INVESTIGATIONS OF FISH ENTRAINMENT BY ARCHIMEDES AND INTERNAL HELICAL PUMPS AT THE RED BLUFF RESEARCH PUMPING PLANT, SACRAMENTO RIVER, CALIFORNIA: FEBRUARY 1997 - JUNE 1998

Annual Report
Red Bluff Research Pumping Plant
Report Series: Volume 7

Prepared by:
Sandra M. Borthwick and Richard R. Corwin
U. S. Bureau of Reclamation
Red Bluff Fish Passage Program
P. O. Box 159
Red Bluff, CA 96080

and

Charles R. Liston
U. S. Bureau of Reclamation
Fisheries Applications Research
Technical Service Center
P. O. Box 25007
Denver, CO 80225-0007

Prepared For:

U. S. Bureau of Reclamation
Red Bluff Fish Passage Program
P. O. Box 159
Red Bluff, CA 96080

October 1999

Disclaimer

The mention of trade names or commercial products in this report does not constitute endorsement or recommendation for use by the Federal Government.

The correct citation for this report is:

Borthwick, S.M., R. R. Corwin, and C.R. Liston. 1999. Investigations of fish entrainment by Archimedes and internal helical pumps at the Red Bluff Research Pumping Plant, Sacramento River, California: February 1997 - June 1998. Red Bluff Research Pumping Plant Report Series, Volume 7. U.S. Bureau of Reclamation, Denver, CO.

INVESTIGATIONS OF FISH ENTRAINMENT BY ARCHIMEDES AND INTERNAL HELICAL PUMPS AT THE RED BLUFF RESEARCH PUMPING PLANT, SACRAMENTO RIVER, CALIFORNIA: FEBRUARY 1997 - JUNE 1998

Annual Report

U. S. Bureau of Reclamation
Fisheries Applications Research
Denver Technical Service Center
P. O. Box 25007
Denver, CO 80225-0007

Abstract. The overall goal of the Red Bluff Research Pumping Plant program is to determine whether Archimedes and/or internal helical pumps can be used to deliver water to canals without harming fish inhabiting the Sacramento River. This report contains results of entrainment monitoring of fish from the Sacramento River during February 1997 through June 1998. Objectives addressed include: determining if differences exist in numbers, species, survival and injury of fish entrained into each of the two types of pumps; and estimating the number of juvenile chinook salmon in each of the four Sacramento River salmon runs entrained annually into the pumps.

Twenty-nine species of fish, 16 native to the Sacramento River, were captured during entrainment monitoring. Juvenile chinook salmon was the most frequently entrained species followed by prickly sculpin, lamprey, Sacramento sucker, Sacramento pikeminnow, and threespine stickleback. These six species comprised 95% of the 17,530 fish entrained. Nearly 90% of the entrained chinook were fall run. Seasonal patterns of chinook salmon entrainment followed those of chinook abundance in the river. Assessment of diel patterns of entrainment revealed that 81% of chinook were entrained at night. This has important implications for pump operations. If it becomes necessary to decrease the number of chinook entrained, a substantial reduction could be made by pumping only during the day.

Ninety-two percent of entrained fish were <100 mm in length. Most chinook salmon (84%) were less than 40 mm fork length. The lowest median fork length for chinook salmon occurred September through October, and December through February reflecting the outmigration of winter and fall chinook fry, respectively.

Because the plant was operated for biological evaluations during all seasons, the number of fish entrained during this study was higher than would occur if the plant were used only for delivering water. Sixty-five percent of the chinook entrained were collected during trials

conducted in December and January, months that the plant would not operate if functioning for water deliveries. The winter of 1997-1998 was wet so the peak of fall chinook outmigration occurred during the winter months and relatively few remained to be vulnerable to spring pumping. In a dry winter, however, spring entrainment rates would be expected to be relatively high since the peak outmigration of fall chinook would be delayed until spring, coinciding with high water demands and continuous pumping.

During this study, 24-hr trials were conducted simultaneously with the U. S. Fish and Wildlife Service's rotary-screw trap sampling to determine the proportion of chinook salmon in the river entrained into the pumping plant during different seasons of the year. Preliminary data from October through December 1997 reveal that the upper estimate of the percentage of riverine chinook entrained into the plant ranged from approximately 0.05 to 0.60. This is well below the the 1.5 to 5.5 percent that was predicted based upon the assumption that chinook are entrained in proportion to the amount of flow diverted into the plant. The low entrainment rate is likely due to the plant intakes being positioned near the bottom of the river whereas the majority of outmigrating chinook salmon inhabit the upper water column.

The number of fish entrained into Archimedes 2 was significantly greater than the number entrained into Archimedes 1 or the internal helical pump, which were not different. Survival of chinook recovered from the holding tanks was 98% for each of the Archimedes pumps and 94% for the internal helical pump. Survival of fish other than chinook was 95% for the Archimedes pumps and 94% for the helical pump. The differences in survival among pumps was not statistically significant for chinook or other species. Percent survival values should not be interpreted strictly as pump passage survival. Captured fish also passed a screening facility, traveled curved bypass channels, up a dewatering ramp, and were routed into a tank where they were held with debris and other fish for up to 14 hours. Factors besides pump passage could affect the survival of entrained fish collected from the holding tanks.

Considering all three pumps, mortality of chinook salmon entrained into the RPP was 3%, and the percentage with sublethal injuries was 2.1. This 5.1 percent mortality and injury is less than anticipated by the Biological Opinion (National Marine Fisheries Service 1993) for the Archimedes pumps (10%) or the internal helical pump (>10%, even as high as 90%). Delayed mortality of chinook was also low, less than or equal to 1 percent for each of the pumps.

Table of Contents

List of Tables

List of Tables (continued)

Table **Page**

List of Figures

List of Appendices

Introduction

Construction of Red Bluff Research Pumping Plant (RPP) was completed in May 1995. The plant is located at river kilometer 391 (river mile 243) on the southwest bank of the Sacramento River just downstream of Red Bluff Diversion Dam (Figure 1). The plant was constructed as a research facility to determine whether two types of experimental pumps could provide water to the Tehama-Colusa and Corning canals without harming fish inhabiting the Sacramento River. Liston and Johnson (1992b) cite 32 species of fish that could be entrained from the river into the RPP. Of particular concern is chinook salmon *Oncorhynchus tshawytscha.* The Sacramento River is unique in supporting four runs of chinook salmon (fall, late-fall, winter, and spring) which are named for the season when the majority of adults enter the river to begin their upstream spawning migration (Vogel and Marine 1991). Populations of all four runs have decreased since the late 1960's although winter chinook have experienced the most dramatic decline (Johnson et al. 1992, Yoshiyama et al. 1998). This prompted the listing of winter chinook as endangered by California in 1989 and by the federal government in 1994.[1] Other runs have also been listed or are proposed for listing.[2] Steelhead *Oncorhynchus mykiss*, another native salmonid in the Sacramento River, was federally listed as threatened in March 1998.[3]

Due to their declining populations, the primary focus of this study has been on monitoring entrainment of juveniles of the four runs of chinook salmon and steelhead. Juvenile chinook salmon migrate past the RPP in each month of the year (Vogel and Marine, 1991). The number of chinook salmon and steelhead entrained into the plant depends upon the water year and the quantity of water requested by users during periods when gates at Red Bluff Diversion Dam (RBDD) are raised. Gates are lowered from May 15 to September 15 creating Lake Red Bluff which allows Sacramento River water to be gravity fed to the canal headworks. Gates are raised from September 15 to May 15; however, water is still needed by irrigators and wildlife refuges during spring and fall months. Therefore, the RPP typically is operated for water deliveries to the canals in the spring (mid-Feb - May 15) and fall (September 15 - October 31) when Lake Red Bluff is dewatered.

Vogel et al. (1988) provide information that can be used to predict seasonal patterns of entrainment of juvenile chinook in wet and dry years. In a wet year approximately 85% of the total annual juvenile out-migration past the RPP occurred during December through March when river discharges were 1133 m^3/s (40,000 ft^3/s) to 2266 m^3/s (80,000 ft^3/s) and reached a

---

[1]Winter chinook was listed as endangered by California in 1989 (California Code of Regulations, Title XIV, Section 670.5), and by the federal government in 1994 (National Marine Fisheries Service; 59 FR 440).
[2]Spring chinook was listed as threatened by California in August 1998 (California Code of Regulations, Title XIV, Section 670.5); spring and fall chinook currently are proposed for federal listing (63 FR 11481).
[3] Steelhead was federally listed as threatened in March 1998 (63 FR 13347).

maximum of 3540 m^3/s (125,000 ft^3/s). Most of the juveniles moving at this time of year were small, fall chinook <50 mm fork length. In a dry year when discharges were typically <425 m^3/s (<15,000 ft^3/s) and occasionally peaked at 566 m^3/s (20,000 ft^3/s) during December through June, the annual peak out-migration of fall chinook was delayed until April through June. Juveniles moving at this time of year were large, 60 - 110 mm fork length. Therefore, it could be predicted that in a wet year most juvenile fall chinook would migrate past RBDD before water demands were high and pumping began; therefore, numbers of chinook entrained would be low. In contrast, during a dry year numbers entrained would be higher due to frequent pumping from April through May 15 coinciding with the peak out-migration of juvenile fall chinook. Numbers of out-migrants were consistently low, typically <1 million per month, during July through November (Vogel et al.1988). Therefore, it could be predicted that numbers entrained into the plant would be low.

The goal of this study is to quantify entrainment of juvenile chinook salmon and other species of fish into the RPP during different seasons of the year. Results of the study will be used to help determine whether Archimedes and/or internal helical pumps can operate satisfactorily with minimal harm to fish in the Sacramento River. If the pumps prove benign, their use would continue to facilitate gates-raised operation of RBDD from mid-September to mid-May with the potential for construction of a larger pumping facility that could deliver water to meet needs year-round.

Specific objectives for this study are to:

1. Record rates of entrainment, mortality and injury for chinook salmon and other species of fish entrained from the Sacramento River by Archimedes and internal helical pumps during different seasons of the year.

2. Compare differences in mortality and injury due to passage through the Archimedes versus the internal helical pump.

3. Estimate the number of individuals in each of the four runs of chinook salmon entrained annually by Archimedes and internal helical pumps.

4. Estimate percentages of each of the four runs of juvenile chinook passing Red Bluff that could be entrained annually into the RPP.

This report addresses the first three objectives. The fourth objective is tightly linked to a companion study entitled *Abundance and seasonal, spatial and diel distribution patterns of juvenile salmonids passing the Red Bluff Diversion Dam, Sacramento River, California.* The study is being conducted by personnel of the U.S. Fish and Wildlife Service (USFWS), Northern Central Valley Fish and Wildlife Office in Red Bluff using rotary screw-traps to estimate abundance and distribution patterns of each of the four runs of juvenile chinook salmon and steelhead passing RBDD. Screw-trap sampling and entrainment trials are conducted simultaneously to estimate the proportion of outmigrating juvenile chinook in each of the four runs that are entrained into the pumping plant. Data collection on this objective is on-going; results of this cooperative effort will be reported in a separate document.

Methods

Plant Operations

The Archimedes and internal helical pumps operated intermittently and entrainment trials were conducted opportunistically during 1995 and 1996, while mechanical modifications were made to pumps, screening facilities, and fish bypasses (McNabb et. al, 1998). By February 1997 mechanical problems with the Archimedes pumps were resolved, and they operated reliably throughout this study. This allowed entrainment trials to be conducted more regularly than in the past and throughout the year to assess seasonal entrainment patterns. The internal helical pump was down for modifications and repairs from mid-July through mid-September 1997 and May through June 1998. None of the pumps operated from January 8 - March 8 1998 due to high river discharges.

During each entrainment trial, pumps operated at full speed for 24 hours beginning at sunrise. Each Archimedes pump operated at 26.5 rpm and delivered an average of 2.5 m^3/s (89 to 90 ft^3/s); the internal helical pump operated at 378 rpm and delivered an average of 2.7 m^3/s (96 ft^3/s). The goal was to operate all three pumps simultaneously to allow numbers entrained and survival and injury of fish to be compared among pumps while operated under similar environmental conditions. Due to mechanical problems with the internal helical pump, however, most trials were conducted using only the two Archimedes pumps.

During a trial, dewatering ramps were lowered and the weir beneath the ramp was adjusted to divert approximately 0.02 m^3/s (0.7 ft^3/s) of flow up the ramp and into one of the two holding tanks (McNabb et al.1998). Fish and debris contained in the bypass flows were also diverted into the holding tanks. The 1.2 m square holding tanks contain water to a depth of 0.9 m when full. They operated as a flow-through system with the water in a tank turning over approximately every 1.2 minutes, discharging into the bypass channel. At these flows, ambient river water quality and relatively non-turbulent conditions were maintained in the holding tanks.

Numbers and Characteristics of Entrained Fish

Fish captured in holding tanks during trials were identified to species, measured (fork length for salmonids, total length for others) to the nearest 1.0 mm, assessed for survival and injury, and inspected for tags, fin clips, or dyes that designate them as hatchery-released fish or as fish from other studies. Injury assessment involved visually inspecting each fish for abnormalities to the integument, eyes, head, and fins. Run membership for chinook salmon was determined from a daily fork-length table generated by Green (1992). On the rare occasion when high numbers of juvenile chinook were entrained, the first 100 chinook removed from each holding tank were processed. Additional chinook were counted and recorded as extra dead or extra alive. For other species, the first 30 fish from each holding tank were processed and the remainder counted and recorded as extra dead or alive. After processing, fish were returned to the river via the bypass conduits that exit the pumping plant into the Sacramento River or released directly into the river downstream of the pump intakes. Each time the holding tanks were cleared of fish, debris was removed and measured volumetrically (cc) using displacement of water in a graduated 20 l bucket.

Larval fish <30 mm length were frequently observed in the holding tanks, especially during spring trials. These fish were not efficiently retained because of the relatively large mesh-size (3.2 mm, 1/8 in) of nets used to trap fish in the tanks. Therefore, data on fish <30 mm are not reported here. Numbers and patterns of larval fish entrainment are being assessed in a separate study under Objective N of the RPP evaluation program (Liston and Johnson 1992a).

Environmental Data

Various data were collected at each sunrise and sunset inspection of the holding tanks. River elevation (ft), and speed (hz) and discharge (cfs) of each pump were recorded from control panels within the plant. Water temperature, dissolved oxygen, and total gases were measured from water passing through the holding tanks. Water temperature and dissolved oxygen were measured using a YSI® Model 55 dissolved oxygen meter. Total gases were measured using a Sweeney® Model DS1-A saturometer. Water turbidity was measured with an HF Scientific® continuously monitoring turbidimeter located in the river water fish facility. A HydroLab® DataSonde water quality monitoring probe was deployed in the river on the east side of RBDD to provide hourly measurements of water temperature, dissolved oxygen, conductivity, and pH. Meteorological data, including precipitation, irradiance in the visible portion of the solar spectrum, wind speed and direction, barometric pressure, and air temperature were continuously collected at the project weather station. Estimates of daily river discharge ($m^3/s;ft^3/s$) past RBDD was provided by Reclamation Operations and Maintenance personnel using data collected at the U. S. Geological Survey's gaging station located near Bend Bridge approximately 24 km upstream.

Rates and Patterns of Entrainment

Data from all entrainment trials, regardless of the number of pumps operated or the length of time they operated, were used to determine seasonal rates of entrainment and diel patterns of entrainment. To assess diel patterns of entrainment, the holding tanks were inspected at sunset and again at sunrise the following day. Times for sunrise and sunset were obtained from the web-site of the U. S. Naval Observatory in Bethesda, Maryland using the coordinates of latitude and longitude for Red Bluff.

Start and end time of each sunrise to sunset and sunset to sunrise monitoring period was recorded. Data on total time monitored along with pump discharge allowed calculation of acre-feet of water pumped during each entrainment trial. Entrainment rates of chinook salmon and other species were estimated for each month as the quotient of the number of chinook salmon entrained divided by the total acre-feet of water pumped during entrainment trials. This data was used to assess seasonal patterns of fish entrainment into the plant.

Estimated Numbers of Fish Entrained

In general, during July 1 - March 31 when juvenile winter chinook may be present in the river near the RPP, two 24-hr trials were conducted each week the pumps operated continuously (i.e., 24 hrs each day). This typically occurred in the spring (March) and fall (September 15 - October 31) when the gates at RBDD were raised yet water was required for agriculture and refuges. At times of the year when pumps were not operated continuously or juvenile winter chinook were not present (April - June), one entrainment trial was conducted each week. These trials were used as samples to estimate, on a weekly basis, the number of chinook in each of the four runs that could be entrained into the pumps. This was done by calculating the number of chinook entrained per hour and multiplying it by the number of hours the pumps operated during the week. Weekly estimates of entrainment were also calculated for steelhead/rainbow trout.

During the period of this study, approximately 26 million juvenile fall chinook were released into Battle Creek from Coleman National Fish Hatchery 56 km upstream of the RPP. Of these, approximately 2 million were coded-wire tagged and adipose fin-clipped resulting in a ratio of 0.083 marked to unmarked fish. This ratio varied somewhat with each release. The ratio from the most recent release was used to estimate the number of hatchery-produced and naturally-produced chinook salmon entrained into the RPP each week. The number of hatchery-produced chinook entrained into the RPP was estimated as the quotient of the number of adipose-clipped fish entrained divided by the ratio of marked to unmarked fish released from Coleman Hatchery. The number of naturally-produced chinook was calculated as the difference between the total number of chinook entrained and the estimated number of hatchery-produced chinook.

Number, Survival, and Injuries of Entrained Fish Compared Among Pumps

Only data from entrainment trials conducted when all three pumps operated simultaneously for 24 hrs were used to compare numbers of fish entrained, and survival and injuries of fish among pumps. This ensured that fish were collected when the three pumps operated under the same water quality and weather conditions, factors which could affect the numbers and condition of entrained fish. The number and survival of fish, by species, entrained into each pump was tabulated and combined for all simultaneous trials. Analysis of variance was used to determine whether numbers entrained or survival differed among pumps for chinook salmon and for all other fish. Injuries were tabulated by type for chinook and all other fish and compared among pumps.

Comparing survival between the two Archimedes pumps was not an objective of this study. During periods when the internal helical pump was inoperable, however, trials were continued using the two Archimedes pumps. Forty-five 24-hr trials were conducted when the two Archimedes pumps operated simultaneously providing an expanded database for assessing numbers and survival of wild fish passed through the Archimedes pumps. This data was tabulated and compared between the two pumps.

Delayed Mortality of Entrained Chinook Salmon

Objective B of the RPP evaluation program is to determine survival and injury to chinook salmon passed through the pumps (Liston and Johnson 1992a). Experiments are conducted using hatchery-reared juvenile chinook salmon as surrogates for wild chinook. Attempts are made to conduct pump passage experiments using *small* (<45mm) and *large* (≥45mm) chinook. After chinook are passed through a pump and collected from a holding tank, they are held in live cages in the river water fish facility for 96 hrs to assess delayed mortality (McNabb et al. 1998). During the period covered in this report, few pump passage experiments were conducted comparing survival of *small* chinook passed through the Archimedes and internal helical pump. Periods when small fish were available from Coleman National Fish Hatchery coincided with periods when the internal helical pump was down for repairs. Therefore, to gain information on delayed mortality of small chinook passed through the two types of pumps, small, wild chinook salmon collected during entrainment trials were held in live cages in the river water fish facility and their survival assessed after 96 hours. Fish collections were not always from simultaneous trials so results are not directly comparable among pumps. A description of the river water fish facility in which the chinook were held can be found in McNabb et al. 1998.

Results

Plant Operations

The study period began with relatively high river discharges in early February 1997 (Figure 2). Rains subsided, however, and discharges decreased to 141 - 425 m^3/s (5,000 - 15,000 ft^3/s) through most of the year. Infrequent storms in late November and December resulted in discharges exceeding 480 m^3/s (17,000 ft^3/s) for short periods. January and February 1998 were very wet with flows frequently between 1020 and 2719 m^3/s (36,000 and 96,000 ft^3/s), peaking near 4276 m^3/s (151,000 ft^3/s) on February 3. Intermittent high flows continued through June. High flows caused the plant to be inoperable from early January through February, mid-to late March and again in mid-May. The proportion of river discharge pumped by the RPP was typically 3 to 4 percent during the low flow spring of 1997 (Figure 2). In contrast, during the high flow spring of 1998, the percent of river flow pumped decreased to 1 to 2 percent. During the study, the percent of river flow pumped was lowest in the spring of 1998 (<1 percent) and highest in late fall (>5 percent) when river flows were typically their lowest.

Information on speed, discharge, and operating time of each pump during this study is provided in Table 1. Both Archimedes pumps were operational except when high river discharges prohibited pumping. Fish entrainment was monitored 27 to 29 percent of the time the Archimedes pumps operated. Forty-nine 24-hr trials were conducted with Archimedes 1 and 52 with Archimedes 2; 45 trials were conducted when both Archimedes pumps operated simultaneously. Due to mechanical problems, the internal helical pump operated for approximately 1500 fewer hours than either of the Archimedes pumps. Entrainment was monitored 30% of the operating time, and thirty-five 24-hr entrainment trials were conducted. Twenty-four 24-hr trials were conducted when all three pumps operated simultaneously allowing survival and injury of fish to be compared among pumps when operated under similar environmental conditions.

Numbers and Characteristics of Entrained Fish

Twenty-nine species of fish were captured during entrainment trials (Table 2). Sixteen species were native to the Sacramento River. Seven species had not been captured during previous entrainment trials. Chinook salmon was the most frequently entrained species followed by prickly sculpin *Cottus asper*, lamprey *Lampetra* spp., Sacramento sucker *Catostomus occidentalis*, Sacramento pikeminnow *Ptychocheilus grandis*, and threespine stickleback *Gasterosteus aculeatus*. These six species comprised 95% of the 17,530 fish captured during entrainment trials.

Ammocoetes comprised 97% of the captured lamprey. The number of ammocoetes entrained was much higher than in previous years (McNabb et al. 1998) due to the pumps operating during all seasons. Fifty-five percent of the ammocoetes were entrained during two trials conducted in late November, a month when trials previously had not been conducted. During these two trials, it appeared that high river flows dislodged ammocoetes from the substrate. Ninety-three percent of the adult lamprey entrained were Pacific lamprey; adults of river and Pacific brook lamprey were entrained less frequently.

Run composition of chinook was 89.3% fall, 6.2% winter, 3.2% spring, and 1.3% late-fall (Table 3). It should be noted that the period covered in this report includes fall and late-fall chinook from brood years 1996 and 1997; winter and spring chinook are from brood year 1997.

Ninety-two percent of fish entrained into the plant were <100 mm in length. Length distributions of the four most frequently entrained species are shown in Figure 3. The majority of chinook salmon (84%) captured were less than 40 mm fork length. Lamprey ammocoetes were all less than 150 mm total length. Total lengths of prickly sculpin were fairly normally distributed with 70% in the 40 to 80 mm range. Most of the entrained Sacramento suckers (56%) were 30-50 mm. The fish most frequently entrained with individuals ≥100 mm in length were lamprey, Sacramento sucker, prickly sculpin, and Sacramento pikeminnow. Of the 97 metamorphosed Pacific lamprey entrained, 76% were greater than 200 mm total length; the remainder were 100 to 140 mm.

The lowest median fork length (mm) for chinook salmon occurred September through October and December through mid-March reflecting the outmigration of winter and fall chinook fry, respectively (Figure 4). The influence of hatchery-released smolts on median fork-length is apparent in April of each year as fork length rises sharply then decreases in May as smolts migrate past Red Bluff. The minimum fork-length was less than 40 mm for most weeks that entrainment was monitored. Maximum fork-length varied widely from week to week, but was typically greater than 60 mm.

Environmental Data
Mean daily water temperatures and dissolved oxygen levels in the Sacramento River during entrainment trials are shown in Figure 5. Mean water temperatures ranged from near 15°C in September and October to less than 7°C in early January. Mean dissolved oxygen values (percent saturation) were typically between 75 and 100 percent. Temperature and dissolved oxygen values measured in the holding tanks were similar to values from the river. Levels of total gases (percent saturation) in the holding tanks were typically between 101 and 104.

Rates and Patterns of Entrainment
The entrainment rate of chinook salmon was less than 0.3 chinook per acrefoot for every month except December and January when the rate increased to 1.3 and 3.4, respectively (Figure 6). This peak corresponded with the fall chinook out-migration. The acre-feet of water pumped in a 24-hr period was approximately 179, 357, and 535 when 1, 2, or 3 pumps were operating, respectively. Figure 7 shows the actual number of chinook salmon entrained per 24 hours of pump operation during each month of this study. The entrainment rate exhibited a seasonal trend being lowest in summer, highest in winter, and intermediate in spring and fall (Figures 6 and 7). Sampling effort varied throughout the year and was highest in the fall when pumps were operated continuously to provide water to the canals and juvenile winter chinook were outmigrating (Figure 6).

The entrainment rate of all fish ranged from 0.1 to 1.4 fish per acre-foot except in January when it reached 3.6. Outmigrating fall chinook comprised the majority (95 percent) of fish entrained in December and January (Figure 6). Chinook salmon comprised the majority of fish entrained in every season except summer when prickly sculpin was the most frequently entrained species. Entrainment rates and patterns of other commonly entrained species is shown in Figure 8.

There was no apparent relationship between entrainment rate and river discharge or turbidity (Figure 9). The greatest factor influencing chinook entrainment rate appeared to be the abundance of chinook in the river. That is, rates were highest in winter during the fall chinook outmigration with small spikes occurring in spring when fall chinook were released from Coleman National Fish Hatchery. A relationship may emerge if entrainment monitoring was conducted more frequently.

The diel entrainment pattern was similar to 1995-1996 with the majority of chinook (81percent) and all other fish (86percent) entrained at night (Table 4). The percent of chinook entrained at night was similar for fall, spring and late-fall chinook; it was somewhat higher for winter chinook. Bluegill and threespine stickleback were the only two frequently captured species that were fairly evenly entrained day and night. This is consistent with previous years' data (McNabb et al. 1998).

Estimated Numbers of Fish Entrained
An objective of this study is to estimate the number of chinook salmon entrained into the RPP. Appendix 1 provides weekly data on the actual number of chinook salmon and steelhead/rainbow

trout sampled during entrainment trials and their estimated number entrained based upon the weekly entrainment rate and hours of pump operation. Fall chinook are categorized as naturally or hatchery produced. Figure 10 summarizes this data for the entire reporting period with all pumps combined. Because fall, late-fall, and winter chinook were entrained during periods when the pumps were regularly used to provide water to the canals, the estimated number entrained was much higher than the actual number sampled. In contrast, spring chinook were entrained in the winter when the pumps were operated primarily for entrainment trials. The actual number of chinook sampled and the estimated number entrained into the pumps during this period were 6,523 and 12,432, respectively.

During spring and fall, the estimated number of chinook entrained far exceeded the actual number sampled because the pump hours were high and the proportion of time entrainment was monitored was low. In contrast, during summer and winter the actual number sampled and estimated number entrained were similar because pump hours were low and the proportion of time entrainment was monitored was high (Figure 11).

Differences in pumping regimes and numbers of chinook entrained in a wet versus a dry spring were observed during this study (Figure 11). Spring of 1997 was very dry requiring frequent use of the RPP to provide water to the canals. Therefore, estimated numbers of chinook entrained far exceeded the actual number sampled during entrainment trials. In contrast, the spring of 1998 was very wet with infrequent use of the RPP; pumps were used primarily for entrainment monitoring so estimated number and number sampled are less disparate than in 1997.

Number, Survival, and Injuries of Entrained Fish Compared Among Pumps

Comparisons Among the Three Pumps

Twenty-four 24-hr trials were conducted with all three pumps operating simultaneously. Differences between patterns of entrainment for chinook and all other fish were observed (Table 5). Most juvenile chinook were entrained into Archimedes 2 (54%), followed by Archimedes 1 (28%), and the internal helical pump (18%). In contrast, for fish other than chinook, Archimedes 1 entrained the greatest number (40%) followed by the internal helical pump (33%), and Archimedes 2 (27%) with the fewest fish. Archimedes 2 appears to have a propensity for entraining fish inhabiting the upper water column, and entrains fewer benthic fish. This pattern was also observed in the 1995 and 1996 data (McNabb et al.1998).

The tendency for more chinook to be entrained into Archimedes 2 was fairly consistent occurring in 75% of the trials. It was less consistent when the number of chinook entrained was low (<15). Analyses of variance revealed that the difference among pumps in the percentage of individuals entrained was significant for chinook salmon (P=0.0001) but not significant for other fish (P=0.66). Tukey's HSD indicated that Archimedes 2 entrained a significantly higher percentage of chinook salmon than Archimedes 1 (P=0.001) and the internal helical pump (P=0.0001), which were not significantly different (P=0.291).

Debris exhibited a similar pattern of entrainment among pumps. Fifty percent of all debris was entrained into Archimedes 2 and 25% into each of the other two pumps. This pattern also was fairly consistent among trials. While conducting experiments and entrainment trials, personnel also observed more larval fish being entrained into Archimedes 2 than into the other two pumps. Studies have not been undertaken to assess why the middle pump entrains more chinook, debris, and larval fish than the other two pumps.

Ninety-four percent of fish entrained during these simultaneous trials were <100 mm in length which is similar to the size distribution of fish entrained in all trials. More than 80% of the chinook salmon entrained were in the 30 - 39 mm size class. Of the four species most commonly entrained during the simultaneous trials, chinook salmon, lamprey, and prickly sculpin exhibited size distributions similar to all trials combined (Figure 12). Sacramento sucker exhibited a more even distribution across size classes with considerably fewer suckers entrained in the 30 to 49 mm size range compared to size distributions from all trials combined (Figures 3 and 12).

Ninety-eight percent of chinook salmon entrained by each of the Archimedes pumps were alive when collected from the holding tanks (Table 5). Survival of chinook collected from the internal helical pump's holding tank was somewhat lower at 94%. Survival of all other fish was 95% for each of the Archimedes pumps and 94% for the internal helical pump. Results of Kruskal-Wallis tests revealed no significant differences among pumps in survival of juvenile chinook salmon or other fish collected from the three pumps' holding tanks (P=0.875 and P=0.84, respectively).

Percent survival was lowest in the internal helical pump, however, it entrained fewer chinook than the Archimedes pumps. Therefore, it contributed less to the overall mortality of fish entrained into the plant. Considering all three pumps combined, overall survival of chinook entrained into the RPP was 97%; survival of all other fish combined was 95%.

While in the holding tank fish survival may be affected by volume and type of debris, amount of water flowing into the tank, amount of time confined in the tank, and presence of other fish. Regression analysis was conducted to assess the relationship between volume of debris and mortality of chinook salmon recovered from the holding tanks (Figure 13). Although these variables were poorly correlated ($r^2 = 0.113$), the regression was significant (P=0.002) suggesting that mortality may be affected by a combination of factors including debris.

The percentage of chinook salmon, dead and alive, removed from the holding tanks servicing Archimedes 1 and Archimedes 2 with injuries was 3.9 and 4.0, respectively (Table 6). The percent injured was higher for chinook removed from the internal helical pump's holding tank (7.9%). This is consistent with the higher mortality rate of chinook passed through the internal helical pump. The percentage of live chinook removed from the tanks with injuries was 2.2, 1.5, and 3.0 for Archimedes 1, Archimedes 2, and the internal helical pump, respectively. Fish other than chinook followed a similar pattern with the highest incidence of injuries in fish removed from the internal helical pump's holding tanks followed by Archimedes 1 and Archimedes 2. For each pump, the frequency of injuries was lower for chinook salmon than for other fish.

The most common injuries to chinook and other fish were observed on the integument (Tables 7 and 8). This was consistent among pumps. These injuries were observed on both live and dead fish. Chinook had fewer injuries than other fish in most injury categories; however, chinook had a higher incidence of abrasions and bulging eyes. Most (97%) of the chinook with bulging eyes were dead. For Archimedes 2 and the helical pump, most of the injuries to chinook salmon were observed in dead fish (65 and 72%, respectively); for Archimedes 1, 48% of the injuries were observed in dead fish. For other fish the incidence of injuries was fairly even between dead and live fish.

Comparisons Between the Archimedes Pumps

Forty-five trials were conducted with the two Archimedes pumps operating simultaneously. This is nearly double the number of trials conducted when all three pumps operated simultaneously. Because most of the additional trials with the Archimedes pumps were conducted in late spring and summer when chinook entrainment rates were low, the number of chinook entrained only increased by 30 and 20 percent for Archimedes 1 and 2, respectively over numbers from trials with all three pumps (Table 9). In contrast, the number of fish other than chinook increased by 70 and 80 percent for Archimedes 1 and 2, respectively, reflecting the high entrainment rate of prickly sculpin during late spring and summer periods.

Survival of chinook salmon was 2 to 4 percent lower than during the simultaneous trials with all three pumps while survival of fish other than chinook was one percent higher for each pump (Table 9). Trials were conducted every month except January and February 1998, covering a wide range of environmental conditions.

Survival of Large Fish (>200 mm) Compared Among Pumps

The majority of fish entrained into the plant were small (<100 mm). There is interest in knowing, however, how effectively these pumps pass large fish (>200 mm) unharmed. The most commonly entrained large fish were hardhead, Pacific lamprey, Sacramento pikeminnow, and Sacramento sucker. Survival of all fish >200 mm during the 24 simultaneous trials was 98, 100, and 96 percent for Archimedes 1, Archimedes 2 and the internal helical pump, respectively (Table 10). Pacific lamprey was the only large species collected dead from the holding tanks.

To increase the sample size, data on survival of all large fish entrained during this study was compiled. Because not all of these trials were conducted when the pumps operated simultaneously under similar environmental conditions, survival among pumps cannot validly be compared. Nevertheless, survival of large fish was similar among the three pumps and slightly higher than data from the simultaneous trials (Table 11). There were no mortalities among the 48 Sacramento pikeminnow or the 87 Sacramento suckers entrained. Of the 256 large fish entrained, four percent were injured. As in small fish, the most common injury was to the integument.

Delayed Mortality of Entrained Chinook Salmon

Chinook salmon <45 mm fork length were not available from Coleman National Fish Hatchery during periods when the internal helical pump was operable. Therefore, entrained wild chinook were used to compare delayed mortality of small chinook between the two types of pumps. Fish collections were not always from simultaneous trials so results are not directly comparable among pumps. The average fork length, however, of chinook passed through each of the three pumps and held for 96 hours was the same (37 mm). Ninety percent were fall chinook entrained in December through March; 6% were winter chinook entrained in September and October, and 4% were spring chinook entrained in December. Because of its higher entrainment rate, the number of chinook held from Archimedes 2 was close to twice that of the other two pumps. Immediate survival of entrained fish was 98% for the Archimedes pumps and 92% for the internal helical pump (Table 12). Fish that survived and were held for 96 hours had greater than 99% survival for each of the experimental pumps.

Discussion

Plant Operations

The Biological Opinion for the RPP predicted that during the juvenile winter chinook outmigration period, 2 percent of the Sacramento River discharge would be diverted into the RPP (National Marine Fisheries Service, 1993). During this study, the average percent of river discharge diverted into the pumping plant was 2.5. The percent was higher, however, during the winter chinook outmigration period. From mid-September through November when 99 percent of the winter chinook were entrained into the RPP, the average percent of river discharge diverted into the plant was 3.8. The higher proportion diverted during this period is due to river discharges at their yearly minimum and water needs at or near their yearly maximum. From mid-September through October all three pumps typically were operated for 24 hours each day to provide water to the canals.

Numbers and Characteristics of Entrained Fish

Because entrainment was monitored for more hours and over a wider range of seasons in this study than in 1995-1996 (McNabb et al. 1998), the number of fish and species entrained was higher. The twenty-nine species entrained represent over 90 percent of the 32 species of Sacramento River fish cited by Liston and Johnson (1992b) as potentially present in the river at Red Bluff. Seven species had not previously been captured during entrainment trials although all, except goldfish *Carassius auratus* had been entrained by rotary screw traps (Johnson and Martin 1997, Martin and Johnson in prep.). Three species collected in screw traps but not in the RPP were black crappie, American shad and redear sunfish.

Juvenile chinook salmon comprised 90% or more of the fish captured in rotary screw traps but only 37% of the fish entrained during trials at the RPP (Johnson and Martin 1997, Martin and Johnson in prep). This difference may be due to the difference in the vertical position of the screw traps and pump intakes in the river. Rotary screw traps sample the top 1.2 m of the water column, whereas the 1.2 m diameter intakes on the RPP pumps are located near the bottom of the river at a depth of approximately 3.6 - 4.8 m.. Studies conducted from 1950 - 1952 by the USFWS in the Sacramento River near Red Bluff assessed the vertical distribution of downstream migrating chinook using a push net to sample at 0.6 m intervals from the surface to a depth of 1.8 m (Azevedo and Parkhurst, 1957). Their sampling revealed that juvenile chinook salmon migrated at all depths, however, the numbers were greatest 0.6 to 1.2 m below the surface and fewest at 1.2 to 1.8 m below the surface. Other studies on outmigrating juvenile Pacific salmon indicate that they generally utilize the entire water column. However, their abundance at different depths within the water column can vary by diel period (McDonald 1960, Edmundson et al. 1968, Wickwire and Stevens 1971), by spatial zone across a river (Dauble et al.1989), by fish size (Wickwire and Stevens 1971), and by water depth (Mains and Smith 1964). Also, results from one river are not necessarily applicable to another. In the Snake River Mains and Smith (1964) found migrating juvenile chinook slightly more abundant in the middle and bottom zones than in the surface zone. However, in the Columbia River they found that chinook favored the surface zone which contained 44% of the catch compared to 27% captured at mid-depth and 29% captured in the bottom zone.

Prickly sculpin and lamprey ammocoetes, both benthic inhabitants, comprised 27 and 22 percent of the entrained fish, respectively, whereas they comprised less than 2% of the fish captured by rotary screw traps. Sacramento pikeminnow comprised 2% of the fish captured by both screw traps and the RPP.

A total of 3,771 lamprey ammocoetes were entrained into the RPP compared to only 123 in 1995-1996. The large increase occurred because trials were conducted during winter high flow periods which appeared to dislodge the ammocoetes from the substrate. In the 1995-1996 study, trials were not conducted during winter.

Eighty-two percent of entrained chinook had fork lengths in the 30-39 mm range compared to only 30% in this size class in the 1995-1996 study. The large increase in the proportion entrained in this size class is attributable to conducting trials during the months of November, December, and January, months that were not sampled in 1995-1996. Also, 1997-1998 was a wet winter so high numbers of post-emergent fall chinook fry were outmigrating during these months (Vogel et al.1988). The next most frequently entrained size class was 70-79 mm which included 6.5% of the chinook. Captures in this size class were influenced by hatchery releases; over 75% were captured in the spring within days of fall chinook smolts being released from Coleman National Fish Hatchery.

The trashracks proved effective at excluding large fish from the RPP. Less than 1.5% of the fish captured during entrainment trials were >200 mm in length. Infrequently, fish that appear too large in girth to pass through the bars on the trashracks have been entrained into the plant. It is believed that these fish gain entry into the sump area during high flows when openings between the trashrack and walkway are submerged.

Rates and Patterns of Entrainment

Excluding February 1998, at least two pumps were operational during each month of this study allowing seasonal patterns of entrainment to be assessed. In general, numbers entrained were low in the summer, increased somewhat in the fall as winter chinook outmigrated, were greatest in the winter as post-emergent fall chinook outmigrated, then decreased through the spring as the fall chinook completed their outmigration. This pattern of entrainment is similar to patterns of chinook abundance observed in the river by Martin and Johnson (in prep). This pattern is also consistent with data on chinook abundance at Red Bluff during a wet winter (Vogel et al. 1988). Heavy rains during December and January of 1996-1997 and 1997-1998 produced high river discharges resulting in the early out-migration of fall chinook salmon at a small size (<50 mm).

Although the entrainment rate of chinook salmon was greatest in December and January, these are months when the plant typically would not be operated if it was functioning only to deliver water. Therefore, it can be predicted that in wet years, most juvenile fall chinook will migrate past the RPP before pumping begins, and the numbers entrained will be low. This occurred in the wet winter of 1997-1998 when fall chinook outmigrated early and few remained in the spring to be entrained into the RPP. In contrast, during a dry winter when the annual peak out-migration of fall chinook is delayed until April through June (Vogel et al. 1988), the number of fall chinook entrained into the plant would be expected to be high due to frequent pumping from April through May 15.

During all seasons of the year except summer, chinook comprised the majority of fish entrained into the plant. Entrainment rates of chinook were lowest from May through August while entrainment rates of other fish, particularly prickly sculpin, were highest during those months. This high entrainment of non-salmonids into the RPP will not occur when the plant is functioning as a water delivery device since it will not be operated from May 15 through September 15 when RBDD gates are lowered.

No apparent relationship existed between entrainment rate and turbidity or discharge in this study. If sampling were conducted more frequently, however, a relationship may emerge. For example, data from USFWS rotary screw traps at RBDD does show a relationship between number of chinook outmigrating and river discharge or turbidity (P. Gaines, USFWS, personal communication.). Screw traps are monitored 5 to 7 days each week while pump entrainment is monitored only once or twice each week. More frequent entrainment monitoring would be necessary to discern such a relationship.

Diel patterns of entrainment were similar to 1995-1996 (McNabb et al. 1998). Most fish were entrained at night. These results are consistent with other studies conducted on migration patterns of juvenile Pacific salmon (McDonald 1960, Mains and Smith 1964, Dauble et al. 1989). McDonald (1960) found that fry of coho, sockeye, pink, and chum salmon initiated downstream movements shortly after dark and terminated these movements as daylight approached. In experiments conducted with sockeye and coho salmon fry, artificial light prevented their normal downstream movement at night.

The diel pattern of entrainment at the RPP has important implications for plant operations. If it was desirable or necessary to reduce the number of fish entrained, it could be accomplished by only pumping during daylight hours. Since 81% of chinook and 86% of all other fish were entrained at night, the numbers entrained would be decreased dramatically.

Results from passage trials conducted with hatchery fish (Objective B) in 1995 and 1996 brought into question whether fish collected from holding tanks accurately reflect diel patterns of entrainment. Preliminary passage trials in 1995 with hatchery fish were conducted during daylight hours. Most chinook salmon released into the pump's intake or outfall resided in the screening facility upstream of the holding tanks for several hours before moving downstream to the holding tanks. When trials were conducted in the 3-4 hours after sunset, chinook moved quickly through the system with over ninety percent of the released chinook recovered within 30 minutes (McNabb et al. 1998). Therefore, it is possible that a fraction of the fish entrained during the day remain upstream of the holding tanks until after sunset at which time they move downstream into the holding tanks. These day-entrained fish would mistakenly be counted as night-entrained fish. Future investigations will assess the percent of chinook entrained into the plant that hold up in the system during the day and move into the holding tanks after sunset.

Estimated Numbers of Fish Entrained

Actual and estimated numbers of chinook entrained into the RPP is related to the hours that the pumps operate. During this study we experienced two very different weather patterns during February - June of 1997 and 1998. After a wet January in 1997, dry conditions prevailed requiring frequent use of the pumping plant. Conditions were so dry by April 1997 that gates of RBDD were lowered for 10 days to allow delivery of water to the canals from Lake Red Bluff. In contrast, wet conditions prevailed through the winter and spring of 1998 keeping water demands low with infrequent use of the plant. This difference in pumping regimes during those two years is reflected in the relatively high actual and estimated numbers of chinook entrained in spring 1997 versus the low numbers in spring 1998. Numbers entrained in April 1997 would have been even higher if the plant had continued to be used rather than lowering the dam gates.

During this study, the RPP was operated for biological evaluations during periods of the year (summer and winter) when it would not be operated if it were being used solely for water deliveries. Therefore, the actual and estimated annual number of chinook salmon and other fish entrained into the plant would be less than determined during this study. Of the 6523 chinook entrained, 65% were collected during trials conducted in December and January, months that the plant would not be operated when functioning for water deliveries to the canals.

The Biological Opinion for the RPP assumed that juvenile chinook salmon would be entrained in proportion to the amount of flow diverted into the plant. Preliminary data from October - December 1997 on the percent of riverine chinook entrained into the RPP refutes this assumption. Based upon 18 entrainment trials conducted simultaneously with the Fish and Wildlife Service's screw trap sampling, the upper confidence interval estimate for percentage of riverine chinook entrained into the plant ranged from approximately 0.05 to 0.60 percent (C.

Martin, USFWS, personal communication). During this period the percent of the river diverted into the RPP ranged from approximately 1.5 to 5.5 percent. As suggested previously, this low entrainment rate may be due to the location of the pump intakes in relation to the vertical distribution of outmigrating juvenile chinook. Another possible explanation is that sweeping velocities along the traskracks in front of the pump intakes deter fish from entering the sump area. The plant was designed to provide a strong sweeping velocity component in front of the trashracks to exclude sediment, debris, and fish. During measurements taken with an acoustic Doppler current profiler in March 1996, sweeping velocities along the trashracks ranged from 2 to 3 ft/s when the two Archimedes pumps were each diverting 93 ft^3/s (Tracy Vermeyen travel report, April 15, 1997).

Number, Survival, and Injury of Entrained Fish Compared Among Pumps

Although there was no statistically significant difference in survival of fish passed through the two types of experimental pumps, percent survival was higher with the Archimedes pumps than with the internal helical pump. Two important differences between these pumps types that may affect fish survival are their speed and the characteristics of the pump's outfall. The helical pump is designed to operate at a much higher speed (350 rpm) than the Archimedes pump (26.5 rpm). During these trials the variable speed drive for the internal helical pump was not functioning and the pump was operated at a higher than optimum speed for pump performance and efficiency (378 rpm). This higher speed may have created conditions that were less fish friendly than if the pump had been operated at the optimum speed. Modifications were made to the pump's gear box in December 1998 to slow the pump speed to 350 rpm which may improve fish survival.

Engineering evaluations have not been made on the pump outfalls, however, there are obvious differences between the discharges of the two pump types (Frizell and Atkinson, 1996). The Archimedes pumps discharge their water in pulses associated with the dumping of water from each flight of the pump. Discharges are centered over the 1.5 m deep channel. Water from the internal helical pump is discharged from a height of approximately 1.0 m above the water surface into the 1.5 m deep channel. The helical pumps' outfall structure is off-center reducing the depth of water that the discharge plunges into to less than 0.5 m on the off-center side. This increases the likelihood that a fish discharged from the pump will strike the channel's concrete substrate. The off-center installation also causes water to slosh from side to side as it travels downstream causing velocity fluctuations along the vertical screens (Frizell and Atkinson 1996).

Survival of fish collected from holding tanks was high for each of the three pumps considering that in addition to passing through a pump, fish in a holding tank traveled the flow stream from the pump outfall to the holding tank. Once in the holding tank, fish were confined for up to 14 hours depending upon when they entered the tank in relation to the sunset or sunrise inspection. While in the holding tank fish survival could be affected by volume and type of debris, amount of water flowing into the tank, length of time confined in the tank, and presence of other fish.

Injuries to fish also may be affected by conditions in the holding tanks. Strikes from debris or predators may account for some of the integument injuries observed. Compared to all other fish, chinook salmon had a higher incidence of bulging eyes, technically known as exophthalmia. This condition has a variety of possible causes including several infectious agents (bacterial and viral) and parasites, nutritional deficiencies, gas supersaturation, kidney functions (increased pressure in the choroid gland), and trauma (Kim True, USFWS, California-Nevada Fish Health Center, personal communication.). Gas supersaturation could likely be ruled out since total gas saturation values measured in holding tanks were below levels found detrimental to fish (Weitkamp and Katz, 1980). However, any of the other causes are possible. Bulging eyes is a symptom of IHN (infectious hematopoietic necrosis), a disease frequently found in fall chinook smolts released from Coleman National Fish Hatchery. However, to avoid handling and adding stress to these diseased fish, entrainment monitoring is generally not conducted when smolts are being released. Therefore, less than 0.3% of chinook entrained with bulging eyes were collected during times when smolts were released from Coleman.

Our data did not show a correlation between debris and chinook mortality in holding tanks. When combined with high flows and/or long holding periods, however, high debris loads may affect survival. Although each entrainment trial began with low flows into the holding tanks, if present, debris impinges on the dewatering ramp decreasing the volume of water passing through the ramp thereby increasing the volume of water going to the holding tanks. Due to the relatively small size of the holding tanks, high flows into the tanks create turbulent conditions which may add to mortality and injuries, especially when coupled with debris and long periods of confinement. Confinement time of individual fish and duration of high flows into the holding tanks were two variables that could not be measured.

Considering all three pumps, overall mortality of chinook salmon entrained into the RPP was 3%. The overall percentage of chinook entrained into the plant with sublethal injuries was 2.1. These rates of mortality and injury are less than the 10% injury and mortality rate expected by the Biological Opinion for Archimedes pumps (NMFS 1993). The Biological Opinion expected the internal helical pump to subject entrained chinook to a "substantially higher rate of injury or mortality", even as high as 90 percent. Although mortality and injury was greater in the internal helical pump, levels were considerably less than expected and not statistically different from the Archimedes pumps.

Experiments conducted under Objective B of the RPP evaluation program provide a better estimate of chinook salmon survival from pump passage than do entrainment trials (McNabb et al. 1998). The condition and history of each treatment group of fish used in these experiments is known and controlled for. Also, during experiments fish are immediately removed from the holding tanks whereas in entrainment trials fish may be held in the holding tanks for several hours and subject to mortality from debris, other fish, or stress of confinement.

Delayed Mortality of Entrained Chinook Salmon

Delayed mortality of wild chinook entrained and held in the river water fish facility was ≤ 1 percent for the Archimedes pumps. This was similar to results with hatchery-produced fish used in Objective B pump passage trials during 1995 - 1996 (McNabb et al. 1998). Delayed mortality was 1 percent in the wild fish passed through the internal helical pump compared to 3 percent in hatchery-produced fish.

Future Monitoring Plans

During this study, 24-hr sunrise to sunrise trials were conducted simultaneously with the FWS screw trap monitoring study to determine the proportion of in-river fish entrained into the RPP. This simultaneous monitoring will continue through 1999. Based upon efficiency trials, FWS has predicted trap efficiency rates which are used with total daily catches to estimate the number of juvenile chinook emigrating past RBDD on any particular day. Ninety percent confidence intervals were constructed around these estimates (Martin and Johnson, in prep). By comparing the number of fish entrained into the RPP to the FWS's estimate of chinook emigrating past RBDD, we will be able to address the final objective of this study. This data will be reported when a sufficient number of trials has been completed to provide reliable estimates during different seasons of the year.

During entrainment monitoring trials in the fall of 1999, efforts will be made to better estimate survival of and injuries to entrained fish. This will be accomplished by monitoring holding tanks at 1 hour intervals for a portion of each sunset to sunrise entrainment period. Because fish will be removed from the holding tanks within at least an hour of entry, pump passage survival and injury will not be confounded with long periods of confinement in a holding tank with debris and other fish.

Trials will be conducted in 1999 to investigate the percent of chinook entrained into the RPP that hold up in the screening facility during the day and move into the holding tanks after sunset. In these trials, hatchery-reared juvenile chinook will be used as surrogates for wild chinook. Samples of 32 fish will be released into the plant intakes at sunrise on day-1. These fish will be dyed with bismarck brown dye to distinguish them from entrained wild chinook. Surrogates will be recovered from tanks at sunset on days-1, and again at sunrise on day-2, and counted. The proportion of fish recovered during the diurnal and nocturnal periods of each entrainment trial will be calculated.

Acknowledgments

Many people were involved in planning, implementing, and facilitating this study. Special thanks go to Dr. Cal McNabb whose work at the RPP in 1995 and 1996 provided the foundation for this study. Cal also provided sage advice and guidance throughout this study. Max Stodolski, manager of Reclamation's Red Bluff Fish Passage Program, greatly facilitated our operations ensuring that supply, equipment, personnel, and pumping needs were met. The following on-site biological evaluation staff each spent many evenings and early mornings collecting field data: Rick Crouch, Zachary Wilson, Drea Traeumer, Jeremy Brasch, Marie-Christine Daems, Sharon Nowak, Ed Weber, and Christy Skelton. They also entered all data into a computer database and checked it for quality control. Judy Lyons, Rick Wydoski, Tom LaCasse, Andrew Montanyo, and Johnnie Boutwell from the Fisheries Applications Research Group at Reclamation's Technical Service Center in Denver helped on-site staff collect, enter, and check data during busy periods of the year. Special thanks go to the Operations and Maintenance Staff at Red Bluff including Wayne Stokes, Steve Quitiquit, and Paul Freeman who facilitated this study by making improvements and modifications to various components of the the pumping plant and fish evaluation facilities. Warren Frizell and Steve Atkinson, engineers on the project, provided useful data on velocities at the pump intakes and between the vertical screens. We thank those who reviewed this report including Dr. Cal McNabb, Dr. Louis Helfrich, Ed Weber, Warren Frizell, Tom Kisanuki, Craig Martin, Phillip Gaines, Mike Tucker, and John Johnson. Rich Johnson, Craig Martin, and Bill McKinney with the U. S. Fish and Wildlife Service, North Central Valley Fish and Wildlife Office provided insightful discussion during this project and full cooperation in coordinating their sampling activities with ours. Funding for this program was provided by Reclamation's Mid-Pacific Region, supplemented by Reclamation's Research and Technology Development Program, Study Number AE CO-98.016 (WATR).

Literature Cited

Azevedo, R. L. and Z. E. Parkhurst. 1957. The upper Sacramento River Salmon and Steelhead maintenance program, 1949 - 1956. U.S. Fish and Wildlife Service Report.

Dauble, D. D., T. L. Page, and R. W. Hanf, Jr. 1989. Spatial distribution of juvenile salmonids in the Hanford Reach, Columbia River. Fishery Bulletin 87(4):775-790.

Edmundson, E., F. E. Everest, and D. W. Chapman. 1968. Permanance of station in juvenile chinook salmon and steelhead trout. Journal of Fisheries Research Board of Canada 25(7):1453-1464.

Frizell, K. W. and S. P. Atkinson. 1996. Engineering shakedown and evaluations at Red Bluff Research Pumping plant, 1995. U. S. Bureau of Reclamation, Technical Service Center, Denver, CO.

Green, S. 1992. Daily fork-length table from data by Frank Fisher, California Department of Fish and Game. California Department of Water Resources, Environmental Services Department, Sacramento.

Johnson, R. R. and C. D. Martin. 1997. Abundance and seasonal, spatial and diel distribution patterns of juvenile salmonids passing the Red Bluff Diversion Dam, Sacramento River, July 1994-June 1995. Red Bluff Research Pumping Plant Report Series, Volume 2. U. S. Fish and Wildlife Service, Red Bluff, California.

Johnson, R. R., D. C. Weigand, and F. W. Fisher. 1992. Use of growth data to determine the spatial and temporal distribution of four runs of juvenile chinook salmon in the Sacramento River, California. Report No. AFF1-FAO-92-15. U. S. Fish and Wildlife Service, Northern Central Valley Fishery Resource Office, Red Bluff, California.

Liston, C. R. and P. L. Johnson. 1992a. Biological and engineering research evaluation plan for a pilot pumping plant at Red Bluff Diversion Dam on the Sacramento River, California. Bureau of Reclamation, Research and Laboratory Services Division, Denver.

Liston, C. R. and P. L. Johnson. 1992b. Design criteria and environmental setting for a pilot pumping plant installation at Red Bluff Diversion Dam on the Sacramento River, California. Bureau of Reclamation, Research and Laboratory Services Division, Denver.

Mains, E. M. and J. M. Smith. 1964. The distribution, size, time and current preferences of seaward migrant chinook salmon in the Columbia and Snake Rivers. Fisheries Research Papers, Washington Department of Fisheries 2(3):5-43.

Martin, C. D. and R. R. Johnson. In prep. Abundance and seasonal, spatial and diel distribution patterns of juvenile salmonids passing the Red Bluff Diversion Dam, Sacramento River. Red Bluff Research Pumping Plant Report Series, Volume 5. U. S. Fish and Wildlife Service, Red Bluff, California.

McDonald, J. 1960. The behavior of Pacific salmon fry during their downstream migration to freshwater and saltwater nursery areas. Journal of the Fisheries Research Board of Canada 17(5):655-676.

McNabb, C.D, C. R. Liston, and S. M. Borthwick. 1998. In-plant biological evaluation of the Red Bluff Research Pumping Plant on the Sacramento River in Northern California: 1995 and 1996. Red Bluff Research Pumping Plant Report Series, Volume 3. U. S. Bureau of Reclamation, Denver, CO.

National Marine Fisheries Service. 1993. Endangered Species Act, Section 7 Consultation-Biological Opinion; a pilot pumping plant program at Red Bluff Diversion Dam. National Marine Fisheries Service, Southwest Region, Long Beach, California (February 2).

Vogel, D. A. and K. R. Marine. 1991. Guide to Upper Sacramento River chinook salmon life history. CH2M Hill, Redding, California.

Vogel, D. A., K. R. Marine and J. G. Smith. 1988. Fish passage action program for Red Bluff Diversion Dam. Report No. FR1/FAO-88-19. U. S. Fish and Wildlife Service, Northern Central Valley Fishery Resource Office, Red Bluff, California.

Weitkamp, D. E. and M. Katz. 1980. A review of dissolved gas supersaturation literature. Transactions of the American Fisheries Society 109:569-702.

Wickwire, R. H. and D. E. Stevens. 1971. Migration and distribution of young king salmon, *Oncorhynchus tshawytscha*, in the Sacramento River near Collinsville. California Department of Fish and Game, Anadromous Fisheries Branch Administrative Report No. 71-4, Sacramento, CA. 18 pages.

Yoshiyama, R. M., F. W. Fisher, and P. B. Moyle. 1998. Historical abundance and decline of chinook salmon in the Central Valley region of California. North American Journal of Fisheries Management 18: 487-521.

Table 1. Summary of pump operations and fish entrainment monitoring at Red Bluff Research Pumping Plant, February 1997 - June 1998.

PARAMETER	ARCHIMEDES-1	ARCHIMEDES-2	INTERNAL HELICAL
Pump Speed (rpm)	26.5	26.5	378
Average Discharge (ft^3/s) (Range)	89.4 (79.5 - 94.5)	90.0 (86.0 - 97.5)	96.3 (82.0 - 101.5)
Period of Pump Operation	1997: Feb - Dec 1998: Jan, Mar -Jun	1997: Feb - Dec 1998: Jan, Mar - Jun	1997: Feb - mid-July; Sep - Dec 1998: Jan, Mar - Apr
Total Hrs. Pump Operated	4544	4424	3052
Total Hrs. Entrainment Monitored	1219	1271	908
% of Time Entrainment Monitored	27	29	30
Number of 24 Hr. Trials Conducted	49	52	35

Table 2. Fish species entrained from the Sacramento River and captured in holding tanks at Red Bluff Research Pumping Plant, February 1997 - June 1998.

SPECIES	NUMBER ENTRAINED	PERCENT OF TOTAL
Chinook salmon (*Oncorhynchus tshawytscha*) [1]	6,523	37
Prickly sculpin (*Cottus asper*) [1]	4,710	27
Lamprey ammocoetes (*Lampetra* spp.) [1]	3,771	22
Sacramento sucker (*Catostomus occidentalis*) [1]	941	5
Sacramento pikeminnow (*Ptychocheilus grandis*) [1]	392	2
Threespine stickleback (*Gasterosteus aculeatus*) [1]	265	2
Bluegill (*Lepomis macrochirus*)	202	1
Riffle sculpin (*Cottus gulosus*) [1]	125	<1
Pacific lamprey (*Lampetra tridentata*) [1]	97	<1
Tule perch (*Hysterocarpus traski*) [1]	80	<1
White catfish (*Ictalurus catus*)	68	<1
California roach (*Hesperoleucus symmetricus*) [1]	65	<1
Hardhead (*Mylopharodon concephalus*) [1]	63	<1
Steelhead/Rainbow trout (*Oncorhynchus mykiss*) [1]	62	<1
Mosquitofish (*Gambusia affinis*)	31	<1
Largemouth bass (*Micropterus salmoides*)	28	<1
Threadfin shad (*Dorosoma petenense*) [2]	24	<1
Unidentified adult lamprey (*Lampetra* spp.) [1]	22	<1
Speckled dace (*Rhinichthys osculus*) [1,2]	16	<1
Green sunfish (*Lepomis cyanellus*) [2]	12	<1
River lamprey (*Lampetra ayresi*) [1]	6	<1
Channel catfish (*Ictalurus punctatus*) [2]	6	<1
Brown bullhead (*Ictalurus nebulosus*)	4	<1
Golden shiner (*Notemigonus crysoleucas*) [2]	3	<1
Hitch (*Lavinia exilicauda*) [1]	3	<1
Sturgeon (*Acipenser spp*) [1]	3	<1
Common carp (*Cyprinus carpio*) [2]	2	<1
Smallmouth bass (*Micropterus dolomieui*)	2	<1
Bullhead (*Ictalurus spp*)	2	<1
Goldfish (*Carassius auratus*) [2]	1	<1
Pacific brook lamprey (*Lampetra pacifica*) [1]	1	<1
TOTAL	17,530	

[1] Species native to the Sacramento River

[2] Species not previously captured during entrainment trials.

Table 3. Run composition of chinook salmon entrained into Red Bluff Research Pumping Plant, February 1997 - June 1998.

RUN	NUMBER ENTRAINED	PERCENT OF TOTAL
FALL	5825	89.3
WINTER	405	6.2
SPRING	209	3.2
LATE-FALL	84	1.3

Table 4. Diel capture of fish most frequently entrained during trials with experimental pumps at Red Bluff Research Pumping Plant, February 1997 - June 1998.

SPECIES	PERCENT CAPTURED	
	DAY	NIGHT
Chinook Salmon		
Fall	20	80
Late-fall	20	80
Winter	10	90
Spring	17	83
All Chinook	**19**	**81**
Prickly Sculpin	12	88
Lamprey Ammocoetes	12	88
Sacramento Sucker	12	88
Sacramento Pikeminnow	23	77
Threespine Stickleback	44	56
Bluegill	45	55
All Fish Except Chinook	**14**	**86**

Table 5. Total number and percent survival of fish species most frequently entrained into experimental pumps at Red Bluff Research Pumping Plant during 24-hour entrainment trials (N=24) conducted from February 1997 - June 1998 when all three pumps ran simultaneously.[1]

SPECIES	ARCHIMEDES 1		ARCHIMEDES 2		INTERNAL HELICAL	
	Number	% Survival[2]	Number	% Survival[2]	Number	% Survival[2]
Chinook Salmon[3]						
Fall run	831	98	1621	99	549	94
Winter run	48	94	103	90	37	100
Spring run	31	90	70	94	16	81
Late-fall run	8	88	12	92	11	82
All Chinook	**918**	**98**	**1806**	**98**	**613**	**94**
Prickly Sculpin	683	98	420	98	501	95
Lamprey Ammocoetes	175	99	126	99	251	98
Sacramento Sucker	29	97	27	89	19	89
Sacramento Pikeminnow	28	100	40	98	14	86
All Fish Except Chinook	**1098**	**95**	**769**	**95**	**906**	**94**
ALL FISH	**2016**	**96**	**2575**	**97**	**1519**	**94**

1 Each entrainment trial started at sunrise and continued for 24 hours.

2 Survival should not be interpreted strictly as pump passage survival. This table represents survival of fish that passed through a pump, then traveled by a screening facility, around curved bypass channels, up a dewatering ramp and into a holding tank. Fish could be held in a holding tank for up to 14 hours depending upon when it arrived in the holding tank in relation to the sunrise or sunset entrainment check. Survival of fish collected from the holding tanks could be affected by the duration it was confined to the tank, the amount of water flowing into the tank, the type and/or volume of debris in the holding tank, or by other fish in the holding tank.

3 Run membership was determined from a daily fork-length table generated by Sheila Greene, California Department of Water Resources, Environmental Services Office, Sacramento (8 May 1992) from data by Frank Fisher, California Department of Fish and Game, Inland Fisheries Branch, Red Bluff (revised 2 February 1992).

Table 6. Percentage of juvenile chinook salmon and other fish entrained into Red Bluff Research Pumping Plant that exhibited injuries when collected from holding tanks during 24 simultaneous entrainment trials conducted with the three pumps from February 1997 - June 1998. The number of fish examined in each category is shown in parentheses.

Groups of Fish	Archimedes 1	Archimedes 2	Internal Helical
All Chinook[1]	3.9 (565)	4.0 (968)	7.9 (570)
Surviving Chinook	2.2 (543)	1.5 (934)	3.0 (531)
Other Fish[1]	5.8 (834)	5.4 (681)	8.1 (695)
Other Surviving Fish	3.8 (789)	3.2 (649)	4.2 (646)

[1] Includes all fish with injuries, whether individuals were alive or dead at the time of collection.

Table 7. Percentage of dead and alive juvenile chinook salmon with specified injuries. Chinook were collected in holding tanks at Red Bluff Research Pumping Plant during 24 simultaneous entrainment trials conducted with the three pumps, February 1997 - June 1998. The number of fish examined from each pump is shown in parentheses.

Type of Injury[1]	Archimedes 1 (565)		Archimedes 2 (968)		Internal Helical (570)	
	Alive	Dead	Alive	Dead	Alive	Dead
Fins						
Eroded >30%	0	0	0	0	0	0.4
Eroded to base	0.2	0	0.1	0.1	0	0.9
Skin						
Bruise	0.5	0.2	0.1	0.2	0.5	1.1
Partially Deskinned	0.2	0.2	0.4	0.3	0	0
Split or Open Wound	0.9	0	0.1	0.4	1.1	1.1
Abrasion	0.4	0.2	0.7	0.4	0.2	0.4
Hemorrhage	0	0.2	0.1	0	0	0
Eyes						
Bulging	0.2	1.2	0	1.7	0.4	1.9
One missing	0	0	0	0	0	0
Both missing	0	0	0	0	0	0.4
Hemorrhage	0	0.2	0	0.1	0.4	0.4
Head						
One operculum missing	0	0	0	0.1	0.2	0.4
Both operculum missing	0	0	0	0	0	0
Open wound or abrasion	0.4	0.4	0.1	0.1	0.2	0.4
Decapitated	0	0	0	0	0	0
Bruise or hemorrhage	0	0	0.2	0	0	0.2

[1]A fish may have more than one type of injury.

Table 8. Percentage of dead and alive fish other than chinook salmon with specified injuries. Fish were collected in holding tanks at Red Bluff Research Pumping Plant during 24 simultaneous entrainment trials conducted with the three pumps, February 1997 - June 1998. The number of fish examined from each pump is shown in parentheses.

Type of Injury[1]	Archimedes 1 (834)		Archimedes 2 (681)		Internal Helical (695)	
	Alive	Dead	Alive	Dead	Alive	Dead
Fins						
Eroded >30%	0.4	0.4	0.1	0.1	0.4	0.6
Eroded to base	1.1	0.2	0.1	0.4	1.4	0.6
Skin						
Bruise	0.5	0	1.0	0.3	0.9	0.1
Partially Deskinned	0	0.5	0.1	0.4	0.3	0.1
Split or Open Wound	0.7	0.8	0.7	0.4	0.6	1.7
Abrasion	0.1	0.2	0.1	0	0	0
Hemorrhage	0.4	0.4	0.4	0.3	1.0	0.7
Eyes						
Bulging	0.1	0.1	0	1.0	0	0.3
One missing	0	0.1	0	0	0	0
Both missing	0	0.1	0	0.1	0	0
Hemorrhage	0	0	0.1	0	0	0
Head						
One operculum missing	0	0	0	0	0	0.1
Both operculum missing	0	0	0	0	0	0
Open wound or abrasion	0.4	0.2	0.1	0.3	0.1	0
Decapitated	0	0.1	0	0.1	0	0.1
Bruise or hemorrhage	0	0	0	0	0	0

[1]A fish may have more than one type of injury.

Table 9. Total number and percent survival of fish species most frequently entrained into the Archimedes pumps at Red Bluff Research Pumping Plant during 24-hour entrainment trials (N=45) conducted from February 1997 - June 1998 when both pumps ran simultaneously.[1]

SPECIES	ARCHIMEDES 1		ARCHIMEDES 2	
	Number	% Survival[2]	Number	% Survival[2]
Chinook Salmon[3]				
Fall run	1062	95	1858	98
Winter run	158	94	255	88
Spring run	41	93	77	95
Late-fall run	33	82	39	90
All Chinook	**1294**	**94**	**2229**	**96**
Prickly Sculpin	1734	95	1437	99
Lamprey Ammocoetes	717	98	792	100
Sacramento Sucker	406	95	424	88
Sacramento Pikeminnow	135	97	151	98
All Fish Except Chinook	**3628**	**96**	**3758**	**96**
ALL FISH	**4922**	**95**	**5987**	**96**

1 Each entrainment trial started at sunrise and continued for 24 hours.

2 Survival should not be interpreted strictly as pump passage survival. This table represents survival of fish that passed through a pump, then traveled by a screening facility, around curved bypass channels, up a dewatering ramp and into a holding tank. Fish could be held in a holding tank for up to 14 hours depending upon when it arrived in the holding tank in relation to the sunrise or sunset entrainment check. Survival of fish collected from the holding tanks could be affected by the duration it was confined to the tank, the amount of water flowing into the tank, the type and/or volume of debris in the holding tank, or by other fish in the holding tank.

3 Run membership was determined from a daily fork-length table generated by Sheila Greene, California Department of Water Resources, Environmental Services Office, Sacramento (8 May 1992) from data by Frank Fisher, California Department of Fish and Game, Inland Fisheries Branch, Red Bluff (revised 2 February 1992).

Table 10. Survival of large fish (>200 mm) entrained into experimental pumps at Red Bluff Research Pumping Plant during 24-hour entrainment trials (N=24) conducted from February 1997 - June 1998 when all three pumps ran simultaneously.

SPECIES (avg; min-max total length in mm)	ARCHIMEDES 1		ARCHIMEDES 2		INTERNAL HELICAL	
	Number	% Survival	Number	% Survival	Number	% Survival
Pacific Lamprey (541; 395 - 686)	22	95	4	100	15	93
Hardhead (229; 200 - 256)	10	100	14	100	3	100
Sacramento Pikeminnow (235; 202 - 320)	10	100	8	100	5	100
Sacramento Sucker (237; 200 - 305)	2	100	7	100	5	100

Table 11. Survival of large fish (>200 mm) entrained into experimental pumps at Red Bluff Research Pumping Plant during all entrainment trials conducted from February 1997 - June 1998. Pumps were not always operated simultaneously under the same conditions, so results among pumps are not directly comparable.

SPECIES (avg; min-max total length in mm)	ARCHIMEDES 1		ARCHIMEDES 2		INTERNAL HELICAL	
	Number	% Survival	Number	% Survival	Number	% Survival
Pacific Lamprey (536; 307 - 732)	39	95	17	100	18	94
Hardhead (237; 200 - 338)	22	95	20	100	5	100
Sacramento Pikeminnow (251; 202 - 480)	20	100	13	100	15	100
Sacramento Sucker (251; 200 - 432)	35	100	43	100	9	100

Table 12. Percent survival of small chinook salmon (<45 mm) entrained into Red Bluff Research Pumping Plant. Fish that were alive at capture were held in live cages in the river water fish facility for 96 hours to assess delayed mortality. Trials were conducted February 1997 - June 1998.

Pump	Number Entrained	Average Fork Length (mm)	% Survival at Capture	% Survival at 96 hrs
Archimedes 1	1077	37	98.2	99.5
Archimedes 2	2061	37	97.5	99.5
Internal Helical	959	37	92.2	99.2

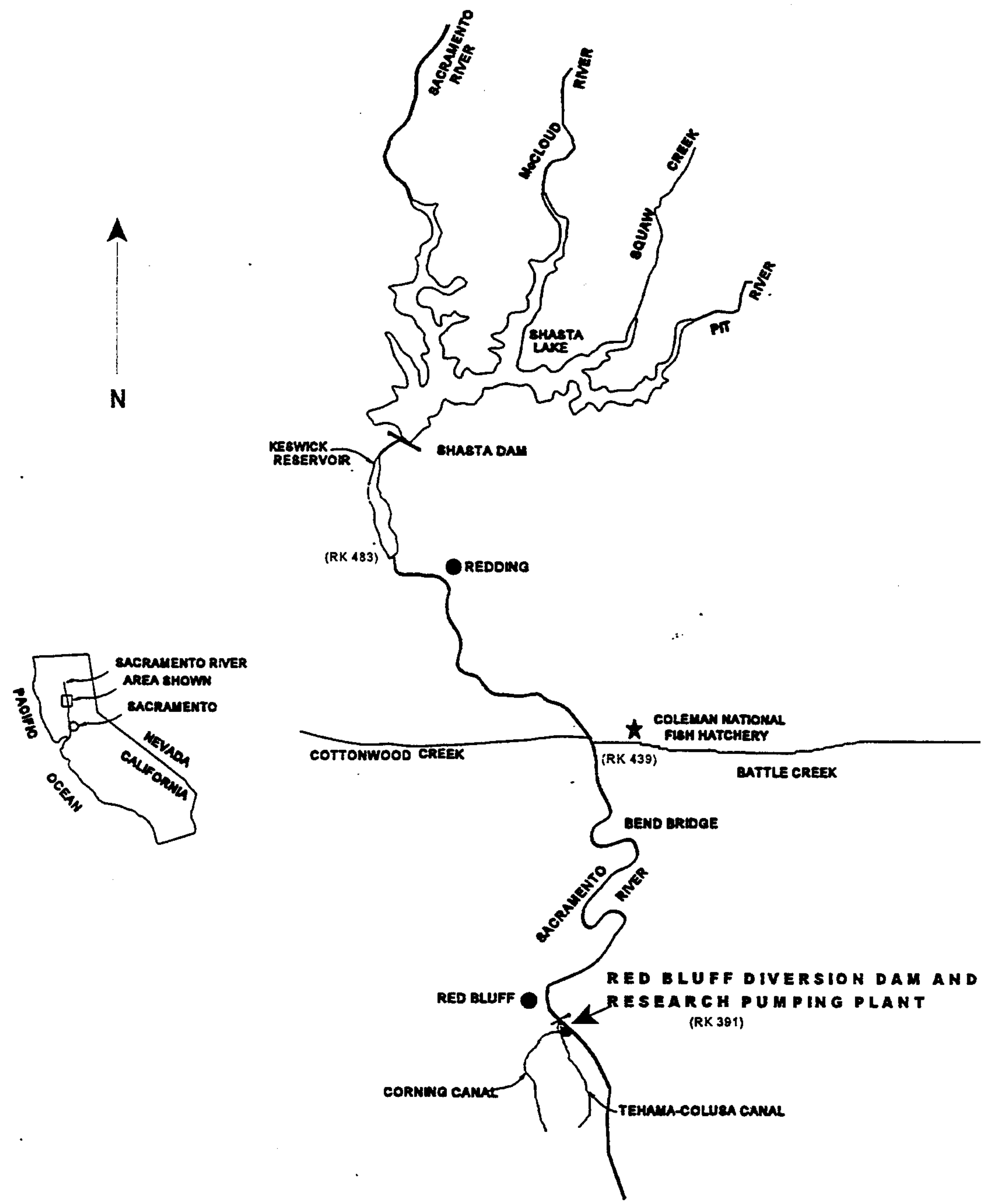

Figure 1. Location of Red Bluff Research Pumping Plant in relation to other features within the upper Sacramento River drainage.

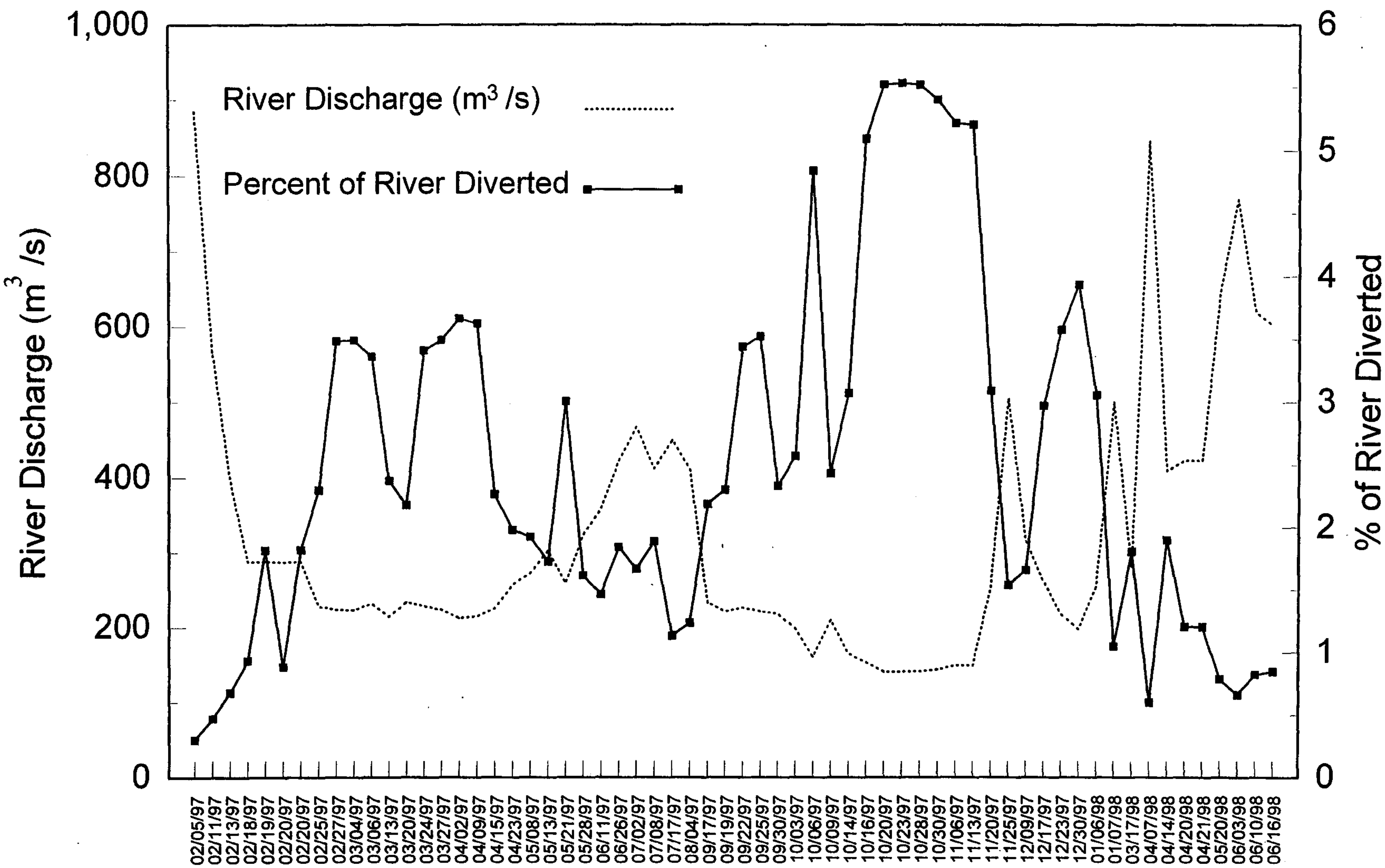

Figure 2. Daily Sacramento River discharge (m^3/s) flowing past Red Bluff Research Pumping Plant and percent of river diverted into the plant during entrainment trials conducted from February 1997 - June 1998.

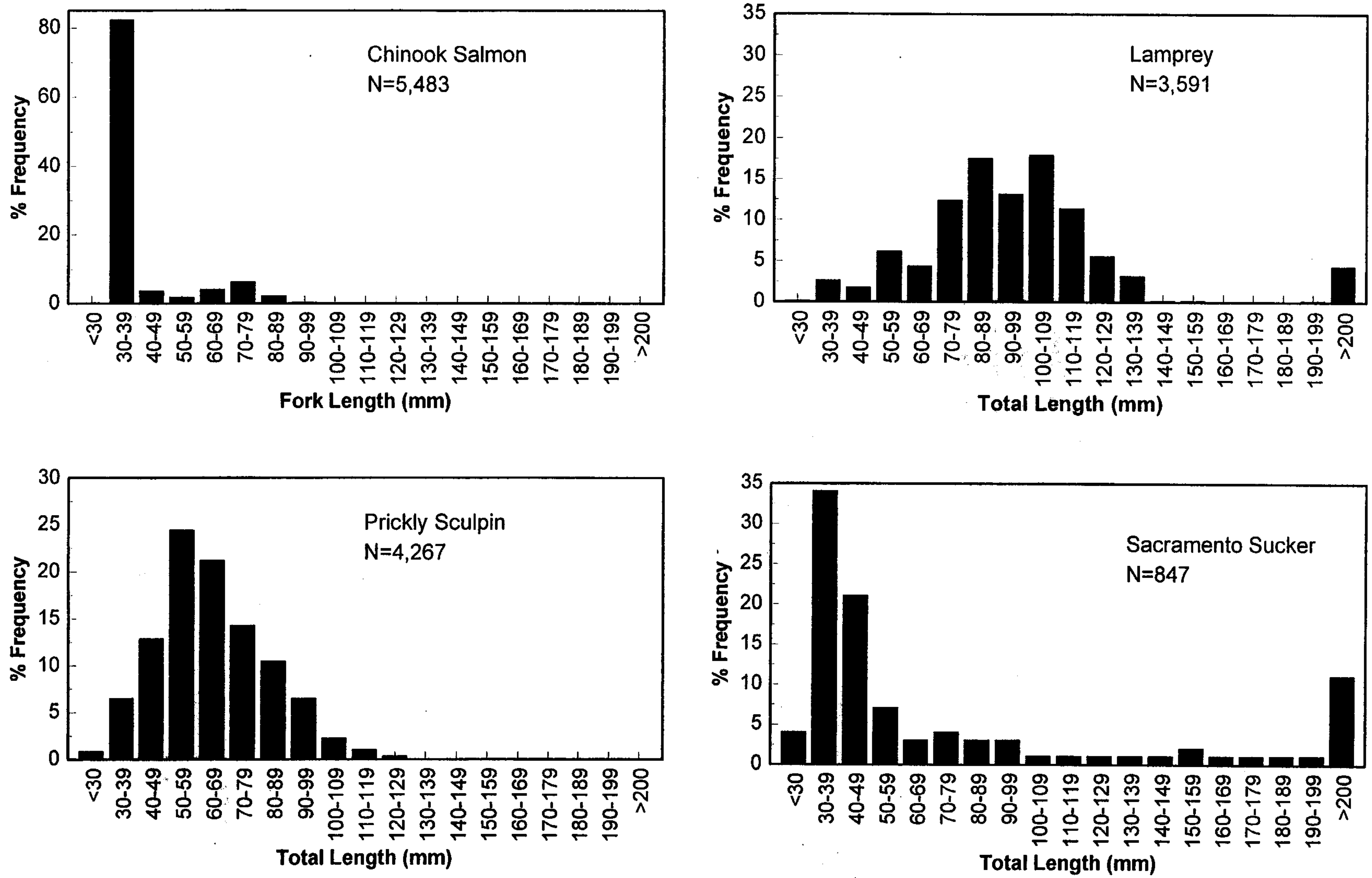

Figure 3. Size-frequency distribution of chinook salmon, lamprey, prickly sculpin, and Sacramento sucker entrained into Red Bluff Research Pumping Plant during entrainment trials conducted February 1997 - June 1998.

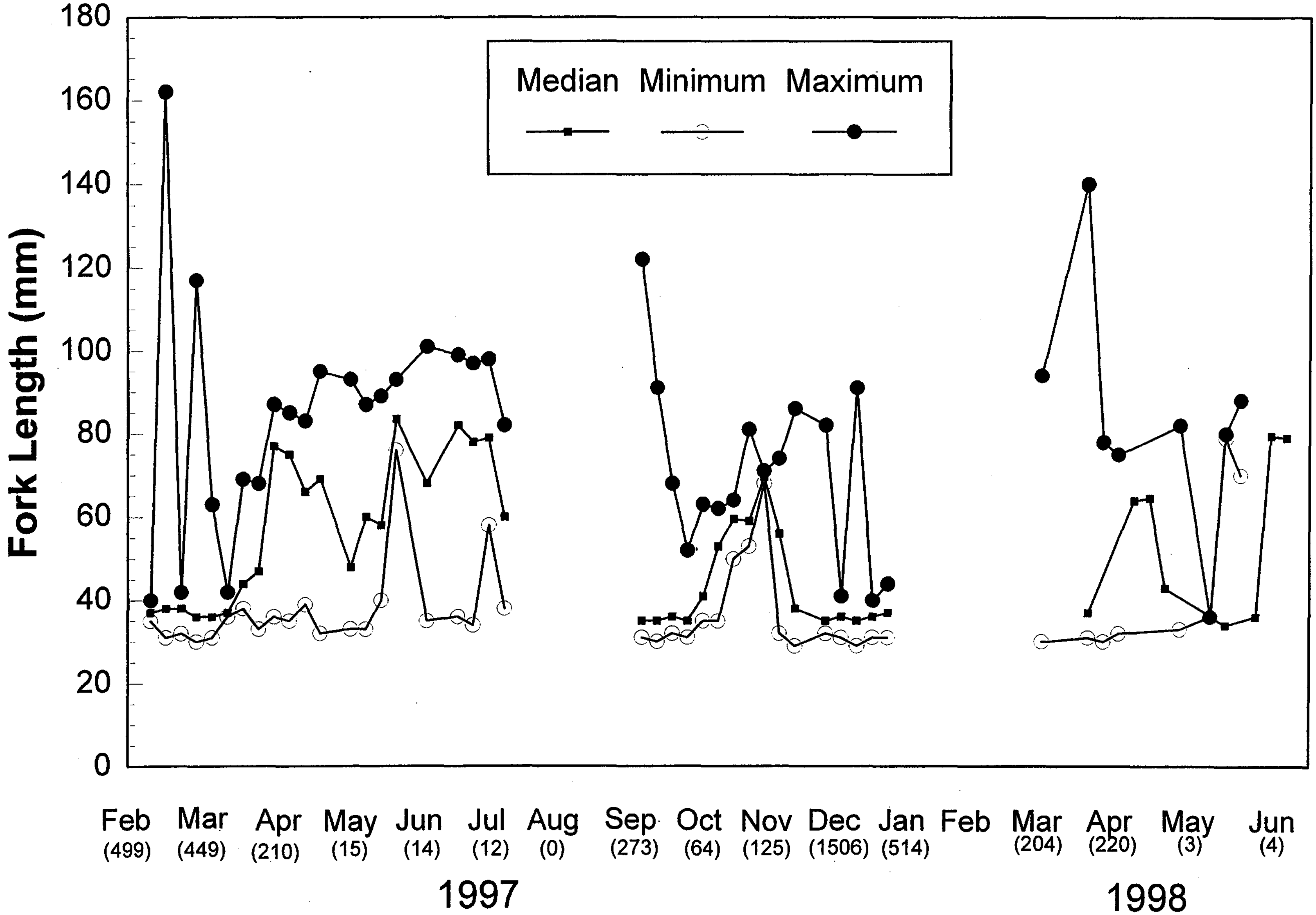

Figure 4. Weekly median, minimum and maximum fork lengths of juvenile chinook salmon entrained into Red Bluff Research Pumping Plant during February 1997 - June 1998. Number of fish measured each month is shown in parentheses. Breaks in the graph indicate weeks when entrainment monitoring was not conducted (February 1998) or chinook salmon were not entrained (all other breaks).

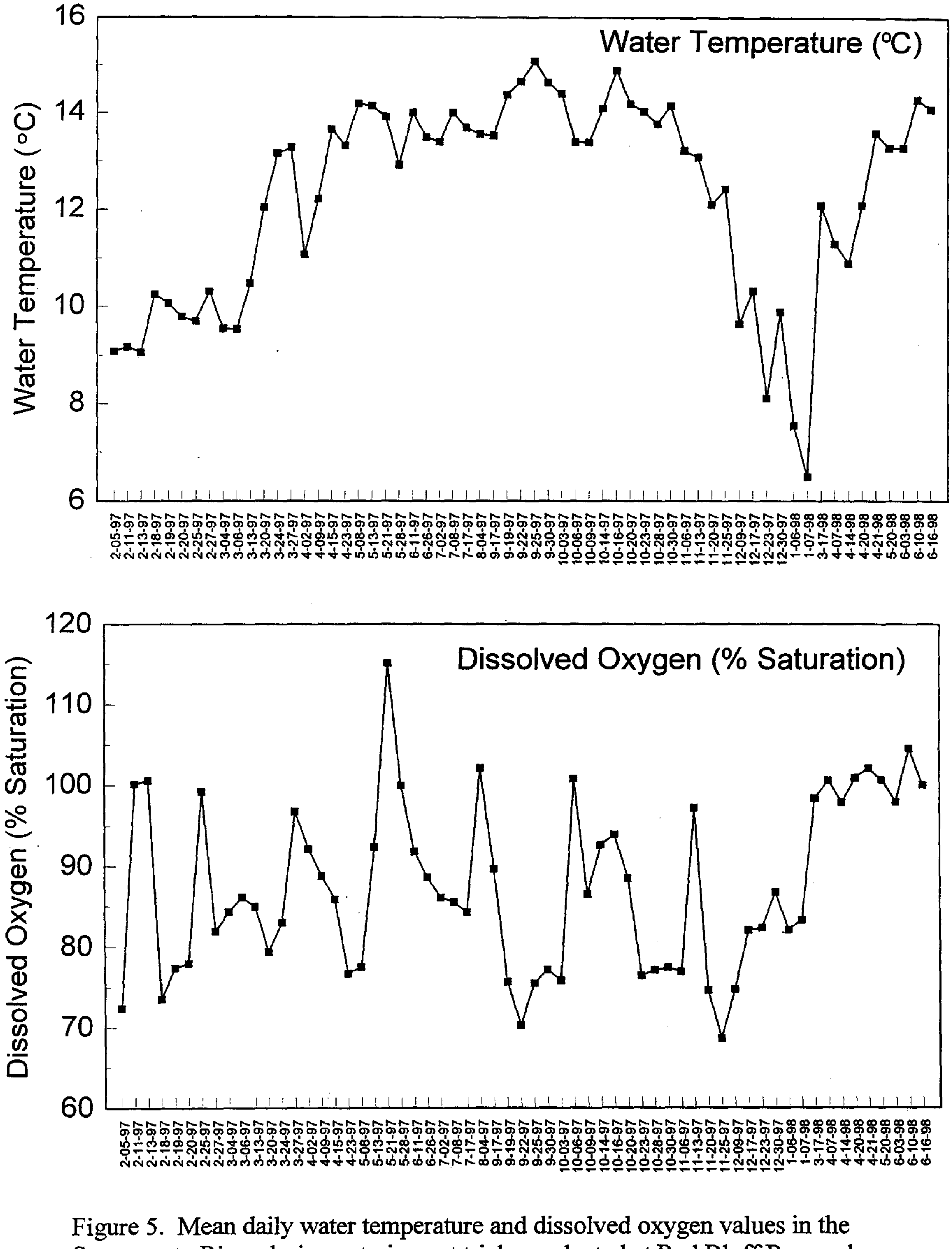

Figure 5. Mean daily water temperature and dissolved oxygen values in the Sacramento River during entrainment trials conducted at Red Bluff Research Pumping Plant from February 1997 - June 1998. Hourly measurements were taken with a Hydrolab Datasonde T water quality probe situated in the river near the east side of Red Bluff Diversion Dam.

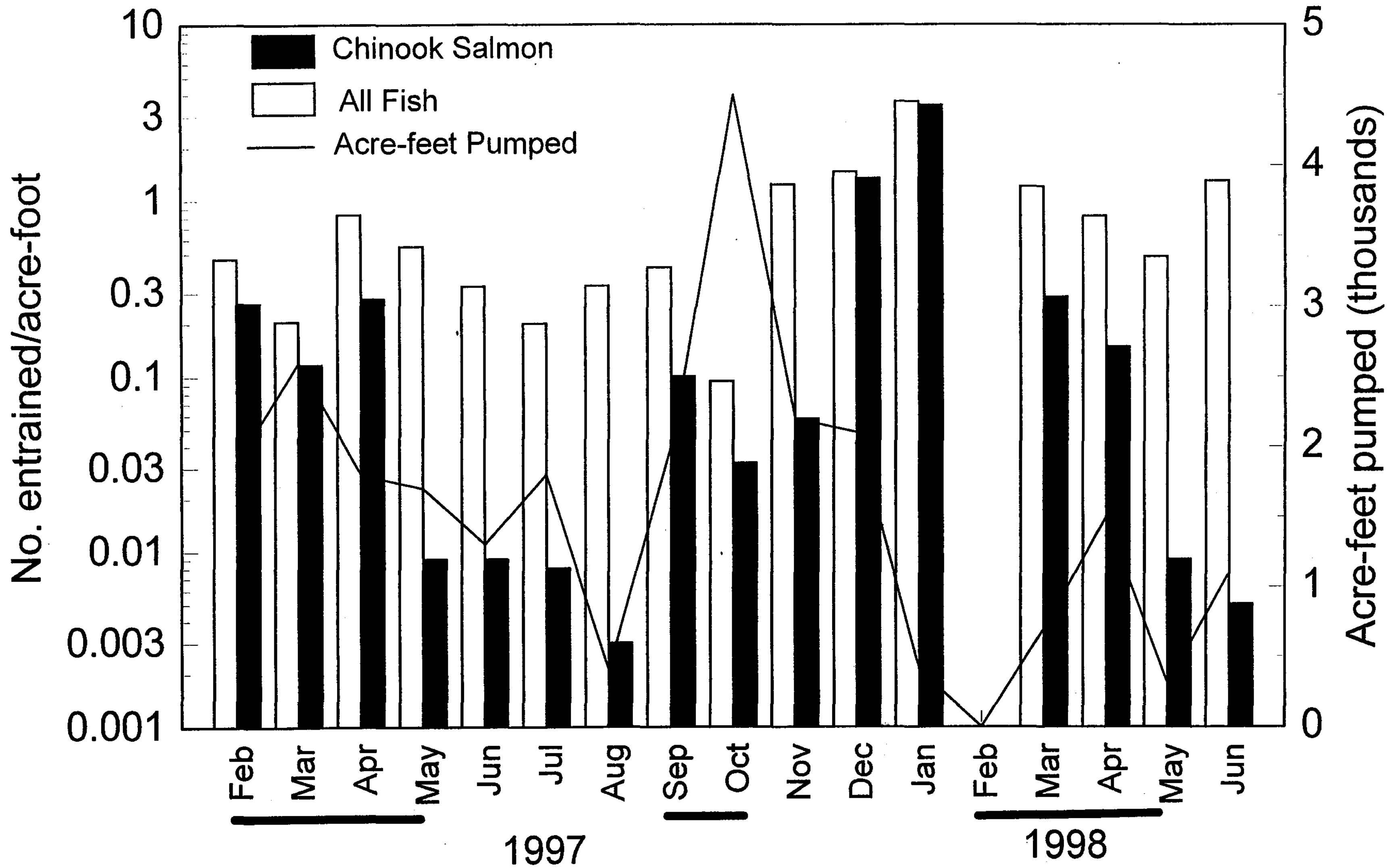

Figure 6. Monthly entrainment rates of chinook salmon and all fish into Red Bluff Research Pumping Plant during trials conducted February 1997- June 1998. Sampling effort is indicated by the number of acre-feet pumped during entrainment trials each month. The pumps did not operate in February 1998. Lines beneath the months indicate periods when the plant is typically operated to provide water to the canals. A log scale is used on the y-axis because of the large range in no. entrained/acre-foot.

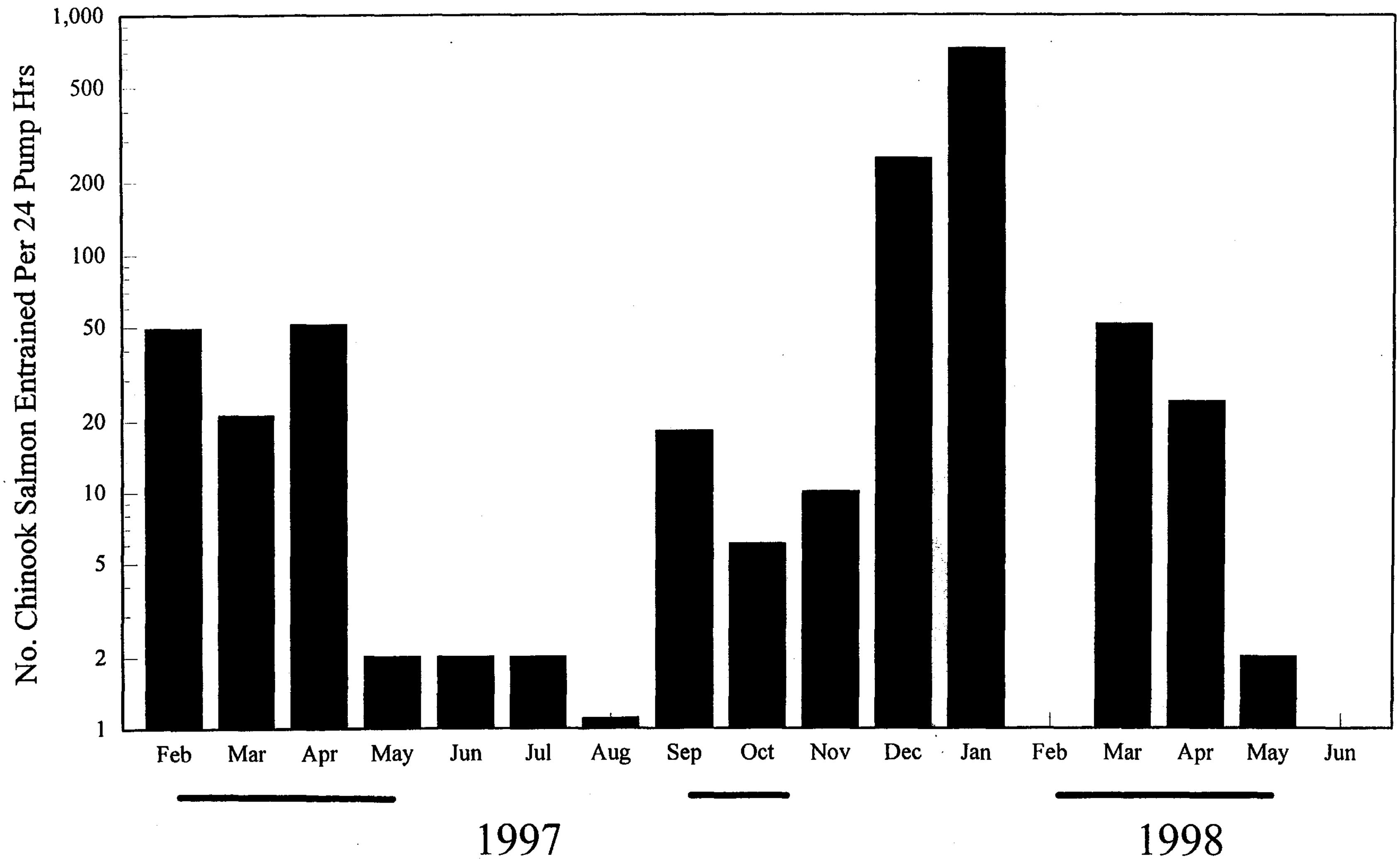

Figure 7. The number of chinook salmon entrained into Red Bluff Research Pumping Plant per 24 hours of pump operation during February 1997 - June 1998. None of the pumps operated in February 1998. Lines beneath the months indicate periods when the plant would typically be used to provide water to canals. A log scale is used on the y-axis because of the large range in number entrained per 24 hours.

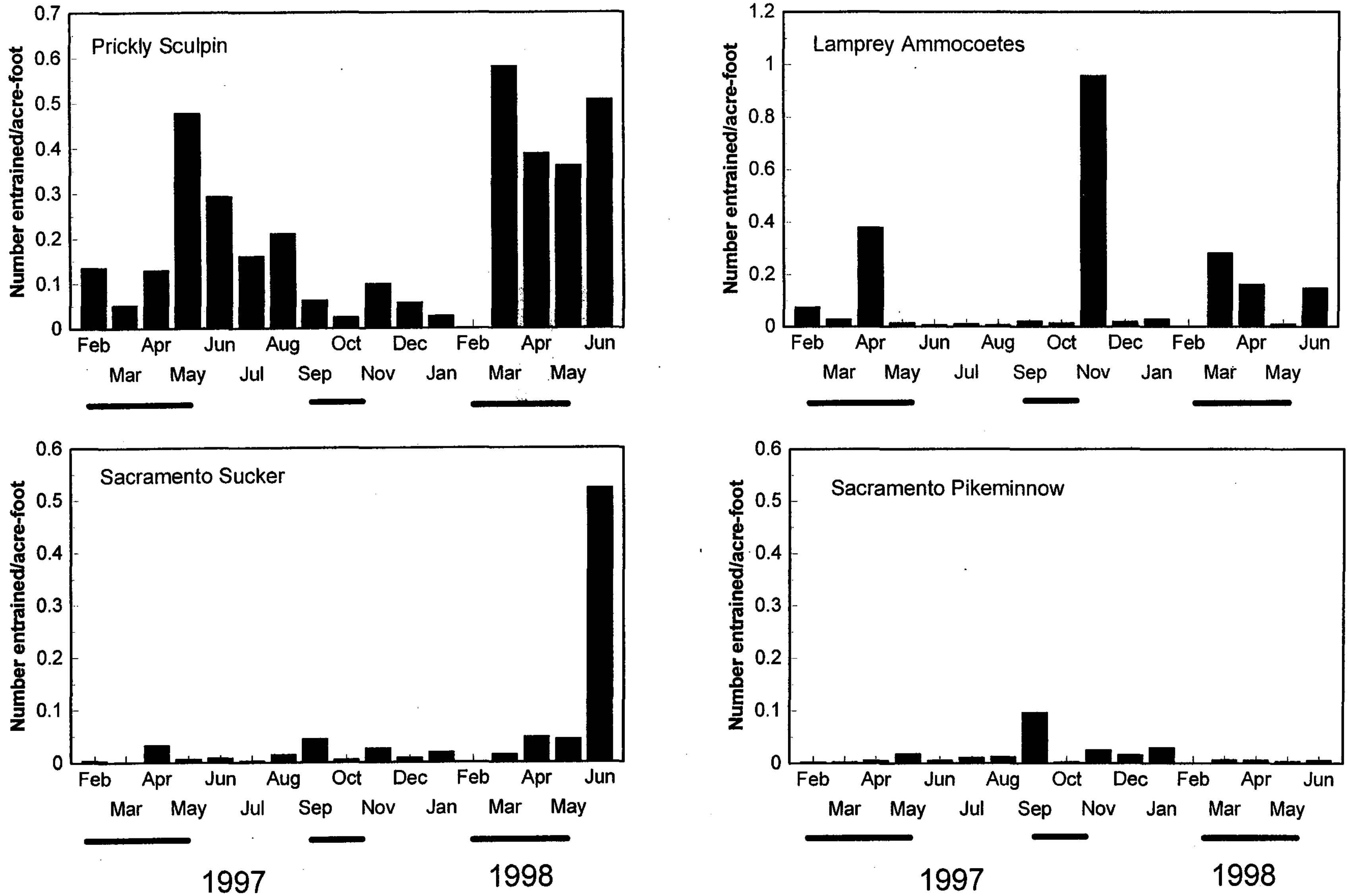

Figure 8. Monthly entrainment rates of four species frequently entrained into Red Bluff Research Pumping Plant, February 1997 - June 1998. The pumps did not operate in February 1998. Lines beneath the months indicate periods when the plant is typically operated to provide water to the canals.

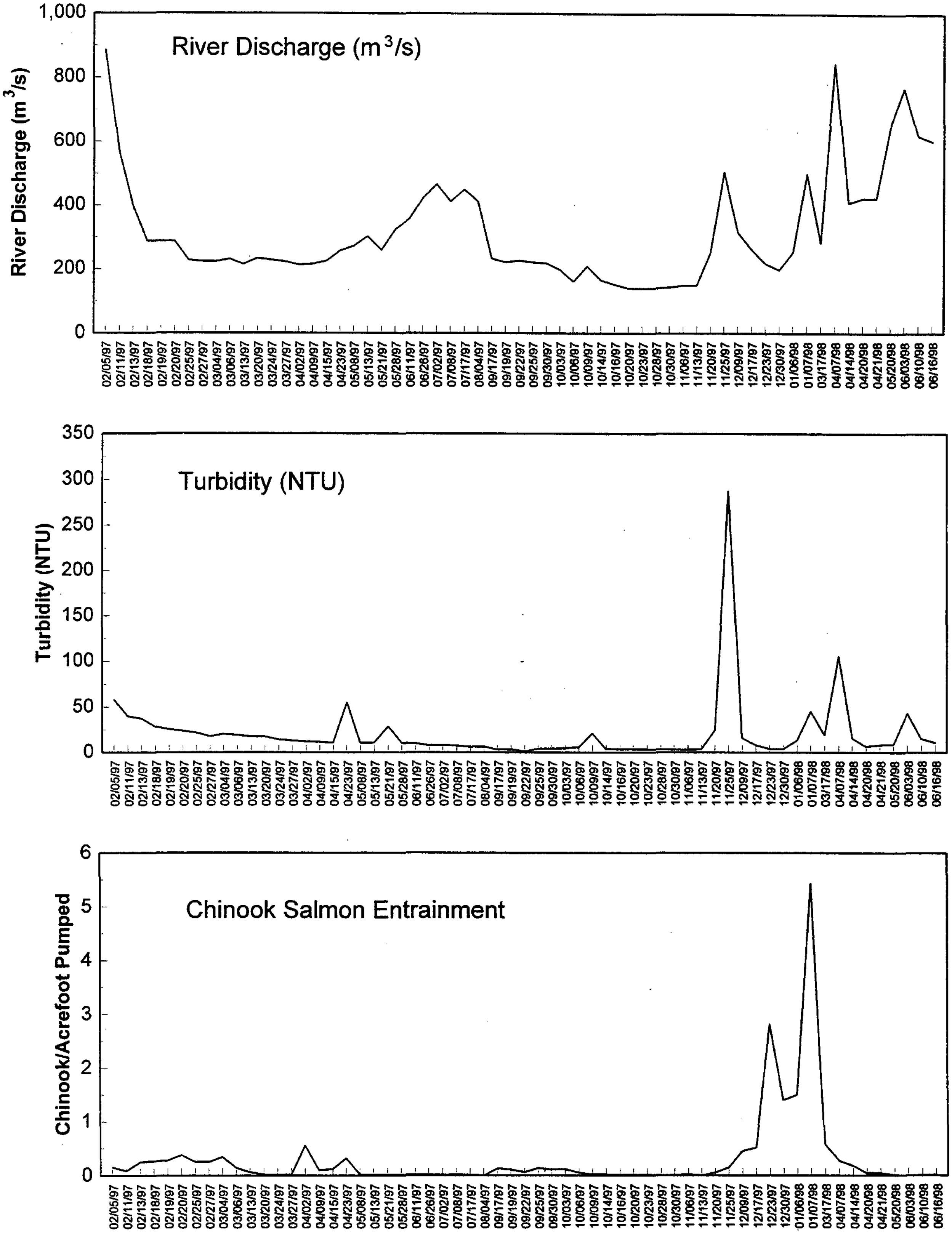

Figure 9. River discharge, turbidity, and entrainment rate of juvenile chinook salmon into Red Bluff Research Pumping Plant on each date that trials were conducted during February 1997 - June 1998.

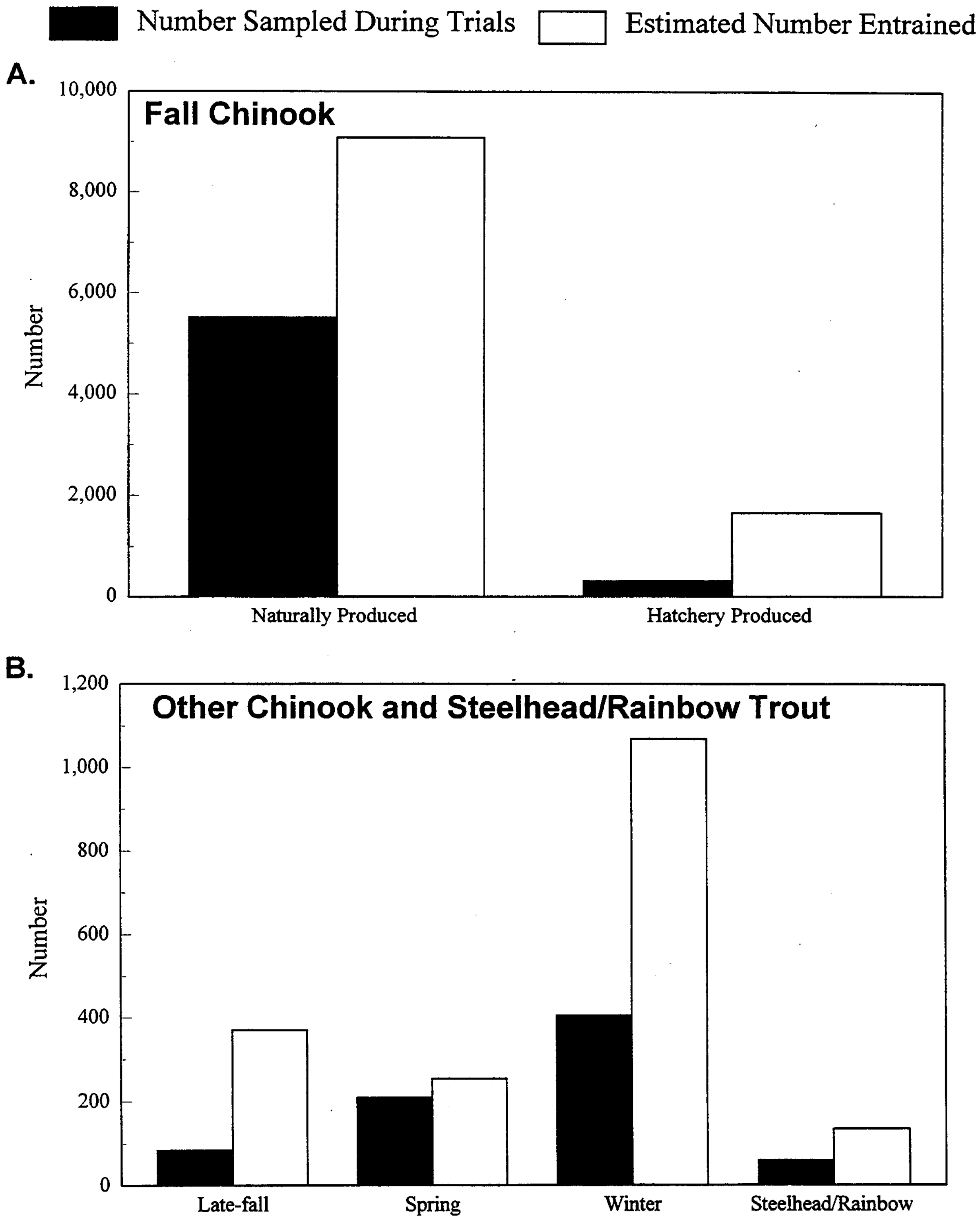

Figure 10. Number of chinook salmon, by run, sampled during entrainment trials and estimated number entrained into Red Bluff Research Pumping Plant, February 1997 - June 1998. A. Fall chinook are designated as naturally or hatchery produced based upon entrainment of adipose-clipped chinook. B. A distinction could not be made between juvenile steelhead and rainbow trout.

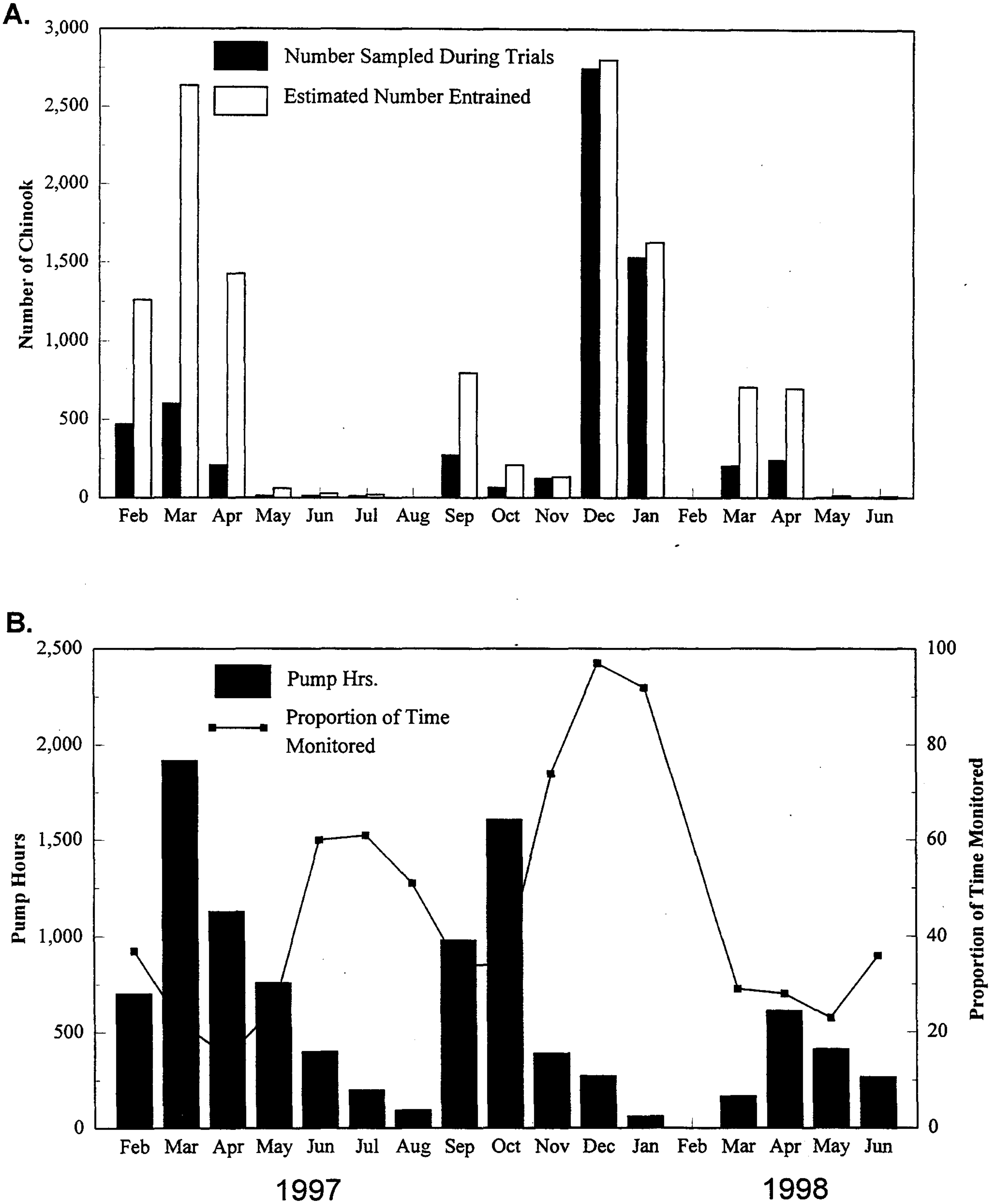

Figure 11. A. The number of chinook salmon sampled and the estimated number entrained into the Red Bluff Research Pumping Plant during each month from February 1997 - June 1998. The pumps were not operated in February 1998. B. The total pump hours and the proportion of time that entrainment of fish into the pumps was monitored each month.

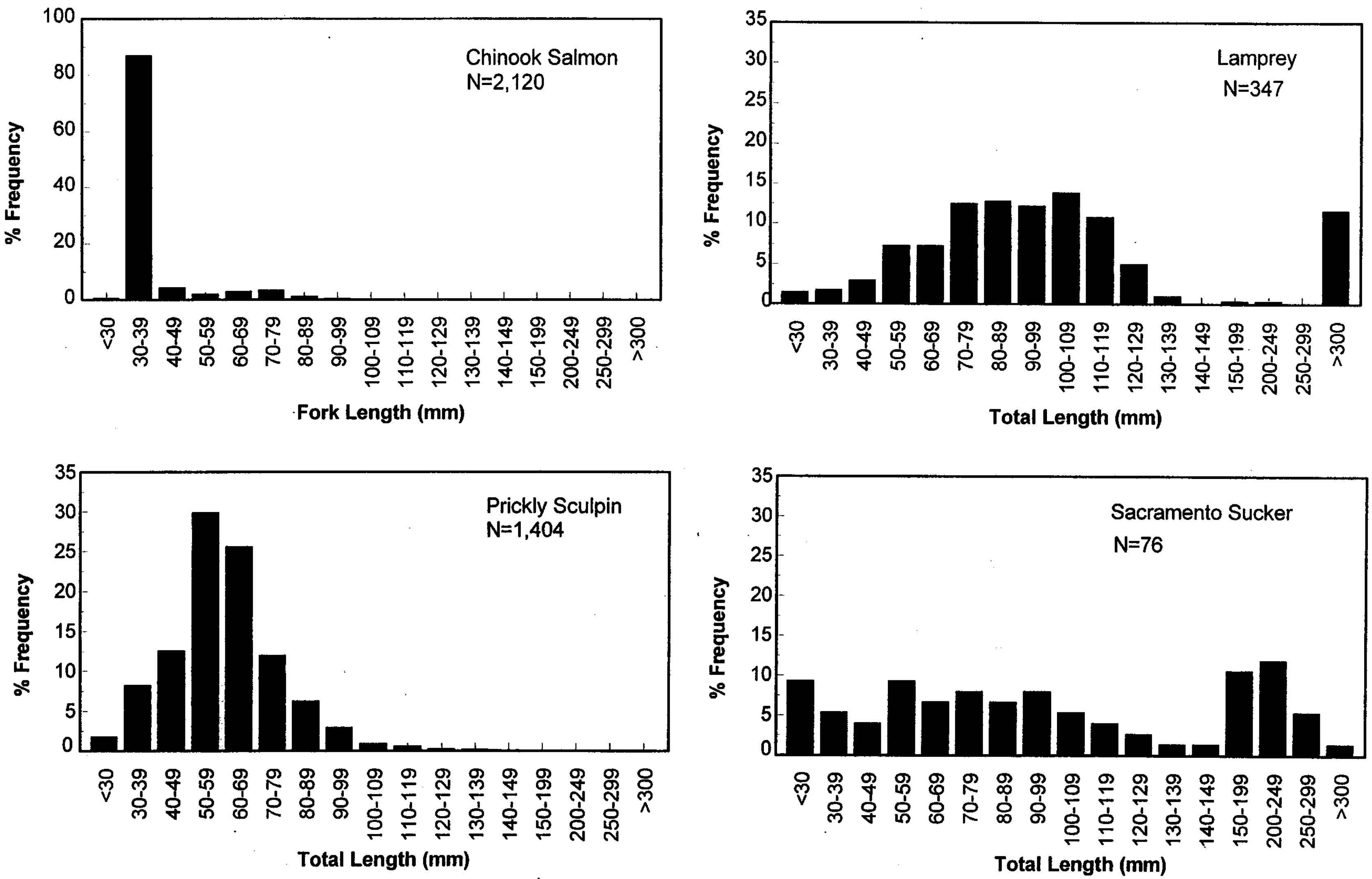

Figure 12. Size-frequency distribution of chinook salmon, lamprey, prickly sculpin, and Sacramento sucker entrained into Red Bluff Research Pumping Plant during 24 entrainment trials conducted when all three pumps operated simultaneously, February 1997 - June 1998.

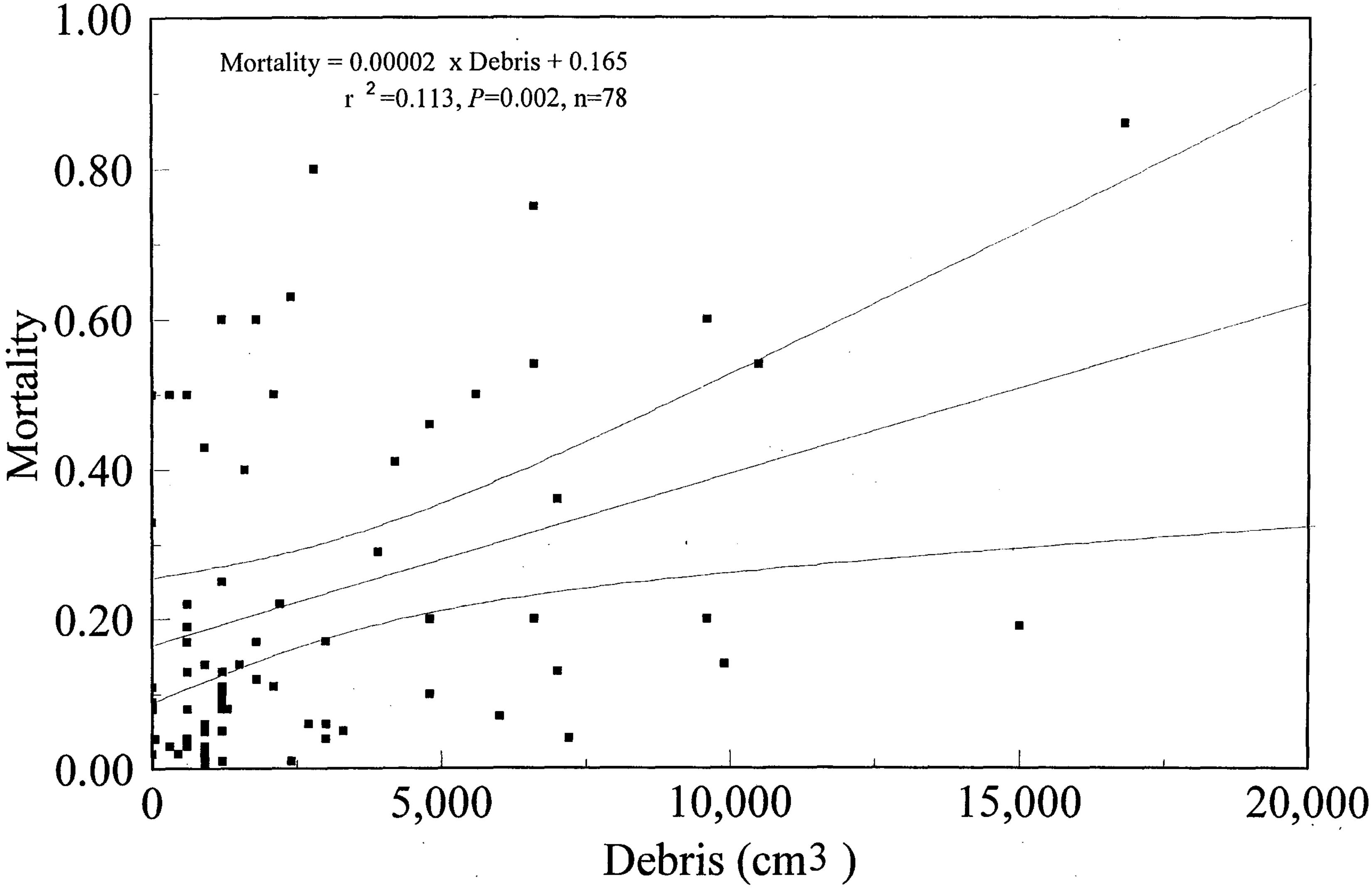

Figure 13. Mean daily mortality of chinook salmon entrained into Red Bluff Research Pumping Plant versus volume of debris entrained during trials conducted from February 1997 through June 1998.

Appendix 1. Weekly summary data for hours each pump operated, hours entrainment was monitored, number of chinook salmon and steelhead/rainbow trout sampled, and estimated number entrained into each pump, February 1997 - June 1998.

Week's Start Date	Pump	Hours Operated	Hours Monitored	NUMBER SAMPLED DURING ENTRAINMENT TRIALS						ESTIMATED NUMBER ENTRAINED					
				CHINOOK SALMON						CHINOOK SALMON					
				Natural Fall[1]	Hatchery Fall[1]	Latefall	Spring	Winter	Trout[2]	Natural Fall[1]	Hatchery Fall[1]	Latefall	Spring	Winter	Trout[2]
2/02/97	3	33	10.25	13	0				1	41.9					3.2
2/09/97	3	113.5	39.56	56		1			4	160.7		2.9			11.5
2/16/97	2	70.5	48	103					1	151.3					1.5
2/16/97	3	104.5	48	98					1	213.4					2.2
2/23/97	1	134	23.95	31						173.4					
2/23/97	2	134	48	112			2		1	312.7			5.6		2.8
2/23/97	3	111.5	38.75	83						238.8					
3/02/97	1	113.5	46.6	77						187.5					
3/02/97	2	135	46.6	106			1			307.1			2.9		
3/02/97	3	166.5	46.6	71					1	253.7					3.6
3/09/97	1	163	24	10					1	67.9					6.8
3/09/97	2	162	24	12						81					
3/16/97	1	160	24	3						20					
3/16/97	2	160	24	4			1			26.7			6.7		

1 The number of hatchery-produced fall chinook was estimated as the quotient of the number of adipose-clipped fish entrained divided by the ratio of clipped and unclipped fish released from Coleman National Fish Hatchery. The number of naturally-produced chinook was calculated as the difference between the total number of chinook entrained and the estimated number of hatchery-produced chinook.

2 Unable to distinguish between juvenile rainbow trout and steelhead.

Appendix 1. Weekly summary data for hours each pump operated, hours entrainment was monitored, number of chinook salmon and steelhead/rainbow trout sampled, and estimated number entrained into each pump, February 1997 - June 1998. Continued.

Week's Start Date	Pump	Hours Operated	Hours Monitored	NUMBER SAMPLED DURING ENTRAINMENT TRIALS						ESTIMATED NUMBER ENTRAINED					
				CHINOOK SALMON						CHINOOK SALMON					
				Natural Fall[1]	Hatchery Fall[1]	Latefall	Spring	Winter	Trout[2]	Natural Fall[1]	Hatchery Fall[1]	Latefall	Spring	Winter	Trout[2]
3/23/97	1	168	48	3					1	10.5					3.5
3/23/97	2	168	48	9						31.5					
3/23/97	3	136	24	5						28.3					
3/30/97	1	121	24	4	22					20.2	110.9				
3/30/97	2	121	24	5	144	3				25.2	726	15.1			
3/30/97	3	143	24	65	55					387.3	327.7				
4/06/97	1	168	24	17		1				119		7			
4/06/97	2	168	24	18		0				126					
4/06/97	3	168	24	17						119					
4/13/97	1	144	24	12	11					72	66				
4/13/97	2	144	24	7	11		1			42	66		6		
4/13/97	3	141.5													
4/20/97	1	168	24	24	11	7			1	168	77	49			7
4/20/97	2	168	24	30	32	11			1	210	224	77			7

1 The number of hatchery-produced fall chinook was estimated as the quotient of the number of adipose-clipped fish entrained divided by the ratio of clipped and unclipped fish released from Coleman National Fish Hatchery. The number of naturally-produced chinook was calculated as the difference between the total number of chinook entrained and the estimated number of hatchery-produced chinook.

2 Unable to distinguish between juvenile rainbow trout and steelhead.

Appendix 1. Weekly summary data for hours each pump operated, hours entrainment was monitored, number of chinook salmon and steelhead/rainbow trout sampled, and estimated number entrained into each pump, February 1997 - June 1998. Continued.

Week's Start Date	Pump	Hours Operated	Hours Monitored	NUMBER SAMPLED DURING ENTRAINMENT TRIALS						ESTIMATED NUMBER ENTRAINED					
				CHINOOK SALMON						CHINOOK SALMON					
				Natural Fall[1]	Hatchery Fall[1]	Latefall	Spring	Winter	Trout[2]	Natural Fall[1]	Hatchery Fall[1]	Latefall	Spring	Winter	Trout[2]
5/04/97	2	165.8	24	1		3			1	6.9		20.7			6.9
5/04/97	3	168	24	2						14					
5/11/97	1	118.5													
5/11/97	2	116.5	24	1		1				4.9		4.9			
5/11/97	3	118.4	24						1						4.9
5/18/97	1	35.4	24	1						1.5					
5/18/97	2	35.1	24	1		1				1.5		1.5			
5/25/97	1	46.1	24	1						1.9					
5/25/97	3	73	24	3						9.1					
6/08/97	1	48.25	24	1		1			1	2		2			2
6/08/97	3	60	24	3		1				7.5		2.5			
6/15/97	1	44.5	24						1						1.9
6/15/97	3	40	24												
6/22/97	1	46.25	24	1		1				1.9		1.9			
6/22/97	2	26.25	24						1						1.1

1 The number of hatchery-produced fall chinook was estimated as the quotient of the number of adipose-clipped fish entrained divided by the ratio of clipped and unclipped fish released from Coleman National Fish Hatchery. The number of naturally-produced chinook was calculated as the difference between the total number of chinook entrained and the estimated number of hatchery-produced chinook.

2 Unable to distinguish between juvenile rainbow trout and steelhead.

Appendix 1. Weekly summary data for hours each pump operated, hours entrainment was monitored, number of chinook salmon and steelhead/rainbow trout sampled, and estimated number entrained into each pump, February 1997 - June 1998. Continued.

Week's Start Date	Pump	Hours Operated	Hours Monitored	NUMBER SAMPLED DURING ENTRAINMENT TRIALS						ESTIMATED NUMBER ENTRAINED					
				CHINOOK SALMON						CHINOOK SALMON					
				Natural Fall[1]	Hatchery Fall[1]	Latefall	Spring	Winter	Trout[2]	Natural Fall[1]	Hatchery Fall[1]	Latefall	Spring	Winter	Trout[2]
6/22/97	3	24.25	24	2		1				2		1			
6/29/97	1	25.25	24												
6/29/97	2	46.25	24	2		1				3.9		1.9			
6/29/97	3	37.25	24												
7/06/97	1	48.5	24	6						12.1					
7/06/97	2	33.25	24			2			1			2.8			1.4
7/06/97	3	33	24	2						2.8					
7/13/97	1	56.25	24	1		1				2.3		2.3			
7/13/97	2	25.5	24												
8/03/97	1	24	24			1						1			
8/03/97	2	69.25	24						2						5.8
9/14/97	1	88.55	47.7					40						74.3	
9/14/97	2	88.55	47.7	1				43	3	1.9				79.8	5.6
9/21/97	1	168	48					21	1					73.5	3.5
9/21/97	2	168	48					59						206.5	

1 The number of hatchery-produced fall chinook was estimated as the quotient of the number of adipose-clipped fish entrained divided by the ratio of clipped and unclipped fish released from Coleman National Fish Hatchery. The number of naturally-produced chinook was calculated as the difference between the total number of chinook entrained and the estimated number of hatchery-produced chinook.

2 Unable to distinguish between juvenile rainbow trout and steelhead.

Appendix 1. Weekly summary data for hours each pump operated, hours entrainment was monitored, number of chinook salmon and steelhead/rainbow trout sampled, and estimated number entrained into each pump, February 1997 - June 1998. Continued.

Week's Start Date	Pump	Hours Operated	Hours Monitored	NUMBER SAMPLED DURING ENTRAINMENT TRIALS						ESTIMATED NUMBER ENTRAINED					
				CHINOOK SALMON						CHINOOK SALMON					
				Natural Fall[1]	Hatchery Fall[1]	Latefall	Spring	Winter	Trout[2]	Natural Fall[1]	Hatchery Fall[1]	Latefall	Spring	Winter	Trout[2]
9/21/97	3	129.5	48			4		24				10.8		64.8	
9/28/97	1	168	48			1		19				3.5		66.5	
9/28/97	2	168	48					61						213.5	
10/05/97	1	165.45	48					10						34.5	
10/05/97	2	168	48					16						56	
10/05/97	3	99	35.4					6						16.8	
10/12/97	1	168	48.2					3	1					10.5	3.5
10/12/97	2	168	48.2					7						24.4	
10/12/97	3	88	24												
10/19/97	1	168	48					7						24.5	
10/19/97	2	168	48					7						24.5	
10/19/97	3	127.75	48					2						5.3	
10/26/97	1	105.7	48					2						4.4	
10/26/97	2	105.7	48					2						4.4	
10/26/97	3	75.2	48					2						3.1	

1 The number of hatchery-produced fall chinook was estimated as the quotient of the number of adipose-clipped fish entrained divided by the ratio of clipped and unclipped fish released from Coleman National Fish Hatchery. The number of naturally-produced chinook was calculated as the difference between the total number of chinook entrained and the estimated number of hatchery-produced chinook.

2 Unable to distinguish between juvenile rainbow trout and steelhead.

Appendix 1. Weekly summary data for hours each pump operated, hours entrainment was monitored, number of chinook salmon and steelhead/rainbow trout sampled, and estimated number entrained into each pump, February 1997 - June 1998. Continued.

Week's Start Date	Pump	Hours Operated	Hours Monitored	NUMBER SAMPLED DURING ENTRAINMENT TRIALS						ESTIMATED NUMBER ENTRAINED					
				CHINOOK SALMON						CHINOOK SALMON					
				Natural Fall[1]	Hatchery Fall[1]	Latefall	Spring	Winter	Trout[2]	Natural Fall[1]	Hatchery Fall[1]	Latefall	Spring	Winter	Trout[2]
11/02/97	1	29.5	24					2						2.5	
11/02/97	2	29.5	24			1		6				1.2		7.4	
11/02/97	3	69.5	24					2						5.8	
11/09/97	1	28.1	24					1						1.2	
11/09/97	2	26.6	24					1						1.1	
11/09/97	3	56	24												
11/16/97	1	25	24				3	6	1				3.1	6.3	1
11/16/97	2	25	24				6	10					6.3	10.4	
11/16/97	3	25	24				1	3					1	3.1	
11/23/97	1	24.5	24				9	11	2				9.2	11.2	2
11/23/97	2	24.5	24				20	9	2				20.4	9.2	2
11/23/97	3	24.5	24				15	19	2				15.3	19.4	2
12/07/97	1	24.5	24	58			29	2		59.2			29.6	2	
12/07/97	3	24.5	24	47			29			48			29.6		
12/14/97	1	24.75	24	55			14			56.7			14.4		

1 The number of hatchery-produced fall chinook was estimated as the quotient of the number of adipose-clipped fish entrained divided by the ratio of clipped and unclipped fish released from Coleman National Fish Hatchery. The number of naturally-produced chinook was calculated as the difference between the total number of chinook entrained and the estimated number of hatchery-produced chinook.

2 Unable to distinguish between juvenile rainbow trout and steelhead.

Appendix 1. Weekly summary data for hours each pump operated, hours entrainment was monitored, number of chinook salmon and steelhead/rainbow trout sampled, and estimated number entrained into each pump, February 1997 - June 1998. Continued.

Week's Start Date	Pump	Hours Operated	Hours Monitored	NUMBER SAMPLED DURING ENTRAINMENT TRIALS						ESTIMATED NUMBER ENTRAINED					
				CHINOOK SALMON						CHINOOK SALMON					
				Natural Fall[1]	Hatchery Fall[1]	Latefall	Spring	Winter	Trout[2]	Natural Fall[1]	Hatchery Fall[1]	Latefall	Spring	Winter	Trout[2]
12/14/97	2	24.75	24	124			24			127.9			24.8		
12/14/97	3	25.5	24	50			9			53.1			9.6		
12/21/97	1	24.5	24	408			5	1		416.5			5.1	1	
12/21/97	2	24.2	24	887			23			894.4			23.2		
12/21/97	3	24.5	24	210			4			214.4			4.1		
12/28/97	1	24.75	24	206						212.4					
12/28/97	2	24.75	24	423			1			436.2			1		
12/28/97	3	24.75	24	136						140.3					
1/04/98	1	10.7	7.92	96					1	129.7					1.4
1/04/98	2	25	24	609					6	634.4					6.3
1/04/98	3	25	24	827			1		13	861.5			1		13.5
3/15/98	1	82.75	24	112			8		1	386.2			27.6		3.4
3/15/98	2	82.75	24	82			2		2	282.7			6.9		6.9
4/05/98	1	50.5	24	21	11	1				44.2	23.1	2.1			
4/05/98	2	24	24	56		6	1	1		56		6	1	1	

1 The number of hatchery-produced fall chinook was estimated as the quotient of the number of adipose-clipped fish entrained divided by the ratio of clipped and unclipped fish released from Coleman National Fish Hatchery. The number of naturally-produced chinook was calculated as the difference between the total number of chinook entrained and the estimated number of hatchery-produced chinook.

2 Unable to distinguish between juvenile rainbow trout and steelhead.

Appendix 1. Weekly summary data for hours each pump operated, hours entrainment was monitored, number of chinook salmon and steelhead/rainbow trout sampled, and estimated number entrained into each pump, February 1997 - June 1998. Continued.

Week's Start Date	Pump	Hours Operated	Hours Monitored	NUMBER SAMPLED DURING ENTRAINMENT TRIALS						ESTIMATED NUMBER ENTRAINED					
				CHINOOK SALMON						CHINOOK SALMON					
				Natural Fall[1]	Hatchery Fall[1]	Latefall	Spring	Winter	Trout[2]	Natural Fall[1]	Hatchery Fall[1]	Latefall	Spring	Winter	Trout[2]
4/12/98	1	100.5	24	44		6				184.3		25.1			
4/12/98	2	75.5	24	19		7				59.8		22			
4/12/98	3	55	24		14	6					32.1	13.8			
04/19/98	1	168	24	13		9				91		63			
04/19/98	2	136	24	2		3				11.3		17			
5/17/98	1	59.5	24			1			1			2.5			2.5
5/17/98	2	79	24	1		1				3.3		3.3			
5/31/98	1	136.5	24						1						5.7
5/31/98	2	136	24			1						5.7			
6/07/98	1	96	24												
6/07/98	2	102.25	24	2						8.5					
6/14/98	1	33.5	24	1						1.4					
6/14/98	2	33.5	24	1					1	1.4					1.4
TOTALS		10,376.8	3343.3	5514	311	84	209	405	59	9085.8	1652.9	369.5	254.4	1068.8	133.7

1 The number of hatchery-produced fall chinook was estimated as the quotient of the number of adipose-clipped fish entrained divided by the ratio of clipped and unclipped fish released from Coleman National Fish Hatchery. The number of naturally-produced chinook was calculated as the difference between the total number of chinook entrained and the estimated number of hatchery-produced chinook.

2 Unable to distinguish between juvenile rainbow trout and steelhead.