequency distribution for Sacramento sucker (*Catostomus occidentalis*) captured by rotary-screw traps at Red Bluff Diversion Dam (RK 391), Sacramento River, CA. Size class intervals reported in 10 mm increments. Data summarized from July 1994 through June 2000.