Fish Interactions in Lower Granite Reservoir, Idaho-Washington

Completion Report

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Abstract

This study, in part, examined interactions of resident fishes on downstream migrating juvenile salmonid fishes in Lower Granite Reservoir from 1994 through 1995. Smallmouth bass *Micropterus dolomieu*, the most abundant and important resident species is widely distributed in Lower Granite Reservoir and exhibited the highest catch per effort in the upstream portion of the reservoir. An estimated 20,911 (17,092-26,197 - 95% confidence intervals) smallmouth bass > 174 mm inhabited the reservoir based on a mark-recapture study. We estimated that 65,400 smallmouth bass > 69 mm were found in the reservoir after adjusting for mortality.

Dietary differences of smallmouth bass were found between 1994 and 1995. Crustaceans comprised a large proportion of smallmouth bass diets in both 1994 and 1995, and salmonids comprised a smaller portion in 1995. Salmonids were found in stomachs of smallmouth bass about every month from April through October of both years. We estimated 82,476 juvenile salmonids were consumed by smallmouth bass in Lower Granite Reservoir in 1994 compared to 64,020 in 1995. About 62% of those losses occurred in the upstream portion of the reservoir.

We sampled more than 14,00 fishes representing 20 species during 1994 and spring 1995. Canonical correspondence analysis was used to generate biplots of species distribution relative to habitat attributes. Mean substrate size, biomass of macrophytes, and depth were the predominant habitat variables. Biplots of these variables and habitat use of juvenile salmon *Oncorhynchus* spp. and steelhead *O. mykiss* overlapped with those of several resident species indicating similarities in habitat use. Discriminant analysis was

used to predict which habitat variables were significant in predicting the absence/presence or high/low abundances of fishes in Lower Granite Reservoir.

We examined factors limiting the abundance of northern squawfish *Ptychocheilus oregonensis* in Lower Granite Reservoir. We found that density dependence did not regulate mortality of northern squawfish at two life stages, from egg to larval and ages 0+ to 3+, but it was significantly correlated with several habitat attributes. Over 35 competing models were developed for these two life stages and temperature was the most significant overall habitat variable.

An index of abundance of juvenile smallmouth bass was related to temperature as was average length. Over-winter survival of juvenile smallmouth bass ranged from 1.9% to 14.3%, although we were unable to demonstrate a significant relationship between water temperature and over-winter survival.

We examined food and feeding guilds of resident and juvenile anadromous salmonid fishes in Lower Granite Reservoir in 1994 and 1995. We found 93 different food items in resident and juvenile anadromous fishes. Numerous prey items were common between resident and juvenile anadromous salmonids especially dipterans, insect parts, and crustaceans. The proportion of dietary items in wild and hatchery salmonids were significantly correlated with several resident fishes including bluegill *Lepomis macrochirus*, pumpkinseed *L. gibbosus*, crappies *Pomoxis* spp., yellow perch *Perca flavescens* and northern squawfish.

The last two aspects of this study examined the distribution and abundances of crayfish and white sturgeon *Acipenser transmontanus*. Catch per efforts for both species were highest in the upstream section of Lower Granite Reservoir. We found that the experimental drawdown in March 1992 may have contributed to the partial collapse of a year class of crayfish. Overall mean size of white sturgeon and movement that ranged from 0 to about 31 km was similar to results from earlier surveys.

Our overall results demonstrate a substantial influence of resident fishes on juvenile anadromous fishes. Predation diet, and similarities in habitat use were the common elements where overlap occurred. Other than the predation losses, we can not identify the effects of the dietary and habitat overlaps on survival of downstream migrating salmonids.

INTRODUCTION

The Snake River between Lewiston, Idaho, and river mile 107.5 (RM 107.5; river kilometer, RKM, 173.1) was free flowing prior to completion of Lower Granite Dam in 1975. Impoundment changed the physico-chemical properties, altered the biotic communities (Bratovich 1985), and transformed this section of the Snake River into a reservoir. Flood control, recreational activities, navigation, and electrical power generation are some of the benefits of Lower Granite Reservoir (Bennett and Shrier 1986).

Little information existed about native and introduced fishes found in this section of the free-flowing Snake River before construction of Lower Granite Dam. Warmwater and coolwater fishes, such as smallmouth bass *Micropterus dolomieu*, black crappie *Pomoxis nigromaculatus*, bluegill *Lepomis macrocheilus*, pumpkinseed *L. gibbosus*, and yellow perch *Perca flavescens*, inhabit the other lower Snake River reservoirs (Anonymous 1974; Bennett et al. 1983). Lower Granite Reservoir provides a corridor for migrating chinook salmon *Oncorhynchus tshawytscha* and steelhead trout *O. mykiss*, and supports numerous introduced fishes. New habitats created by the construction of dams and reservoirs have caused many introduced and native lacustrine fish populations to increase (Bratovich 1985).

Prior to the mid-1980s, little fishery information was available on Lower Granite Reservoir. Fish sampling in Lower Granite Reservoir was initiated in 1985 to evaluate habitat use of resident fishes and migratory salmonids (Bennett and Shrier 1986). The use of dredged material for potential habitat enhancement from experimental deposition was initiated in 1987 and was monitored through 1993 (Bennett et al. 1988, 1990, 1991, 1993a, 1993b, 1995a, 1995b). The principal focus of this multiyear monitoring was to identify areas of fish and benthic macroinvertebrate concentrations and the importance of habitat characteristics. Additional related work included identifying habitat use by resident fishes (Dresser

1996), assessing predator use and age-0 salmonid use of specific reservoir locations (Curet 1994), and estimating northern squawfish *Ptychocheilus oregonensis* and smallmouth bass predation on salmonids (Chandler 1993; Curet 1994). Also, information was collected on white sturgeon *Acipenser transmontanus* distribution, abundance, and habitat use (Lepla 1994).

Information on the interactions of migratory salmonids and resident fishes is currently not available. In 1994, Bennett et al. assessed predatory interactions of smallmouth bass and juvenile anadromous salmonids and estimated population abundance of smallmouth bass. Specific habitat characteristics were also associated with the abundance of various resident fishes in Lower Granite Reservoir both at the species and community levels. The information presented in this report includes monitoring conducted in 1994 and 1995, and provides additional information on potential interactions of resident fishes and anadromous salmonids from the proposed drawdown of the reservoir.

OBJECTIVES

1. To qualify and quantify the predatory influence of smallmouth bass on juvenile chinook salmon in Lower Granite Reservoir;
2. To determine habitat use, fish species associations, and species overlap in shallow water habitat in Lower Granite Reservoir;
3. To identify factors limiting the abundance of northern squawfish in Lower Granite Reservoir;
4. To identify factors affecting abundance of smallmouth bass in Lower Granite Reservoir;
5. To evaluate food and feeding guilds for resident and juvenile anadromous salmonid fishes in Lower Granite Reservoir;
6. To determine size composition and relative abundance of crayfish in the Lower Granite Reservoir; and
7. To monitor abundance and habitat use of white sturgeon in Lower Granite Reservoir.

STUDY AREA

Lower Granite Reservoir is the uppermost impoundment on the lower Snake River extending from Lower Granite Dam (RM 107.5; RKM 173.1), Washington, to the Snake and Clearwater rivers in Idaho. The reservoir is approximately 103 km long and has a surface area of 3,602 ha , a mean depth of 16.6 m, and a maximum depth of 42.1 m (Curet 1994). Lower Granite Reservoir has been maintained at minimum operating pool (MOP) during late spring and summer since 1991.

Shoreline substrates in Lower Granite Reservoir vary from riprap, mud-sand beaches, to basalt cliffs with adfluvial fans (Curet 1994). The shoreline is comprised of riprap (45.9%; 46.7 river kilometers), basalt cliffs (32%; 33.0 river kilometers), sand-cobble (3.5%, 3.5 river kilometers), sand-talus (8.0%; 8.2 river kilometers), and sand (9.8%; 9.8 river kilometers). Bottom substrates in deep water areas (> 15.2 m) include fine sediment with particles smaller than sand (< 0.061 mm; Bennett et al. 1988). *Potomogeton crispus* is the predominate submerged aquatic vegetation found in shallow water (<3.3 m), although *P. filiformis* has also been reported (Bennett et al. 1993a).

Objective 1. To qualify and quantify the predatory influence of smallmouth bass on juvenile chinook salmon in Lower Granite Reservoir.

Stocks of juvenile anadromous salmonids that migrate through Lower Granite Reservoir include steelhead, yearling chinook, and, to a lesser extent, subyearling chinook. Approximately 5,900,000 steelhead, 3,700,000 yearling chinook, and 31, 000 subyearling chinook were collected from April to August 1995 at the juvenile collection facility at Lower Granite Dam (Figure 1). In all, 175 fall chinook redds were counted during 1994 in the Clearwater (n = 122), Salmon (n = 37), Grand Ronde (n = 15), and Snake (n = 1) rivers (W. Connor, US Fish and Wildlife Service, Ashsaka, ID, personal communication), yielding approximately 233,928 to 304,722 subyearling fall chinook. Estimates of 30% (W. Connor, US Fish and Wildlife Service, Ashsaka, ID, personal communication) and 75% (C. Eaton, Department of Fish and Wildlife, University of Idaho, Moscow, ID, unpublished data) were used to determine egg-to-fry survival. The lower estimate of 30% survival reflects the increase in mortality experienced by chinook eggs as a result of prolonged exposure to incubation water temperatures < 4.5° C (Combs and Burrows 1957). Survival estimates of 90% and 95% were used for fry-to-smolt and smolt-to-reservoir life stages (W. Connor, US Fish and Wildlife Service, Ashsaka, ID, personal communication).

Effects of over-harvest, increased hatchery releases, loss of spawning and rearing habitat, and mortality of adults and juveniles at hydropower dams have contributed to the decline of Pacific salmon *Oncorhynchus* spp. stocks within the Snake River system (Salo and Stober 1977; Raymond 1979). Rieman et al. (1991) stated that smolt losses as a result of predation in the John Day Reservoir may be similar to mortality at the dams and could represent the single most important source of smolt mortality. Curet (1994) was the first to evaluate smallmouth bass consumption of out-migrating juvenile salmonids in Lower Granite Reservoir. He

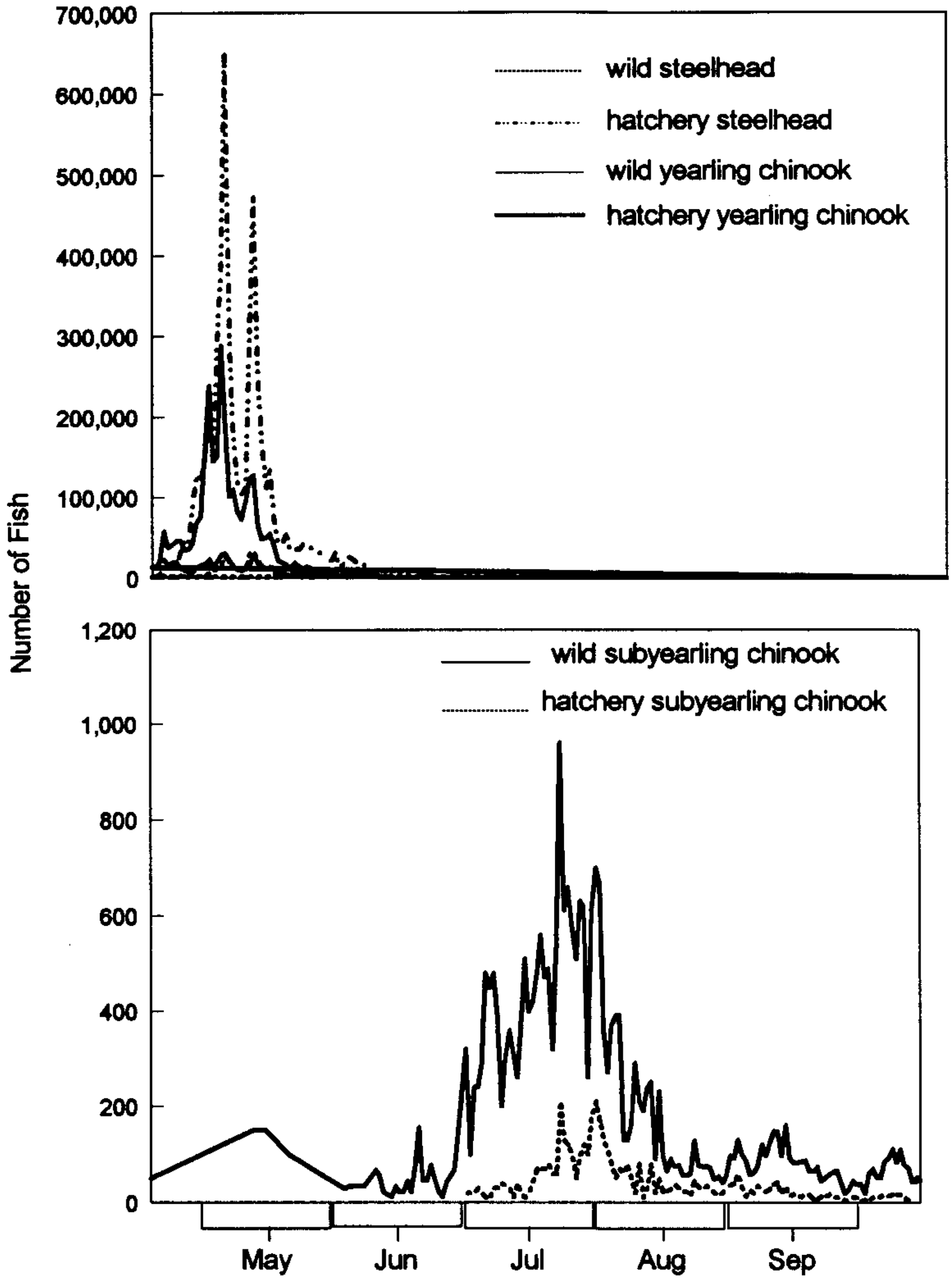

Figure 1. Out-migration of salmonids through Lower Granite Reservoir during 1995 based on counts at the juvenile collection facility at Lower Granite Dam. Note different scales used for each plot.

reported mean daily consumption ranging from 0.03 to 0.06 smolts/smallmouth bass/day, which was similar to those reported by Rieman et al. (1991) for John Day Reservoir. Curet's study was conducted following an experimental test drawdown of Lower Granite Reservoir and the study area was restricted to the upper one-third of the reservoir.

We evaluated the predatory influence of smallmouth bass on juvenile salmonids throughout the entire Lower Granite Reservoir during 1994 and 1995. Estimates of absolute and relative abundance of smallmouth bass were combined with mean daily consumption rates of juvenile salmonids to evaluate spatial differences in consumption to estimate total loss of juvenile anadromous salmonids to predation by smallmouth bass in Lower Granite Reservoir.

METHODS

Smallmouth Bass Collection

Three strata (stratum 1 RM 131.0-139.75, RKM 210.9-225.0; stratum 2 RM 120.0-131.0, RKM 193.2-210.9; and stratum 3 RM 107.5-120.0, RKM 173.1-193.2) were defined in Lower Granite Reservoir for sampling smallmouth bass (Figure 2). The shoreline (103 km) was divided into 0.4-km sections of similar habitat types and each section represented one sample unit, thus yielding 258 possible sites. The number of sites sampled within each stratum and habitat type was determined by the proportional allocation formula (Scheaffer et al. 1990). In 1994, 50 sites were randomly selected and sampled on a monthly basis from April through November. In June 1994, an additional 148 sites were randomly sampled to determine an estimate of absolute abundance of smallmouth bass. Sixty sites were randomly sampled in 1995 and each site was sampled semimonthly from May through July and monthly in April and from August through November.

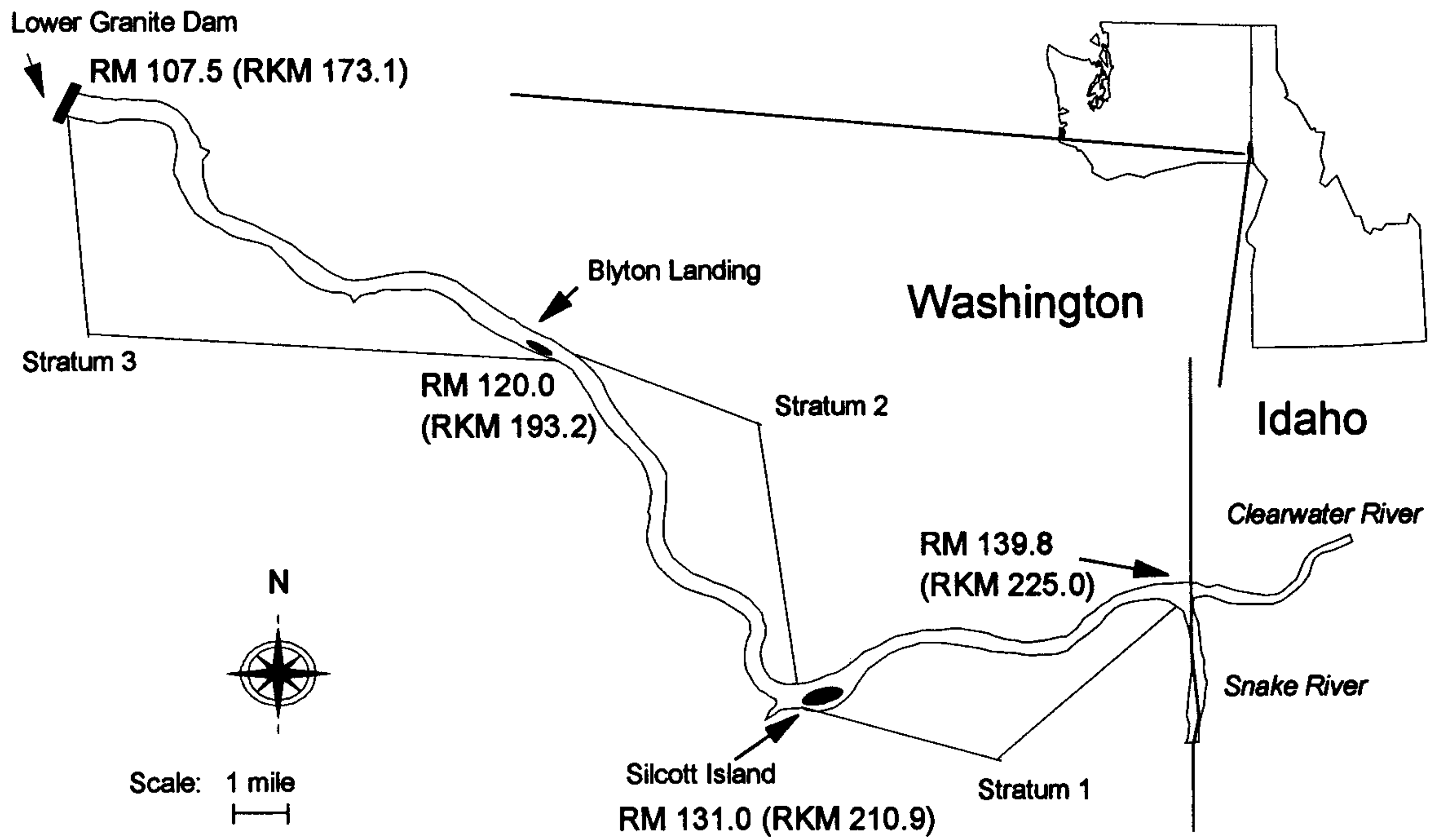

Figure 2. Locations of strata in Lower Granite Reservoir, Idaho-Washington, where fish were sampled monthly from April to November 1994 and 1995.

Electrofishing, beach seining, and angling were used for shoreline collections. Electrofishing was conducted by traveling parallel to the shoreline and operating with current turned on through the length of the site. A constant electrical output of 400 volts at 3 to 5 amps was used to stun fish without causing mortality. Both daytime and nighttime collections were made by electrofishing.

Beach seining was conducted using a 30.5-m x 2.4-m beach seine with a 2.4-m x 2.4-m x 2.4-m bag constructed of 0.6-cm knotless nylon mesh. The seine was placed parallel to and approximately 15 m from the shoreline. The seine was pulled toward the shore to sample an area of approximately 464 m^2. Beach seining was conducted over cobble, talus, and sand/silt habitats. One to three hauls were conducted at each location depending on the shoreline substrate.

Angling was conducted during April and May 1994. Anglers fished rocky outcroppings and underwater benches using a variety of natural and artificial lures.

All resident fishes and juvenile salmonids sampled were placed in live wells immediately upon capture and measured for length, weighed (g), and released. Resident fishes were measured to total length (TL) and salmonids to fork length (FL). Smallmouth bass > 174 mm were marked with an individually numbered Floy tag. Stomach contents of selected fish were evacuated using a modified lavage technique (Seaberg 1957), flushed into a mesh filter, and transferred to a sample container where they were preserved in 10% formalin solution. We have used the lavage technique effectively to sample stomachs from several species including salmonids (Bennett and Shrier 1986) with no known mortality. Fish sampled for food items were anaesthetized with MS 222 prior to having stomach samples taken and then allowed to fully recover prior to release. Prey items were removed with foreceps when lavage was not successful.

Absolute Abundance Estimation

A multiple census mark-recapture study was developed to estimate absolute abundance of smallmouth bass in Lower Granite Reservoir. The smallmouth bass population was modeled as a "closed" population. This assumes no births, deaths, or migrations occurred during the sampling period. We also assumed that the probability of capture for marked and unmarked smallmouth bass was equal and constant throughout the sampling period (Garthwaite and Buckland 1990).

Knowledge of seasonal movements of smallmouth bass allowed us to more effectively sample with shoreline oriented gear. Smallmouth bass redistribute in the spring, moving from deep to shallow water where they resume feeding activity (Coble 1975). Montgomery et al. (1980) stated that movement of smallmouth bass into deep water occurs after spring spawning. Smallmouth bass were marked at several randomly selected sites throughout the reservoir from 12 April through 10 June 1994. The recapture effort was conducted from 14 June through 30 June 1994 and consisted of sampling 148 randomly selected sites distributed throughout the reservoir. Only data collected during the spring period (April - June) were included in our estimate of absolute abundance, as Overton (1965) suggests that the effect of population changes in time can be reduced by limiting the duration of the sampling period.

The Schnabel Estimator (Schnabel 1938), as modified from Overton (1965), was used to estimate absolute abundance of smallmouth bass in Lower Granite Reservoir:

$$\hat{N} = \frac{\sum (c_t m_t)}{((\sum r_t) + 1)}$$

where: c_t = total sample taken on day t,

m_t = number of marked fish in population at start of day t, and

r_t = number of recaptures on day t.

We used a Poisson Distribution to calculate confidence intervals due to the low number of recaptures (5% - 10%). The following equation was used to normalize the variance estimation (Ricker 1975a): $r' = \sum r_t + 1.92 \pm 1.96\sqrt{\sum r_t + 1}$

To determine upper and lower bounds of the confidence interval for the absolute abundance estimate, r' was inserted into the following equation:

$$\hat{N} = \frac{\sum (c_t m_t)}{r'}$$

Our absolute abundance estimate applied to smallmouth bass > 174 mm in Lower Granite Reservoir. As a result of the presence of salmonid and nonsalmonid prey fishes in the diets of smallmouth bass as small as 70 mm TL (Poe et al. 1991), the abundance estimate was further modified to incorporate smallmouth bass 70 to 174 mm. Our population estimate was expanded to include smallmouth bass 70 to 174 mm by estimating the instantaneous mortality rate and adjusting for the loss of smallmouth bass through mortality. Catch per unit effort (CPUE) was used as a measure of abundance for ages 1, 2, and 3. The instantaneous mortality rate was calculated using the following equation:

$$Z = \ln N_t - \ln N_{t+1}$$

where: N_t = catch/effort of age t, and

N_{t+1} = catch/effort of age t + 1.

Age class determination was used to estimate mortality by catch curve. Length-at-age information was used to determine the age composition of a particular length class.

We used scale analysis to determine ages of bass collected. Scales were removed at the extension of the pectoral fin ventral to the lateral line. Impressions of each scale were made on acetate slides using 52° C heat and a 5,000 PSI press. Scales were aged using a Vantage Com IV Microform 45X reader. Each scale was read two to three times before the position of the focus, annuli, and scale edge were marked on a piece of paper. A Houston Hipad tablet was used to digitize the scale readings. Back-calculated mean length-at-age was determined with DISBCAL (Frie 1982) using the Frazer Lee method (Carlander 1982): $Ln = a + \frac{Sn}{Sc}(Lc - a)$

where: a = intercept value of best straight line relationship,

Sn = scale measurement to a given annulus, n,

Sc = scale measurement to edge, and

Lc = length of fish at capture.

Relative Abundance Estimation

Relative abundance based on CPUE and relative density estimates were used to determine if abundance of smallmouth bass differed among the three strata. Additionally, relative abundance was used to detect seasonal changes in smallmouth bass distribution. A single measure of CPUE was calculated for each stratum by combining measures from individual sites within a particular stratum. Relative density was calculated by dividing CPUE of a specific stratum by the CPUE for the entire reservoir (Beamesderfer and Rieman 1991). The relative distribution of smallmouth bass was determined based on the assumption that CPUE is directly proportional to density.

Dietary Collection and Analysis

Stomach contents of smallmouth bass > 69 mm were analyzed to describe seasonal changes in diet and to determine consumption rates and total loss of juvenile salmonids. When possible, prey fish were identified immediately upon removal from the stomach. Otherwise, preserved prey items were consolidated in the lab into categories of salmonid, nonsalmonid, unknown fish, crayfish, insects, and miscellaneous. Prey were identified to the lowest practical taxon. Number and digested weight of each prey item were recorded. When possible, parts of insects were combined with similar prey items and the total number estimated. Partially digested, unidentifiable insects were weighed as a group. Digested weights were obtained by blotting prey items dry and weighing the items to the nearest milligram.

Estimated live weights of prey fish were used in the analysis. Live weights of prey fish were estimated from fork length (nearest mm) to weight (g) regression equations developed by Vigg et al. (1991). When prey fish were too digested to measure lengths, lengths of diagnostic bones and nape to tail lengths were used to determine fork lengths using regression equations developed by Hansel et al. (1988). Lengths of diagnostic bones were taken from cleithrum, opercle, dentary, and hypural bones found in stomach samples. Vertebrae shape was used to distinguish between salmonid and nonsalmonid prey fish when preferred bony structures were absent.

Species identification for unknown salmonid prey fish was determined by comparing length frequencies of smolts collected at Lower Granite Dam within 7 days of the predator collection. Bennett et al. (1993a, 1993b) and Curet (1994) used the range of lengths of juvenile salmonids captured to identify unknown salmonids in stomach samples of northern squawfish and smallmouth bass in Lower Granite Reservoir.

Frequency of occurrence and percent weight.- Seasonal changes in diets of smallmouth bass were determined using percent frequency of occurrence and percent weight of prey items. Values of frequency of occurrence and percent weight were determined for specific prey types and groups.

Daily ration and numerical consumption.- Due to the possibility of length related differences in dietary composition and salmonid consumption, analysis was conducted using four length classes of smallmouth bass: 70 - 174 mm, 175 - 249 mm, 250 - 389 mm, and > 389 mm. Curet (1994) used three length groups of smallmouth bass (< 250 mm, 250 - 389 mm, and > 389 mm) to describe daily consumption of subyearling chinook salmon in Lower Granite Reservoir. Mean daily consumption rates of juvenile salmonids were determined following procedures outlined in Vigg et al. (1991):

$$C = \sum_{i=1}^{t} \sum_{l=1}^{s} \frac{\sum_{k=1}^{p} W_{ij}}{F_{ij}}$$

where: C = daily consumption (g) by an average predator;

W_{ij} = undigested weight of prey fish of a given size category (*j*) during a given diel time interval (*i*); and

F_{ij} = the number of potential predators from the sample that could have contained prey fish of size *j* that were no more than 90% digested during period *i*.

Daily ration (mg prey/g predator) and numerical consumption (prey/predator) are determined by dividing C (daily consumption) by mean predator and prey weights for the sample as follows:

daily ration = C * 1000/mean predator weight (g); and

numerical consumption = C/mean prey weight (g).

Data from individual smallmouth bass stomachs, based on specified selection criterion, were pooled to estimate mean daily ration and numerical consumption. Several comparisons were made using selection criteria, such as length of predator, prey type, and location and date of collection. Pooling of predator stomachs yields a single estimate of mean daily ration and numerical consumption, thus preventing direct calculation of confidence intervals. However, we estimated confidence intervals (95%) by the bootstrap resampling method (Shao and Dongsheng 1995). The mean consumption rate estimated from the initial pooling of selected smallmouth bass stomachs was used as the point estimate for the 95% confidence interval. The resampling procedure randomly chose records from the entire smallmouth bass data set and selected those, with replacement, that met the specified selection criterion. For each iteration, a new data set was constructed from the smallmouth bass records that met the specified selection criterion. The new data set contained a number of records equal to that of the initial data set used to generate the point estimate. One hundred iterations were performed and resulted in a data set of 100 estimates of numerical consumption that was then used to construct a 95% confidence interval around the initial point estimate.

Loss of salmonids to smallmouth bass.- Procedures presented by Rieman et al (1991) were used to calculate total loss of juvenile salmonids to smallmouth bass predation:

$$L_{ij} = PS_iC_{ij}D_jG_{ij}$$

where: L_{ij} = the loss of salmonids to size group i during month j,

P = the number of smallmouth bass > 70 mm,

S_i = the proportion of each predator population within size group i,

C_{ij} = consumption of predator size group i during month j,

D_j = the number of days in month j, and

G_{ij} = the proportion of juvenile salmonids in predator size group i during month j.

RESULTS

Absolute Abundance

In all 2,396 smallmouth bass were sampled in Lower Granite Reservoir and marked with Floy tags from 12 April to 30 June 1994. Lengths of tagged smallmouth bass ranged from 175 to 473 mm. During the recapture effort, 910 smallmouth bass were collected and 84 were tagged, yielding an overall tag recovery rate of approximately 10%. A modified Schnabel estimator yielded an absolute abundance estimate of 20,911 smallmouth bass > 174 mm with a 95% confidence interval from 17,092 to 26,197. Catches of smallmouth bass > 174 mm from spring (April - June) 1994 and 1995 by electrofishing indicated that more than 80% of the smallmouth bass were between 175 and 249 mm, 15% to 17% from 250 to 389 mm, and less than 1% were > 389 mm (Figure 3).

Pooled beach seine collections from 1988 to 1995 in Lower Granite Reservoir indicated an annual survival rate of 0.47 for smallmouth bass 70 to 174 mm (Figure 4). The estimated survival rate combined with the abundance of smallmouth bass > 174 mm revealed an abundance of approximately 44,490 smallmouth bass from 70 to 174 mm in Lower Granite Reservoir. Combining the two abundance estimates yields a population abundance of roughly 65,400 smallmouth bass > 69 mm in Lower Granite Reservoir. Using the mean of length compositions, the number of smallmouth bass from 70 to 174 mm was 44,490, from 175 to 249 mm was 17,565, from 250 to 389 mm was 3,137, and > 389 mm was 209 (Figure 5).

Relative Abundance

Catch per unit effort increased for all length classes based on captures by electrofishing from April to July 1995 in all strata (Figure 6, Appendix Table 1). Catch per unit efforts of smallmouth bass 70 to 174 mm during June and July 1995 in stratum 1 were higher than observed in strata 2 and 3. Those of smallmouth bass 175 to 249 mm, 250 to 389 mm, and > 389 mm were similar among strata within months.

Diet Composition

Stomach contents from smallmouth bass > 69 mm were sampled during 1994 and 1995. In all 1,207 stomachs were sampled in 1994 and 3,059 in 1995.

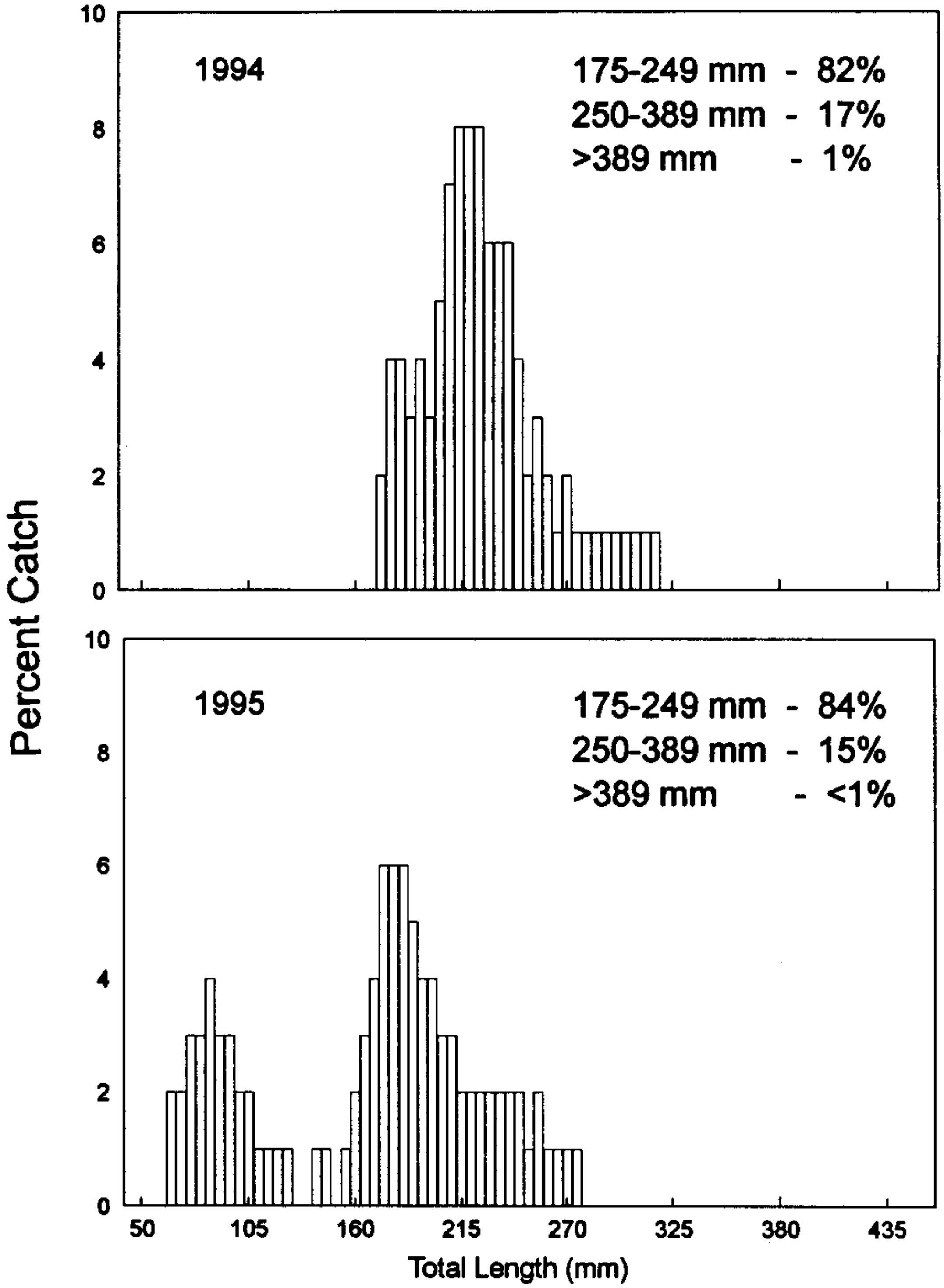

Figure 3. Length distributions of smallmouth bass sampled by electrofishing during spring 1994 and 1995 in Lower Granite Resevoir.

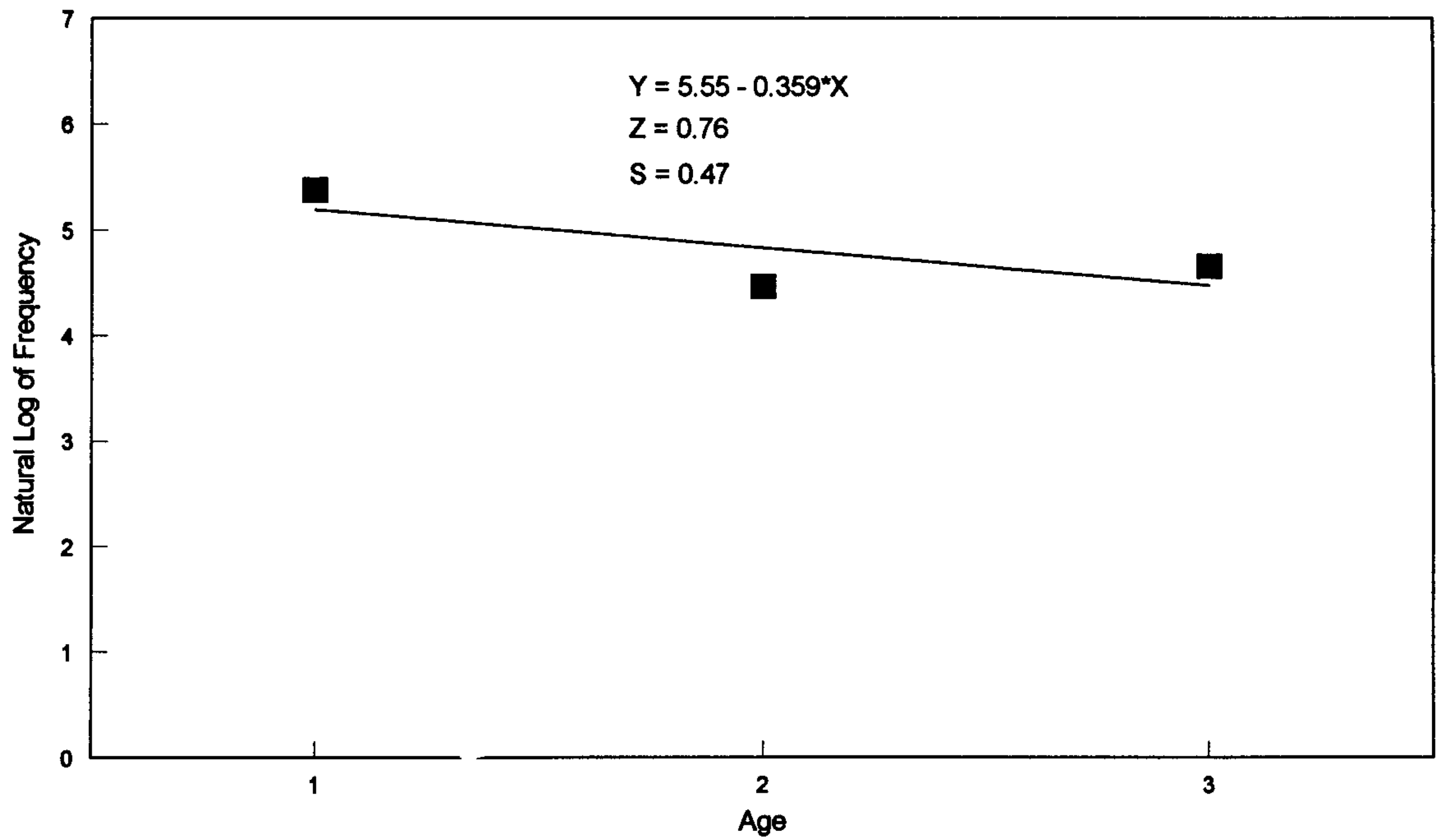

Figure 4. Catch curve and regression line of smallmouth bass ages 1 to 3 collected by beach seining from April to June 1988 through 1995. The regression line was used to estimate survival.

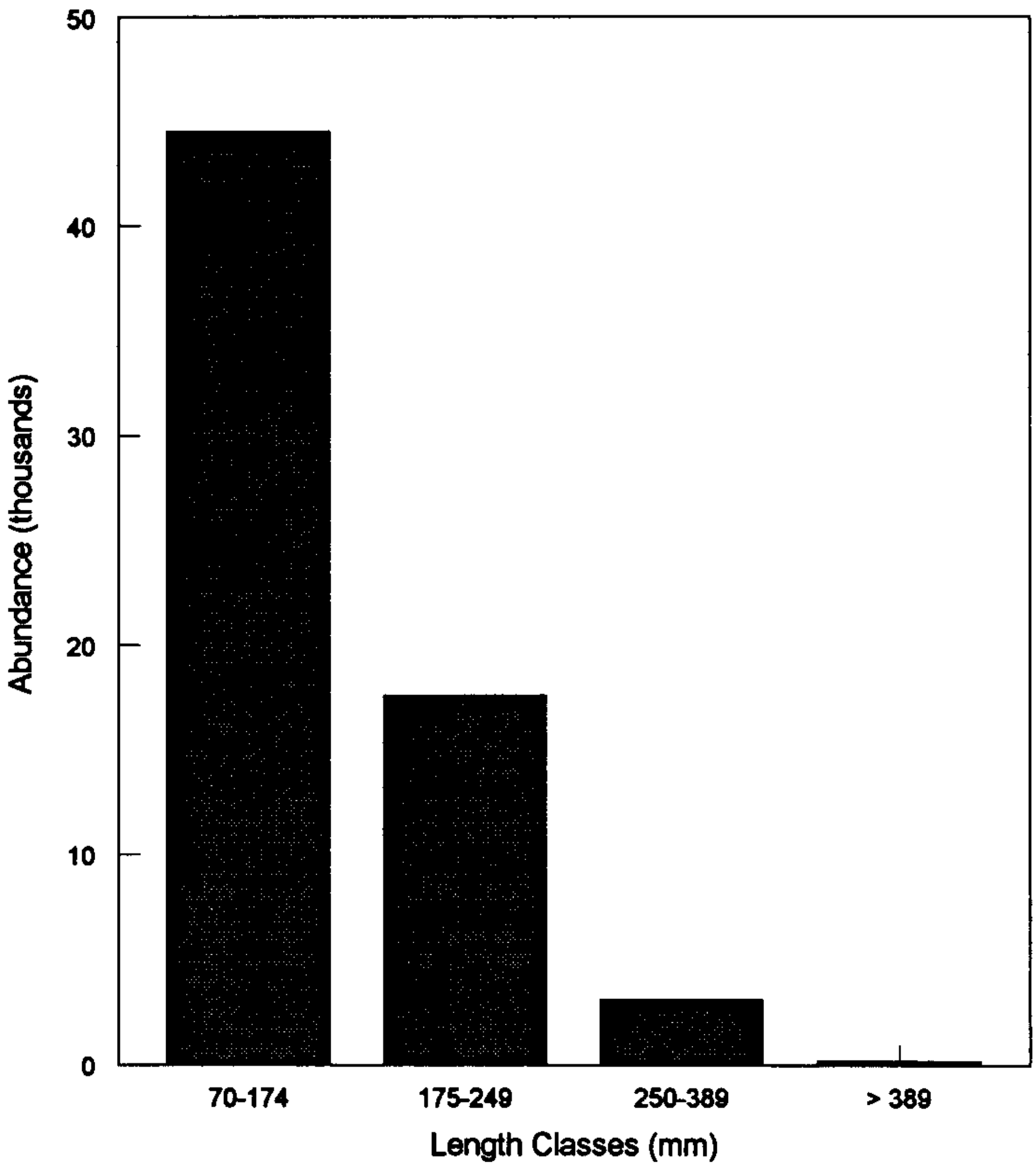

Figure 5. Estimated abundance of four length classes of smallmouth bass in Lower Granite Reservoir based on beach seining and electrofishing collections.

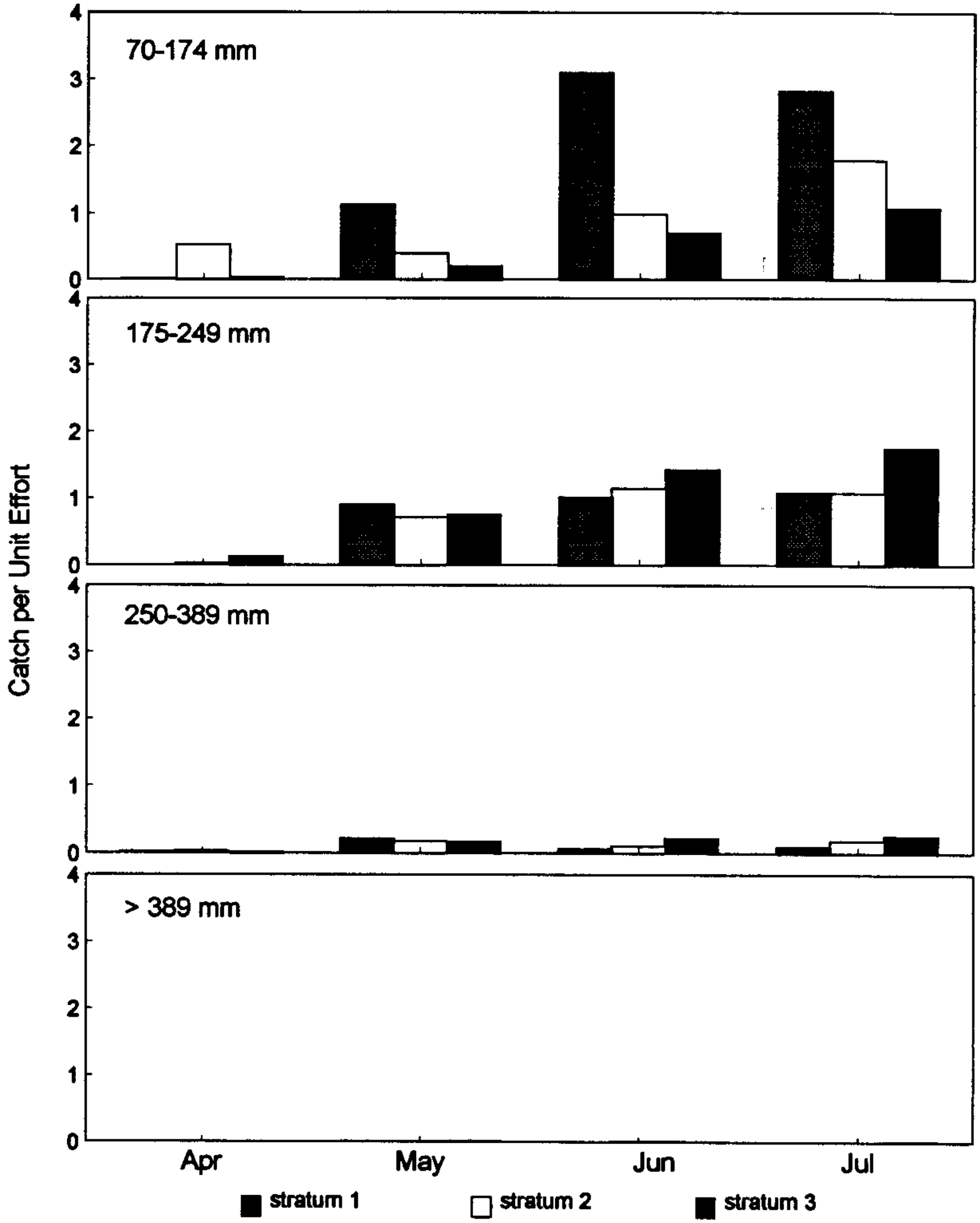

Figure 6. Catch per unit effort (CPUE) of smallmouth bass 70 - 174 mm, 175 - 249 mm, 250 - 389 mm, and > 389 mm in length among strata collected by electrofishing from April to July 1995 in Lower Granite Reservoir. Stratum 1 - RM 131.0 - 139.75 (RKM 210.9 - 225.0); stratum 2 - RM 120.0 - 131.0 (RKM 193.2 - 210.9); stratum 3 - RM 107.5 - 120.0 (RKM 173.1 - 193.2).

Approximately 80% of the samples were from smallmouth bass ranging in length from 70 to 249 mm (Figure 7).

Fish were the most important prey item by weight from April through June for all smallmouth bass based on stomach samples, whereas crustaceans and insects increased in importance after June in 1994 and 1995 (Figure 8). Salmonids accounted for 89% (1994) and 56% (1995) of the total diet weight of prey consumed from April through June (Figure 8).

Distinct differences in the percent weight of salmonids, nonsalmonids, crustaceans, and insects consumed by smallmouth bass were found among length classes in 1994 and 1995 (Figure 9). As predator length increased, the importance of fish in diets of smallmouth bass increased and the importance of insects decreased. Crayfish comprised 43.9% (1994) and 37.7% (1995) of the total weight of prey consumed by smallmouth bass 70 to 174 mm (Tables 1 and 2). Salmonids were absent from stomach samples of smallmouth bass 70 to 174 mm in 1994 and contributed 0.28% of the total diet weight in 1995. Crayfish were the most important food item by weight for smallmouth bass 175 to 249 mm in 1994 (56.6%) and 1995 (64.4%; Tables 1 and 2). Fin fish were second in importance constituting 28.7% (1994) and 26.3% (1995) of the total diet weight. Salmonid prey accounted for 5.5% and 3.5% of the total diet weight in 1994 and 1995, respectively. Salmonids comprised 62.1% of the total diet weight of food items for smallmouth bass 250 to 389 mm in 1994, whereas in 1995 fish (45.9%) and crayfish (50.2%) were about equal in importance. Fish were the dominant prey items of smallmouth bass > 389 mm in 1994 and 1995, accounting for 63.8% (1994) and 92.2% (1995) of the total weight. Salmonids comprised 75.2% in 1994 and 36.3% in 1995 of the total weight of fish in the diets of smallmouth bass > 389 mm.

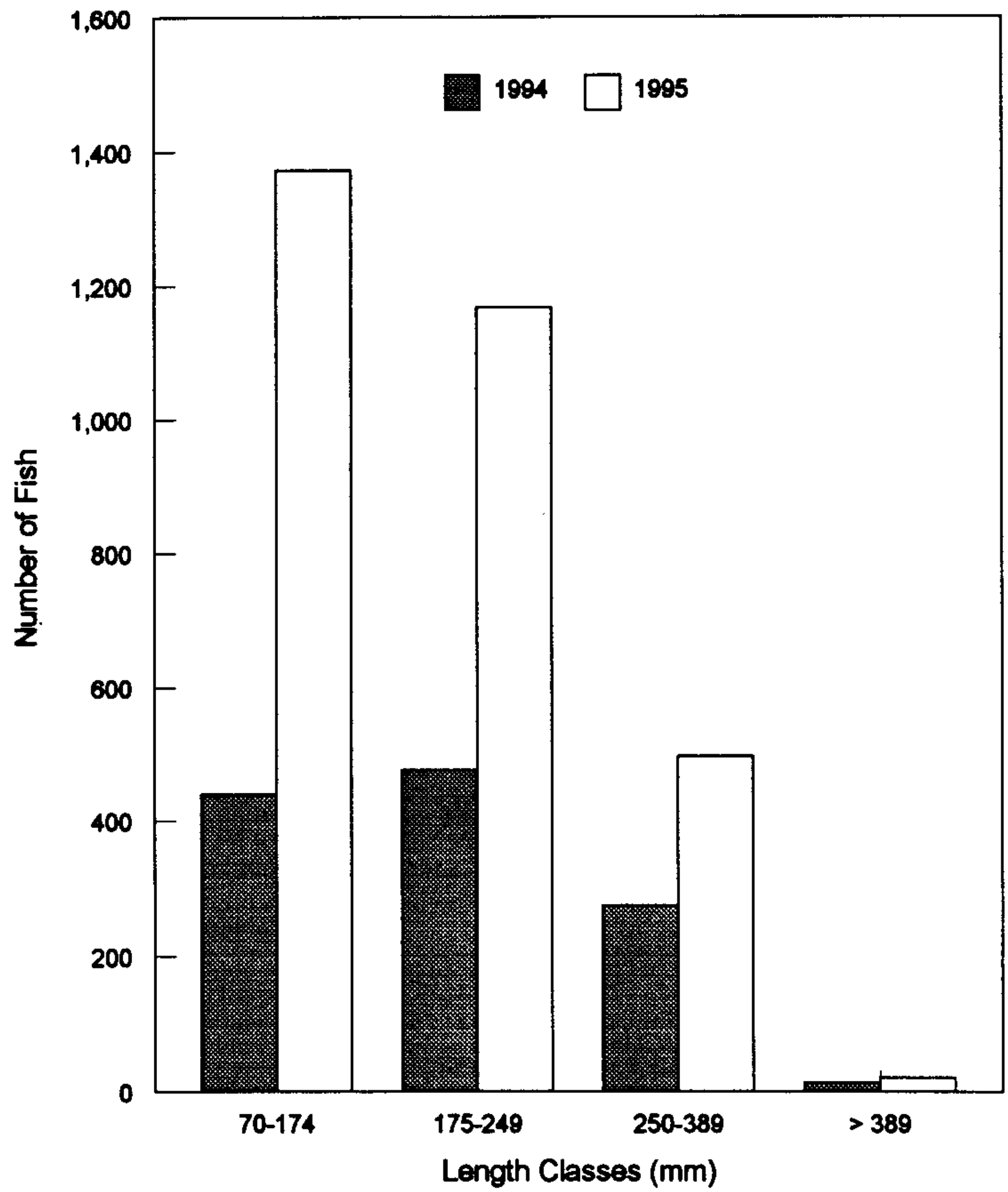

Figure 7. Length frequency of smallmouth bass sampled for dietary analysis during 1994 and 1995 in Lower Grantite Reservoir.

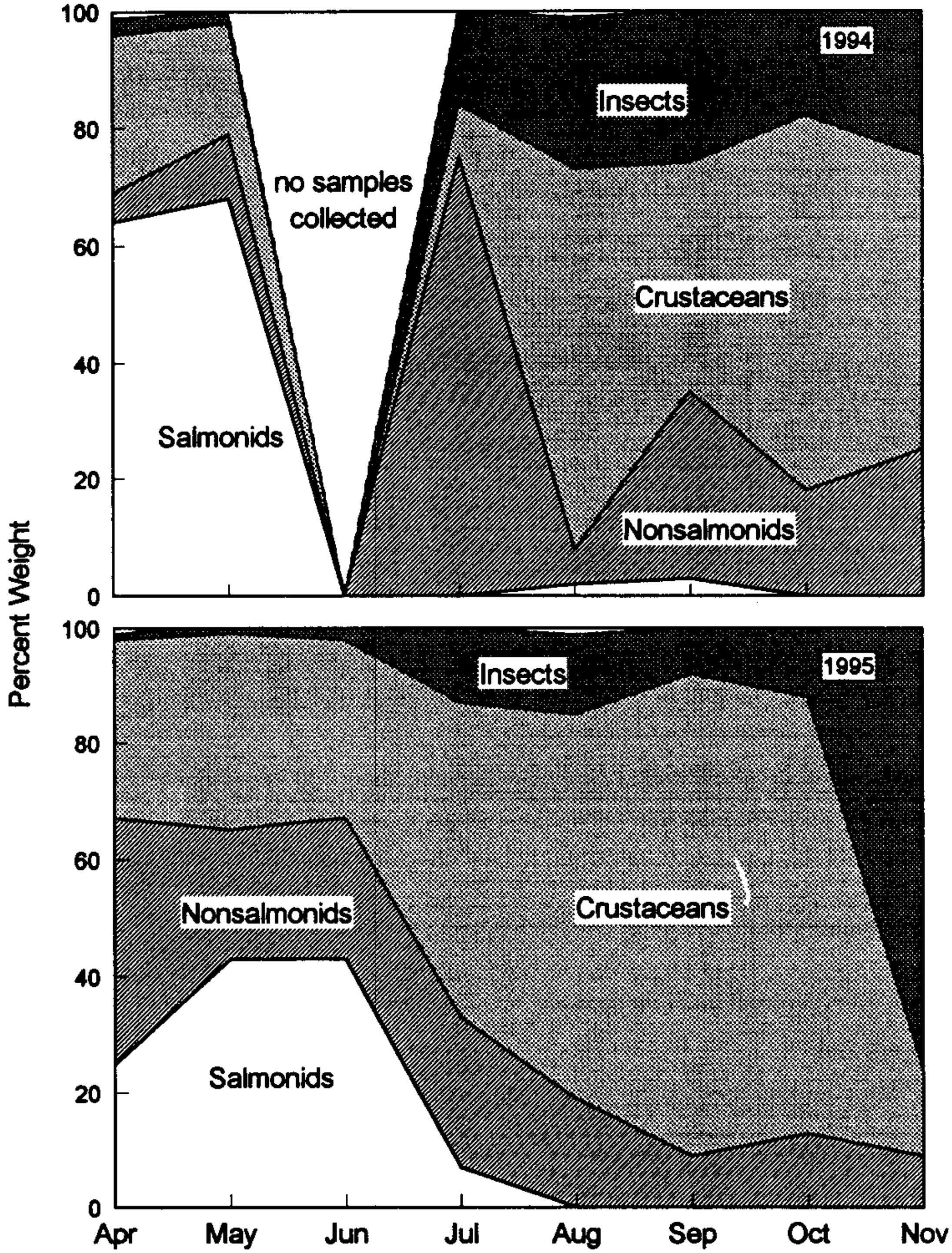

Figure 8. Monthly variation in diet composition, based on percent weight of sample, for smallmouth bass collected during 1994 and 1995 in Lower Granite Reservoir.

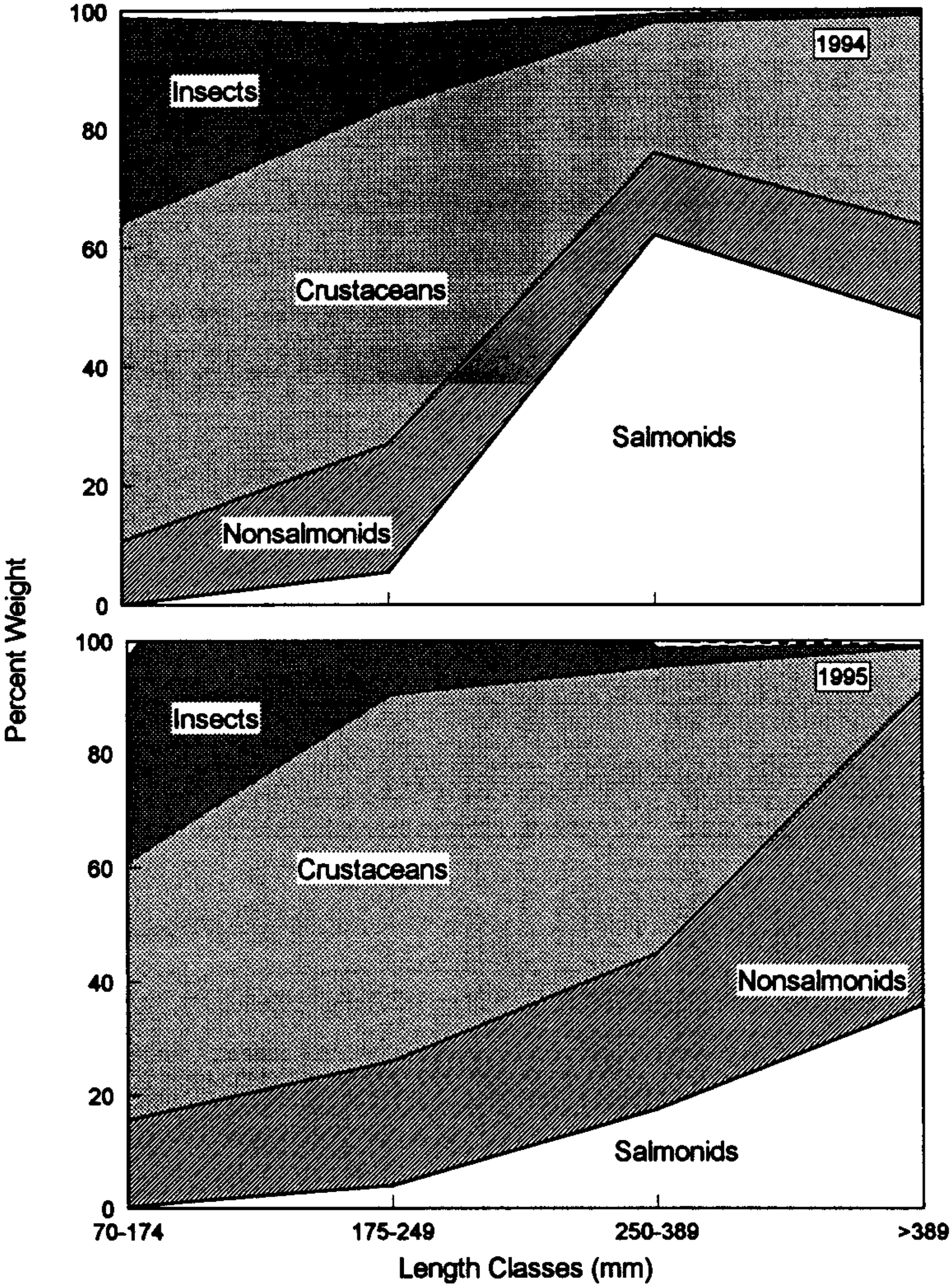

Figure 9. Variation in diet composition, based on percent weight of sample, of four length classes of smallmouth bass collected during 1994 and 1995 in Lower Granite Reservoir.

Table 1. Relative importance of prey items based on percent frequency of occurrence (FO) and weight (WT) for four length classes of smallmouth bass collected from Lower Granite Reservoir during 1994.

	70 - 174 mm		175 - 249 mm		250 - 389 mm		>389 mm	
Prey items	(FO)	(WT)	(FO)	(WT)	(FO)	(WT)	(FO)	(WT)
Osteichthyes	8.92	10.73	26.82	28.74	49.21	76.45	85.71	63.77
Uni.[a] fish	1.05	0.07	4.96	1.77	6.35	0.57	28.57	0.00
Chinook	0.00	0.00	3.79	3.45	11.64	46.60	14.29	47.99
Steelhead	0.00	0.00	0.00	0.00	2.65	13.92	0.00	0.00
Uni. salmonids	0.00	0.00	1.46	2.00	3.17	1.54	0.00	0.00
Cyprinidae	2.10	2.64	4.66	2.33	4.76	3.37	0.00	0.00
Catostomidae	1.31	2.17	2.33	0.70	2.65	0.88	0.00	0.00
Centrarchidae	2.36	2.93	1.75	11.75	2.65	2.89	0.00	0.00
Cottidae	0.00	0.00	0.87	0.22	2.65	0.70	0.00	0.00
Ictaluridae	0.52	2.19	2.62	5.03	2.65	1.01	0.00	0.00
Percidae	0.00	0.00	0.29	0.00	0.00	0.00	0.00	0.00
Larval fish	0.26	0.09	0.87	0.16	0.00	0.00	0.00	0.00
Uni. nonsalmonids	1.57	0.64	6.12	1.34	15.34	4.99	42.86	15.79
Crustacea	82.15	53.55	83.09	56.62	64.55	21.94	42.86	35.16
Cladocera	30.71	5.39	13.70	0.52	3.17	0.01	0.00	0.00
Copepoda	6.56	0.00	4.37	0.00	3.70	0.00	0.00	0.00
Amphipoda	56.17	4.06	48.10	1.05	30.69	0.07	28.57	0.16
Isopoda	2.62	0.16	1.46	0.01	0.53	0.00	0.00	0.00
Decapoda	31.50	43.93	53.64	55.04	46.03	21.86	42.86	34.99
Insecta	91.34	34.69	91.84	14.00	79.37	1.41	57.14	1.07
Uni. insects	30.18	3.32	34.40	2.37	27.51	0.24	28.57	0.00
Diptera	85.56	25.86	86.01	7.46	71.96	0.92	57.14	1.02
Ephemeroptera	14.70	2.81	24.49	1.53	13.23	0.14	14.29	0.05
Hemiptera	3.94	0.04	2.33	0.11	0.53	0.00	0.00	0.00
Homoptera	1.84	0.03	1.17	0.00	0.00	0.00	0.00	0.00
Hymnoptera	6.56	1.01	7.29	0.92	3.17	0.09	0.00	0.00
Coleoptera	2.36	0.18	4.37	0.17	2.65	0.00	0.00	0.00
Trichoptera	14.17	1.44	14.58	0.50	4.23	0.01	0.00	0.00
Mollusca	0.26	0.01	0.29	0.00	0.00	0.00	0.00	0.00
Other Items	6.04	1.02	4.66	0.64	1.59	0.20	0.00	0.00

[a] Uni. = unidentified

Table 2. Relative importance of prey items based on percent frequency of occurrence (FO) and weight (WT) for four length classes of smallmouth bass collected from Lower Granite Reservoir during 1995.

	70 - 174 mm		175 - 249 mm		250 - 389 mm		>389 mm	
Prey items	(FO)	(WT)	(FO)	(WT)	(FO)	(WT)	(FO)	(WT)
Osteichthyes	7.48	17.67	18.86	26.32	29.31	45.85	47.37	92.23
Uni.[a] fish	2.94	2.10	4.52	0.87	6.15	0.83	10.53	0.90
Chinook	0.27	0.27	1.28	3.45	2.36	7.42	0.00	0.27
Steelhead	0.00	0.00	0.00	0.00	0.71	8.20	21.05	35.42
Uni. salmonids	0.09	0.01	0.10	0.02	0.95	1.78	5.26	0.58
Cyprinidae	0.62	5.39	2.06	4.48	1.89	3.97	5.26	3.23
Catostomidae	0.27	3.07	2.06	3.95	3.78	4.64	0.00	0.00
Centrarchidae	0.45	3.77	3.24	8.60	7.09	11.58	5.26	51.58
Cottidae	0.09	0.22	0.00	0.00	0.95	0.13	0.00	0.00
Ictaluridae	0.53	0.29	2.65	3.75	3.55	5.71	5.26	0.53
Percidae	0.27	1.69	1.47	0.60	2.36	1.32	0.00	0.00
Larval fish	1.96	0.87	2.85	0.19	2.13	0.02	0.00	0.00
Uni. nonsalmonids	0.53	0.00	1.38	0.42	2.13	0.24	0.00	0.00
Crustacea	74.62	45.32	76.82	64.44	65.72	50.27	47.37	7.36
Cladocera	20.93	1.73	6.58	0.01	1.42	0.00	0.00	0.00
Copepoda	8.46	0.00	6.97	0.00	7.57	0.00	21.05	0.00
Amphipoda	58.41	5.27	39.98	0.42	19.15	0.06	5.26	0.00
Isopoda	8.82	0.58	4.62	0.05	2.13	0.01	0.00	0.00
Decapoda	18.70	37.73	51.67	63.96	52.25	50.21	26.32	7.36
Insecta	77.92	35.97	73.77	8.77	67.38	3.59	47.37	0.41
Uni. insects	20.57	7.54	18.17	1.81	9.69	0.51	10.53	0.12
Diptera	58.06	12.14	55.11	2.00	46.57	0.29	15.79	0.00
Ephemeroptera	34.37	12.24	34.18	4.06	32.15	2.44	31.58	0.29
Hemiptera	3.12	0.09	2.55	0.04	1.89	0.01	0.00	0.00
Homoptera	1.51	0.19	0.98	0.08	1.18	0.03	0.00	0.00
Hymnoptera	8.19	2.58	8.94	0.40	3.78	0.13	0.00	0.00
Coleoptera	3.21	0.21	3.34	0.12	1.89	0.09	0.00	0.00
Trichoptera	13.54	0.98	14.24	0.25	7.80	0.09	0.00	0.00
Mollusca	0.00	0.00	0.29	0.01	0.00	0.00	0.00	0.00
Other Items	4.10	1.04	4.32	0.45	3.55	0.28	0.00	1.04

[a] Uni. = unidentified

Daily Ration

The mean daily ration (mg prey/g predator) of all prey fishes consumed by smallmouth bass was low during spring (April - June), increased through summer (July - September), and decreased in fall (October - November) during 1994 and 1995 (Figure 10). The mean daily ration of salmonids was 2.580 mg/g during spring 1994 and 1.725 mg/g during spring 1995. The mean daily ration of salmonids in summer 1994 (6.190 mg/g) was substantially higher than that observed during summer 1995 (0.940 mg/g). Salmonids were absent from smallmouth bass stomachs examined during fall 1994 and 1995.

No salmonids were identified in stomach samples of smallmouth bass 70 to 174 mm or > 389 mm in April 1995 (Figure 11). The mean daily ration of salmonids was 0.232 mg/g for smallmouth bass 175 to 349 mm and 0.242 mg/g for smallmouth bass 250 to 389 mm during April 1995. Salmonids were consumed by smallmouth bass 70 to > 389 mm during May 1995. The mean daily ration of salmonids was lowest for smallmouth bass 70 to 174 mm (0.903 mg/g), followed by bass 175 to 249 mm (1.917 mg/g) and 250 to 389 mm (2.066 mg/g). The highest mean daily ration of salmonids was for smallmouth bass > 389 mm (8.939 mg/g). Mean daily ration of salmonids consumed by smallmouth bass decreased in June 1995. Juvenile salmonids were not observed in stomachs of smallmouth bass 70 to 174 mm sampled during June. Additionally, the mean daily ration of salmonids consumed by smallmouth bass 175 to 249 mm (0.263 mg/g) was lower than that for bass 250 to 389 mm (1.288 mg/g). Smallmouth bass > 389 mm had the highest mean daily ration of salmonids (2.243 mg/g) in June. The mean daily ration of salmonids for smallmouth bass 70 to 174 mm in July 1995 was 0.144 mg/g compared to 2.507 mg/g for bass 175 to 249 mm and 2.297 mg/g for bass 250 to 389 mm. No salmonids were observed in stomach samples of smallmouth bass > 389 mm in July.

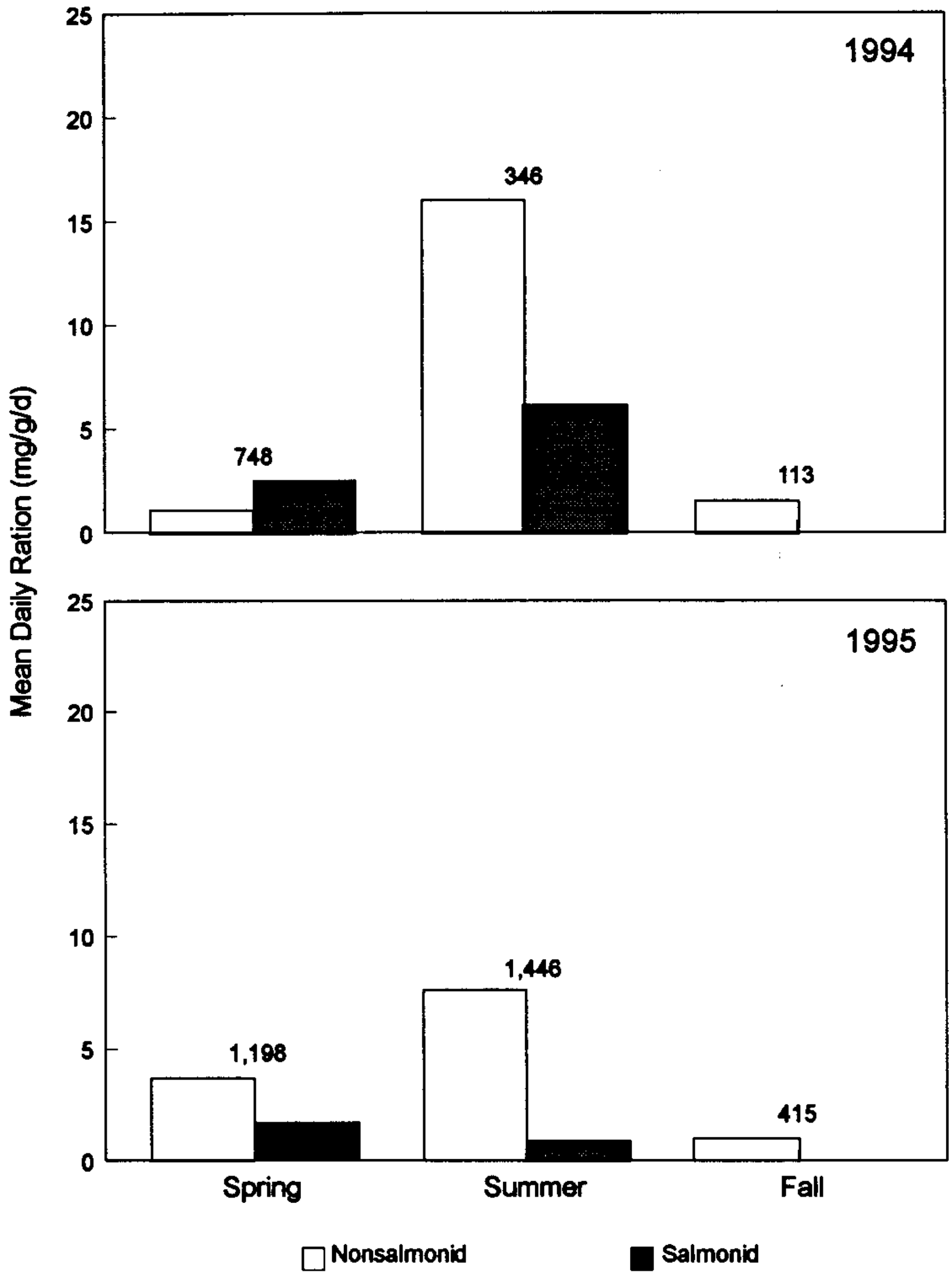

Figure 10. Mean daily ration of fishes consumed by smallmouth bass during spring (April-June), summer (July-September), and fall (October-November) during 1994 and 1995 in Lower Granite Reservoir.

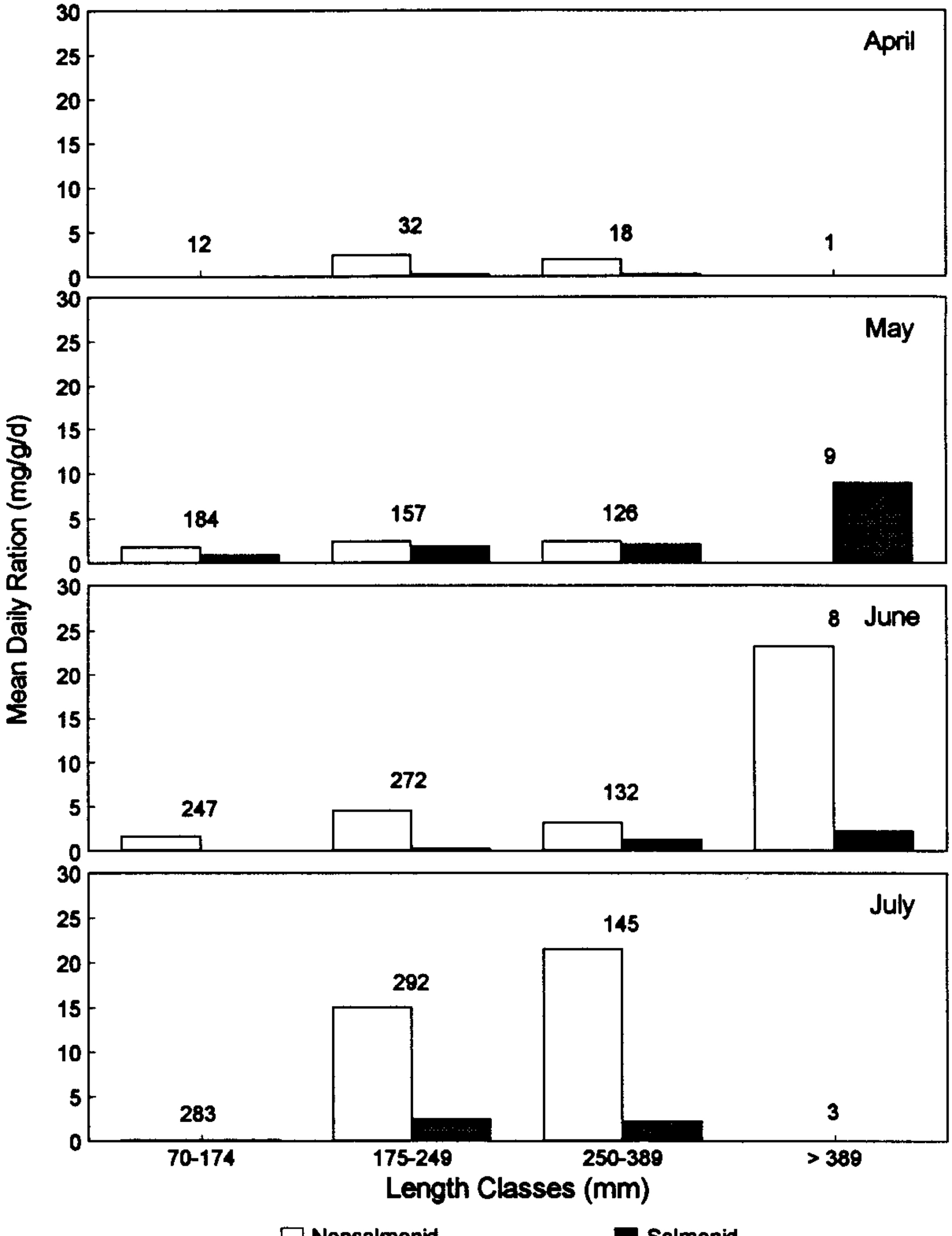

Figure 11. Mean daily ration of fishes consumed by four length classes of smallmouth bass in Lower Granite Reservoir during April through July 1995.

Numerical Consumption

Mean number of juvenile salmonids consumed by smallmouth bass > 69 mm in 1994 was low during April (0.054 prey/predator/day) and May (0.024 prey/predator/day), highest in August (0.375 prey/predator/day), and decreased in September (0.162 prey/predator/day; Table 3). The mean number of nonsalmonids consumed by smallmouth bass > 69 mm was 0.015 prey/predator/day in May 1994, exceeded 0.300 prey/predator/day from July through October, and decreased in November to 0.036 prey/predator/day (Table 3).

In 1995, the mean number of salmonids consumed by smallmouth bass > 69 mm was 0.014 prey/predator/day in April, increased to 0.018 prey/predator/day in May, decreased in June to 0.007 prey/predator/day, and increased to 0.013 prey/predator/day in July (Table 3). Mean number of nonsalmonids consumed by smallmouth bass > 69 mm ranged from 0.051 to 0.064 prey/predator/day from April to August 1995, decreased to 0.013 prey/predator/day in September, and 0.002 prey/predator/day by November (Table 3).

Spatial Trends in Salmonid Consumption and Prey Weight

Consumption rates of juvenile salmonids by smallmouth bass > 69 mm were variable among strata in April through July 1995 (Figure 12). Consumption of salmonids was observed exclusively in stratum 3 during April (0.024 prey/predator/day). In May the mean daily consumption rate of salmonids was highest in stratum 3 (0.027 prey/predator/day) and lowest in stratum 1 (0.009 prey/predator/day). The mean daily consumption rate of salmonids was 0.013 prey/predator/day in stratum 3 during June. Mean daily consumption rate of salmonids in July was highest in stratum 1 (0.032 prey/predator/day) followed by strata 2 (0.012 prey/predator/day) and 3 (0.003 prey/predator/day). Consumption rates were generally lower within strata 1 and 2 in May and strata 2 and 3 in July.

Table 3. Mean number of salmonids and nonsalmonids consumed (prey/predator/day) by smallmouth bass sampled in Lower Granite Reservoir during 1994 and 1995.

Year	Length (mm)	Prey	Consumption	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
1994	70 - 174		N[a]	-	222	-	1	83	81	33	20
			W[b]	-	41	-	60	38	29	45	14
		Salmonid	n[c]	-	-	-	-	-	-	-	-
			w[d]	-	-	-	-	-	-	-	-
		Nonsalmonid	n	-	0.003	-	0.000	1.427	0.514	-	-
			w	-	1.300	-	0.300	0.500	0.500	-	-
	175 - 249		N	24	249	-	16	71	71	40	6
			W	131	124	-	125	120	109	101	99
		Salmonid	n	0.037	0.020	-	-	0.000	1.862	-	-
			w	0.100	8.200	-	-	0.100	1.600	-	-
		Nonsalmonid	n	-	0.024	-	0.734	0.807	2.813	0.000	0.175
			w	-	2.800	-	0.100	10.500	3.400	2.100	1.400
	250 - 389		N	16	222	-	1	14	8	11	3
			W	303	298	-	401	225	226	265	306
		Salmonid	n	0.100	0.054	-	-	0.000	-	-	-
			w	16.700	21.000	-	-	9.300	-	-	-
		Nonsalmonid	n	-	0.029	-	-	0.774	-	0.452	-
			w	-	21.000	-	-	0.600	-	1.800	-
	>389		N	-	15	-	-	-	-	-	-
			W	-	831	-	-	-	-	-	-
		Salmonid	n	-	0.043	-	-	-	-	-	-
			w	-	12	-	-	-	-	-	-

Table 3. Continued

Year	Length (mm)	Prey	Consumption	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
1994	>389	Nonsalmonid	n	-	-	-	-	-	-	-	-
			w	-	-	-	-	-	-	-	-
	>69		N	40	708	-	18	168	160	84	29
			W	200	168	-	136	88	74	101	62
		Salmonid	n	0.054	0.024	-	-	0.375	0.162	-	-
			w	12.600	17.400	-	-	3.200	1.600	-	-
		Nonsalmonid	n	-	0.015	-	0.385	0.438	0.485	0.304	0.036
			w	-	14.100	-	0.200	5.000	1.900	1.900	1.400
1995	70 - 174		N	12	184	247	283	206	171	146	123
			W	31	21	25	22	23	24	22	17
		Salmonid	n	-	0.005	-	0.005	-	-	-	-
			w	-	4.100	-	0.600	-	-	-	-
		Nonsalmonid	n	-	0.016	0.006	0.004	0.046	-	0.006	0.002
			w	-	2.300	7.100	0.900	4.400	-	2.100	0.900
	175 - 249		N	32	157	272	292	141	147	118	9
			W	112	110	108	107	109	106	91	82
		Salmonid	n	0.012	0.023	0.006	0.030	-	-	-	-
			w	2.100	9.300	4.900	9.100	-	-	-	-
		Nonsalmonid	n	0.040	0.062	0.058	0.145	0.117	0.018	0.017	-
			w	6.700	4.300	8.400	11.100	10	4.700	7.800	-
	250 - 389		N	18	126	132	145	30	27	16	3
			W	289	291	255	244	215	217	185	149

Table 3. Continued

Year	Length (mm)	Prey	Consumption	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
1995	250 - 389	Salmonid	n	0.027	0.017	0.018	0.024	-	-	-	-
			w	2.600	35.700	17.900	23	-	-	-	-
		Nonsalmonid	n	0.108	0.104	0.050	0.381	0.138	0.171	-	-
			w	5	6.800	16.200	13.800	24.700	17.600	-	-
	>389		N	1	9	8	3	-	1	-	-
			W	1,242	1,073	1,056	741	-	1,296	-	-
		Salmonid	n	-	0.248	0064	-	-	-	-	-
			w	-	38.700	37.100	-	-	-	-	-
		Nonsalmonid	n	-	-	0.266	-	-	-	-	-
			w	-	-	92.300	-	-	-	-	-
	>69		N	63	476	659	723	377	346	280	135
			W	165	142	118	104	70	78	61	24
		Salmonid	n	0.014	0.018	0.007	13.900	-	-	-	-
			w	2.400	23	15.700	13.900	-	-	-	-
		Nonsalmonid	n	0.051	0.054	0.054	0.082	0.064	0.013	0.011	0.002
			w	5.800	5.300	12.600	12.300	10	13.300	5.600	0.900

[a] N = sample size
[b] W = mean predator weight (g)
[c] n = mean consumption
[d] w = mean prey weight

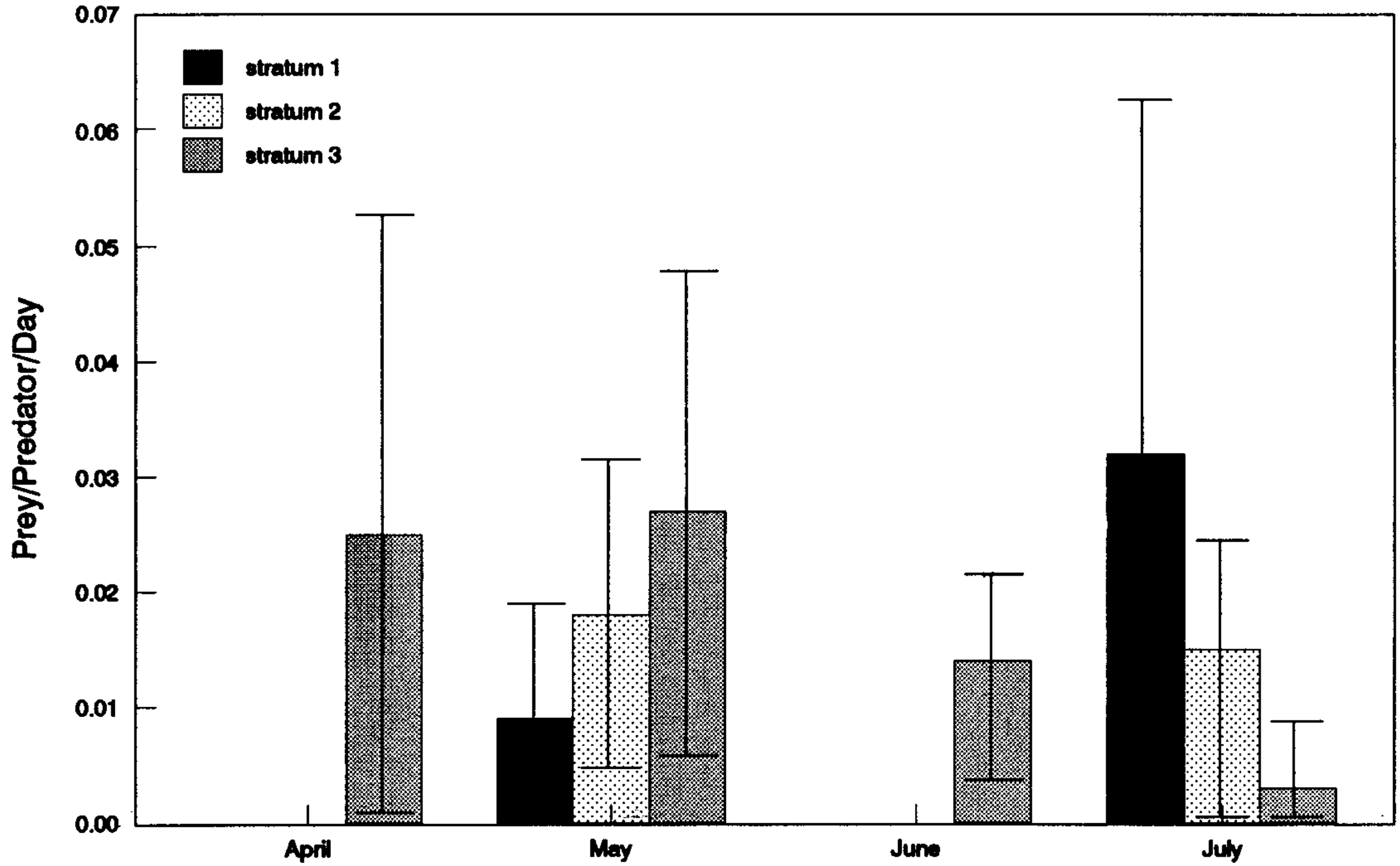

Figure 12. Mean daily consumption rates (prey/predator) of salmonids by smallmouth bass sampled from April through July 1995 within three strata of Lower Granite Reservoir. Upper and lower bounds of 95% confidence interval are also indicated.

The mean weight (g) of salmonids consumed in stratum 3 during April 1995 was low (2.4 g) compared to that in May (26.8 g; Figure 13). Mean salmonid prey weight in stratum 3 was 15.7 g in June and 51.0 g in July.

Size Selectivity

Smallmouth bass that consumed salmonids ranged between 85 and 474 mm. Lengths of salmonids consumed by smallmouth bass ranged from 21 to 293 mm FL (Figure 14). Approximately 32% of ingested salmonids were < 76 mm, 57% ranged from 76 to 150 mm, and 11% were > 150 mm. Although variable, a positive linear relationship ($P < 0.05$; $r^2 = 0.34$) between lengths of smallmouth bass (TL) and ingested salmonids (FL) was determined by pooling data for 1994 and 1995 (Figure 15). Fork lengths of ingested salmonids were similar to average daily fork lengths of juvenile chinook collected at Lower Granite Dam during April and May 1994 (Figure 16). Fork lengths of ingested salmonids and fork lengths of subyearling chinook collected at Lower Granite Dam were also similar during April, May, and July 1995 (Figure 16). Mean fork lengths of salmonids consumed during August and September were generally smaller than mean fork lengths of out-migrants.

Estimated Loss

In 1994 approximately 82,476 juvenile salmonids were consumed by smallmouth bass in Lower Granite Reservoir (Table 4) compared to approximately 64,020 juvenile salmonids in 1995 (Table 5). Juvenile chinook salmon comprised 93% (1994) and 81% (1995) of all salmonids ingested (Tables 4 and 5). Smolt losses in May 1994 accounted for 42% of the total annual loss as a result of smallmouth bass predation; 62% of the loss occurred in stratum 1 (Table 4). We found a substantial difference in estimated losses of juvenile salmonids among strata in 1995. Losses occurred predominately in strata 2 and 3 during April and May (44%

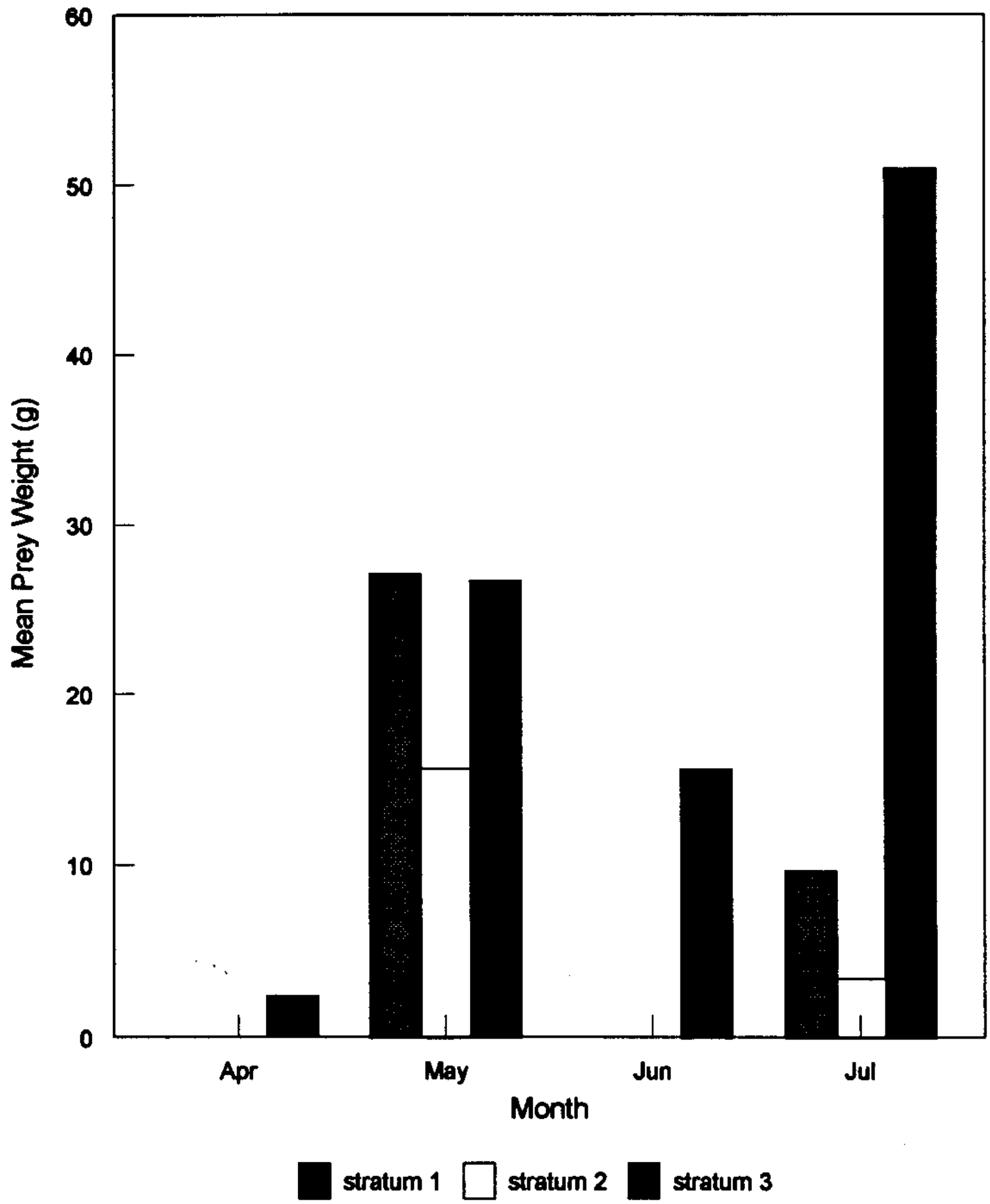

Figure 13. Mean weight (g) of salmonids consumed by smallmouth bass (all lengths combined) sampled in three strata in Lower Granite Reservoir from April through July 1995. Stratum 1 - RM 131.0 - 139.75, stratum 2 - RM 120.0 - 131.0, stratum 3 - RM 107.5 - 120.0. RM = river mile.

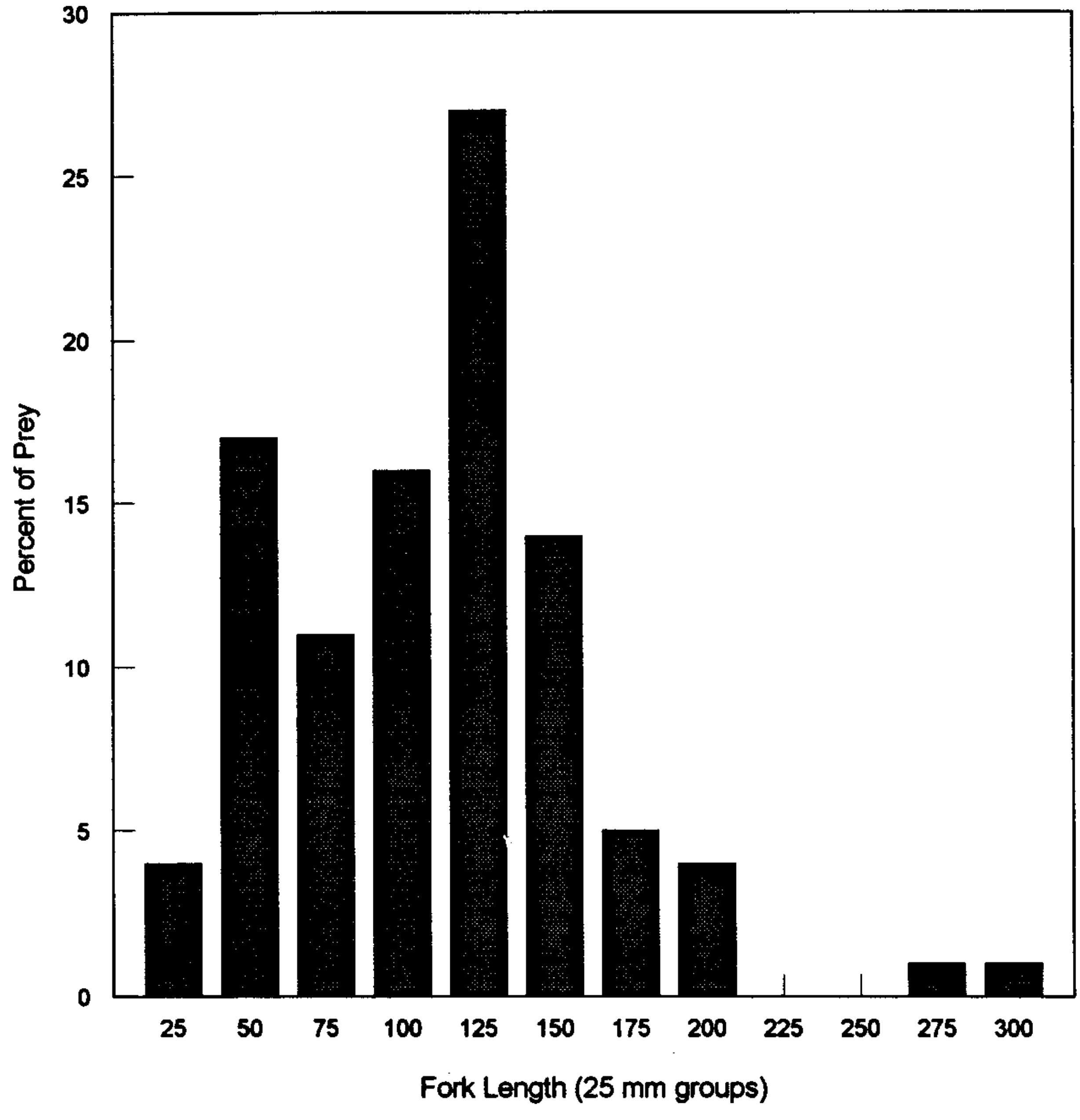

Figure 14. Length distribution of salmonid prey (fork length) consumed by smallmouth bass in 1994 and 1995 in Lower Granite Reservoir.

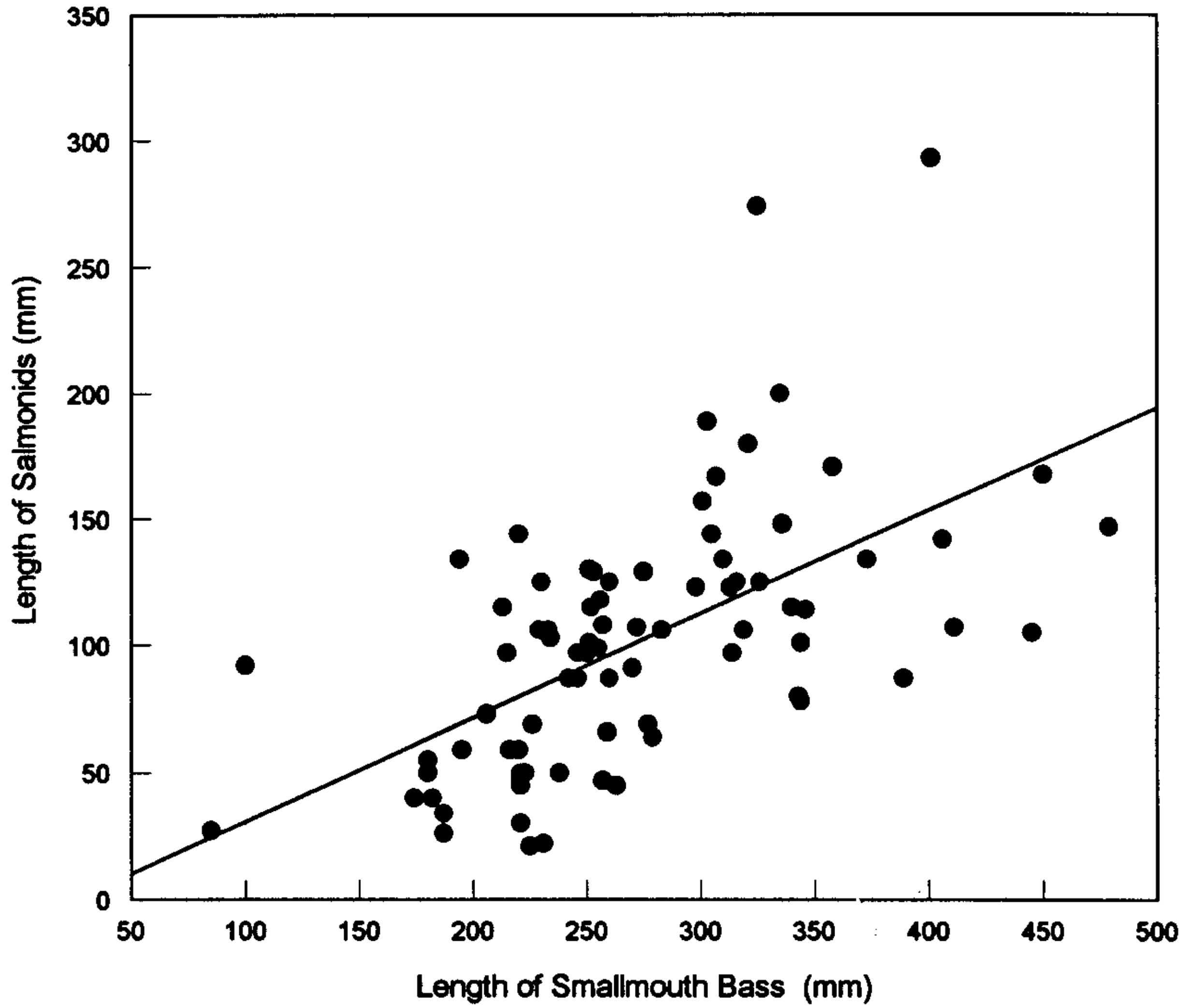

Figure 15. Relationship between lengths of smallmouth bass (total length) and ingested salmonids (fork length) sampled during 1994 and 1995 in Lower Granite Reservoir.

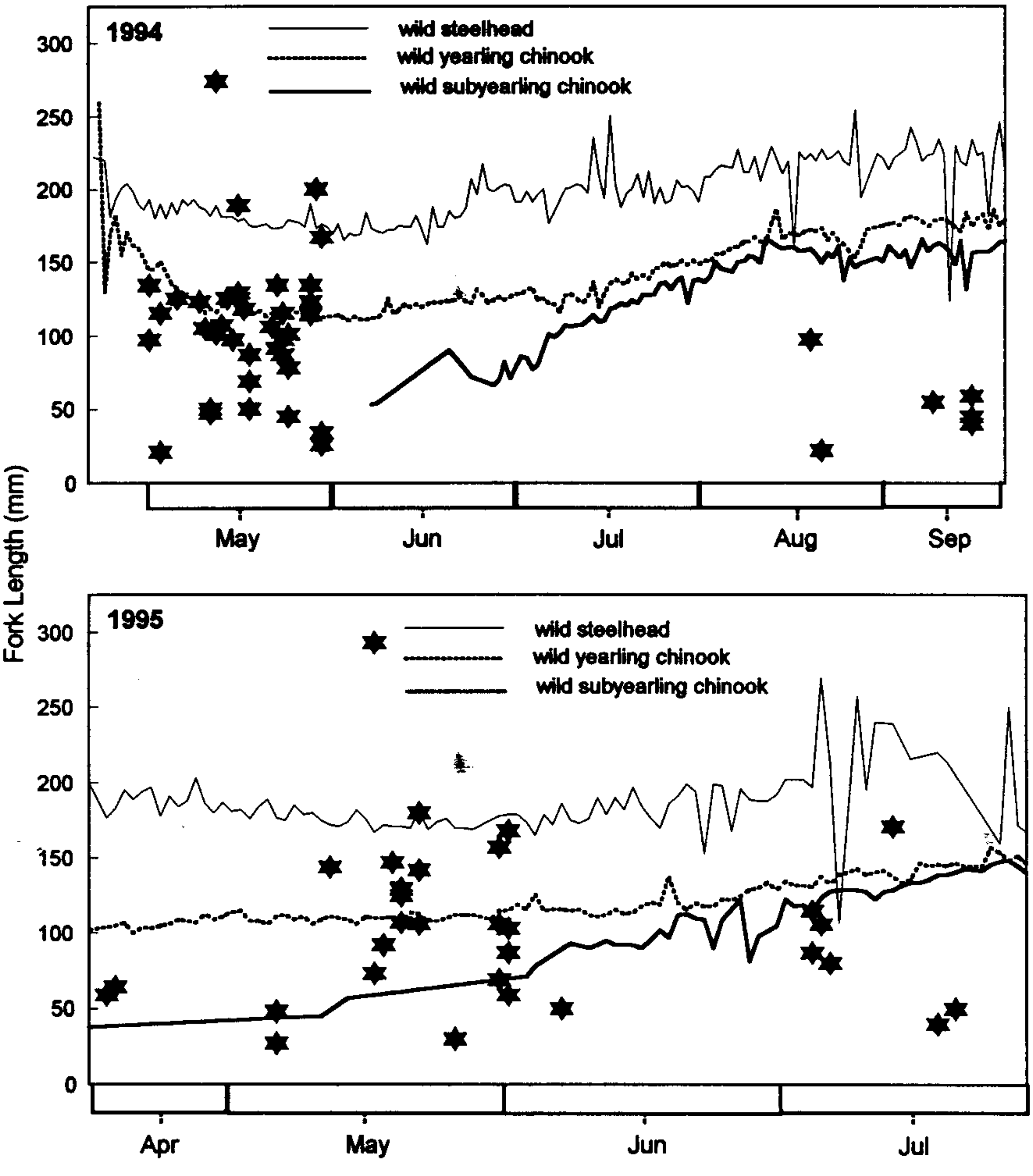

Figure 16. Fork lengths (stars) of ingested salmonids and average daily lengths (lines) based on catches at the juvenile bypass facility in Lower Granite Dam during 1994 and 1995. Average lengths were estimated for dates when no passage occured.

Table 4. Estimated loss of juvenile salmon and steelhead to predation by smallmouth bass by length, month, and strata from April to September 1994 in Lower Granite Reservoir.

	Length (mm)	Apr	May	Jun	Jul	Aug	Sep
Stratum 1[a]	70 - 174	-	-	na	-	-	-
	175 - 249	21,276	21,515	na	-	-	8,429
	250 - 389	-	-	na	-	-	-
	>389	-	-	na	-	-	-
Monthly loss in Stratum 1		21,276	21,515	na	-	-	8,429
Percent of total		26	26	na	-	-	10
Stratum 2	70 - 174	-	-	na	-	-	-
	175 - 249	-	7,059	na	-	-	11,275
	250 - 389	2,640	1,399	na	-	-	-
	>389	-	-	na	-	-	-
Monthly loss in Stratum 2		2,640	8,458	na	-	-	11,275
Percent of total		3	10	na	-	-	14
Stratum 3	70 - 174	-		na	-	-	-
	175 - 249	-	1,968	na	-	-	-
	250 - 389	4,197	2,574	na	-	-	-
	>389	-	144	na	-	-	-
Monthly loss in Stratum 3		4,197	4,686	na	-	-	-
Percent of total		5	6	na	-	-	-
Total monthly loss		28,113	34,659	na	-	-	19,704
Percent of total		34	42	na	-	-	24
Loss of chinook		28,113	28,767	na	-	-	19,704
Percent of monthly total		100	83	na	-	-	100
Loss of steelhead		-	5,892	na	-	-	-
Percent of monthly total		-	17	na	-	-	-
Total chinook loss	76,584						
Percent of total	93						
Total steelhead loss	5,892						
Percent of total	7						
Total loss	82,476						

[a] Stratum 1 - RM 131.0 - 139.75 (RKM 210.9 - 225.0), stratum 2 - RM 120.0 - 131.0 (RKM 193.2 - 210.9), stratum 3 - RM 107.5 - 120.0 (RKM 173.1 - 193.2). RM indicates river mile, RKM indicates river kilometer.

Table 5. Estimated loss of juvenile salmon and steelhead to predation by smallmouth bass by length, month, and strata from April to July 1995 in Lower Granite Reservoir.

	Length (mm)	Apr	May	Jun	Jul
Stratum 1[a]	70 - 174	-	-	-	10,746
	175 - 249	-	4,883	-	7,704
	250 - 389	-	-	-	495
	>389	-	355	-	-
Monthly loss in Stratum 1		-	5,238	-	18,945
Percent of total		-	8	-	30
Stratum 2	70 - 174	-	2,528	-	-
	175 - 249	-	7,024	-	5,397
	250 - 389	-	805	-	1,148
	>389	-	513	-	-
Monthly loss in Stratum 2		-	10,670	-	6,545
Percent of total		-	17	-	10
Stratum 3	70 - 174	-	2,749	-	-
	175 - 249	7,421	3,568	2,258	-
	250 - 389	2,257	711	1,617	751
	>389	-	848	242	-
Monthly loss in Stratum 3		9,678	7,876	4,117	751
Percent of total		15	12	6	1
Total monthly loss		9,678	23,984	4,117	26,241
Percent of total		15	37	6	41
Loss of chinook		9,678	16,069	3,623	22,567
Percent of monthly total		100	67	88	86
Loss of steelhead		-	7,915	494	3,674
Percent of monthly total		-	33	12	14
Total chinook loss	51,937				
Percent of total	81				
Total steelhead loss	12,083				
Percent of total	19				
Total loss	64,020				

[a] Stratum 1 - RM 131.0 - 139.75 (RKM, 210.9 - 225.0), stratum 2 - RM 120.0 - 131.0 (RKM 193.2 - 210.9), stratum 3 - RM 107.5 - 120.0 (RKM 173.1 - 193.2). RM indicates river mile, RKM indicates river kilometer.

of total), whereas 40% of the total annual smolt loss during July occurred in strata 1 and 2 (Table 5).

Diel Consumption

Fish were consumed throughout the diel period with elevated rates of salmonid consumption during morning hours by smallmouth bass 175 to 249 mm (2400 - 0800 hours) and bass > 389 mm (2400 - 0400 hours; Figures 17). Salmonid consumption was highest between 1600 and 1800 hours for smallmouth bass 250 to 389 mm.

DISCUSSION

Abundance

The mark-recapture effort for smallmouth bass was conducted over a relatively short period (April - June 1994) when capture rates of bass > 174 mm are typically highest in Lower Granite Reservoir. We observed little sport angling activity during the April through June period, limiting the removal of tagged smallmouth bass from the reservoir. Also, we do not believe tagged bass would be more vulnerable to angling. Violation of the assumptions associated with estimating the abundance of a "closed" population were thereby minimized. Beamesderfer and Rieman (1988) reported that estimates of smallmouth bass abundance, population size structure, and annual mortality rate were susceptible to size-selective bias, but the relatively small degree of bias associated with abundance estimates did not warrant correction for size-selectivity.

The estimated abundance of 65,400 smallmouth bass > 69 mm in Lower Granite Reservoir is equivalent to 18.2 fish/ha and 3.4 fish/ha for smallmouth bass > 199 mm. Beamesderfer and Rieman (1991) found a density of 1.8 fish/ha for smallmouth bass > 199 mm in John Day Reservoir. Carlander (1977) reported 16 to 164 fish/ha based on densities of 10 smallmouth bass populations although lengths

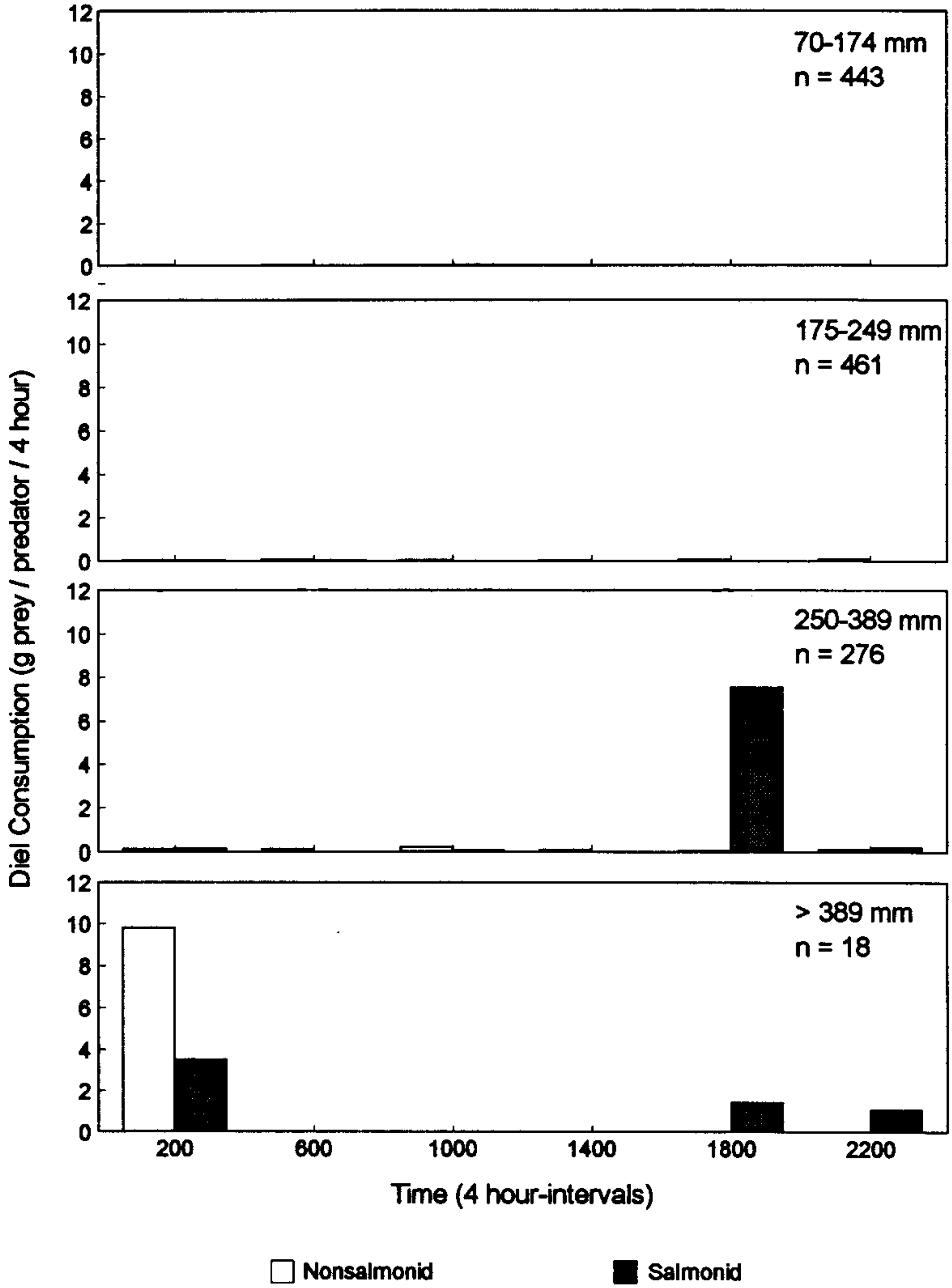

Figure 17. Diel consumption, in 4-hour intervals, of prey fishes consumed by smallmouth bass sampled in April through June 1995 in Lower Granite Reservoir.

of these 10 populations were not given. Additionally, Paragamian (1991) reported that smallmouth bass densities ranged from 2 to 911 fish/ha for 22 sites examined in Iowa. The lowest densities of the Iowa sites occurred in silt laden habitats. Densities in Lower Granite Reservoir are not the lower end of those reported in the literature.

Diet Composition

Seasonal changes in diet composition observed during 1994 and 1995 in Lower Granite Reservoir demonstrated the opportunistic feeding behavior commonly reported for smallmouth bass (Keating 1970; Coble 1975; Pflug and Pauley 1984). Smallmouth bass fed heavily on fish, principally juvenile salmonids, from April through July during 1994 and 1995. As passage of juvenile salmonids at Lower Granite Dam decreased, smallmouth bass fed more heavily on crayfish and nonsalmonids. Stomach samples of adult smallmouth bass sampled in Lower Granite Reservoir by Bennett and Shrier (1986) contained similar amounts of salmonids (26.0%) and decapoda (22.8%) during spring based on percent wet weight. We found that the diets of smallmouth bass were dominated by decapoda (86.5%) during summer. Shively et al. (1996) documented the ability of northern squawfish in the Clearwater River, Idaho, to switch rapidly from a diet consisting mostly of crayfish (38%) to one primarily of salmonids (86%). Therefore, the increase in salmonids in the diets of smallmouth bass may be attributed to an increase in juvenile salmonid density possibly resulting from hatchery releases upstream or the clumping of wild fish.

We found that, as predator length increased, diets of smallmouth bass sampled in Lower Granite Reservoir shifted from insects to fish. Poe et al. (1991) reported the same trend for smallmouth bass in John Day Reservoir. Smallmouth bass shift from relatively small to larger prey items as they grow (Coble 1975; George and

Hadley 1979). Dunsmoor et al. (1991) reported that zooplankton were the most important food item of smallmouth bass < 200 mm in Brownlee Reservoir, Idaho, while smallmouth bass > 200 mm preyed chiefly on crayfish and fish. Fish (salmonids and nonsalmonids) accounted for more than 60% of the total diet weight of smallmouth bass > 249 mm in Lower Granite Reservoir during 1994 and 1995. Diets of smallmouth bass > 199 mm in John Day Reservoir averaged 82% (weight) fish (Vigg et al. 1991), and though predator sizes were not the same as our data from Lower Granite Reservoir, Vigg et al. clearly demonstrated the importance of fish in the diets of larger smallmouth bass. Total diet weight of salmonids in smallmouth bass diets in 1994 ranged from 0% for bass 70 to 174 mm to 48% for bass > 389 mm. In 1995 salmonids accounted for 0.28% of the total diet weight of smallmouth bass 70 to 174 mm compared to 36% for that of smallmouth bass > 389 mm.

Daily Ration

Mean daily ration of all prey fishes ingested by smallmouth bass increased from April through August 1994 and from April through July 1995. Increases in mean daily ration coincided with increases in reservoir water temperature (Figure 18). Vigg et al. (1991) also observed an increase in daily fish ration of smallmouth bass in John Day Reservoir from April through August.

Peaks in daily ration of salmonids by smallmouth bass were observed during May and July 1995 in Lower Granite Reservoir. Increases in daily ration of salmonids coincided with peak passage of juvenile salmonids at Lower Granite Dam. Daily counts of steelhead and yearling chinook were highest in May and subyearling chinook passage was highest in July, suggesting a possible density dependent relationship between salmonid consumption by smallmouth bass and juvenile salmonid abundance. The relationship between daily ration and smolt

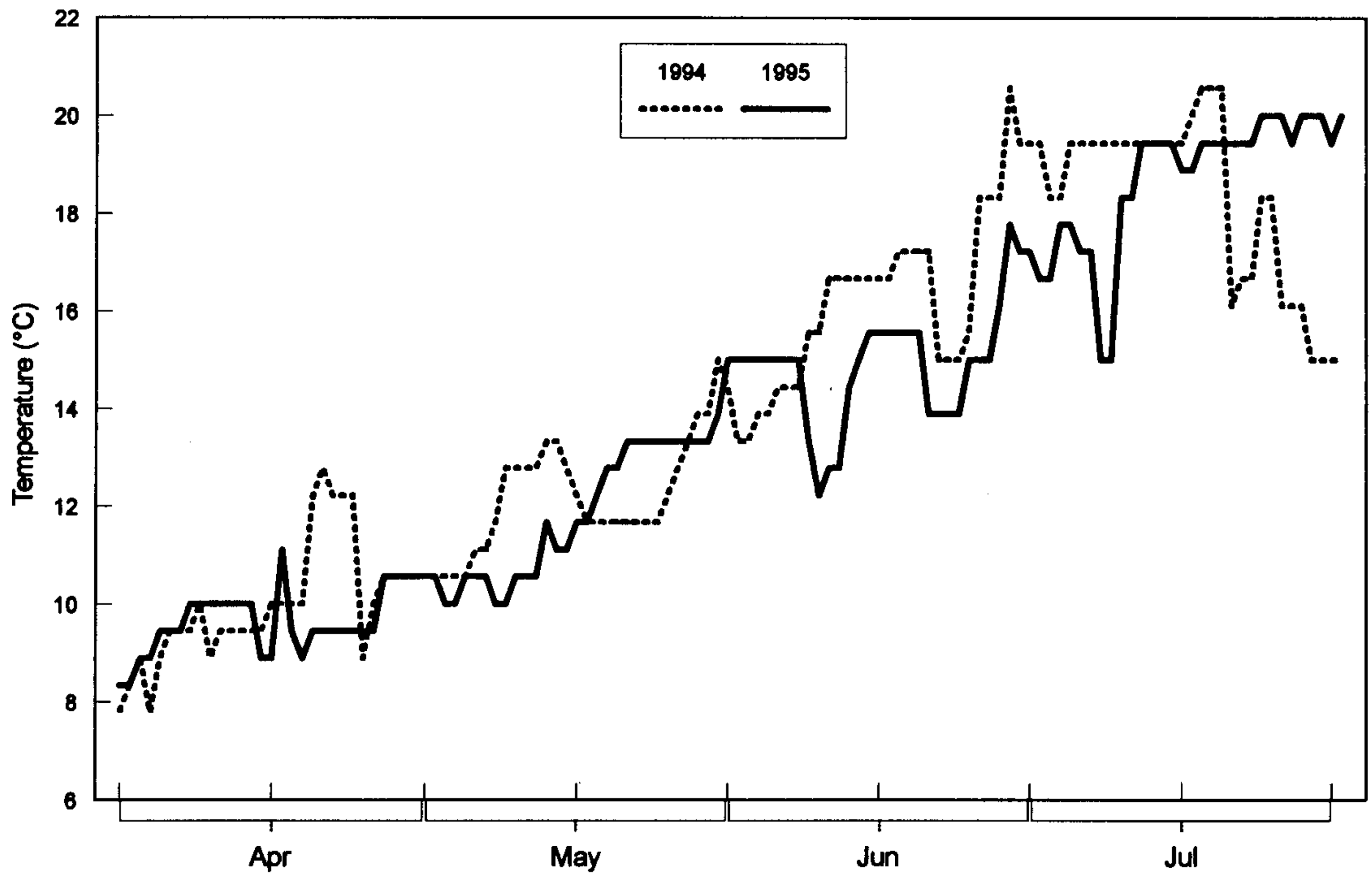

Figure 18. Average daily water temperature recorded from April through July 1994 and 1995 at Lower Granite Dam.

passage may be similar to that reported by Petersen et al. (1990). They observed a density dependent relationship between smolt consumption rate of northern squawfish and smolt density in the boat restricted zone of McNary Dam.

Daily ration of fish in Lower Granite Reservoir by smallmouth bass increased with predator size in 1995. The highest daily ration of salmonids (8.94 mg/g) was observed for smallmouth bass > 389 mm. The highest daily ration of all prey fishes (25.46 mg/g) was similar to that reported for smallmouth bass in John Day Reservoir (28.7 mg/g; Vigg et al. 1991). Mean daily ration was highest for smallmouth bass > 389 mm, which differs from the results of Vigg et al. (1991) who reported that fish ration was highest for smallmouth bass 200 mm (30.4 mg/g) and decreased for larger smallmouth bass in John Day Reservoir.

Numerical Consumption

Vigg et al. (1991) noted that temperature may be the most influential factor regulating consumption rates of fishes. Consumption rates of smallmouth bass during 1994 and 1995 were closely linked to increasing water temperatures, as they were relatively low during April and May and were high from July through September. Water temperatures in 1994 and 1995 were approximately 8° C at the beginning of April and reached a maximum of 23° C in August 1994 and 20° C in July 1995 (Figure 18). Optimal water temperatures for smallmouth bass range from 12 to 31° C depending on age and acclimation (Ferguson 1958; Barans and Tubb 1973).

Higher water temperatures and lower flows and turbidity in spring 1994 compared to spring 1995 may have enhanced predation of salmonids by smallmouth bass (Figures 18 -20). Numerical consumption rates of salmonids in April and May 1994 were 0.054 and 0.024 prey/predator/day, whereas those during April and May 1995 were 0.014 and 0.018 prey/predator/day. The increased turbidity in 1995

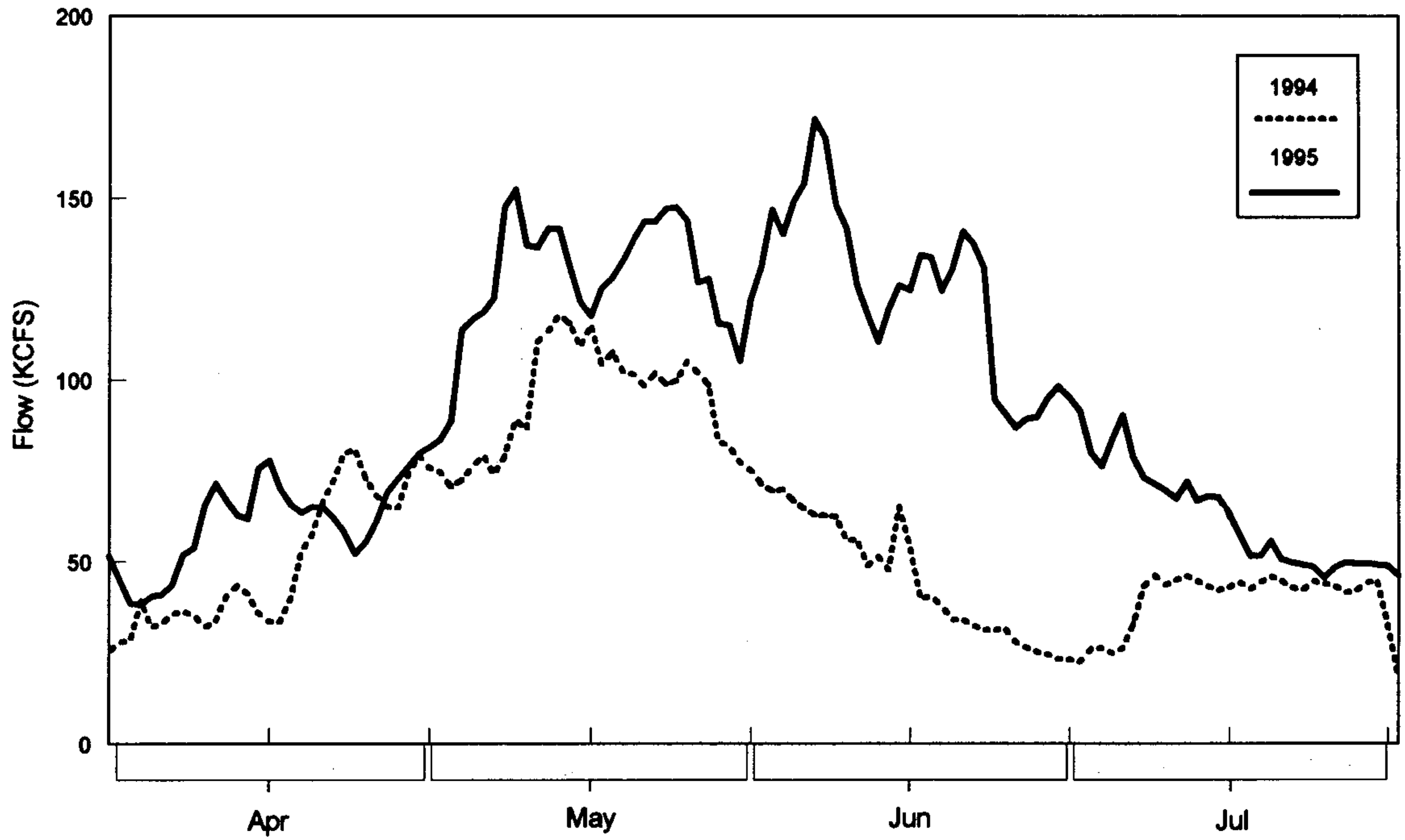

Figure 19. Total daily outflow through Lower Granite Dam from April through July 1994 and 1995.

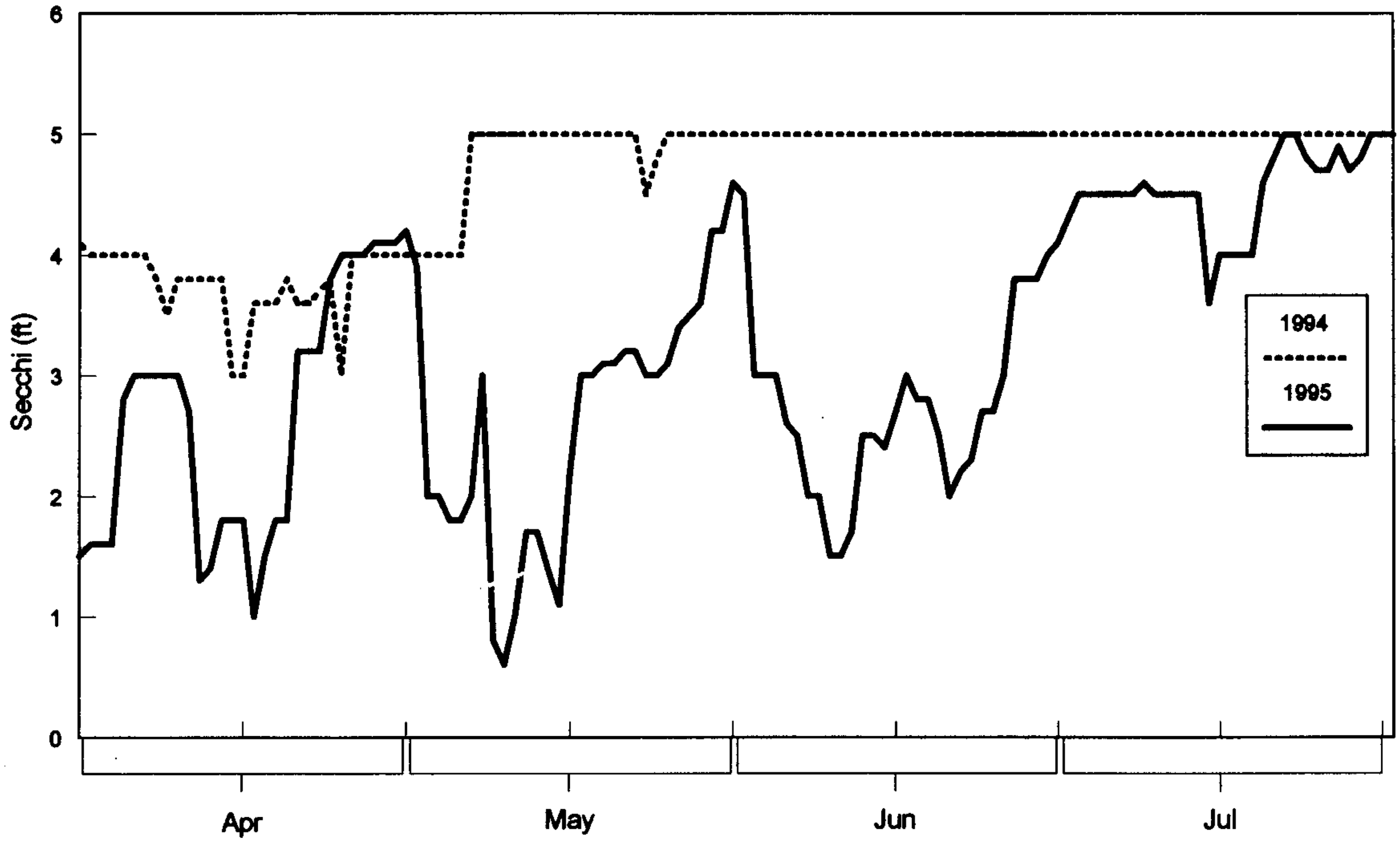

Figure 20. Turbidity measured daily by secchi disk from April through July 1994 and 1995 at Lower Granite Dam.

(Figure 20) may have decreased the ability of smallmouth bass to locate and capture prey, as bass are visually oriented predators and are generally associated with areas of low turbidity (Todd and Rabeni 1989). Our data support the findings of Bennett et al. (1993a, 1993b) who indicated higher flows and coinciding higher turbidities in Lower Granite Reservoir resulted in lower salmonid consumption by northern squawfish.

Spatial Trends in Salmonid Consumption and Prey Weight

Weights of salmonids consumed by smallmouth bass in Lower Granite Reservoir fluctuated seasonally. Larger salmonids were consumed in April and May when steelhead and yearling chinook abundance in the reservoir was highest. Smaller salmonids were consumed during July when subyearling chinook typically rear and migrate through the reservoir. Prey weights of salmonids were consistent between strata 1 (27.2 g) and 3 (26.8 g) in May, suggesting an even distribution of prey throughout the reservoir. The distribution of salmonid prey weights in July appeared to be nonrandom with considerably smaller prey consumed in strata 1 (9.7 g) and 2 (3.5 g) compared to stratum 3 (51.0 g). The lower prey weights in strata 1 and 2 are probably representative of the presence of subyearling chinook in the upper portion of the reservoir. Subyearling chinook rear in littoral areas of Lower Granite Reservoir until shoreline water temperatures exceeded 18° C (Curet 1994). Subyearling chinook rear in littoral habitats characterized by sand substrate and reduced water velocity; habitat located predominately in the upper portion of Lower Granite Reservoir. Knowledge of subyearling chinook habitat use and mean lengths and weights of salmonid prey suggest that majority of juvenile salmonids consumed during July 1995 in Lower Granite Reservoir were subyearling chinook.

Estimated Loss

Estimated losses of salmonids by smallmouth bass in Lower Granite Reservoir varied among months and strata indicating a complex interaction between predator and prey. Highest losses of salmonids to predation coincided with peaks of passage of steelhead and yearling and subyearling chinook at Lower Granite Dam during May and July. The highest losses of juvenile salmonids to predation in John Day Reservoir also coincided with peak abundance of juvenile salmonids in the reservoir (Rieman and Beamesderfer 1991).

Smolt out-migration through Lower Granite Reservoir typically occurs in the beginning of April and consists primarily of steelhead and yearling chinook. Conversely, subyearling chinook are present in the reservoir for an extended period when water temperatures are near annual maxima and spawning activity has subsided. Water temperatures during April in Lower Granite Reservoir are typically < 10° C, while smallmouth bass do not actively feed when water temperatures are < 15° C (Carlander 1977). As water temperatures rise, mature smallmouth bass initiate spawning activity. Suitable water temperatures for spawning (13 to 21° C reported by Carlander 1977; 12 to 25° C reported by Graham and Orth 1986) typically occur from mid-June to late July in Lower Granite Reservoir. Bennett et al. (1983) observed active spawning nests of smallmouth bass from mid-June to late July 1979 and 1980 in Little Goose Reservoir. Heidinger (1976) reported that consumption rates of male centrarchids are depressed during spawning season due to their nest guarding behavior. This is probably why consumption rates were lower in June and July.

Due to differences in the number and size differences of out-migrants among stocks, we believe that losses should be estimated for each stock of juvenile salmonids (steelhead and yearling and subyearling chinook). The influence of smallmouth bass predation on subyearling chinook in Lower Granite Reservoir is considerably higher than that on any other stock due to the timing and duration of subyearling chinook in the reservoir, their relatively low numbers, and their small size. Subyearling chinook can rear from 22 to 112 days within a particular reservoir (Miller and Sims 1984; Bennett et al. 1993a, 1993b; Curet 1994). Poe et al. (1991) related the increase in smallmouth bass predation that occurred during August in John Day Reservoir to the overlapped distributions of smallmouth bass and subyearling chinook within the littoral areas of the reservoir.

The estimated loss of juvenile salmonids in Lower Granite Reservoir (82,476 in 1994; 64,020 in 1995) is substantially less than that attributed to smallmouth bass predation in John Day Reservoir (243,000 for a population of 31,948 to 37,959 smallmouth bass > 200 mm; Rieman and Beamesderfer 1991). Our results agree with those of Rieman and Beamesderfer (1991) who showed higher predation by smallmouth bass on chinook stocks (2.5 million consumed) compared to steelhead stocks (148,000 consumed) out-migrating through John Day Reservoir. The relative influence of mortality due to predation by smallmouth bass in Lower Granite Reservoir was highest for subyearling chinook in 1995. Partitioning estimated losses among stocks indicates that smallmouth bass predation accounts for probably less than 0.02% of the reservoir mortality experienced by steelhead and yearling chinook, but may account for 7% of the reservoir mortality experienced by subyearling chinook in Lower Granite Reservoir. Water temperature appears to be the most important environmental factor influencing smallmouth bass consumption rates of salmonids. We have found that consumption rates of salmonids are relatively low during April and increase through July as water temperatures rise. Comparing reservoir conditions, in terms of flow, turbidity, and water temperature, between 1994 and 1995 suggested that salmonid consumption by smallmouth bass was 22% higher during a lower flow year. Reduced predation would probably result under more managed flow conditions during low flow years.

Flow in the Snake River was augmented from May to mid-July 1995 to potentially assist juvenile salmonids migrating downstream. An indirect benefit of flow augmentation may be the suppression of smallmouth bass consumption rates by decreased water temperatures and consequent reduction in losses of juvenile salmonids to predation. However, the infusion of cold water into Lower Granite Reservoir may inadvertently prolong the rearing period of subyearling chinook, thus increasing the length of the predation period by smallmouth bass.

Objective 2. To determine habitat use, fish species associations, and species overlap in shallow water habitat in Lower Granite Reservoir.

The influence of habitat factors on fish assemblages has been well documented in many small and medium sized streams (Leonard and Orth 1988; Lobb and Orth 1991; Chipps et al. 1994; Hawkes et al. 1986; Moyle and Vondracek 1985). Lobb and Orth (1991) reported that abiotic and biotic factors interact to determine the structure of fish assemblages in streams. Schlosser (1987) indicated that physical habitat structures, such as depth, water velocity, and substrate, influence species composition in small, warmwater streams in the Midwest. Similar observations were made by Dupont (1993) on the Pend Oreille River, Idaho. He found that physical habitat variables, such as water velocity, temperature, depth, substrate, and aquatic vegetation, affected the distribution and abundance of the fish community. Bain et al. (1988) reported similar results on the West River in southern Vermont where changes in depth, water velocity, substrate, and cover resulted in shifts in fish species composition.

Little is known about fish-habitat associations or factors affecting fish distribution and abundance in Lower Granite Reservoir and other lower Snake River reservoirs. The recent changes in operation of hydroelectric facilities and manipulations of reservoir water levels in the lower Snake River have underscored the need for a broader perspective at the community-level in studying fish-habitat associations in Lower Granite Reservoir. By studying these associations, we may develop a better understanding of effects of management alteration and, ultimately, determine factors affecting habitat, fish abundance, and distribution.

METHODS

Fish Collection

Lower Granite Reservoir was partitioned into 400-m sections, and 53 littoral sites were randomly selected for sampling in 1994 and 34 additional sites were sampled during spring 1995 (Figure 21). Nighttime electrofishing (Objective 1 - Methods) was used to sample randomly selected sites within Lower Granite Reservoir during summer (June - September) and fall (October - November) 1994 and spring (April - May) 1995 to assess relative abundance and distribution of fishes in littoral habitats.

Habitat Evaluation

Depth (m), bottom water temperature (° C), mean water velocity (m/s), mean substrate size (mm), slope (%), and biomass of aquatic macrophytes (g/m^2) were measured at each site sampled for fish. Water velocity, depth, and temperature were measured along two transects parallel to the shoreline at distances of 1.0 and 3.0 m. Three measurements were taken at each transect for a total of six measurements per sampling location. Water velocities were measured with a Swoffer Model 2100-A2 digital electronic current meter, depth profiles were measured with a single transducer recording echosounder, and water temperatures were measured with a YSI Model 54 dissolved oxygen and temperature meter. Slope was measured at the shoreline with a clinometer.

Ten substrate samples were collected with a Ponar dredge to determine mean substrate size at all sites sampled for fish. Sites that could not be sampled by dredge were sampled with a circular frame randomly tossed above the waterline at three locations per site and all boulders within the frame were measured. We assumed substrates below the surface at these sites were similar to those at shore. Substrate samples collected by dredge were oven-dried at 105° C for 72 hours and

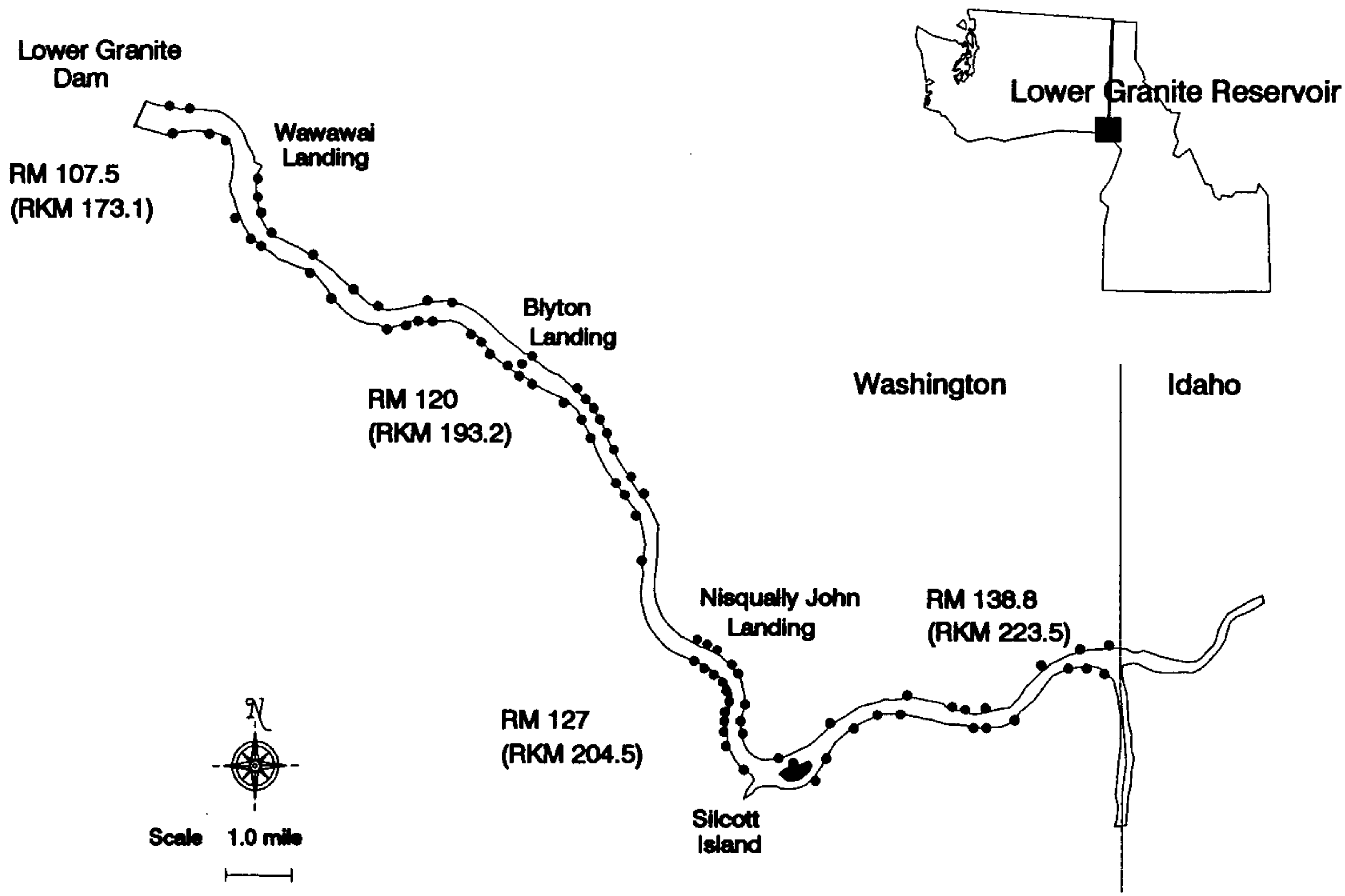

Figure 21. Specific locations sampled by electrofishing during summer (June - September) and fall (October - November) 1994 and spring (April - May) 1995 in Lower Granite Reservoir. RM indicates river mile, RKM indicates river kilometer, ● indicates sampling location.

gently depressed before sieving (because fine sediments usually cake). Substrates were sieved using standard sieve sizes and separated into size categories ranging from 18 to 50 mm (cobble/rubble), 2.1 to 17.9 mm (gravel), and sand (<2.0 mm) based on the modified Wentworth classification (Cummins 1962).

Snorkeling was used to assess the presence or absence of submerged aquatic macrophytes at all sites. At sites with macrophytes, a 0.5-m^2 frame was used to collect 12 samples per site and wet weight biomass (g/m^2) estimates were determined for each site. Slope was measured at the shoreline with a clinometer.

Multivariate Analysis

Depth, velocity, macrophyte biomass, water temperature, and substrate measurements were $\log(x+1)$ transformed to normalize the data as recommended by Gauch (1982) and Green (1979). Percent slope data were arc-sine transformed before statistical analysis to reduce heteroscedasticity (Green 1979; Sokal and Rohlf 1981). Mean CPUE for all fishes were calculated seasonally for each transect and CPUE data were transformed ($\log(x+1)$) prior to analysis. Site by species and site by habitat matrices for summer, fall, and spring were used in canonical correspondence analysis (CCA) using the program CANOCO (Ter Braak 1986). Canonical correspondence analysis identifies a habitat basis for species ordination by revealing patterns of variation in species composition expressed by the habitat variables (Copp 1991). Canonical correspondence analysis generates a biplot that illustrates the main patterns of variation in community composition accounted by the habitat variables, as well as the species distribution along each habitat variable (Ter Braak 1986). Ter Braak (1986) reported that the biplot generated by CCA provides a weighted least-squares approximation of the weighted averages of the species with respect to the habitat variables. The measure of goodness of fit (sum of all eigenvalues) expresses the percent variation of the weighted averages accounted by the biplot. In the biplot, the length of an arrow representing the habitat variable is equal to the rate of change in the weighted average and is a measure of how much the species distribution differs along that habitat variable (Ter Braak 1986; Copp 1991).

Discriminant analysis (Hair et al. 1995) was performed on classes of absence/presence or high/low abundance data for key species or species complexes. We used discriminant analysis to determine if a set of habitat variables could predict the absence/presence or high/low abundance of selected species or species complexes in Lower Granite Reservoir. Selected species included smallmouth bass, northern squawfish, chiselmouth *Acrocheilus alutaceus*, juvenile steelhead, and juvenile chinook salmon. Species complexes included *Pomoxis* spp. complex comprised of black and white crappie *Pomoxis annularis*, *Catostomus* spp. complex comprised of largescale *Catostomus macrocheilus* and bridgelip suckers *C. columbianus*, and *Lepomis* spp. complex comprised of pumpkinseed and bluegill. Cluster analysis (Ludwig and Reynolds 1988; BASICA) was performed on CPUE data matrices to distinguish transects with high abundances from transects with low abundances.

Analysis was restricted to juvenile, subadult, and adult fishes because young-of-the-year fishes often introduce significant sampling error in community analysis (Angermeir 1987). Anadromous fishes were not included in the summer analysis (June - September) as a result of sampling limitations set by the 1974 Endangered Species Act (ESA).

RESULTS

Fish Composition

A total of 14,392 fishes representing 20 species was sampled in 4,373 minutes of nighttime electrofishing (Table 6). Smallmouth bass was the most abundant

Table 6. Number of fishes collected by nighttime electrofishing in Lower Granite Reservoir during summer 1994, fall 1994, and spring 1995.

Species	Summer 1994	Fall 1994	Spring 1995	Total
Chiselmouth	119	72	645	836
Common carp	3	0	0	3
Bridgelip sucker	349	224	824	1,397
Largescale sucker	1,742	362	1,985	4,089
Sculpin	21	2	10	33
Brown bullhead	13	10	3	26
Yellow bullhead	59	1	4	64
Pumpkinseed	290	21	39	350
Bluegill	21	11	8	40
Peamouth	19	1	32	52
Smallmouth bass	3,440	210	1,809	5,459
Madtom	1	0	2	3
Steelhead[a]	0	648	113	761
Chinook salmon[a]	0	82	202	284
White crappie	37	1	444	482
Yellow perch	52	1	21	74
Black crappie	14	5	25	44
Northern squawfish	117	27	221	365
Mountain whitefish	2	0	25	27
Redside shiner	1	1	1	3
Total	6,300	1,679	6,413	14,392

[a] yearling and subyearling

species sampled and accounted for 37.9% of the total number of fishes (n=5,459). Largescale sucker was next in abundance and accounted for 28.0% (n=4,089) of the total number of fishes sampled. Other species that accounted for at least 5.0% of the total number of fishes sampled included bridgelip suckers (9.7%), chiselmouth (5.8%), and juvenile steelhead (5.3%).

Macrophytes

Twelve of the 53 sites randomly sampled each month from June through November had macrophyte development (Figure 22). All sites exhibiting macrophyte growth were characterized by substrates consisting primarily of sand (< 2.0 mm) with the exception of transects located at RM 113.1 (RKM 182.1) on the north shoreline and RM 120.0 (RKM 193.2) on the south shoreline. Macrophytes were first observed in late June and biomass peaked in August. Two species, *P. crispus* and *P. filiformis*, were collected throughout Lower Granite Reservoir during 1994. *Potamogeton filiformis* was found predominately in upstream transects (RM 125 - RM 138.6, RKM 201.3 - 223.1) located at RMs 131.8 (RKM 212.2), 134.3 (RKM 216.2), and 134.6 (RKM 216.7) and downstream at RM 115.8 (RKM 186.4) in Lower Granite Reservoir.

During July the highest mean macrophyte density (109.9 g/m^2) was observed at RM 115.8 (RKM 186.4), followed by 106.6 g/m^2 at RM 110.6 (RKM 178.1) and 84.7 g/m^2 at RM 113.1 (RKM 182.1). Macrophyte densities in the upstream sections of Lower Granite were lower and ranged from 33.6 to 40.9 g/m^2 (Figure 22). Highest densities during August were observed at RM 110.6 (RKM 178.1; 213.2 g/m^2) followed by RM 115.8 (RKM 186.4; 167.7 g/m^2). Macrophyte densities at RM 131.8 (RKM 212.2), 134.3 (RKM 216.2), and 134.6 (RKM 216.7) ranged from 55.0 to 61.9 g/m^2. During September macrophyte densities at all transects

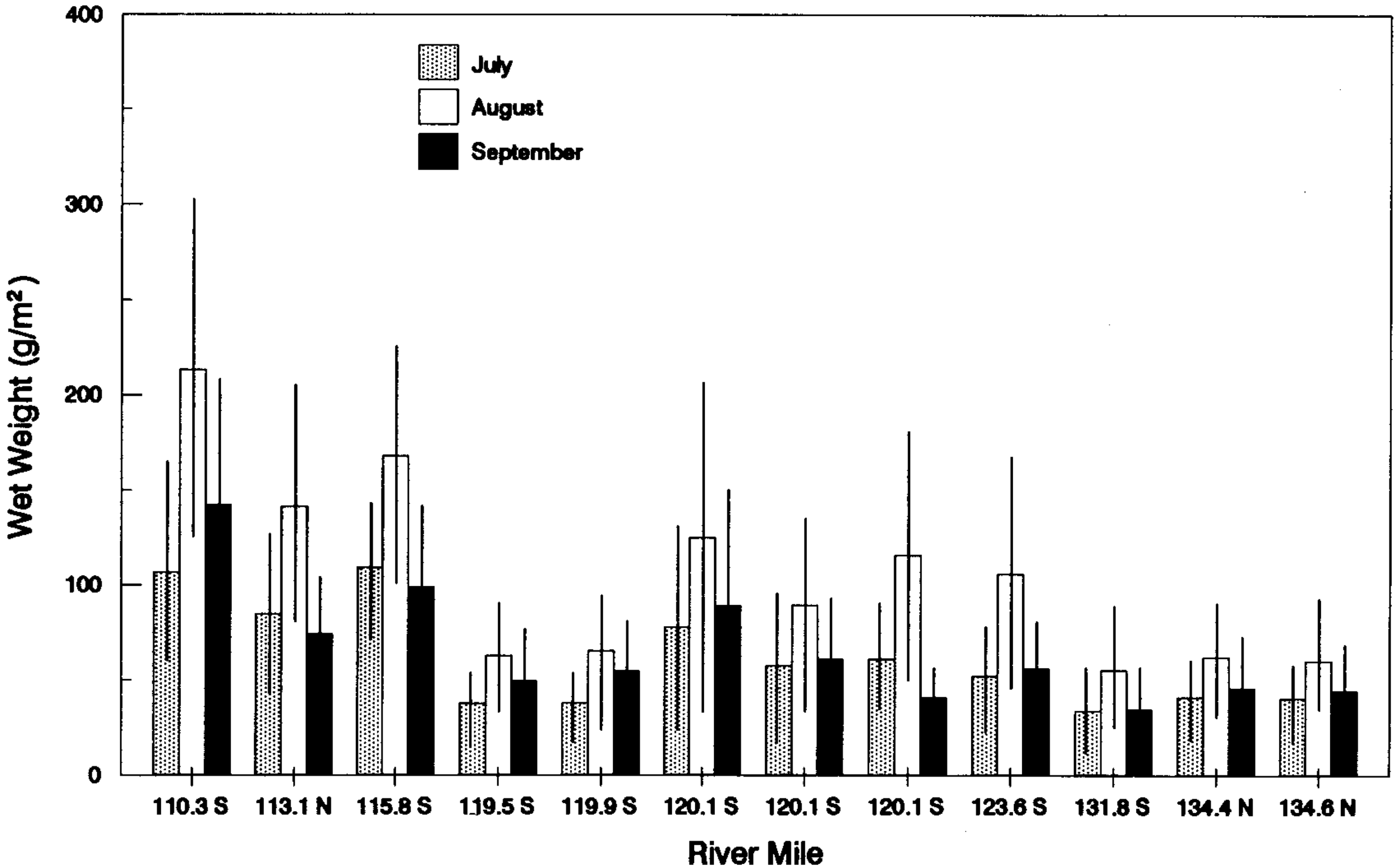

Figure 22. Wet weight biomass (g/m^2) of aquatic macrophytes collected during July through September 1994 along north (N) and south (S) shorelines in Lower Granite Reservoir. Vertical bars represent 95% confidence intervals.

decreased, and by October and November 1994 macrophytes were decomposed. No macrophytes were observed during spring 1995 (April - May) sampling.

Velocity

Mean bottom water velocities recorded during summer (June - September) ranged from 0.0 to 0.015 m/s. Daily mean velocities were variable among locations and time of sampling (Figure 23). Highest mean velocities were recorded during summer 1994 at RMs 108.7 (RKM 175.0; 0.012 m/s), 109.2 (RKM 175.8; 0.014 m/s), and 109.4 (RKM 176.1; 0.015 m/s), approximately 1.2 to 3.2 river kilometers upstream of Lower Granite Dam. Bottom velocities were elevated above adjacent sections at RM 119.6 (RKM 192.6; 0.013 m/s) on the main channel side of Centennial Island during the summer. No measurable velocities were recorded during fall (October - November) at all river miles, except at RMs 138.6 (RKM 223.1) and 138.8 (RKM 223.5). Highest mean velocities during spring 1995 occurred in the upstream section of Lower Granite Reservoir. Mean velocities ranged from 0.0 to 0.091 m/s.

Temperature

Mean water temperatures recorded at sites throughout Lower Granite Reservoir ranged from 6.5 to 23.9° C during 1994 (Figure 24). The highest recorded temperatures occurred during August. In July, the widest variation in recorded temperatures was 5.3° C, whereas that for June was 4.8° C. Bottom temperatures ranged from 6.5 to 9.0° C during November 1994 and those from April to May 1995 ranged from 9.6 to 11.7° C.

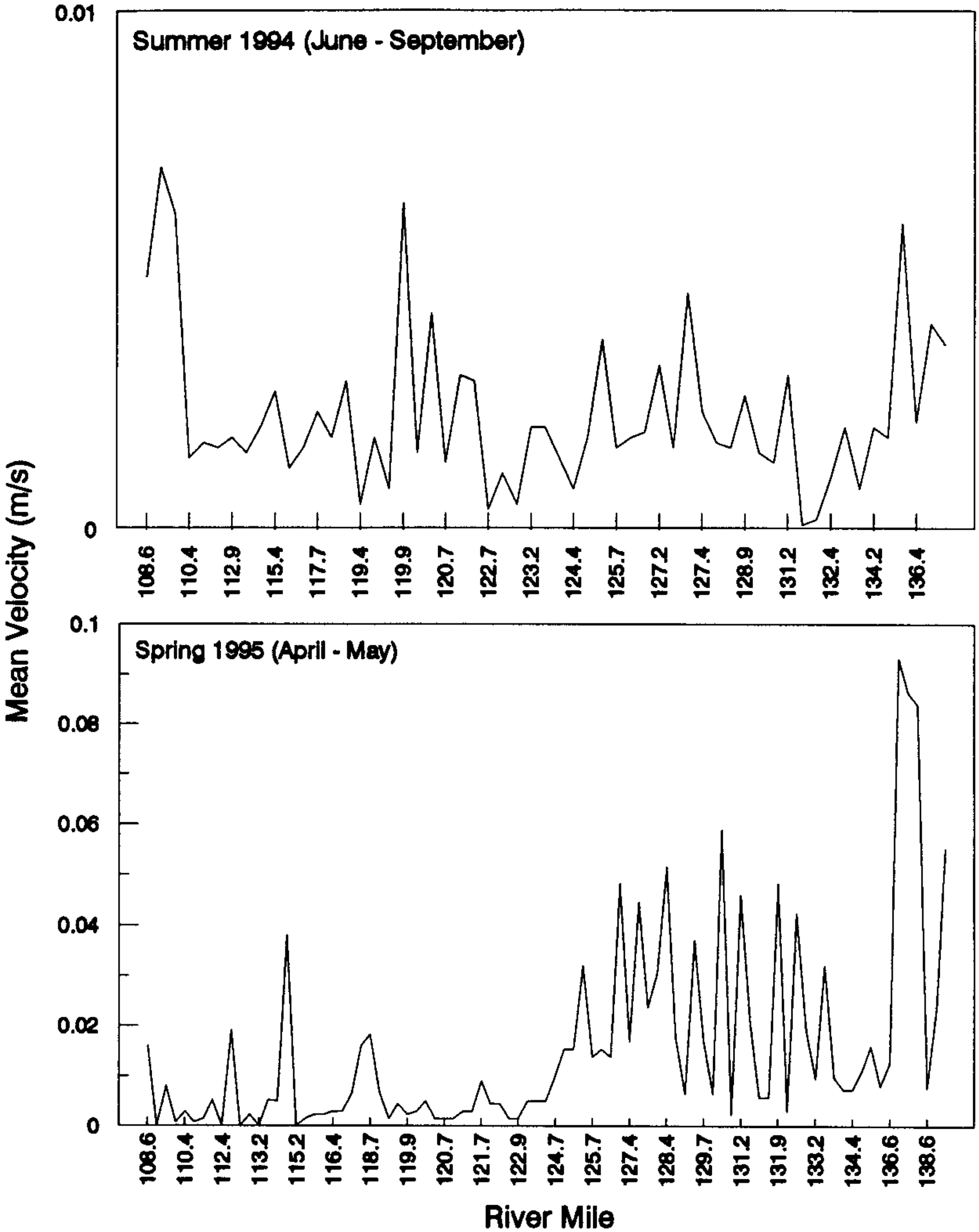

Figure 23. Bottom velocity (m/s) at locations sampled by electrofishing during summer (June - September) 1994 and spring (April - May) 1995 in Lower Granite Reservoir. Note that different scales are used for each plot.

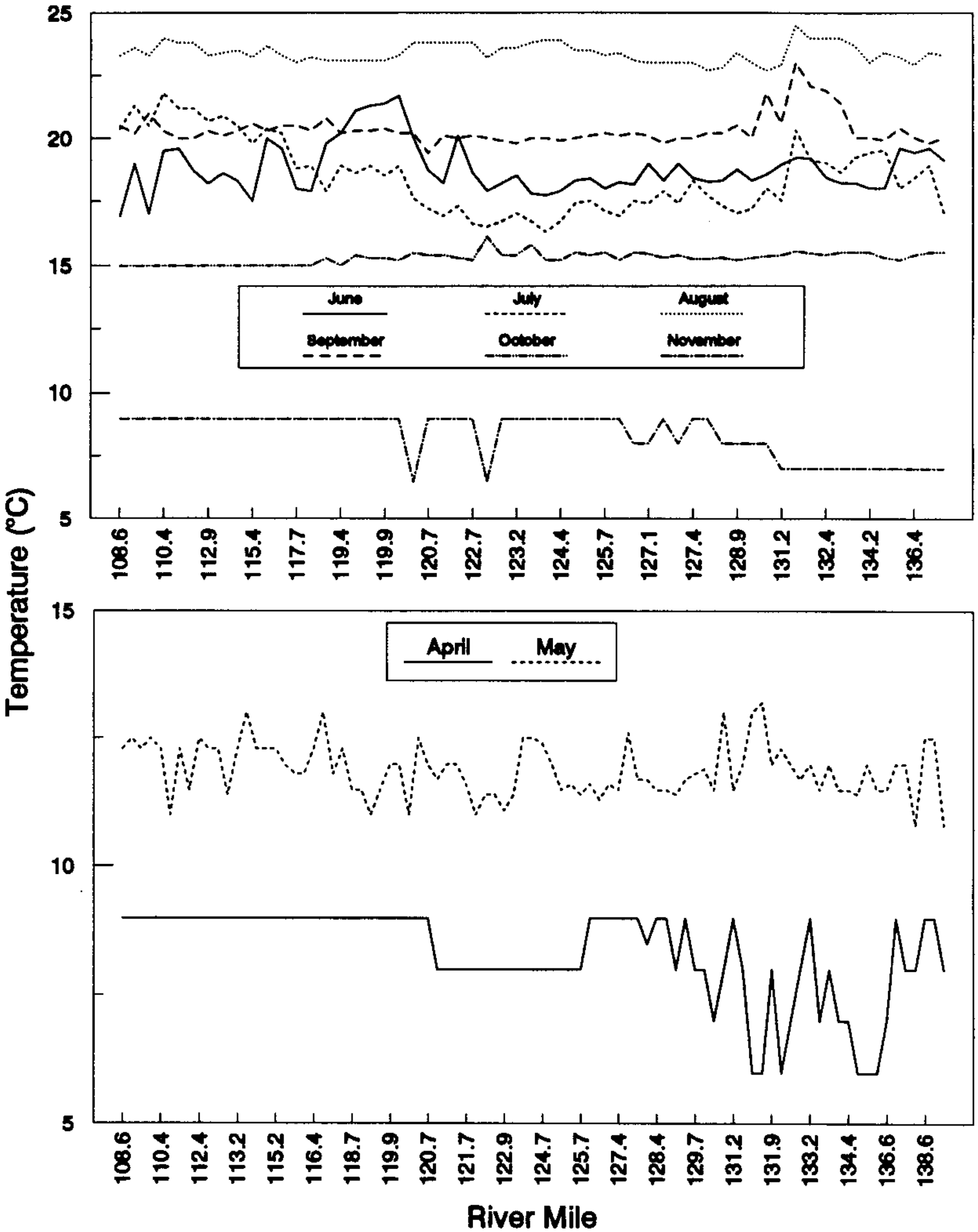

Figure 24. Mean water temperature (°C) at locations sampled by electrofishing during summer (June - September) and fall (October - November) 1994 and spring (April - May) 1995 in Lower Granite Reservoir. Note that different scales are used for each plot.

Substrates

Four types of substrates were identified along the shoreline in Lower Granite Reservoir during 1994 and 1995 (Appendix Table 2). Cliff (> 1000 mm) substrate was found predominantly on the south shoreline, riprap (250 - 400 mm) on the north shoreline, sand (< 2.0 mm) in the upper reservoir, and cobble/rubble (2.0 - 250 mm) throughout the reservoir.

Depth

Depth measurements taken at 1.0 and 3.0 m from the shoreline revealed substantial differences among sites (Appendix Table 2). Depths associated with cliff habitats ranged from 0.7 to 6.7 m. The shallowest depths, from 0.30 to 0.7 m, coincided with sand substrates (< 2.0 mm). Depths at areas covered by cobble/talus ranged from 0.5 to 1.4 m, whereas depths at riprap (250 - 400 mm) areas ranged from 0.5 to 2.6 m.

Slope

The mean slope of shoreline measured throughout Lower Granite Reservoir was 21.6%. Cliff habitats had slopes ranging from 10% to 91.0% (Appendix Table 2). Mean slopes for riprap habitats ranged from 15.0% to 32.0%, mean slopes for cobble/rubble habitats ranged from 8.0% to 25.0%, and the mean slopes for sand habitats were approximately 7.9%.

Fish-Habitat Ordination

Intraset correlations for data collected during the summer 1994 electrofishing (June - September) effort revealed that the predominant variables for predicting microhabitat use along canonical axis 1 (CCA 1) were mean substrates size (-0.73), macrophytes (0.46), and depth (-0.62; Table 7). The predominate variable along

Table 7. Intraset correlations of habitat variables with the first four axes of canonical correspondence analysis (CCA) for summer (June - September) 1994, fall (October - November) 1994, and spring (April - May) 1995.

		Intraset correlations axis			
Season	Variable	1	2	3	4
Summer 1994	Velocity	-0.13	-0.03	-0.12	0.09
	Temperature	0.39	-0.43	0.05	-0.03
	Slope	-0.35	0.03	0.24	-0.20
	Macrophytes	0.46	0.15	0.15	0.28
	Depth	-0.62	0.11	0.13	-0.16
	Substrates	-0.73	-0.13	0.02	-0.09
Fall 1994	Velocity	0.32	0.11	0.25	0.02
	Temperature	-0.07	-0.24	0.05	-0.01
	Slope	-0.03	-0.17	0.26	0.12
	Depth	0.08	-0.47	0.09	0.15
	Substrates	0.10	-0.46	0.23	-0.06
Spring 1995	Velocity	-0.07	0.35	0.29	-0.07
	Temperature	0.02	-0.37	0.13	-0.19
	Slope	-0.25	-0.14	0.20	0.21
	Depth	-0.37	-0.09	0.25	0.16
	Substrates	-0.68	-0.02	0.06	0.02

canonical axis 2 (CCA 2) was water temperature (-0.43). The species-habitat correlation on the first axis (CCA 1) was high (0.79), while the correlations of other axes were lower (Table 8). Habitat variables in conjunction with species points accounted for 74.6% (CCA1) and 89.5% (CCA 2) of the variation in the weighted averages of the 16 species and six habitat variables measured during summer 1994 (Table 9). Eigenvalues for the summer 1994 effort indicated that the habitat gradients were quite short (Table 10).

The biplot of canonical correspondence analysis of fish-habitat associations for the summer 1994 effort revealed that the majority of species was ordinated to the right of center, indicating a selection of habitats with macrophytes, shallow depths, decreased slopes, and small substrates (Figure 25; Appendix Table 3). Species that demonstrated a strong preference for these habitats included northern squawfish, chiselmouth, *Pomoxis* spp., and yellow perch. Smallmouth bass and bridgelip sucker exhibited wide habitat use with high abundances generally found in areas with larger substrates, deeper depths, and increased slopes. Largescale sucker, which was ordinated near the origins of CCA 1 and CCA 2, showed little habitat preference. Although *Lepomis* spp. illustrated a wide range of habitat use, abundance was generally higher at habitats with elevated temperatures, macrophytes, small substrates, decreased depths, and decreased slopes. Northern squawfish and smallmouth bass selected different habitat types and slightly overlapped in habitat use.

Intraset correlations for fall 1994 (October - November) revealed that the predominant variable describing CCA 1 was water temperature. Depth and substrate described CCA 2 (Table 7). The species-habitat correlation for CCA 1 was 0.78 and correlations of the other axes were lower (Table 8). Habitat variables in conjunction with the species accounted for 49.4% (CCA 1) and 83.1% (CCA 2) of the variation in the weighted averages of the 17 species and five habitat variables

Table 8. Species-habitat correlations for the first four axes of canonical correspondence analysis for summer (June - September) 1994, fall (October - November) 1994, and spring (April - May) 1995 in Lower Granite Reservoir.

	Axis			
Season	1	2	3	4
Summer 1994	0.789	0.574	0.377	0.395
Fall 1994	0.781	0.624	0.438	0.262
Spring 1995	0.693	0.504	0.427	0.323

Table 9. Species-habitat relation (% variation explained) for the first four axes of canonical correspondence analysis for summer (June - September) 1994, fall (October - November) 1994, and spring (April - May) 1995 in Lower Granite Reservoir.

	Axis			
Season	1	2	3	4
Summer 1994	74.6	89.5	93.7	97.2
Fall 1994	49.4	83.1	93.4	97.4
Spring 1995	65.8	84.4	92.0	97.2

Table 10. Eigenvalues for the first four axes of canonical correspondence analysis for summer (June - September) 1994, fall (October - November) 1994, and spring (April - May) 1995 in Lower Granite Reservoir.

Season	Axis				Sum of Eigenvalues
	1	2	3	4	
Summer 1994	0.195	0.039	0.001	0.009	0.261
Fall 1994	0.126	0.086	0.026	0.010	0.256
Spring 1995	0.125	0.035	0.014	0.010	0.189

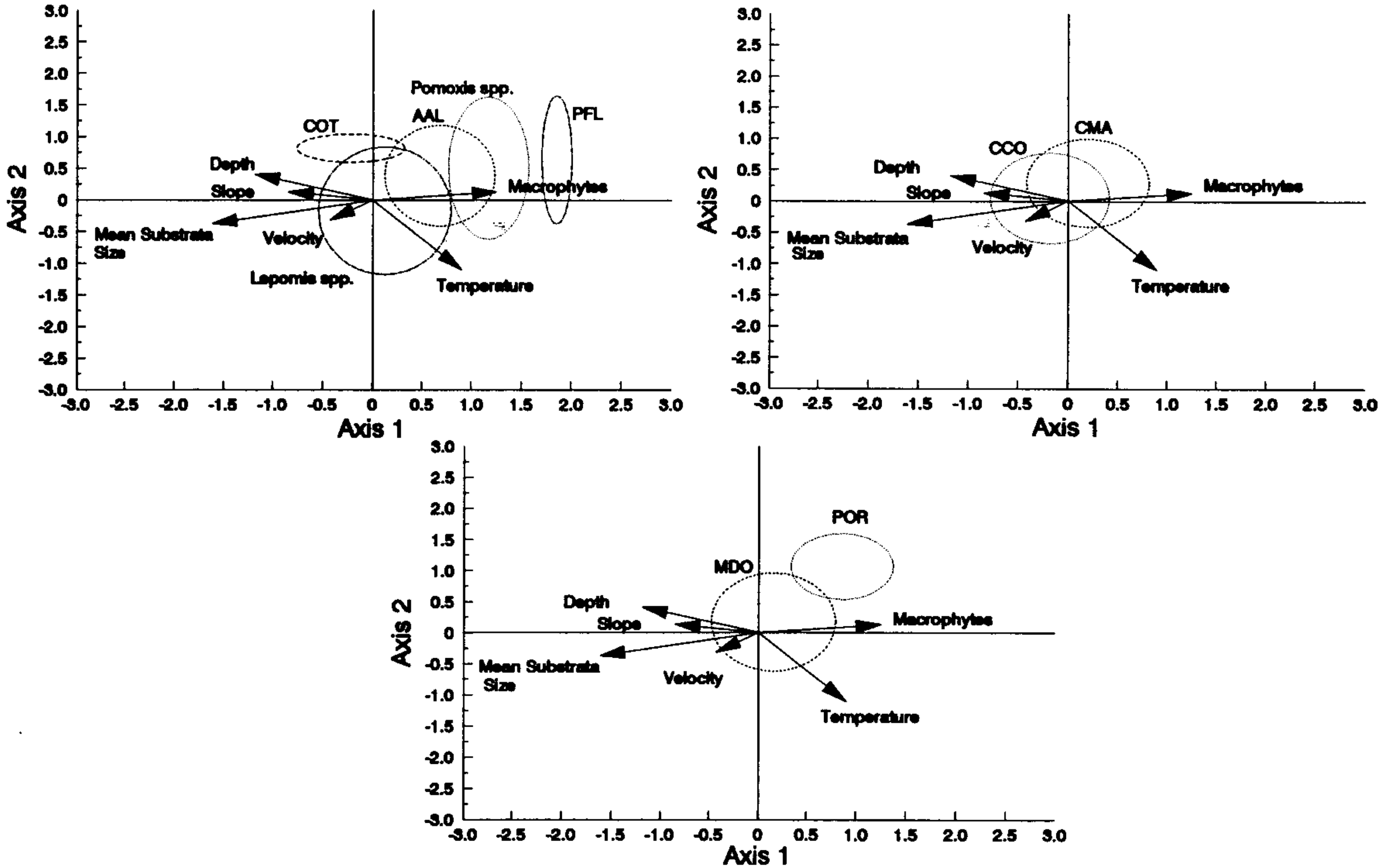

Figure 25. Ordination diagram based on canonical correspondence analysis of fish abundance (catch per unit effort) collected by electrofishing at 53 locations during summer (June - September) 1994 in Lower Granite Reservoir with respect to six habitat variables (arrows). Areas of habitat use by individual species are encompassed by circles. Species codes are listed in Appendix Table 3.

(Table 9). Eigenvalues for the fall (0.256) were lower than those for the summer (0.261) indicating the habitat variables were collected over shorter gradients (Table 10).

The biplot of canonical correspondence analysis of fish-habitat associations for fall 1994 revealed that yellow perch, *Pomoxis* spp., northern squawfish, and largescale sucker were ordinated in the upper middle of the biplot (Figure 26). Positioning in this region of the biplot indicated a preference for shallow depths, decreased slopes, and small substrates. Species showing a strong preference for this region included yellow perch and *Pomoxis* spp., while northern squawfish and bluegill exhibited similar but broader preferences. Northern squawfish and smallmouth bass exhibited different but overlapping habitat use during fall 1994. Juvenile chinook salmon, juvenile steelhead, smallmouth bass, and largescale sucker were located near the origin of the biplot indicating wide distribution in varied habitats (Figure 26). Species located in the lower left corner of the biplot preferred habitats with increased water temperatures, slightly larger substrates, and increased depths.

During spring (April - May) 1995, the intraset correlations revealed that the predominant variable describing CCA 1 was mean substrate size (-0.68), while CCA 2 was described by velocity (0.35) and water temperature (-0.37; Table 7). The species-habitat correlation for CCA 1 during spring was lower (0.69) than those of summer (0.789) and fall (0.781; Table 8). Approximately 65.8% (CCA 1) and 84% (CCA 2) of the species-habitat variation was attributed to the first two axes (Table 9) and eigenvalues for spring 1995 (0.189) were lower than those of summer (0.261) and fall (0.256) 1994 (Table 10).

The canonical correspondence biplot for spring 1995 revealed similar habitat use trends as those for fall 1994 (Figures 26 and 27). A majority of the species selected habitats characterized by small substrates (<2.0 mm) and decreased slopes

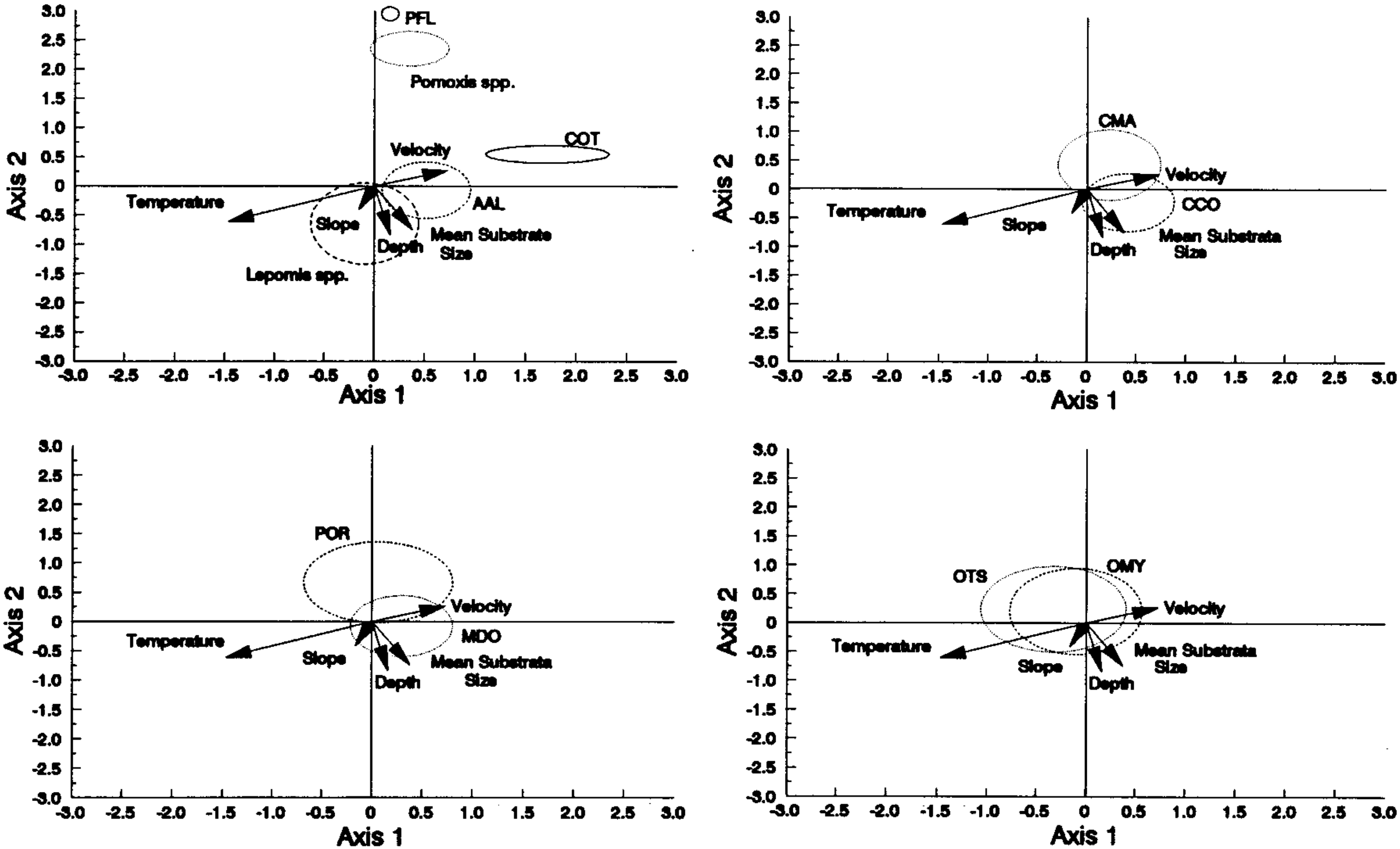

Figure 26. Ordination diagram based on canonical correspondence analysis of fish abundance (catch per unit effort) collected by electrofishing at 53 locations during fall (October - November) 1994 in Lower Granite Reservoir with respect to five habitat variables (arrows). Areas of habitat use by individual species are encompassed by circles. Species codes are listed in Appendix Table 3.

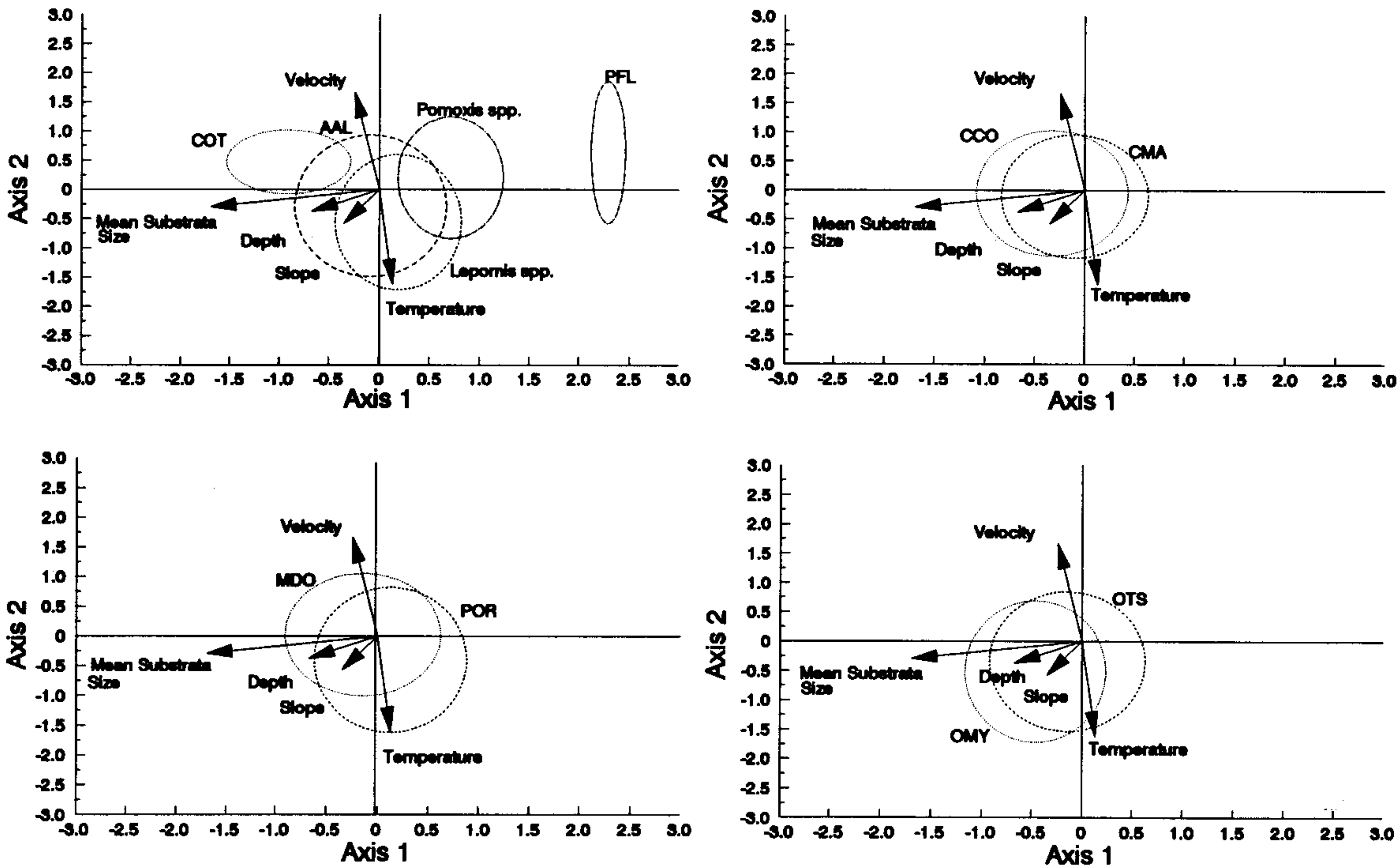

Figure 27. Ordination diagram based on canonical correspondence analysis of fish abundance (catch per unit effort) collected by electrofishing at 87 locations during spring (April - May) 1995 in Lower Granite Reservoir with respect to five habitat variables (arrows). Areas of habitat use by individual species are encompassed by circles. Species codes are listed in Appendix Table 3.

and depths (Figure 27). Sculpin selected habitats with increased velocities, lower water temperatures, and larger substrates. Juvenile chinook salmon and smallmouth bass were ordinated near the center of the biplot indicating a wide selection of habitats (Figure 27).

Discriminant Analysis

Linear discriminant analysis indicated that habitats where *Lepomis* spp., *Pomoxis* spp., and *Ictalurus* spp. were consistently absent were more often correctly identified than habitats where these complexes were present during summer 1994 (Table 11; Appendix Table 4). Error rates for the correct classification of absence for these species complexes ranged from 35.7% for *Ictalurus* spp. to 25.7% for *Lepomis* spp. and *Pomoxis* spp. Habitats with high abundances (CPUE >1.1) for *Catostomus* spp. were correctly identified 73.3% of the time. Error rates for correct classification of habitats where chiselmouth and northern squawfish were absent ranged from 42.9% to 32.0%. Both the absence and presence of northern squawfish were correctly identified more than 66% of the time. Habitats with high abundances (CPUE >1.0) of smallmouth bass were more often correctly identified (72.7%) than habitats with low abundances. The standardized canonical discriminant function coefficients for key species and species complexes were recorded in Appendix Table 4 for summer (June - September) and fall (October - November) 1994 and spring (April - May) 1995.

Stepwise discriminant analysis performed on habitat variables determined which variables were significant in predicting the absence/presence or high/low abundance of selected species and species complexes in Lower Granite Reservoir during summer 1994 (Table 12). Of the six habitat variables measured, mean size of substrate was significant ($P<0.01$) in determining the high/low abundance of smallmouth bass. Areas in which smallmouth bass were abundant (CPUE >1.0)

Table 11. Discriminant analysis classification matrix (% correctly classified) based on absence/presence or high/low abundance of key species or species complexes at location in Lower Granite Reservoir during summer (June - September) 1994, fall (October - November) 1994, and spring (April - May) 1995.

Species/	Summer 1994		Fall 1994		Spring 1995	
Species complexes	1[a]	2[b]	1	2	1	2
Catostomus spp.						
High abundance	73.3	26.6	60.0	40.0	71.8	28.1
Low abundance	45.9	54.0	58.9	41.1	30.9	69.1
Pomoxis spp.						
Absence	74.3	25.7	-	-	68.7	31.3
Presence	47.1	52.9	-	-	30.7	69.4
Lepomis spp.						
Absence	74.3	25.7	-	-	52.5	47.7
Presence	47.1	52.9	-	-	42.9	57.1
Ictalurus spp.						
Absence	64.3	35.7	-	-	-	-
Presence	50.0	50.0	-	-	-	-
Chiselmouth						
Absence	57.1	42.9	58.8	41.0	38.9	61.1
Presence	58.1	41.9	21.4	78.6	34.8	65.2
Northern squawfish						
Absence	68.0	32.0	64.9	35.1	67.7	32.3
Presence	33.3	66.7	52.9	47.1	41.1	58.9
Smallmouth bass						
High abundance	72.7	27.3	63.2	36.8	50.0	50.0
Low abundance	46.7	53.3	40.0	60.0	45.1	54.9
Steelhead trout						
Absence	-	-	57.7	42.3	54.4	45.7
Presence	-	-	25.0	75.0	39.0	61.0
Chinook salmon						
Absence	-	-	73.3	26.7	57.1	42.9
Presence	-	-	25.0	75.0	51.1	48.9

[a] 1 = class 1
[b] 2 = class 2

Table 12. Significant habitat variables in stepwise discriminant analysis of absence/presence or high/low abundance of key species and species complexes during summer (June - September) 1994, fall (October - November) 1994, and spring (April - May) 1995 in Lower Granite Reservoir.

Species/Species complexes	Summer 1994	Fall 1994	Spring 1995
Chinook salmon[a]	-	Temperature (<12.8°C)** Depth (<2.5 m)**	None
Steelhead[a]	-	Temperature (<13.0°C)**	None
Chiselmouth	None	Substrates (>50.0 mm)*	None
Northern squawfish	Substrates (<2.0 mm)** Depth (<1.6 m)*	None	None
Catostomus spp.	Substrates (>50.0 mm)**	None	Ddepth (<1.5 m)* Substrates (<2.0 mm)*
Ictalurus spp.	None	-	
Lepomis spp.	Depth (<1.5 m)**	None	None
Pomoxis spp.	Depth (<1.5 m)**	None	Substrates (<2.0 mm)** Temperature (>12.0°C)**
Smallmouth bass	Substrates (>250.0 mm)**	Temperature (>13.2°C)*	None

[a] juvenile and subyearlings; * - significant at 0.05; ** - significant at 0.01; - not analyzed by discriminant analysis; none - no habitat variables were significant at 0.05 or 0.01.

generally had substrates > 250.0 mm. Absence/presence of northern squawfish was determined by mean size of substrate (<2.0 mm) and shallow depths (P<0.05). No variables were significant (P<0.05) in determining the absence/presence of chiselmouth and *Ictalurus* spp. during summer 1994 in Lower Granite Reservoir. Depth (<1.54 m) was a significant (P<0.05) variable in determining the absence/presence of *Lepomis* spp. and *Pomoxis* spp. Additionally, depth was significant (P<0.01) in determining the high/low abundance of *Catostomus* spp.

During fall 1994, correct classification into absence/presence or high/low abundance for selected species or species complexes ranged between 21.4% and 78.6% (Table 11). Habitats where juvenile chinook salmon were absence/presence were more correctly identified than other selected species (73.3% and 75.0%). Correct classification of habitats without chiselmouth and juvenile steelhead was low (Table 11). Correct classification for the presence of chiselmouth was high (78.6%), as was the presence of juvenile steelhead (75.0%). Habitats with high/low abundances of smallmouth bass (CPUE>1.0) and low abundances of *Catostomus* spp. (CPUE>1.1) were correctly classified 63.2% and 60.0% of the time. Northern squawfish absence was correctly classified 64.9% of the time.

Stepwise discriminant analysis of habitat variables indicated water temperature was the most significant (P<0.05) habitat variable determining the absence/presence or high/low abundance of smallmouth bass and juvenile steelhead during fall 1994 (October - November) in Lower Granite Reservoir (Table 12). Water temperature and depth were the two more significant habitat variables determining the absence/presence of juvenile chinook salmon (P<0.05). Substrate was the most important variable in determining presence/absence of chiselmouth.

Correct classification of absence/presence or high/low abundance for selected species and species complexes was high during spring 1995; error rates ranged from 28.1% to 61.1% (Table 11). Discriminant analysis indicated that correct classification for smallmouth bass, *Lepomis* spp., and juvenile chinook salmon was low. Habitats high and low in abundance of *Catostomus* spp. were correctly identified 71.8% and 69.1%. The error rate for correct classification of habitats without and with northern squawfish was 32.2% and 41.1%. Correct classification of habitats with chiselmouth occurred 65.2% of the time. Absence and presence of *Pomoxis* spp. occurred 68.7% and 69.4% of the time.

Stepwise discriminant analysis of habitat variables indicated mean substrate size and water temperature were significant variables ($P < 0.05$) when determining the absence/presence of *Pomoxis* spp. and high/low abundance of *Catostomus* spp. during spring 1995 (Table 12). Stepwise discriminant analysis of habitat variables for northern squawfish, chiselmouth, juvenile chinook salmon, juvenile steelhead, smallmouth bass, and *Lepomis* spp. indicated none of the variables sampled was significant during spring 1995.

DISCUSSION

Canonical Correspondence Analysis

Ter Braak (1986) reported that canonical correspondence analysis provides a description of species-habitat relationships by assuming a response model that is common to all species. In this model, Ter Braak (1986) assumed that a single set of underlying habitat variables exist and all species respond to these variables. The advantage of canonical correspondence analysis over other techniques is that it focuses on the relations among species and measured habitat variables and provides an automated interpretation of the ordination axes (Ter Braak 1986). The strength of canonical correspondence analysis is derived from its relation to maximum likelihood Gaussian ordination.

Examination of the eigenvalues for summer (June - September) and fall (October - November) 1994 and spring (April - May) 1995 indicate the habitat variables were measured along a relatively narrow range of conditions. Thus, the occurrence of a species may simply increase or decrease monotonically along the measured habitat variables. Ter Braak (1986) reported that in cases where species-habitat relationships are monotone representative results can be expected, however, care is required for interpretation of the ordination biplots. If additional conditions were violated, species located near the center of the ordination biplot may have their optima there, but the location may be unrelated to the axes. Species-habitat correlations for summer and fall 1994 and spring 1995 were high, thus indicating species and habitat variables were related. As a result, canonical correspondence analysis appears to work well for these data.

Fish-Habitat Association

Substrate, depth, water temperature, and macrophytes were significant in determining the absence/presence and high/low abundance of selected species and species complexes in Lower Granite Reservoir during summer and fall 1994 and spring 1995. Similar results were found by Dupont (1993) on the Pend Oreille River in northwestern Idaho. He found that habitat types were determined by velocities, depth, substrate, vegetation, and distance from the shore. This study and Dupont (1993) differ from findings in warmwater streams (Meffe and Sheldon 1988; Bain et al. 1988; Lobb and Orth 1991) where habitat types were determined by depth and velocities. Unlike large run-of-river reservoirs like Lower Granite Reservoir and Pend Oreille River, habitat in warmwater streams generally consists of riffles, runs, and pools. Lower Granite Reservoir lacks the riffle-pool characteristics of streams and is characterized by wide channel width, deep depths (mean depth 16.6 m), lack of shallow water areas (~8%), and modified shoreline habitat through the placement of riprap.

Smallmouth bass, largescale suckers, and bridgelip suckers were the more abundant fishes sampled in Lower Granite Reservoir during summer and fall 1994 and spring 1995 (75.6%). Smallmouth bass selected habitats with larger substrates (>250.0 mm), deeper depths, and increased slopes (>20 degree gradient) over areas with smaller substrates (<2.0 mm), macrophytes, and shallow depths (<2.0 m). These findings agree with Leonard and Orth (1988), Todd and Rabeni (1989), Rankin (1986), and Probst et al. (1984) who indicated that presence of rocky substrates is a key element for smallmouth bass habitat. Smallmouth bass tend to be absent in areas composed of silt and sand substrates (Rankin 1986; Todd and Rabeni 1989; Lyons 1991). Habitat use by smallmouth bass in Lower Granite Reservoir corroborate findings from Scott and Crossman (1973) who reported that smallmouth bass are usually found around rock shoals and talus slopes and use deeper waters during summer.

Bridgelip and largescale suckers occupied different habitat types in Lower Granite Reservoir. Bridgelip sucker generally selected larger substrates (>50.0 mm) with increased slopes and depths during summer and fall 1994 and spring 1995. Abundances of bridgelip suckers at sites with larger substrates may be related to their morphological adaptations for feeding. Carl et al. (1967) suggested that cartilaginous edges of the jaws of suckers may be used for scraping algae from hard substrates. Largescale sucker, which were orientated near the origin of the biplots for all seasons, showed little preference for or against any particular habitat type, thus indicating they are habitat generalists.

Shallow water areas comprised approximately 10% of the surface area of Lower Granite Reservoir (Bennett and Shrier 1986). Substrates in these areas generally consist of small particles (<2.0 mm) with few rocks and boulders and patches of aquatic macrophytes. The importance of shallow water areas for fishes has been demonstrated by this research, as a majority of species we sampled selected shallow waters. Selection of shallow, vegetated areas with small substrates (<2.0 mm) by northern squawfish in Lower Granite Reservoir differs from their habitat selection in other river systems. Dupont (1993) reported that northern squawfish in the Pend Oreille River, Idaho, selected rocky shorelines with deeper depths and higher velocities. Northern squawfish selecting habitats with smaller substrates (<2.0 mm) in Lower Granite Reservoir may be related to interspecific associations with other species. Generally, habitats with large angular substrates (riprap) and deeper depths (>2.0 m) were selected by smallmouth bass, and CPUE in these areas often exceeded 1.0 fish/minute. The presence of smallmouth bass at these habitats may be associated with northern squawfish being collected in higher abundance in habitats with smaller substrates. Schoener (1974) and Werner et al. (1977) indicated that the more abundant species generally do not overlap in habitat use to reduce the potential for competition (Schoener 1974). Dupont (1993) reported that the three more abundant fishes in the Pend Oreille River, such as northern squawfish, yellow perch, and peamouth, exhibited differences in habitat selection that may have been related to a strategy to occupy habitats that reduce competition among the species.

Although northern squawfish had low abundances (2.5%; n=365) compared to smallmouth bass (37.9%; n=5,459) in areas we sampled, reduction of competition or predation may explain why northern squawfish selected shallow water habitat. Werner et al. (1977) suggested that predation on small size classes may result in habitat segregation. Pollard (H. Pollard, Idaho Department of Fish and Game, Lewiston, ID, personal communication) observed that northern squawfish abundance in Anderson Ranch Reservoir decreased after smallmouth bass were introduced. Pollard observed similar responses in Brownlee Reservoir where he found that habitats with high abundances of northern squawfish were void of squawfish after introductions of smallmouth bass. A majority of the northern squawfish collected in our study ranged from 120 to 250 mm, while smallmouth bass ranged from 100 to 520 mm. Anglea (S.M. Anglea, Department of Fish and Wildlife, University of Idaho, Moscow, unpublished data) indicated that smallmouth bass > 175 mm were abundant in Lower Granite Reservoir with a population estimate of approximately 21,000 individuals. Indirect population estimates of northern squawfish > 250 mm by Chandler (1993) and Bennett et al. (1993b) suggested that between 7,500 and 15,000 squawfish inhabit Lower Granite Reservoir.

Shallow water areas may be preferred by juvenile or subadult northern squawfish. Previous studies (Bennett et al. 1991, 1993a, 1993b, 1995a, 1995b) indicated sites preferred by juvenile and subadult northern squawfish during this study generally had high abundances of larval fishes; many of these fishes were northern squawfish or cyprinids. Scott and Crossman (1973) reported that young northern squawfish generally inhabit onshore waters during summer months and feed on surface insects before moving offshore in fall.

Chiselmouth have a cartilaginous sheath for specialized feeding habits (Scott and Crossman 1973). We expected chiselmouth to select habitats with larger substrates (>2.0 mm), although during summer chiselmouth selected habitats with smaller substrates (<2.0 mm) and aquatic vegetation. Selection of these habitats suggests that juvenile and subadult chiselmouth may use these areas for rearing and feeding before moving offshore in the fall. During summer, chiselmouth ranged in length from 100 to 150 mm. These chiselmouths may be less specialized in their feeding habits and may depend on drift for insects. Davis (M. Davis, Department of Fish and Wildlife, University of Idaho, Moscow, ID, unpublished data) indicated that drift of aquatic insects occurred in mid-water columns in the upstream portions of Lower Granite Reservoir. Scott and Crossman (1973) reported that young chiselmouth (20 to 100 mm) feed largely on surface insects. During spring 1995, chiselmouth selected habitats with larger substrates (>50.0 mm) and increased velocity. Chiselmouth collected in the spring were larger in size (>250 mm) indicating that they may have more specialized feeding habits.

Pomoxis spp., pumpkinseed, and yellow perch preferred habitats consisting of small substrates (<2.0 mm), increased water temperatures, and aquatic macrophytes. Our findings agree with those of Dupont (1993) who reported that yellow perch and black crappie were collected in higher abundance in vegetated areas, shallower waters, small substrate, and lower velocities in the Pend Oreille River. Although chi-square analysis by Dupont (1993) indicated yellow perch selected these types of habitats, he reported that they displayed habitat generalist characteristics. We observed similar results in Lower Granite Reservoir.

Pumpkinseeds generally selected sites with shallow depths (<2.0 m), small substrates (<2.0 mm), and aquatic vegetation. Exceptions were in the downstream portion of Lower Granite Reservoir (RMs 110.9 and 111.2; RKMs 178.5 and 179.0) where pumpkinseed selected sites characterized by large angular boulders (riprap), increased slopes (>20.0 degrees gradient), and deeper depths (>2.0 m). Use of many of these sites may be related to their microhabitat characteristics. Video footage taken during the March 1992 experimental drawdown revealed a roadbed with sand, cobble, and small boulder substrates. During MOP, this submerged road is approximately 3.0 m from the surface and 45.7 m from the riprap shoreline, thus creating a barrier between the shoreline and the main channel of the reservoir. The submerged roadbed may create habitat diversity and cover, and may provide food or spawning areas for pumpkinseed.

If pumpkinseed, yellow perch, and *Pomoxis* spp. were habitat generalists, we expected these fishes to be more abundant in adjacent sites exhibiting similar habitat characteristics; however, this was not observed in Lower Granite Reservoir.

The main reason these species were not observed in adjacent sites was probably related to their low abundances throughout the reservoir. Extensive electrofishing, gill netting, and beach seining efforts at in-water disposal and reference sites by Bennett et al. (1988, 1990, 1991, 1993a, 1993b, 1995a, 1995b) indicated that the abundances of these fishes have remained low since initial sampling efforts in 1986 (Bennett and Shier 1986). Unpublished data by Lepla (K. Lepla, Idaho Power Company, Boise, ID) and Curet (T.D. Curet, Idaho Fish and Game, Salmon, ID) indicated that abundance of pumpkinseeds, yellow perch, and *Pomoxis* spp. in the upstream areas (above RM 125.1; RKM 201.4) of Lower Granite Reservoir was low, except in backwater areas behind Silcott Island (RM 131.4; RKM 211.6). Abundances of yellow perch, *Pomoxis* spp., and *Lepomis* spp. appear to be regulated by reservoir-wide factors rather than site specific factors. Density independent (water flow, temperature, and water level fluctuation management) and density dependent factors (competition) during early life stages probably affect recruitment and abundance of these fishes.

Discriminant Analysis

We used discriminant analysis to develop discriminant functions for selected species and species complexes in Lower Granite Reservoir. Discriminant functions would allow us to predict absence/presence or high/low abundance of species based on habitat variables in Lower Granite Reservoir and possibly at other reservoirs within the Columbia River Basin. If a drawdown were to occur in Lower Granite Reservoir, then the potential to predict and manage the fish communities by habitat manipulations or water management programs may be possible.

Our findings using discriminant analysis suggest that absence was generally predicted more correctly a greater proportion of time than presence for the *Lepomis* spp., *Pomoxis* spp., *Ictalurus* spp. complexes and chiselmouth during summer 1994 in

Lower Granite Reservoir. High correct classifications of absence for these fishes may be related to carrying capacity. Sampling efforts by Bennett et al. (1988, 1990, 1991, 1993a, 1993b, 1995a, 1995b) have indicated that abundance of these species in Lower Granite Reservoir have remained low over time. Research efforts during this study also suggests pumpkinseeds, white and black crappie, chiselmouth, and Ictalurids may be below carrying capacity at sites with similar habitat characteristics. High abundances of *Catostomus* spp. and smallmouth bass were correctly classified more often than low abundances. Classifications of high abundance for both *Catostomus* spp. and smallmouth bass also may have been related to sample size. This high abundance group had a larger sample size that may have resulted in these larger groups having a higher chance of correct classification.

Correct classifications during fall 1994 was highest for both juvenile chinook salmon and juvenile steelhead suggesting that we could predict areas of absence/presence. Predictive ability for both juvenile steelhead and juvenile chinook salmon decreased during the spring and may be related to high numbers of hatchery fish released upstream. Smallmouth bass high/low abundance was correctly classified 63.2% and 60.0% during fall 1994 and was approximately 50% for high/low abundance during spring 1995. Low classification rates during spring 1995 may be related to water temperatures. Typically in early spring when water temperatures are < 9.0 C, smallmouth bass are found offshore near the bottom in deep water areas (Scott and Crossman 1973). This is supported by research conducted by Bennett et al. (1991, 1993a, 1993b, 1995a, 1995b) who indicated that catches for most species are generally low in the littoral areas of Lower Granite Reservoir during late fall, winter, and early spring. Low correct classification for the absence/presence of both the *Lepomis* spp. and *Pomoxis* spp. complexes during spring 1995 may be related to water temperatures and the off-shore distribution of these fishes.

Correct classification for the absence/presence of northern squawfish was generally consistent across all seasons indicating that we could predict areas of use and nonuse. Correct classification of absence/presence for northern squawfish ranged from 47.1 to 68.0%. Research by Bennett et al. (1990, 1991, 1993a, 1993b, 1995a, 1995b) indicated that northern squawfish abundance has decreased in Lower Granite Reservoir from 1991 through 1995, which may be related to the Sport Reward Program (S. Smith, Washington Department of Fish and Wildlife, Pullman, WA, personal communication).

Presence of chiselmouth was more correctly classified than absence during fall 1994 and spring 1995. Correct classification of presence for chiselmouth may have been related to specialization in their feeding behaviors. Chiselmouth collected during fall 1994 and spring 1995 were generally > 250 mm; this size of chiselmouth may have been more specialized in using their cartilaginous sheath for scrapping algae from hard substrates than smaller chiselmouths.

Management Implications

Our research indicates that substrates may be the most important variable for determining absence/presence, high/low abundance, and species diversity in Lower Granite Reservoir. Both small (<2.0 mm) and large (>250.0 mm) angular substrates were significant in determining preferred habitats and location of key species and species complexes. Habitat manipulations or changes in water management regimes in Lower Granite Reservoir could affect the fish community, distribution, and diversity (Dresser 1996). Dupont (1993) reported that decreased water levels in the Pend Oreille River, Idaho, increased velocities and erosion that resulted in the loss of habitat by exposing gravel bars and decreasing shallow water areas. Ward and Stanford (1983) and Denslow (1985) reported that frequent disturbances associated with changing water flows can result in habitat homogeneity.

Gorman and Karr (1978) suggested that habitat homogeneity may result in decreased diversity in the fish community. We would expect a decrease in fish diversity and habitat heterogeneity in Lower Granite Reservoir if substantial decreases in water levels occurred (> 10.6 m). During March 1992 an experimental test drawdown was conducted in Lower Granite Reservoir. Observations during this time indicated that large angular boulders (riprap) covered the area between normal reservoir pool (733 m) downward to approximately 9.1 m. Importance of these areas was demonstrated by the relative abundance of smallmouth bass during this study conducted during normal reservoir operations. Generally, smallmouth bass CPUEs were higher than 1.0 at a majority of these sites, regardless of velocities, water depths, or gradient of slopes. At a drawdown stage of approximately 10.0 m, the large angular boulders were exposed and Lower Granite Reservoir resembled a river with increased velocities and narrow, steep shorelines composed primarily of silt. Coble (1975) reported that smallmouth bass will select rocky substrates to prevent downstream displacement during the winter. Also, at a drawdown stage of 10.0 m, all backwater and shallow water areas were dewatered, moving many fishes that selected shallow water (< 2.0 m) with small substrates (< 2.0 mm) and low velocities (< 0.005 m/s) into the main channel. Dupont (1993) reported that pumpkinseed, black crappie, tench *Tinca tinca*, largemouth bass *Micropterus salmoides*, and brown bullhead *Ameiurus nebulosus* selected areas with increased velocity and deeper waters during a drawdown phase on the Pend Oreille River, Idaho. Sheehan et al. (1990), Carlson (1992), and Pitlo (1992) illustrated the importance of shallow water areas with low velocities during over-wintering periods. These studies were further substantiated by Bennett and Dupont (1993) in Box Canyon Reservoir, Washington. They found pumpkinseed, brown bullhead, black crappie, largemouth bass, and tench were higher in abundance in sloughs where water levels remain stable than in main channel areas, indicating the importance of stable water levels to maintain heterogeneous habitat.

The US Army Corps of Engineers have conducted habitat enhancement projects, primarily for salmonids, by creating shallow water areas and islands using dredged materials. In 1988 and 1989 dredged materials were removed from the confluence of the Snake and Clearwater rivers and deposited to construct an underwater plateau and an island near RM 120.0 (RKM 193.2; Bennett et al. 1990). Monitoring by Bennett et al. (1990, 1991, 1993a, 1993b, 1995a, 1995b) suggests enhancement of predator populations, such as smallmouth bass and northern squawfish, has not occurred. Meanwhile electrofishing, beach seining, gill netting, and larval sampling efforts suggest abundances of pumpkinseed, *Pomoxis* spp., and American shad *Alosa sapidissima* have increased at in-water disposal sites (Bennett et al. 1990, 1991, 1993a, 1993b, 1995a, 1995b). Heterogeneous habitats affect fish composition, community structure, and abundance in Lower Granite Reservoir based on this analysis. The selection of shallow water areas with small substrates by a majority of the fishes indicate the importance of habitat heterogeneity for resident fishes.

The downstream section (downstream of RM 120.0; RKM 193.2) of Lower Granite Reservoir is characterized by steep basalt cliffs on the south shoreline and large angular boulders on the north shoreline. This area is also characterized by increased slopes (>20.0 degree gradient), deep depths (>3.0 m), and few shallow water habitat areas (<2.0 m) with small substrates (<2.0 mm). Sampling at nondisposal sites in this portion of Lower Granite Reservoir by Bennett et al. (1990, 1991, 1993a, 1993b, 1995a, 1995b) indicated that abundance of smallmouth bass was high. Creation of additional shallow water habitat with dredged materials would increase the habitat heterogeneity within this section of the reservoir. Our research has demonstrated the importance of shallow water habitat areas with small substrates for resident fishes in the reservoir. By creating shallow water areas in the downstream sections of Lower Granite Reservoir, habitat heterogeneity could be increased and possibly also diversity and abundance.

Objective 3: *To identify factors limiting the abundance of northern squawfish in Lower Granite Reservoir.*

Factors that limit the abundance of northern squawfish in Lower Granite Reservoir have not been previously addressed. Lower Granite Reservoir has been maintained at MOP during late spring and summer since 1991. The coincidental increase in abundance of larval and juvenile northern squawfish in 1991 and 1992 (Bennett et al. 1994a) suggested the potential for inadvertent population enhancement through reservoir management. Two weeks of water level fluctuation during 1992 may have accounted for a decreased larval abundance relative to 1991 (Bennett et al. 1994a), suggesting that water level fluctuation may be important in limiting abundance of larval northern squawfish. Decreased survival of the 1991 and 1992 year classes in subsequent years (Bennett et al. 1994a) suggested the importance of identifying factors limiting northern squawfish abundance in Lower Granite Reservoir. Managers are interested in the factors that limit northern squawfish abundance because of squawfish predation on juvenile salmonids and the potential for enhancing squawfish numbers through reservoir management practices.

METHODS

Field Collections

We divided Lower Granite Reservoir into three strata (Obective 1 - Methods; Figure 2). The number of sites sampled in each stratum was selected proportionally according to the size of the stratum. Sites sampled within each stratum were chosen randomly in proportion to the availability of habitat types within the strata (Appendix Table 5). Six major habitat types (sand, talus, cobble, cliff, riprap, and embayments) were identified in Lower Granite Reservoir and each was quantified during the 1992 test drawdown (Curet 1994). Resident fishes were sampled along the shoreline by nighttime electrofishing (Objective 1 - Methods) and in deep waters by gill netting.

Gill netting was conducted similarly to previous years in Lower Granite Reservoir (Bennett et al. 1988, 1990, 1991, 1993a, 1993b, 1995a, 1995b). Small (69 m x 1.8 m with 1.3-, 1.9-, 2.5-, and 3.2-cm mesh sizes) and large (69 m x 1.8 m with 3.2-, 4.4-, and 5-cm bar mesh) mesh nets were set in June and July 1995 at randomly selected sites (RM 110.0 - 138.0; RKM 177.1 - 222.2) and depths (2.4 - 26 m) within each stratum to locate the most suitable habitat for collection of northern squawfish. Small-mesh nets were checked hourly and large-mesh nets were checked every 3 hours to prevent destruction of fishes trapped in the net, particularly salmonids. Small mesh gill nets were used in 1995 to compliment catches made in Lower Granite Reservoir in previous years.

Larval fish were sampled at 23 randomly chosen 1-mile sites from late May through mid-September 1994. We sampled at biweekly intervals with paired plankton nets (0.5 m; Bennett and Shrier 1986) and a custom built, hand-drawn beam trawl (LaBolle et al. 1985). Paired plankton nets were towed at night approximately 1.5 m/s for 3 minutes at the surface and 1 m in depth. Three hauls were made at each site on each night we sampled providing six samples/location/sampling date. The beam trawl was pulled along the shoreline over a standard distance of 15.25 m during the daytime. Three hauls were made along the shoreline in each shallow (< 1 m) and deeper (> 1 m) water for a total of six hauls/location/sampling date. Handbeam samples were not collected from riprap or cliff sites in 1994 but they were in 1995.

In 1995 larval fish were sampled biweekly with the hand-drawn beam trawl from late May through early September. We sampled upstream of RM 125.0 (RKM 201.3) and sampling efforts were stratified by habitat type. Approximately 10% of each habitat type (riprap, sand, cobble, talus, and embayment) was sampled during each sampling event (Appendix Table 6). Seven to nine sites were randomly chosen for each sampling event and eight 15.2 m hauls, each approximately 1.0 m in depth, were taken at each site.

These techniques have been used effectively to collect larval northern squawfish and other fishes in Lower Granite Reservoir (Bennett et al. 1993a, 1993b). Although larval fish data have been collected for several years in Lower Granite Reservoir, previous sampling was related to specific locations and not habitat attributes. Habitat characteristics, such as velocity, depth, shoreline substrate, gradient, and others, were correlated with abundance of larval fish. Abundance of larval fish was used to assess the importance of shallow water habitat for rearing.

Data Analysis

Mortality rates for specific year classes of northern squawfish in Lower Granite Reservoir were examined to determine at which stage in the life cycle they are limited. The limited life stage was determined by the period when mortality was the highest.

Fall electrofishing collections most accurately represented the size composition of the northern squawfish community in Lower Granite Reservoir (Figure 28). Fall collections were used to estimate mortality of year classes through time. Data collected by gill netting were used to compare relative abundance and mortality rates of those year classes of northern squawfish (>350 mm). Length frequency distributions were proportioned into age frequencies using MIX software (Ichthus Data Systems 1988). Age frequencies were used to construct catch curves for the 1985 through 1994 year classes to estimate mortality rates of northern squawfish through time as described by Ricker (1975a).

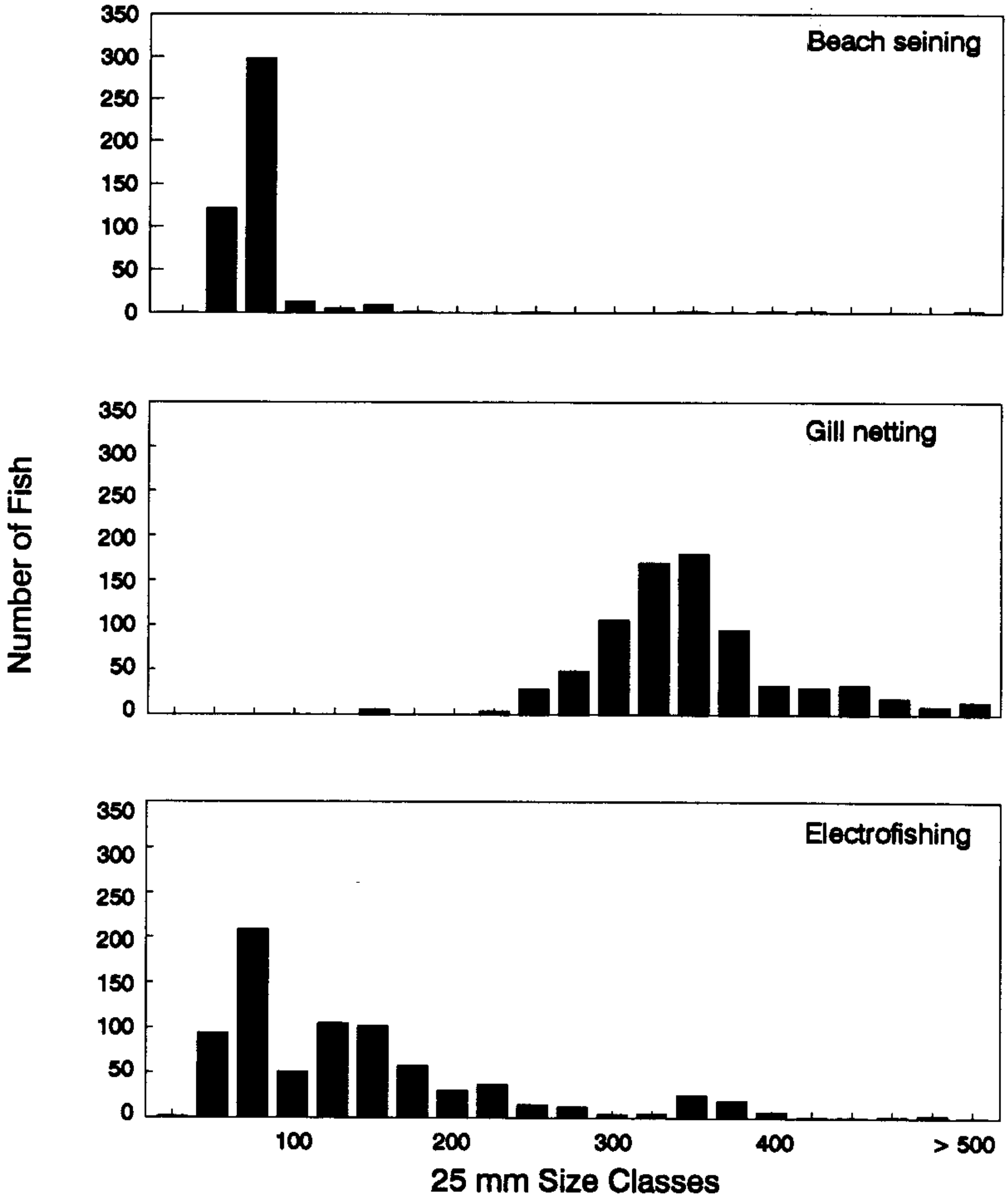

Figure 28. Length frequencies of northern squawfish collected by beach seining, gill netting, and electrofishing from 1985 through 1995 in Lower Granite Reservoir.

Egg to larval mortality was estimated from total potential egg production by adult northern squawfish and estimates of abundance of larval northern squawfish in Lower Granite Reservoir from 1989 through 1995. Potential egg production was calculated using abundance of adult (> 280 mm) female northern squawfish multiplied by mean fecundity (29,688 eggs/female) of squawfish in Columbia River reservoirs (Zimmerman et al. 1995). Abundance of larval northern squawfish was estimated from larval fish collections from 1989 through 1995 (Bennett et al. 1991, 1993a, 1993b, 1994a, 1995a, 1995b).

Catch and effort data from previous gill netting efforts (Bennett et al. 1991, 1993a, 1993b, 1995a, 1995b; Chandler 1993) and the Sport Reward Program (S. Smith, Washington Department of Fish and Wildlife, Pullman, WA, unpublished data) were used to estimate the abundance of adult northern squawfish in Lower Granite Reservoir prior to any known removals prior to 1987. Total number of adult northern squawfish was calculated using both Leslie and DeLury depletion estimators (Ricker 1975a). The mean of seven abundance estimates was considered to be the initial (1987) population size of adult northern squawfish in Lower Granite Reservoir. Number of female northern squawfish was estimated as 56.3% of the total adult population (A. Knutsen, Oregon Department of Fish and Wildlife, Clackamas, unpublished data). We assumed the initial population size of adult northern squawfish was stable and that all removals resulted in a direct reduction of the adult population. Population size after 1987 was then determined to be the initial population size minus the sum of prior adult northern squawfish removals.

Total larval northern squawfish abundance was estimated as the sum of the biweekly abundance estimates in each of nine strata. Strata included upper (RM 131.0-139.75; RKM 210.9 - 225.0), middle (RM 120.0-131.0; RKM 193.2 - 210.9), and lower (RM 107.5-120.0; RKM 173.1 - 193.2) reaches of Lower Granite Reservoir. These strata were further subdivided into shallow near shore (< 0.48 m), deep near shore (0.48 - 1.0 m), and offshore (> 1.0 m) locations. Shallow handbeams, deep handbeams, and plankton net samples were used to represent shallow near shore, deep near shore, and offshore areas, respectively. Larval fish samples collected from each strata were assumed to be random within the strata. Since collections made in offshore areas at depths > 1 m showed low northern squawfish abundance, estimates of larval northern squawfish abundance in deeper waters were not used and are not included in our estimates of total annual abundance. We assumed recruitment to our gears to be constant and assumed biweekly samples to be independent events. Biweekly larval abundance was estimated as the sum of the mean density of larvals collected in each stratum multiplied by the volume of water within that stratum calculated at a water level of 733 ft MSL (Battelle Pacific Northwest Labs, Richland, Washington, unpublished data). Annual total abundance of larval northern squawfish from 1989 to 1995 was estimated as the sum of biweekly abundance estimates in each year.

The degree to which mortality of northern squawfish in Lower Granite Reservoir is regulated by density dependent factors was examined using methods described by Varley and Gradwell (1968). Log transformed regressions of catch per unit of effort at time n+1 ($CPUE_{n+1}$) against that at time n ($CPUE_n$) and $CPUE_n$ against $CPUE_{n+1}$ were plotted for the limited life stage(s) of northern squawfish in Lower Granite Reservoir. Density dependence was assumed to act on the population if two criteria were satisfied: (1) both regressions plotted on the same side of the slope of unity, and (2) the slopes of both regressions differed significantly from 1. The degree to which density dependent factors regulate the northern squawfish population in Lower Granite Reservoir was inferred by the degree to which the slopes of the two regressions differed from 1 (Southwood 1966).

Key factor analysis (Morris 1963) was used to determine the relative importance of factor(s) potentially limiting the abundance of northern squawfish in

Lower Granite Reservoir. Key factor analysis is a modified multiple regression technique that examines the role of both density dependent and density independent factors in controlling population change. The general model for key factor analysis is:

$$CPUE_{n+1} = a + CPUE_n(DD) + DI$$

where: $CPUE_{n+1}$ = catch per unit of effort at time n+1,

$CPUE_n$ = catch per unit of effort at time n,

DD = density dependent factors,

DI = density independent factors, and

a = y intercept of the model.

Competing models were constructed to examine the role of density dependent and density independent factors in explaining population change during the limited life stage. Growth rate during the limited stage was used as an index of density dependent population response. Density independent factors modeled examined the role of flow, water temperature, turbidity, and water level fluctuation in predicting change in the northern squawfish population. Sampling effort was also examined to determine if there has been an effect on CPUE from sampling at different numbers of locations among years.

Habitat use by larval northern squawfish could not be assessed using key factor analysis, however, availability of suitable habitat to larval fish has been shown to be important in determining their survival (Scheidegger and Bain 1995; Bestgen and Williams 1994). Jacobs Utilization Index (Lechowicz 1982) was used to examine habitat preference of larval cyprinids collected in 1995 from Lower Granite Reservoir. The Jacobs Utilization Index has a value of zero under random habitat use and varies between preferred (+1) and avoided (-1) habitats.

RESULTS

Egg to Larval Northern Squawfish

We estimated the preremoval population size of adult northern squawfish as 4,195 as population estimates ranged from 3,669 to 5,076 (Table 13) with relatively narrow confidence intervals (2,984 to 7,205). To estimate annual egg production, we estimated the proportion of mature female northern squawfish as 56.3% (Oregon Department of Fish and Wildlife, OR, unpublished data) with a mean fecundity of 29,866 (Zimmerman et al. 1995).

Mean annual instantaneous mortality for northern squawfish in the egg to larval stage from 1989 through 1995 in Lower Granite Reservoir was 5.60 (Figure 29). Annual instantaneous mortality estimates for northern squawfish in the egg to larval stage ranged from 1.39 (1991) to 15.35 (1995; Table 14).

We rejected the hypothesis that density dependent factors are influencing the egg to larval stage of northern squawfish in Lower Granite Reservoir. The two necessary regressions (natural log # larvae on natural log # eggs and natural log # eggs on natural log # larvae) plotted on opposite sides of unity, and only the slope of natural log # larvae on natural log # eggs (0.122) differed significantly from one ($P < 0.05$; Figure 30). The slope of natural log # eggs on natural log # larvae was 4.06 ($P > 0.05$).

Predictive modeling of northern squawfish survival in the egg to larval stage in Lower Granite Reservoir yielded 68 competing models (Appendix Table 7); five of these models were significant ($P < 0.05$; Table 15). Variables of flow (1), water temperature (1), and water level fluctuations (2) in Lower Granite Reservoir contributed to the significant models and one significant model related to water temperature conditions in the Clearwater River.

Models containing the median Julian date of flows $\geq$ 75 Kcfs ($P = 0.023$; $r^2 = 0.849$) and mean Julian date of temperatures $\geq$ 20° C ($P = 0.017$; $r^2 = 0.869$) in

Table 13. Population estimates using Leslie and DeLury depletion estimators for northern squawfish (> 250 mm) in 1987 in Lower Granite Reservoir obtained using data collected by gill netting (years 1987 to 1995) and the Northern Squawfish Sport Reward Program (S. Smith, Washington Department of Fish and Wildlife, Pullman, WA, personal communication.

Data analyzed	Years analyzed	Variables regressed[a]	Initial estimate	Prior removals	Estimated 1987 population
Leslie method					
GN[b]	1987 - 1994	GN CPUE/K_t	3,669	0	3,669
GN	1987, 1989 - 1994	GN CPUE/K_t	5,076	0	5,076
GN and SRP[b]	1990 - 1993	GN CPUE/K_t	3,769	0	3,769
GN and SRP	1991 - 1993	GN CPUE/K_t	3,969	0	3,969
GN and SRP	1991 - 1993	SRP CPUE/K_t	4,510	0	4,510
SRP	1991 - 1993	SRP CPUE/K_t	3,608	859	4,467
DeLury method					
SRP	1991 - 1993	SRP CPUE/E_t	3,266	641	3,907
Mean estimate					4,195

[a] CPUE = catch per unit effort, K_t = cumulative catch, E_t = cumulative effort
b GN = gill netting
c = SPR = Northern Squawfish Sport Reward Program

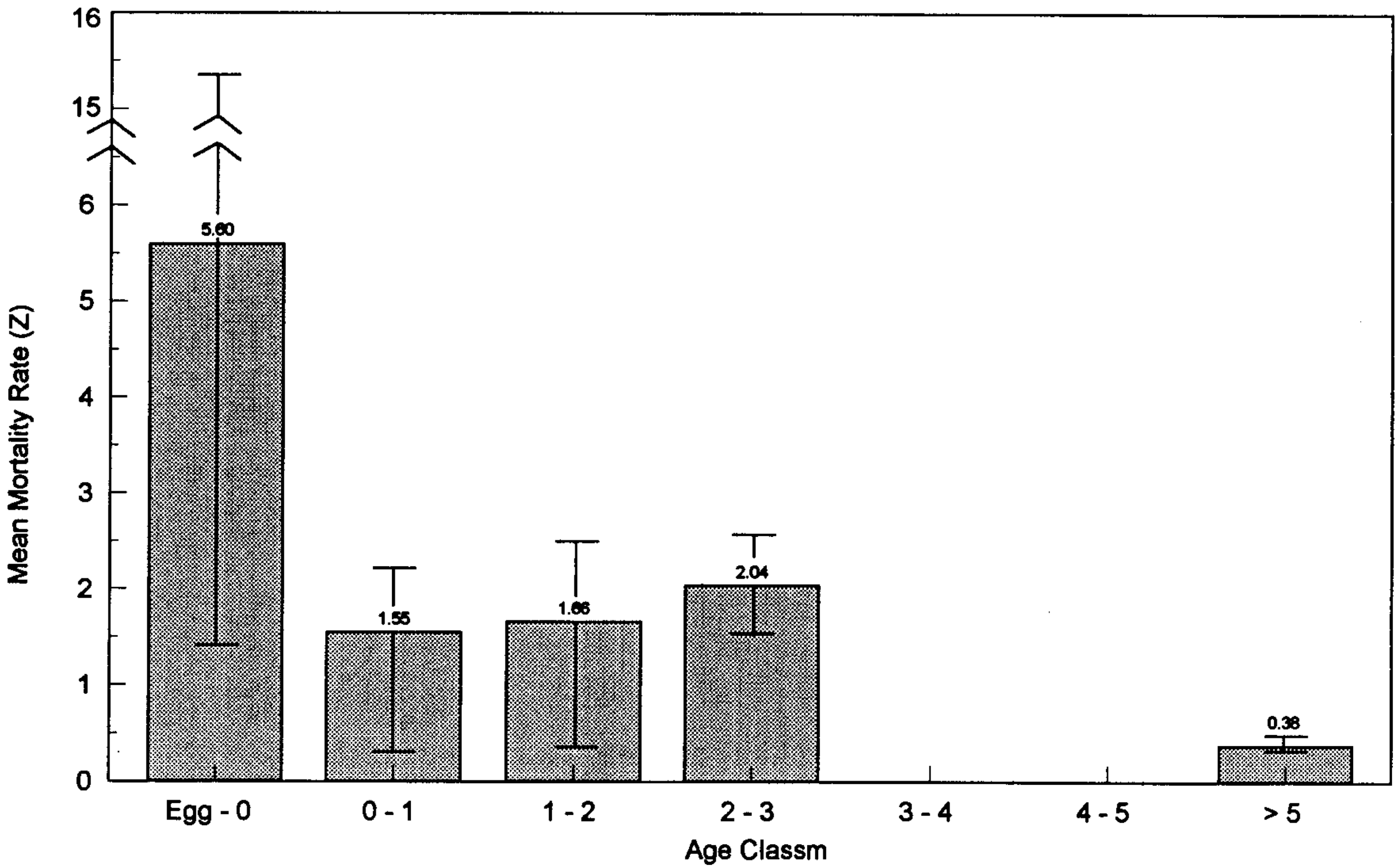

Figure 29. Mean instantaneous annual mortality rates by age class for northern squawfish in Lower Granite Reservoir. Lines indicate range of annual estimates by age class.

Table 14. Estimated population size, egg production, larval production, and egg to larval mortality estimates by year for northern squawfish in Lower Granite Reservoir.

Year	Prior removals	Population estimate	Females	Fecundity[a]	Eggs produced	Larvals produced	Mortality (Z)
1987	0[b]	4,195	2,362	29,866	70,537,071	-	-
1988	58[b]	4,137	2,329	29,866	69,561,826	-	-
1989	71[b]	4,066	2,289	29,866	68,367,993	1,991,694	3.54
1990	313[b]	3,753	2,113	29,866	63,105,036	1,125,166	4.03
1991	199[b]	3,554	2,001	29,866	59,758,939	14,955,092	1.39
1992	798[c]	2,756	1,552	29,866	46,340,922	31,325	7.30
1993	1,748[d]	1,008	568	29,866	16,949,074	105,177	5.08
1994	438[d]	570	321	29,866	9,584,298	0	15.35
						Mean mortality	5.60

[a] Source: Zimmerman et al. 1995
[b] Source: Chandler 1993
[c] Source: Chandler 1993; Washington Department of Fish and Wildlife, unpublished data
[d] Source: Washington Department of Fish and Wildlife, unpublished data

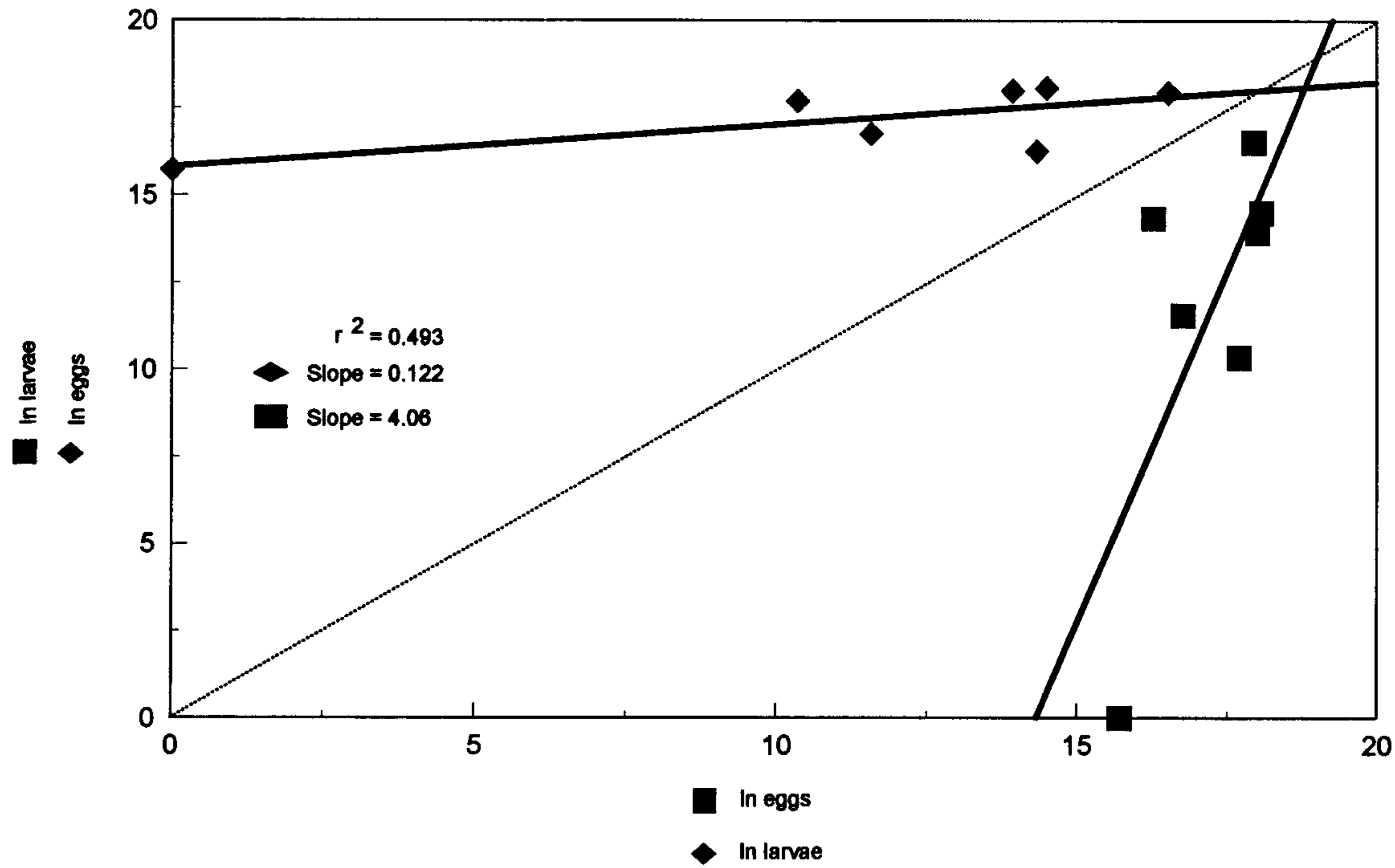

Figure 30. Plot used to test for density dependence acting on the egg to larval stage of northern squawfish in Lower Granite Reservoir.

Table 15. Variables used in significant ($P<0.05$) predictive models for survival of northern squawfish in egg to larval stages.

Location	Variable	Correlation with mortality	Model significance	r^2	Period represented
Lower Granite	MD[a] $\geq$ 75 kcfs	-	0.023	0.849	Annual
	MN[b] $\geq$ 20°C	-	0.017	0.870	Mar 1 to Sep 15
	forebay var. Jun	+	0.004	0.939	Jun
	forebay var. Jul	+	0.035	0.814	Jul
Clearwater River	Jul DD[c] > 10°C	+	0.035	0.813	Jul

[a] MD = median Julian date
[b] MN = mean Julian date
[c] DD = degree days

Lower Granite Reservoir were significant predictors of survival of northern squawfish in egg to larval stage. Water level fluctuation (forebay variance) in June (r^2 = 0.932; P=0.05) and July (r^2 = 0.815; P=0.034) also significantly affected northern squawfish survival in egg to larval survival stage. The model containing number of degree days > 10° C in the Clearwater River in July (r^2 = 0.814) was also significant (P = 0.035). These five significant predictive models for egg to larval survival of northern squawfish explained between 63% and 87% of the variance.

Because no larval northern squawfish were identified from larval fish collections from Lower Granite Reservoir in 1995, we examined the habitat preference/avoidance of larval cyprinids. A total of 430 larval cyprinids was collected by hand-drawn beam trawl in 1995. Cyprinid larvae were most frequently collected from sand habitats (Appendix Table 5) and were most abundant in July (Appendix Table 6).

Jacobs Utilization Index values (D) showed that in 1995 larval cyprinids preferred embayment (0.89), sand (0.80), and cobble (0.25) habitats (Figure 31). Sand, embayment, and cobble habitats make up approximately 19% of the area sampled in 1995 above RM 125.0 (RKM 201.3; Table 16; Appendix Table 5). Larval cyprinids avoided riprap (-0.86) and talus habitats (-0.46; Figure 31), habitats that compose approximately 81% of the area sampled upstream of RM 125.0 (RKM 201.3).

Juvenile Northern Squawfish

Mean annual instantaneous mortality for juvenile northern squawfish (ages 0+ through 3+) sampled in Lower Granite Reservoir ranged from 1.55 (age 0+ to 1+) to 2.04 (age 2+ to 3+) with a weighted mean of 1.70 (Figure 29). We rejected the hypothesis that density dependent factors affect northern squawfish between the

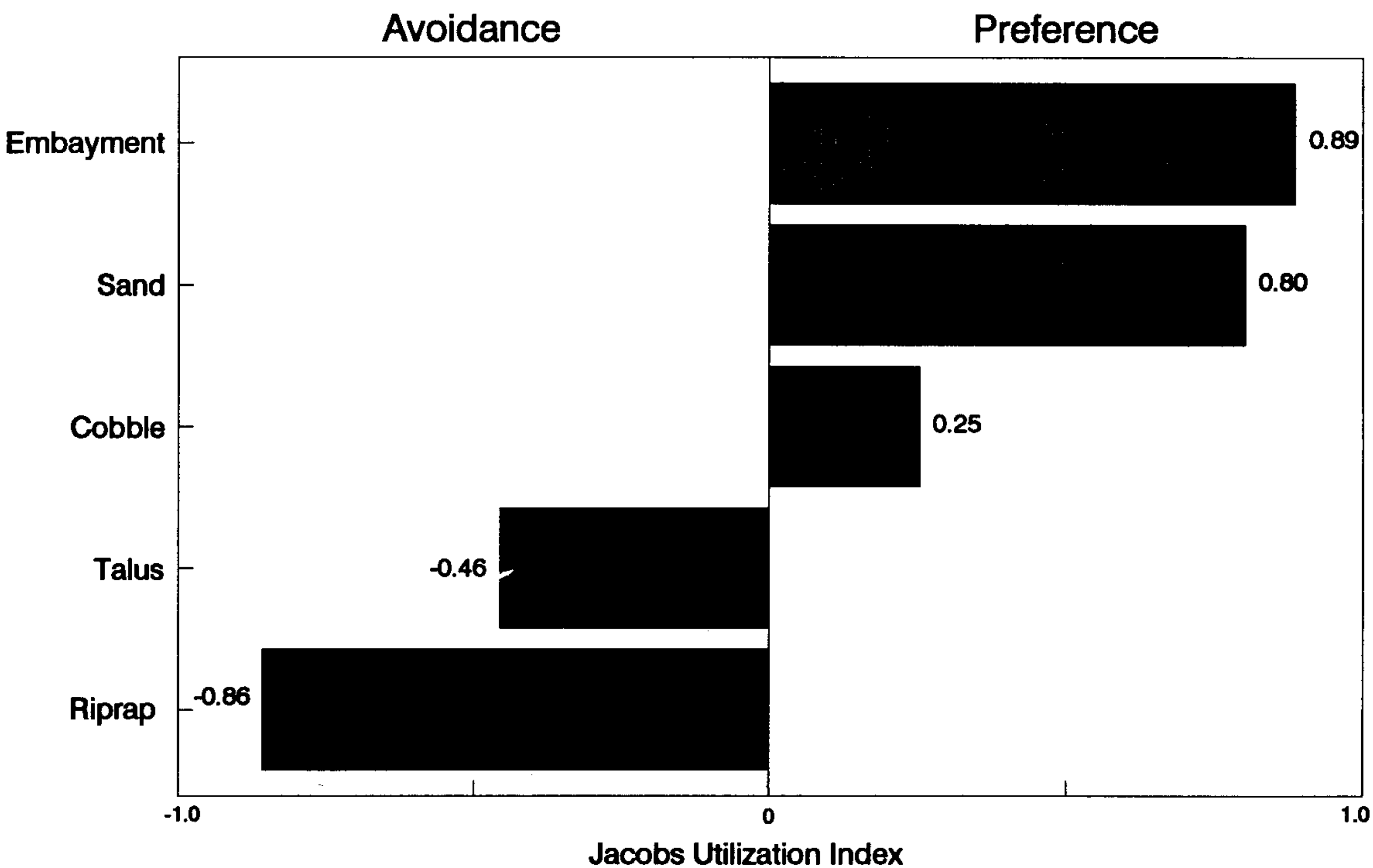

Figure 31. Values based on Jacobs Utilization Index indicating avoidance or preference of habitat used by larval cyprinidae based on collections during 1995 in Lower Granite Reservoir.

Table 16. Habitat availability, number of cyprinids collected, and Jacobs Utilization Index by habitat type for larval fish collections from Lower Granite Reservoir during 1995.

Habitat	Habitat available (mi)	Habitat proportion	Cyprinidae collected	Cyprinidae proportion	Jacobs D[a]
sand	3.25	0.137	257	0.589	0.801
talus	4.50	0.189	35	0.080	-0.456
embayment	0.25	0.011	65	0.149	0.886
riprap	14.75	0.621	49	0.112	-0.857
cobble	1.00	0.042	30	0.069	0.254
totals	23.75	1.000	436	1.000	

[a] Jacobs $D = r_i - p_i / r_i + p_i - (2 r_i p_i)$ where: r_i = relative number of cyprinids identified and p_i = relative abundance of habitat in sample

ages of 0+ and 3+ because both regressions (ln $CPUE_{n+1}$ on ln $CPUE_n$ and ln $CPUE_n$ on ln $CPUE_{n+1}$) plotted on opposite sides of unity, and only the slope of one regression (natural log $CPUE_{n+1}$ on natural log $CPUE_n$; 0.693) differed significantly ($P < 0.05$) from one (Figure 32). The slope of natural log $CPUE_n$ on ln $CPUE_{n+1}$ was 0.974 ($P > 0.10$; Figure 32).

Predictive modeling of juvenile northern squawfish survival in Lower Granite Reservoir yielded 35 competing models with overlapping information (Appendix Table 8). Seventeen of these models were significant ($P < 0.05$) in predicting survival of juvenile northern squawfish (Table 17). Variables related to water temperature conditions and timing (8) provided the most significant models followed by growth rate of juvenile northern squawfish (1), forebay level and variance in water level (4), flow conditions and timing (3), and turbidity (1). The model containing median Julian date of water temperatures $\geq$ 10° C had the highest predictive value ($r^2 = 0.810$) and explained approximately 50% of the additional variance in survival (variance in ln $CPUE_{n+1}$ not explained by ln $CPUE_n$; $r^2 = 0.623$; Figure 32). The model containing the number of days with flows $\geq$ 75 kcfs had the lowest predictive value ($r^2 = 0.706$) and explained approximately 22% of the additional variance in survival.

Eight models examining water temperature conditions and timing in Lower Granite Reservoir were significant ($P < 0.05$) in predicting juvenile northern squawfish survival. The coefficients of determination (r^2) for models containing median Julian date (MD) when reservoir water temperatures equaled or exceeded various levels were 0.810 for 10° C ($P = 0.016$), 0.791 for 15° C ($P = 0.020$), and 0.760 for 20° C ($P = 0.028$; Table 17). Coefficients of determination of models including mean Julian date (MN) of water temperatures $\geq$ 10, 15, and 20° C were 0.786 ($P = 0.021$), 0.791 ($P = 0.020$), and 0.744 ($P = 0.033$), respectively (Table 17). Median (MD) and mean Julian (MN) dates for each water temperature examined

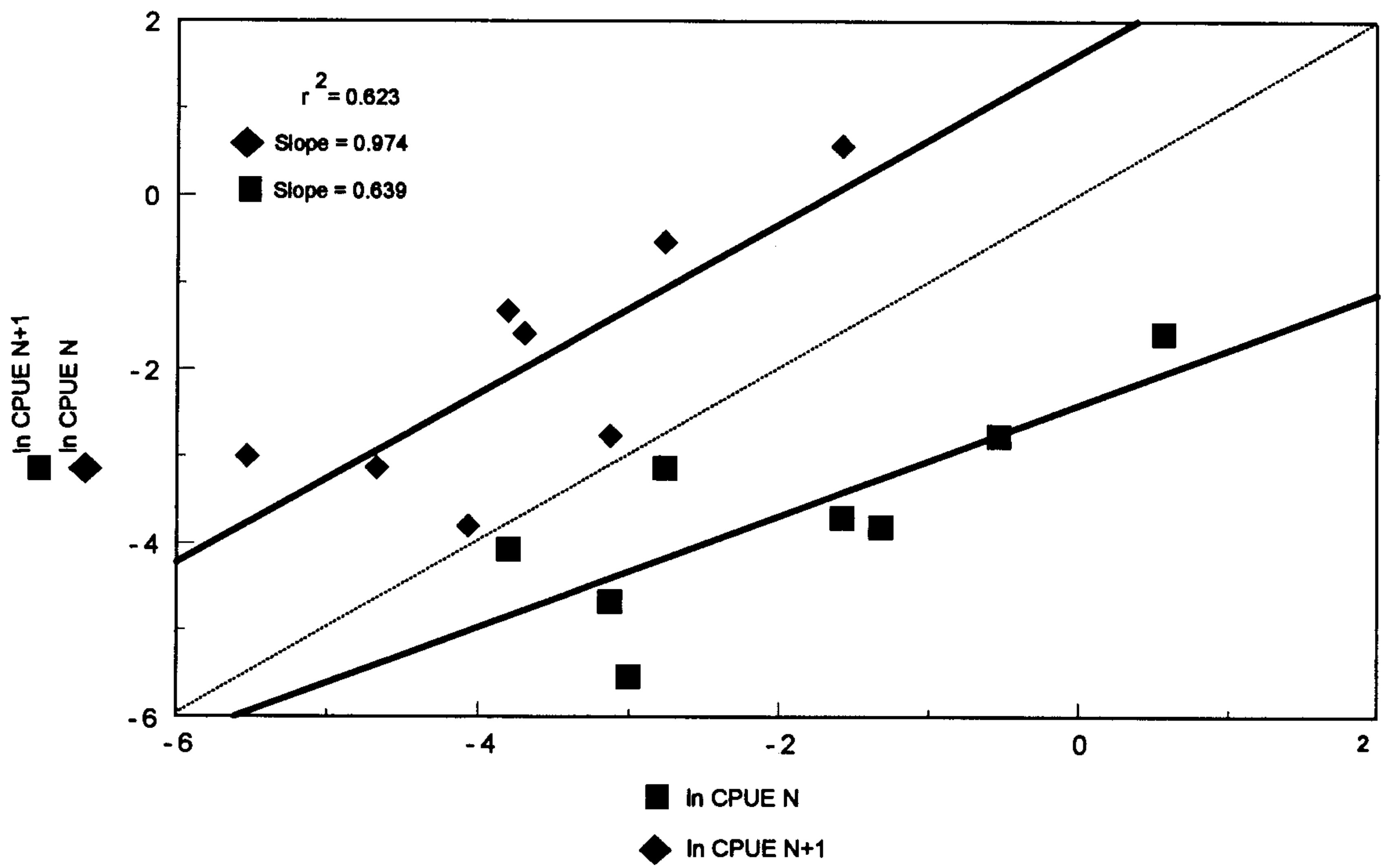

Figure 32. Plot used to test for density dependence acting on the juvenile northern squawfish population in Lower Granite Reservoir.

Table 17. Variables used in significant (P<0.05) predictive models for juvenile northern squawfish survival.

Variable	Correlation with mortality	Model signficance	r^2	Period represented
Days ≥ 50 kcfs	+	0.042	0.718	Annual
Days ≥ 75 kcfs	+	0.047	0.706	Annual
MN[a] ≥ 75 kcfs	+	0.028	0.759	Annual
Days ≥ 15°C	-	0.030	0.754	Annual
Winter days ≥ 10°C	-	0.040	0.723	Dec 1 to Feb 28
MN ≥ 20°C	+	0.033	0.744	Annual
MN ≥ 15°C	+	0.020	0.791	Annual
MN ≥ 10°C	+	0.021	0.786	Annual
MD[b] ≥ 20°C	+	0.028	0.760	Annual
MD ≥ 15°C	+	0.020	0.791	Annual
MD ≥ 10°C	+	0.016	0.810	Annual
Mean secchi	-	0.045	0.712	Mar 1 to Jun 30
MOP[c] forebay var.	+	0.033	0.744	Apr 15 to Sep 30
Non-MOP forebay var.	-	0.019	0.797	Oct 1 to Apr 14
Non-MOP forebay level	+	0.022	0.785	Oct 1 to Apr 14
Winter forebay var.	-	0.031	0.750	Dec 1 to Feb 28
Instantaneous growth	-	0.029	0.757	Annual

[a] MN = mean Julian date
[b] MD = median Julian date
[c] MOP = minimum operating pool

were significantly ($P < 0.05$) positively correlated (Table 18). Models including the timing of water temperatures explained between 32% (MN $\geq$ 20° C) and 50% (MD $\geq$ 10° C) of the additional variation in survival. Annual duration (number of days) of water temperatures $\geq$ 15° C also yielded a significant ($P = 0.030$) model for predicting juvenile northern squawfish survival ($r^2 = 0.754$), as did the number of days that water temperatures were $\geq$ 10° C from 1 December through 28 February ($P = 0.040$; $r^2 = 0.723$).

Annual instantaneous growth rate was included in a significant ($P = 0.029$) predictive model of juvenile northern squawfish survival in Lower Granite Reservoir. The model containing instantaneous growth rates for juvenile northern squawfish ($r^2 = 0.757$) explained approximately 36% of the additional variance in survival; instantaneous growth rate was negatively correlated with mortality (Table 16).

Three significant predictive models for juvenile northern squawfish survival examined the number of days flows to Lower Granite Reservoir were $\geq$ 50 kcfs ($r^2 = 0.718$, $P = 0.042$) and 75 kcfs ($r^2 = 0.706$, $P = 0.047$), and mean Julian date $\geq$ 75 kcfs ($r^2 = 0.759$, $P = 0.028$). Mean secchi measurement from 1 March through 30 June at Lower Granite Dam was also a significant predictor of juvenile northern squawfish survival ($P = 0.045$, $r^2 = 0.712$).

Variance of forebay elevation under MOP conditions (1 May - 30 September; $r^2 = 0.744$, $P = 0.033$), non-MOP conditions (1 October - 31 April; $r^2 = 0.797$, $P = 0.019$), and during winter (1 December - 28 February; $r^2 = 0.750$, $P = 0.031$) yielded significant ($P < 0.05$) models for predicting survival of juvenile northern squawfish. The mean forebay level during non-MOP conditions was also significant ($P = 0.021$) in predicting juvenile northern squawfish survival ($r^2 = 0.786$). No models examining variation in forebay water level during individual months of MOP

Table 18. Correlation between variables used in significant ($P < 0.05$) predictive models for survival of juvenile northern squawfish.

Variable	D[e] 50 kcfs	D 75 kcfs	MN 75 kcfs	Winter D15°C	D10°C	MD20°C	MD15°C	MD10°C
Days ≥ 50 kcfs	1.00	0.92*	-0.00	-0.56	0.20	0.49	0.57	0.21
Days ≥ 75 kcfs		1.00	-0.32	-0.48	0.20	0.29	0.36	0.09
MN[a] ≥ 75 kcfs			1.00	-0.34	0.18	0.51	0.54	0.28
Days ≥ 15°C				1.00	-0.29	-0.39	-0.53	0.01
Winter days ≥ 10°C					1.00	0.14	0.43	0.54
MD[b] ≥ 20C						1.00	0.84*	0.59
MD ≥ 15°C							1.00	0.70*
MD ≥ 10°C								1.00
MN ≥ 20°C								
MN ≥ 15°C								
MN ≥ 10°C								
Mean secchi								
MOP[c] forebay variance								
Winter forebay variance								
Non-MOP forebay variance								
Mean non-MOP forebay level								
Instantaneous growth rate								

Table 18. Continued

	MN20°C	MN15°C	MN10°C	Mean secchi	MOP FB[d] var.	winter FB var.	Non-MOP FB var.	Non-MOP FB level	Growth[redacted]
Days ≥ 50 Kcfs	0.26	0.41	0.24	-0.92*	0.55	-0.08	-0.44	0.43	0.49
Days ≥ 75 Kcfs	0.11	0.19	0.16	-0.94*	0.60	0.18	-0.40	0.31	0.57
MN ≥ 75 Kcfs	0.42	0.54	0.31	0.18	-0.04	-0.39	-0.28	0.44	-0.16
Days ≥ 15°C	-0.17	-0.32	-0.18	0.54	-0.28	0.29	0.41	-0.42	-0.16
Winter days≥10°C	0.56	0.57	0.56	-0.32	0.69*	-0.05	-0.63	0.58	-0.48
MD ≥ 20°C	0.84*	0.79*	0.60	-0.37	0.18	-0.64	-0.71*	0.84*	0.16
MD ≥ 15°C	0.61	0.95*	0.74*	-0.45	0.22	-0.67	-0.84*	0.90*	0.15
MD ≥ 10°C	0.31	0.82*	0.96*	-0.21	0.34	-0.46	-0.85*	0.85*	-0.31
MN ≥ 20°C	1.00	0.62	0.34	-0.08	0.31	-0.66	-0.58	0.74*	0.45
MN ≥ 15°C		1.00	0.84*	-0.27	0.09	-0.72*	-0.85*	0.91*	0.09
MN ≥ 10°C			1.00	-0.27	0.35	-0.40	-0.90*	0.89*	-0.27
Mean secchi				1.00	-0.70*	-0.11	0.54	-0.47	-0.38
MOP forebay var.					1.00	0.54	-0.58	0.48	-0.57
Winter forebay var.						1.00	0.22	-0.38	-0.43
Non-MOP forebay var.							1.00	-0.96*	0.05
Mean non-MOP forebay level								1.00	0.02
Instantaneous growth rate									1.00

* = significant correlations ($P < 0.05$)
[a] MN indicates mean Julian date
[b] MD indicates median Julian date
[c] MOP indicates minimum operating pool
[d] FB indicates forebay
[e] D = day

conditions (May - September) were significant predictors of juvenile northern squawfish survival (Appendix Table 8).

The significance of predation in affecting mortality of northern squawfish was assessed (Objective 1). Anglea (S.M. Anglea, Department of Fish and Wildlife, University of Idaho, Moscow, ID, unpublished data) estimated that approximately 118,500 northern squawfish were consumed by smallmouth bass in Lower Granite Reservoir during 1995. Consumed average weight of northern squawfish was approximately 9 g, which corresponds to an average length of 105 mm and age between 1 and 2 (Bennett et al. 1983).

DISCUSSION

Egg to Larval Northern Squawfish

We estimated adult (> 250 mm) northern squawfish abundance in Lower Granite Reservoir prior to any known removals (before 1987) at 4,195 individuals (1.16/ha). This estimate is notably lower than that for John Day Reservoir (85,316, 4.4/ha; Beamesderfer and Rieman 1991). Ward et al. (1995) also found abundance in Lower Granite Reservoir to be much lower than that in John Day Reservoir. Northern squawfish sampling efforts throughout Lower Granite Reservoir by the Oregon Department of Fish and Wildlife have largely been unsuccessful (S. Smith, Washington Department of Fish and Wildlife, Pullman, , personal communication).

Northern squawfish abundance in Lower Granite Reservoir seems to be limited in the egg to larval stage. We estimated mean annual instantaneous mortality rate of northern squawfish during egg to larval development as 5.60 or an annual survival rate of about 0.37%. Mean egg to larval mortality for northern squawfish is considerably higher than that of juveniles (age 0+ to 3+; $Z = 1.70$) or adults ($Z = 0.38$; Chandler 1993) in Lower Granite Reservoir and, therefore, probably is the life history stage that has the greatest effect on northern squawfish abundance.

We acknowledge that our estimates of egg to larval mortality are probably underestimates. We assumed a stable adult population size so that all removals resulted in a direct reduction in numbers of adult northern squawfish. Removals of adult northern squawfish from Lower Granite Reservoir since 1987 have totaled more than 4,330 fish (Chandler 1993; S. Smith, Washington Department of Fish and Wildlife, unpublished data), similar to our population estimate. Immigration from the Snake and Clearwater rivers may have occurred and our population estimate was low. However, in June and July of 1995, we sampled 445 gill net hours in Lower Granite Reservoir and collected only five adult northern squawfish, corroborating estimates of low population abundance. An underestimate of the population size also would underestimate the number of eggs produced after 1987, and subsequently underestimate the mortality rate of egg to larval stage. However, we do not believe that this contributed negatively to our modeling, as mortality rates would be relative among years.

We did not find a density dependent effect on the egg to larval stages of northern squawfish development in Lower Granite Reservoir (Appendix Table 9). Density dependence is accepted if both regressions (natural log # larvae on natural log # eggs and natural log # eggs on natural log # larvae) plot on the same side of unity and have slopes significantly different from 1 (Varley and Gradwell 1968). Our data for northern squawfish egg and larval abundance yielded regressions that plotted on opposite sides of unity, with only one regression having a slope significantly different from 1.

Our analysis showed that water level fluctuations during June and July in Lower Granite Reservoir affect survival of larval northern squawfish. Water level fluctuation has been hypothesized to have a negative influence on northern squawfish recruitment (Rieman and Beamesderfer 1990; Bennett et al. 1994a) but never demonstrated. Larval northern squawfish are most abundant along the shallow shorelines of Lower Granite Reservoir in June and July (Bennett et al. 1991, 1993a, 1993b, 1994b, 1995a, 1995b) and our findings suggest that survival of larval northern squawfish is reduced under less stable water levels during shoreline rearing. Because larval northern squawfish commonly rear in areas of shallow, low gradient, they may be subject to stranding on the shore by wave action or in near-shore vegetation when water levels decline (Bennett et al. 1994a). Because of the small size of northern squawfish, their low motility may contribute to stranding.

Timing (mean Julian date) of water temperatures $\geq$ 20° C in Lower Granite Reservoir was found to be an important factor affecting survival of larval northern squawfish. We showed that earlier occurrence of temperatures $\geq$ 20° C relates to increased mortality of larval northern squawfish. Consumption rate of fishes increases with water temperature (Vigg and Burley 1991; Niimi and Beamish 1974) and predation rates on larval northern squawfish probably increase with earlier reservoir warming. Curet (1994) showed that larval fishes were an important dietary item of juvenile fall chinook salmon in Lower Granite Reservoir. Therefore, predation by juvenile salmon and possibly other fishes may contribute to decreased survival of larval northern squawfish.

A positive relationship between larval mortality and temperatures beyond an optimal level has been shown to exist in fishes (Pepin 1991; Kroll et al. 1992) including the Colorado squawfish (*P. lucius*; Bestgen and Williams 1994). Earlier occurrence of high temperatures ($\geq$ 20° C) could reduce survival of larval northern squawfish by inhibiting growth and development. Development rates of larval fishes, and specifically the Colorado squawfish, vary directly with water temperature (Bestgen and Williams 1994). The preferred temperature of larval northern squawfish is probably near 20° C, and warming ≥ 20° C in Lower Granite Reservoir could inhibit survival of northern squawfish larvae.

Timing (median Julian date; MD) of flows ≥ 75 kcfs was a significant variable affecting survival of larval northern squawfish. However, its importance is unclear because of its colinearity with water level fluctuations. Our data indicate that MD ≥ 75 kcfs occurs in early to mid-May in most years shortly before the probable spawning time (June) of northern squawfish in Lower Granite Reservoir. Median Julian date ≥ 75 kcfs in Lower Granite Reservoir is strongly correlated with water level fluctuations in June ($P = 0.02$) and July ($P = 0.07$; Table 19). Discharge levels have been suggested as a possible spawning cue for Colorado squawfish (Tyus 1990; Nesler et al. 1988). We believe that timing of flows ≥ 75 kcfs could affect egg to larval survival of northern squawfish by determining the timing of the spawning run and subsequently the conditions (i.e. temperatures or flows) that eggs and larvae experience. Earlier occurrence of flows ≥ 75 kcfs in Lower Granite Reservoir relates to higher egg to larval mortality. If spawning were triggered by flows, then earlier spawning may expose northern squawfish eggs and larvae to conditions less favorable to their survival possibly through food limitation.

Number of degree days > 10° C in the Clearwater River during July was significant in predicting northern squawfish survival from egg to larval stages of development. We modeled effects of the number of degree days > 10, 15, and 20° C in May, June, and July in the Snake and Clearwater rivers. The period from May through July is when the majority of northern squawfish spawning probably occurs. However, no other models in the Snake ($0.19 \leq P \leq 0.26$) and Clearwater ($0.11 \leq P \leq 0.26$) rivers were significant predictors of egg to larval mortality. Water temperature effects are undoubtedly important in determining rates of development and survival of larval fishes (Bestgen and Williams 1994; Wang and Eckmann 1994;

Table 19. Correlation between variables included in significant ($P < 0.05$) predictive models for egg to larval survival of northern squawfish.

Location	Variable	MD[a] 75 ≥75 kcfs	MN[b] ≥20°C	Jun FB[c] variance	Jul FB variance	CWR[d] Jul DD≥10°C
Lower Granite	MD ≥ 75 kcfs	1.00	0.09	-0.69*	-0.57	0.33
	MN ≥ 20°C		1.00	-0.56	-0.21	-0.35
	Jun FB variance			1.00	0.48	0.27
	Jul FB variance				1.00	0.26
Clearwater River	Jul DD[e] > 10°C					1.00

* = significant correlations ($P<0.05$)
[a] MD = median Julian date
[b] MN = mean Julian date
[c] FB = forebay
[d] CWR = Clearwater River
[e] DD = degree days

Kroll et al. 1992; Pepin 1991), but these were not highly significant on larval mortality.

The significant predictive models for egg to larval survival of northern squawfish relate to environmental conditions in Lower Granite Reservoir, and explain the majority of the variation in survival ($r^2 > 0.81$). We believe that northern squawfish from Lower Granite Reservoir spawn in the Snake or Clearwater rivers. Larval sampling has shown that they rear in Lower Granite Reservoir during the larval stage. Our data suggest that larval mortality is probably more important in limiting abundance of northern squawfish than spawning or hatching success. Egg and larval stages have differing physiological tolerances (Bestgen and Williams 1994) so that optimal conditions for hatching success and larval survival may differ. Mortality during the various developmental stages of fishes between the egg and late larval stages may be affected by different factors during each stage (Houde 1987). Unidentifiable larval cyprinids are normally considerably more abundant than those that are of an identifiable size (approximately 18 mm total length), suggesting that the majority of larval mortality probably occurs before the larvae reach 18 mm. We believe abundance of northern squawfish in Lower Granite Reservoir is probably limited by mortality during the early larval stage of development. Our work suggests additional research should more closely evaluate mortality between egg and late larval (> 18 mm) stages for northern squawfish in Lower Granite Reservoir.

Larval cyprinids prefer those habitats least available (embayment, sand, and cobble) and avoid those habitats most available (riprap and talus) upstream of RM 125.0 (RKM 201.3) in Lower Granite Reservoir. Preferred habitats accounted for approximately 19% of the area sampled in 1995. In contrast, 81% of the larval cyprinids collected in 1995 were collected from embayment (15%), sand (59%), or cobble (7%) habitats. The majority of larval cyprinids collected from embayment areas was generally carp. High concentrations of carp were observed spawning in embayment areas (RM 130.5 south; RKM 210.1) in late June which coincided with increased abundance of cyprinid larvae collected from these areas. Eighty-nine percent of all larval cyprinids collected from embayment habitat in 1995 were collected in late June. The selection of embayment areas by larval cyprinids then probably over-represents that by larval northern squawfish.

The strong preference for sand habitats by cyprinids was strongly influenced by sampling at RM 134.0 to 135.0 (RKM 215.7 - 217.4; south shoreline) during all sampling periods in 1995. Cyprinids collected from this part of Lower Granite Reservoir represented 94% of those collected from sand habitats in 1995, and supported previous findings (Bennett et al. 1991, 1993a, 1993b, 1994a, 1994b).

Cobble habitat was identified in the upper reach of Lower Granite Reservoir near RM 126 (RKM 202.9). Past larval collections have shown that the majority of larval northern squawfish are collected in areas farther upstream (Bennett et al. 1991, 1993a, 1993b, 1994a, 1994b). Preference of larval cyprinids for limited habitat types suggests that any future additions of sand or cobble habitats in areas above RM 126 (RKM 202.9) may enhance suitable rearing area for larval cyprinids, and possibly northern squawfish in Lower Granite Reservoir.

Abundance of Juvenile Northern Squawfish

Our data and others suggest factors affecting the abundance of juvenile northern squawfish in Lower Granite Reservoir are more significant at younger ages. We estimated mean annual instantaneous mortality rate of northern squawfish from ages 0+ to 3+ in Lower Granite Reservoir at 1.70, whereas Chandler's (1993) estimate ($Z=0.38$) of average annual instantaneous mortality (> age 5) was considerably lower. We did not have data to estimate mortality rates for squawfish 3+ to 5 years of age, but believe mortality would be more comparable to older fish.

We rejected the effect of density dependent factors acting on the juvenile northern squawfish population in Lower Granite Reservoir. Density dependence is accepted if both regressions (ln $CPUE_{n+1}$ on ln $CPUE_n$ and ln $CPUE_n$ on ln $CPUE_{n+1}$) plot on the same side of unity and have slopes significantly different from 1 (Varley and Gradwell 1968). Therefore, we concluded density independent factors were more important in affecting mortality of northern squawfish in Lower Granite Reservoir. Our data for juvenile northern squawfish abundance yielded regressions that plotted on opposite sides of unity, and only the regression of ln $CPUE_{n+1}$ on ln $CPUE_n$ had a slope significantly different from 1 (slope = 0.64; $P < 0.05$).

We found 17 significant density independent factor models that enhanced prediction of juvenile northern squawfish survival. Eight were related to water temperature, one to growth rate, and three to flow conditions. Mortality of juvenile northern squawfish was positively correlated with timing of water temperatures (mean and median Julian date $\geq$ 10, 15, and 20° C) and flows ($\geq$ 75 kcfs) and with duration of flows ($\geq$ 50 and 75 kcfs), whereas juvenile mortality was negatively correlated with duration of water temperatures and rate of growth.

Water temperature conditions relate to survival of fishes (Kroll et al. 1992; Pepin 1991; Pitcher and Hart 1982). Timing of water temperature conditions in Lower Granite Reservoir was the most important factor in predicting juvenile northern squawfish survival. Water temperature is considered one of the most important physical factors in controlling fish abundance and distribution (Moyle and Cech 1988; Lagler, et al. 1962). Vital processes in fishes are generally accelerated in warmer water (Cech et al. 1994; Lemons and Crawshaw 1985; Lagler et al. 1962), which is beneficial to growth and survival until water temperatures exceed optimal levels (Baker and Wigham 1979; Brett 1979). Timing of temperatures $\geq$ 10, 15, and 20° C enhanced our predictive models (r^2 range = 0.744 - 0.810) relative to duration of annual temperatures $\geq$ 15° C (r^2 = 0.754) or winter water temperatures $\geq$ 10° C (r^2 = 0.723). Therefore, timing of water temperatures is more important in predicting survival of juvenile northern squawfish than duration of water temperatures. Our data indicate that delayed warming of the reservoir contributes to higher mortality of juvenile northern squawfish.

The timing of water temperature conditions affects the length of growing season for juvenile northern squawfish. Earlier reservoir warming provides a longer growth period for juvenile northern squawfish. However, we found nonsigificant negative correlations between growth rate and mean (P = 0.51) and median (P = 0.45) Julian dates of water temperatures $\geq$ 10° C. Water temperatures at which growth occurs in northern squawfish have not been defined, but for most freshwater fishes growth patterns are closely associated with annual fluctuations in water temperature (Pitcher and Hart 1982; Bond 1979; Brett 1979). Growth of many fishes begins when spring water temperatures are near 10° C (Carlander 1969), and the majority of fish growth normally occurs in spring and summer (Bond 1979) unless summer water temperatures exceed optimum for growth (Baker and Wigham 1979; Lagler et al. 1962). Annual spring water temperature conditions in Lower Granite Reservoir are more variable than summer or fall and probably have the greatest effect on the timing of water temperature conditions (Figure 33). Later reservoir warming then leads to increased mean and median Julian dates of temperatures $\geq$ 10° C and probably to a decreased length of growing season available to juvenile northern squawfish. In this case, growth is regulated by temperature but not in a density dependent manner as shown earlier. Water temperature conditions in Lower Granite Reservoir probably, in part, limit the abundance of juvenile northern squawfish with later reservoir warming (increased median and mean Julian date of temperatures) being most important.

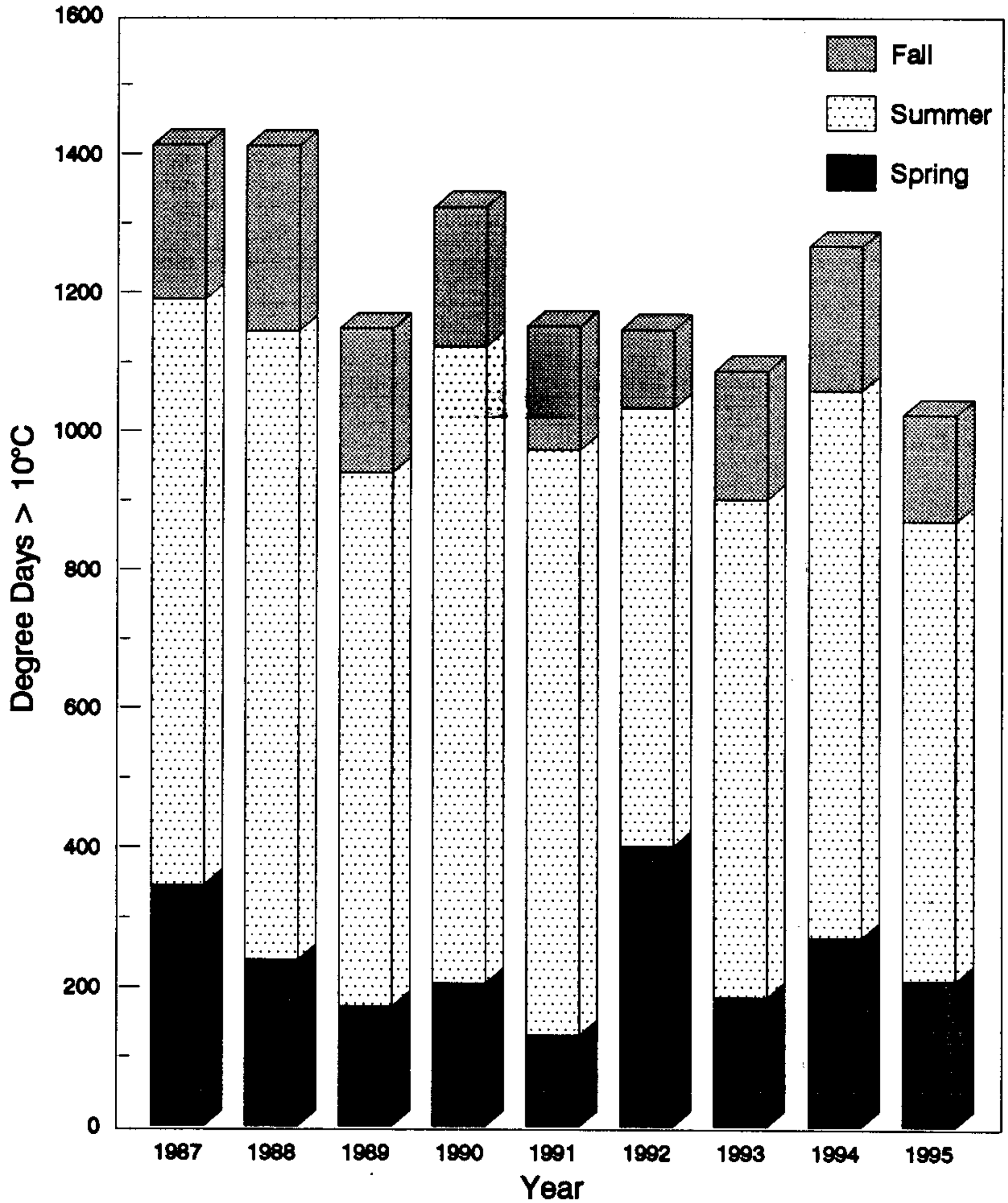

Figure 33. Degree days > 10°C by season; fall (October through November), summer (July through September), and spring (April through June) from 1987 through 1995 in Lower Granite Reservoir.

We believe higher summer water temperatures may have a negative effect on growth of northern squawfish in Lower Granite Reservoir. Many fish exhibit growth inhibition at temperatures beyond some optimum level (Moyle and Cech 1988; Tacon and Cowey 1985; Baker and Wigham 1979; Ursin 1979). Black (1953) determined the upper lethal temperature for northern squawfish at 29.3° C. For most adult fishes the preferred temperature is approximately 13° C below the lethal temperature. The preferred temperature for young fish (i.e. age 0) is approximately 9.5° C below the lethal temperature (Clark 1969). This suggests that juvenile northern squawfish have a preferred temperature between 16.3 and 19.8° C, falling within the 10 to 20° C preferred temperature range proposed by Vigg and Burley (1991). Also, optimal temperatures for growth are normally within $\pm$ 2° C of preferred temperatures for temperate fishes (Kellogg and Gift 1983). Surface temperatures in Lower Granite Reservoir exceed 20° C in July through September of most years coinciding with the greatest predictable effect on growth rate of juvenile northern squawfish in July and August (Table 20). Increased mean water temperatures in July and August probably result in slow growth of juvenile northern squawfish. Later reservoir warming allows a shorter duration of high temperatures and accounts for the negative correlation of growth rate with duration of temperatures greater than or equal to 20° C ($P < 0.05$; Appendix Table 10).

Growth rates of juvenile northern squawfish in Lower Granite Reservoir are being affected by water temperature and ultimately mortality. Growth rates of juvenile northern squawfish were negatively correlated to mortality rates. Therefore, increased growth leads to increased survival. Higher survival in larger fishes, particularly in the early life history stages has been strongly supported (Wang and Eckmann 1994; Pepin 1991, 1993; Rice et al. 1993; Buijse and Houthuijzen 1992). Increased size can enhance survival by reducing risk of predation (Miller 1979), increasing buffering against environmental fluctuations, and increasing competitive

Table 20. Predictable effect (r^2) of monthly water temperatures on growth rates of juvenile northern squawfish from 1987 through 1994 in Lower Granite Reservoir.

	r^2 values	
Month	Mean temperature versus growth	Maximum temperature versus growth
Apr	0.02	0.01
May	0.05	0.10
Jun	0.06	0.18
Jul	0.50	0.30
Aug	0.36	0.04
Sep	0.20	0.27
Oct	0.00	0.03
Nov	0.23	0.05

success (Ricklefs 1979). Relative metabolic rate of fishes decreases with increased size (Brett and Groves 1979), therefore, based on energetics larger size is beneficial.

Duration of flows $\geq$ 75 kcfs and timing of flows $\geq$ 75 kcfs accounted for a significant amount of juvenile mortality in Lower Granite Reservoir. Duration and timing of flows accounted for about 20% to 30% of the variation in water temperature conditions in Lower Granite Reservoir. Therefore, inflows to Lower Granite Reservoir indirectly affect juvenile northern squawfish survival. Higher spring flows generally result in cooler water temperatures and slower reservoir warming leading to decreased survival of juvenile northern squawfish.

Mean secchi disc readings were predictors of juvenile northern squawfish survival and were significantly ($P < 0.05$) negatively correlated with annual duration of flows $\geq$ 50 and $\geq$ 75 kcfs. Mean secchi disc readings were usually negatively correlated to timing of temperatures $\geq$ 10, 15, and 20° C. We believe water transparency is a collinear function of flow that masks the importance on northern squawfish survival.

The importance of water level fluctuation on mortality of northern squawfish from age 0+ to 3+ was found, although its action is not clear. Forebay mean water levels (non-MOP conditions) and variation (non-MOP and winter conditions) were significant predictors of juvenile northern squawfish survival in Lower Granite Reservoir. Juvenile northern squawfish normally inhabit shallow (< 1 m) water until their first winter when they move offshore and subsequently inhabit deeper habitats (Beamesderfer 1983), probably with little effect from winter water level fluctuations. Northern squawfish older than age 0+ are probably sufficiently mobile to avoid the effect of water level fluctuations if they do inhabit shallow water areas during non-MOP or winter conditions. For these reasons we believe that forebay levels and variations are collinear with the timing of reservoir temperatures, and that timing of reservoir temperatures are important in limiting the survival of juvenile northern squawfish in Lower Granite Reservoir.

In a related study (Objective 1) diets of smallmouth bass in 1995 contained juvenile squawfish in Lower Granite Reservoir, although predation on northern squawfish by other species is negligible (M. Davis, Department of Fish and Wildlife, University of Idaho, Moscow, personal communication). Based on our estimates of abundance, less than 2.5% of northern squawfish between age 0+ and 3+ are being consumed annually by smallmouth bass in Lower Granite Reservoir compared to mean annual mortality of 82% ($Z = 1.70$). Thus, we do not consider predation on juvenile northern squawfish as a significant component of annual mortality in Lower Granite Reservoir.

Water temperature also affects predation by smallmouth bass. Increased water temperature may lead to increases in foraging rate and success (Persson 1986), consumption rate (Vigg and Burley 1991; Niimi and Beamish 1974), and metabolic rate (Cech et al. 1994; Lemons and Crawshaw 1985) of fishes up to an optimal temperature. Predation on northern squawfish by smallmouth bass is probably, in part, a function of water temperature; warmer temperatures increase predation and result in a longer period of consumption of juvenile northern squawfish. Although consumption of juvenile northern squawfish in 1995 was low and waters in Lower Granite Reservoir warmed slowly because of a higher than "normal" runoff, our data suggest that predation on northern squawfish in Lower Granite Reservoir is probably not a significant component of overall mortality in any year. Even at twice the predation rate observed in 1995, juvenile squawfish mortality from predation probably is not significant in affecting survival.

Egg to larval mortality is most important in limiting abundance of northern squawfish in Lower Granite Reservoir. However, juvenile mortality is probably also important in limiting abundance of certain year classes of northern squawfish in

Lower Granite Reservoir. Instantaneous mortality estimates for egg to larval stages of northern squawfish were highly variable among years and ranged from 1.39 (25% survival) to 15.35 (< 0.001% survival). Estimated mean annual instantaneous mortality of juvenile northern squawfish was 1.70 (18% survival) and ranged from 0.27 to 2.53. The significance of juvenile mortality was observed in 1991 when large numbers of larval squawfish were collected, although few age-0 squawfish were collected during fall 1991.

Our data indicate that reservoir management practices are important in determining survival of larval and juvenile northern squawfish in Lower Granite Reservoir. In-water disposal of dredged materials above RM 125 (RKM 201.3) in Lower Granite Reservoir may increase survival of larval northern squawfish by increasing availability of preferred rearing habitats, particularly sand and cobble.

Timing of reservoir warming in Lower Granite Reservoir is the most important factor influencing survival of juvenile northern squawfish. Flow augmentation used in recent years to facilitate the subyearling chinook smolt outmigration results in increased duration of higher flows and thus, later reservoir warming that reduces survival of juvenile northern squawfish. Conversely, cooler water temperatures in Lower Granite Reservoir due to flow augmentation however, may enhance survival of larval northern squawfish by decreasing the duration of temperatures (> 20° C) that may be detrimental to their development. Management of Lower Granite Reservoir at MOP conditions through June and July enhances survival of larval northern squawfish, probably by reducing stranding of larvae on the shore. Other aspects of MOP conditions may also enhance survival of juvenile northern squawfish, although the relationship is less clear. Because larval and juvenile northern squawfish rear primarily in shallow low gradient areas in Lower Granite Reservoir, we believe that summer water level fluctuations of 0.3 to 0.6 m, particularly during June and July, may have a pronounced negative impact on their survival.

Objective 4. To identify factors affecting abundance of smallmouth bass in Lower Granite Reservoir.

Survival of young-of-the-year fish is an important factor in determining recruitment and cohort strength in fish populations (Kramer and Smith 1960; Shuter et al. 1980; Coutant and DeAngelis 1983). Water temperature, water level fluctuation, wave action, air temperature, food availability, predation, and turbidity are factors that influence early survival in fishes (Kramer and Smith 1962; Miller and Kramer 1971; Summerfelt 1975). Graham and Orth (1986) showed that water temperature and streamflow influence time of spawning and reproductive success of smallmouth bass; water temperature was more important than discharge. When mean daily water temperature suddenly decreased, the spawning activity of smallmouth bass ceased, resulting in two distinct spawning periods. Eggs and larvae released during the first spawning period experienced higher mortality due to nest desertion by the guarding male. Montgomery et al. (1980) stated that acute water level fluctuations resulting from hydroelectric power generation at Priest Rapids Dam influenced smallmouth bass spawning success by retarding or halting egg development. Lower Granite Reservoir experiences wide fluctuations in surface elevation, flow, and water temperature during spring from snow melt and reservoir management operations. Smallmouth bass spawn when water temperatures are about 15° C (Carlander 1977; Coutant and DeAngelis 1983). In Lower Granite Reservoir 15° C occurs from late May to mid-July. Bennett et al. (1983) observed the initiation of smallmouth bass spawning activity in Little Goose Reservoir on 18 June 1979 and 15 June 1980.

Based on analysis of limiting factors in the lateral lakes of northern Idaho, Bowles (1985) identified over-winter survival as the dominant factor in regulating recruitment and subsequent year-class strength in largemouth bass. Shuter et al. (1980) demonstrated a significant relationship between winter mortality and size at the end of the first growing season for northern populations of smallmouth bass. The quality and duration of the growing season determines the length of age-0 smallmouth bass at the end of the first growing season. Bennett et al. (1994a) found that growth of smallmouth bass in Lower Granite Reservoir was related to the abiotic factors of water temperature and water level fluctuation.

As the interaction between smallmouth bass and juvenile salmonids in Lower Granite Reservoir receives more attention, the ability to identify critical stages in the life history of this predator becomes increasingly important. Understanding the influence of water temperature and water level fluctuations on spawning success and over-winter survival will provide critical insight for future management plans related to smallmouth bass in Lower Granite Reservoir.

METHODS

Spawning success and over-winter survival was determined from beach seine collections conducted during May and August from 1987 through 1995 (Objective 1). Mean daily water temperature, flow, and surface elevation were obtained from US Army Corps of Engineer records at Lower Granite Dam.

We used the number of young-of-year smallmouth bass per haul (fish/haul) in August beach seine collections as an index of spawning success. We evaluated five water temperature variables to determine which characteristic most influenced growth and abundance of age-0 smallmouth bass:

JNTMP = mean June temperature (° C);

$D_{15\text{-}10}$ = the sum of the number of degree days (D_{10}), after J15 and J15C, when water temperature was > 10° C:

$$D_{10} = \sum_{i=1}^{j} \frac{(C_i - 10) + (C_{i+1} - 10)}{2} d_{i,i+1}$$

where: C_i = mean temperature (° C) on recording date i,

i = sampling dates $i = 1$ to j,

$d_{i,i+1}$ = number of days between consecutive temperature samples (*i to i+1*);

J15 = Julian date when water temperature reached 15C;

J15C = Julian date after which water temperature remained at or above 15° C until fall cooling period; and

DJ15C = number of days between J15 and J15C.

Over-winter survival was calculated as the ratio of CPUE by beach seine of yearling smallmouth bass in May to subyearling smallmouth bass the previous August. The relationship between duration of growing season, average length of subyearling smallmouth bass, CPUE of subyearling smallmouth bass in August, and duration of winter period was compared to over-winter survival using regression analysis.

RESULTS

Spawning Success

Catch per unit effort of young-of-the-year smallmouth bass during August was highest in 1987 (18.6 fish/haul) and lowest during 1989 (2.67 fish/haul), 1993 (0.71 fish/haul), and 1995 (0.02; Figure 34). We found that cumulative degree-days explained generally one-third ($r^2 = 0.27$; $P = 0.18$) of the annual variability in CPUE of age-0 smallmouth bass in August (Figure 35).

Mean total lengths of young-of-the-year smallmouth bass in August ranged from 46 to 66 mm among years, and these lengths were significantly related to mean June temperatures ($P < 0.05$) and cumulative degree days up to the collection date ($P < 0.05$; Figure 36). No significant relationship ($P > 0.05$) was observed among timing variables (J15, J15C, and DJ15C) and measures of abundance.

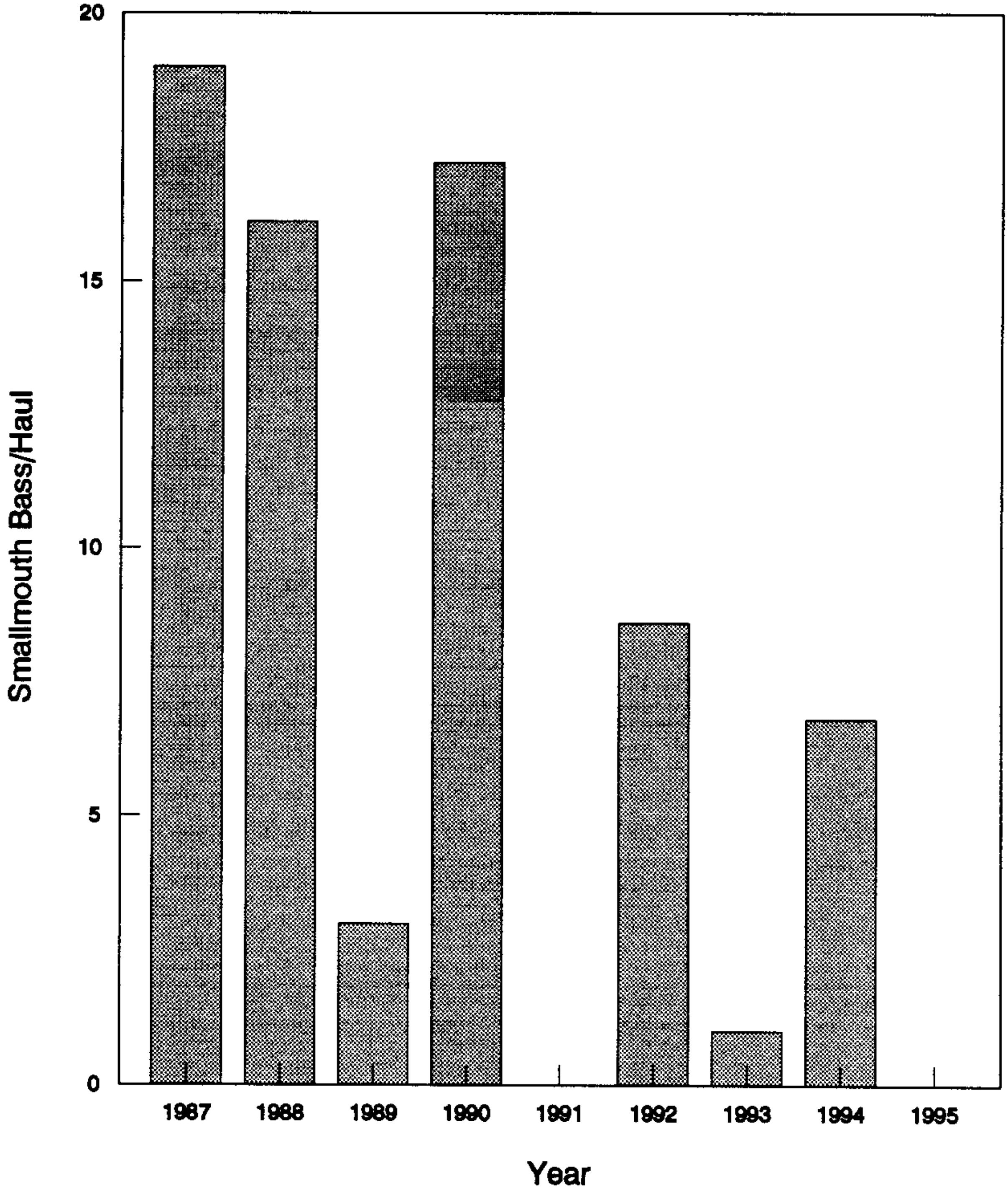

Figure 34. Catch per unit effort of smallmouth bass in August beach seining collections from 1987 through 1995 in Lower Granite Reservoir.

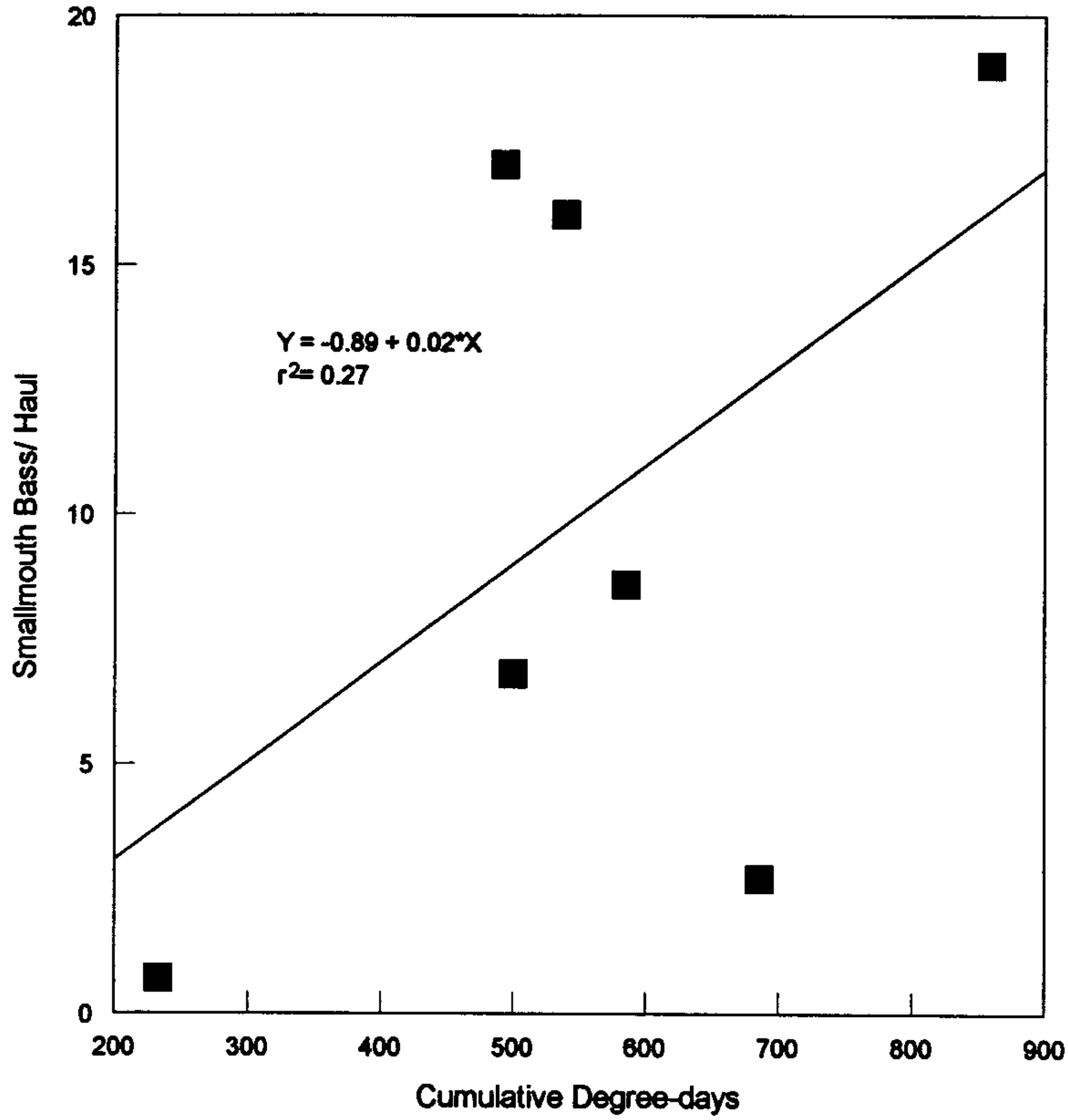

Figure 35. Relationship between catch per unit effort and cumulative degree-days up to collection date from 1987 to 1994 for smallmouth bass collected by beach seine in Lower Granite Reservoir.

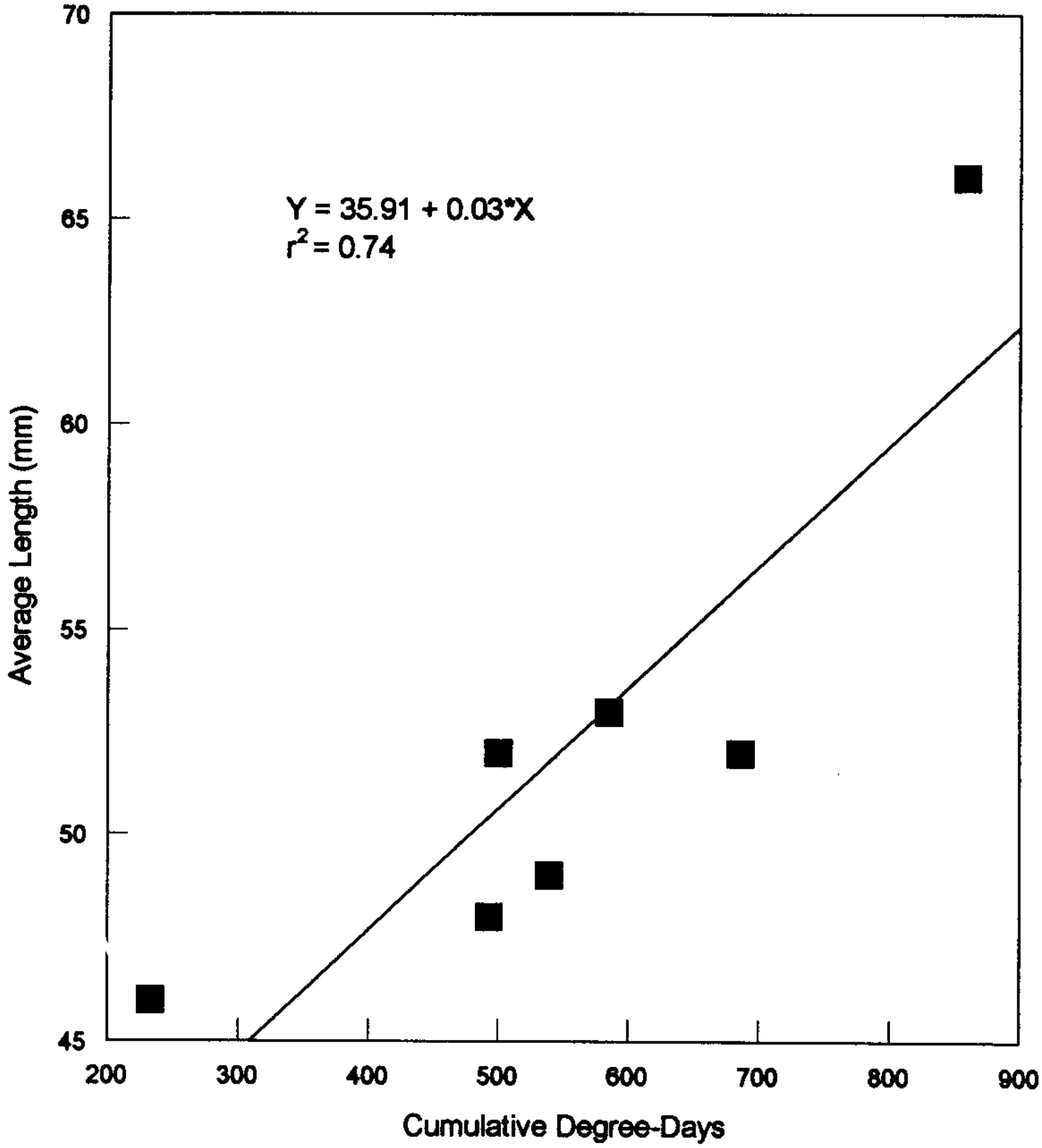

Figure 36. Relationship between average length of smallmouth bass and cumulative degree-days. Smallmouth bass were collected in Lower Granite Reservoir by beach seining from 1987 to 1994 up to the August collection date.

Over-Winter Survival

We estimated over-winter survival for the 1987, 1988, 1989, 1990, and 1994 cohorts. Over-winter survival ranged from 1.9% (1987) to 14.3% (1990) among years (Figure 37). Mean length of yearling smallmouth bass collected during May ranged from 58 to 94 mm among years (Figure 38). We were unable to identify a significant relationship ($P > 0.05$) between water temperature variables and over-winter survival. Additionally, over-winter survival of smallmouth bass was not significantly ($P > 0.05$) related to mean lengths from either August or May collections. Mean length of subyearling smallmouth bass, duration of growing season, and CPUE of August collections were not significantly ($P > 0.05$) related to over-winter survival. The duration of winter (number of days between 10° C in the fall and 10° C in the spring) did not differ significantly among years.

DISCUSSION

Spawning Success

Spring run-off and releases from Dworshak Reservoir influence the flow and temperature of water entering Lower Granite Reservoir during the smallmouth bass spawning period. Although higher flows can influence spawning success by scouring nests, lowering water temperatures, and increasing siltation. Scouring of smallmouth bass spawning nests in Lower Granite Reservoir is not likely due to the relatively low shoreline velocities that occur throughout the reservoir. Only decreased water temperatures are a potential effect in Lower Granite Reservoir. Water temperature influences the timing of spawning, the nest guarding behavior of male smallmouth bass, and the duration of the growing season.

Our results suggest that water temperature and duration of the first growing season are important factors in regulating spawning success and growth of subyearling smallmouth bass. Serns (1982) observed a significant relationship

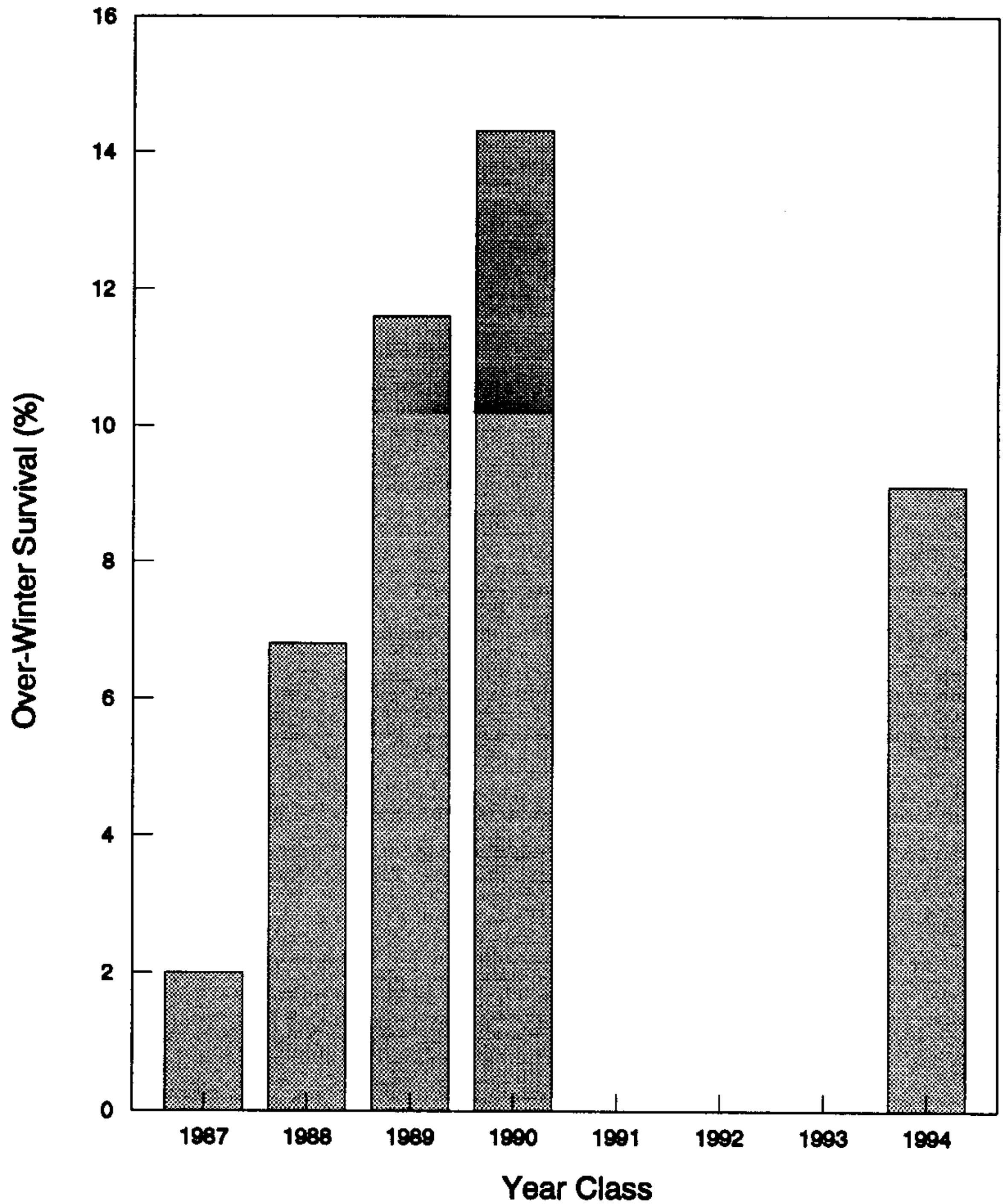

Figure 37. Smallmouth bass over-winter survival of the 1987, 1988, 1989, 1990, 1991, and 1994 cohorts in Lower Granite Reservoir.

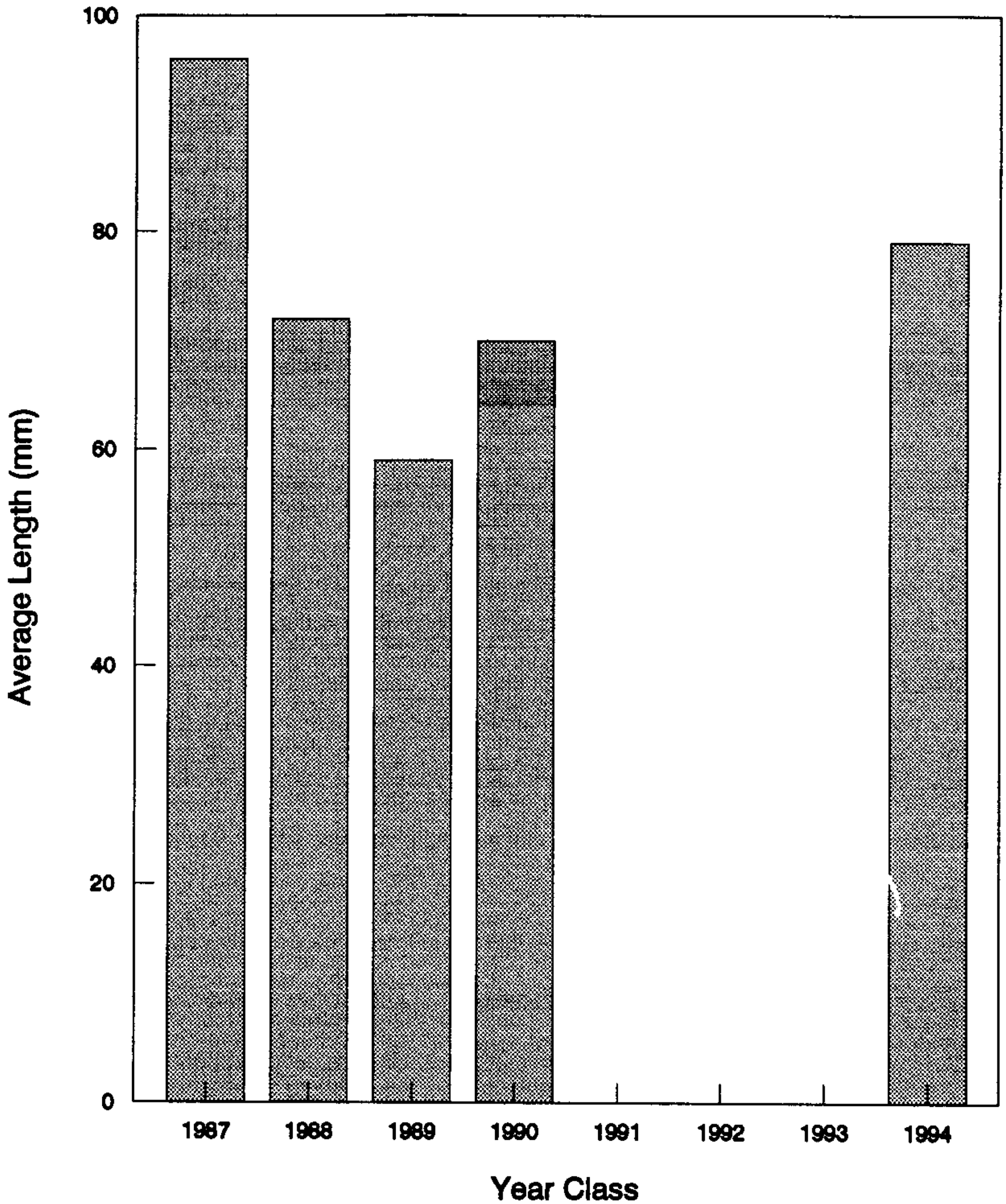

Figure 38. Average lengths of the 1987, 1988, 1989, 1990, and 1994 cohorts of smallmouth bass from May beach seine collections at Lower Granite Reservoir.

between water temperature during the first growing season of smallmouth bass and abundance in fall. However, our results differ because we observed a significant relationship between water temperature in June and mean length of age-0 smallmouth bass in fall whereas Serns (1982) did not. Other authors have noted the importance of water temperature in regulating growth of smallmouth bass (Coble 1967; Carlander 1977; Coutant and DeAngelis 1983). Our work shows that the magnitude and duration of the growing season is more important than the timing of spawning in predicting first year abundance and growth of smallmouth bass.

Over-Winter Survival

Our evaluation of the influence of first year temperatures and length of subyearling smallmouth bass in August on over-winter survival proved inconclusive. Higher over-winter survival would be expected from cohorts that attained a longer length at the end of the first growing due to increased energy stores of larger fish (Oliver et al. 1979). Shuter et al. (1985) noted that size at the end of the first growing season was related to over-winter survival. They observed smallmouth bass < 60 mm in fall collections, but failed to collect fish of this size the following spring. Over-winter survival in Lower Granite Reservoir may not be related to first year growth, if winter conditions were mild enough that no survival advantage is experienced by larger smallmouth bass. Over-winter survival in streams may be reduced by excessive flows that can dislodge juvenile bass from holding positions within rock crevices or by increasing over-wintering energey demands. Flows of a magnitude capable of flushing juvenile smallmouth bass from over-winter holding habitat most likely do not occur in Lower Granite Reservoir.

Our effort has identified first year water temperatures as a factor that may regulate spawning success and growth of smallmouth bass. Future studies examining smallmouth bass recruitment should collect data on additional variables such as food availability and quality, spawning locations, direct observations of spawning smallmouth bass, quality of spawning period, and over-winter habitat selected by subyearling smallmouth bass. With the addition of these variables, we may be able to identify other factors that influence spawning success and over-winter survival.

Objective 5. To evaluate food and feeding guilds for resident and juvenile anadromous salmonid fishes in Lower Granite Reservoir.

METHODS

Collection Procedures

Three strata (stratum 1 RM 131.0 - 139.75, RKM 211 - 225; stratum 2 RM 120.0 - 131.0, RKM 193.2 - 211; and stratum 3 RM 1075.5 - 120.0, RKM 173.1 - 193.2) and 258 possible sites were identified in Lower Granite Reservoir for sampling salmonids and resident fishes (Objective 1; Figure 2). In 1994, 50 sites were randomly sampled on a monthly basis. In 1995, 60 sites were randomly sampled semimonthly from May through July and monthly in April and August through November. Collections were made by electrofishing and beach seining (Objective 1).

All resident fish and juvenile salmonids sampled were placed in live wells immediately upon capture, and their length and weight were measured (Objective 1). We sampled a maximum of 10 to 15 stomachs per location per species within each of the three strata (Objective 1)

Dietary Collection and Lab Analysis

Stomach contents of hatchery and wild steelhead and chinook salmon and more abundant resident fishes were analyzed to describe seasonal changes in diet. Preserved prey items were consolidated into 11 categories: nonfood items, miscellaneous aquatics, insects, crustaceans/molluscs, terrestrial insects, ephemeroptera, plecoptera, trichoptera, diptera, insect parts/unrecognizable food, non-Salmonidae, and Salmonidae (Table 21). Prey were identified to lowest practical taxon. Number and digested weight (blot dried) of each prey item were recorded. When possible, parts of insects were combined with similar prey items and the total number for each group was estimated. Partially digested, unidentifiable

Table 21. Food item and category of items taken from stomachs of resident and juvenile anadromous fishes in Lower Granite Reservoir during 1994 and 1995.

Food item	Category
Detritus	Nonfood
Plant (food)	Nonfood
Plant (nonfood)	Nonfood
Inorganic items	Nonfood
Hydra	Misc. aquatics
Planariidae	Misc. aquatics
Nematoda	Misc. aquatics
Hirudinea	Misc. aquatics
Oligochaeta	Misc. aquatics
Polychaeta	Misc. aquatics
Crustaceans	
Amphipoda	
Corophium	Crustaceans/molluscs
Gammarus	Crustaceans/molluscs
Exuviae	Nonfood
Cladocera	Crustaceans/molluscs
Leptodora	Crustaceans/molluscs
Copepoda	Crustaceans/molluscs
Decapoda (crayfish)	Crustaceans/molluscs
Isopoda	Crustaceans/molluscs
Ostracoda	Crustaceans/molluscs
Arachnida	Terrestrial insects
Acari (water mites)	Terrestrial insects
Aquatic insects	
Collembola	Misc. aquatics
Ephemeroptera (UID[a], adults)	Ephemeroptera
Baetidae	Ephemeroptera
Caenidae	Ephemeroptera
Ephemerellidae	Ephemeroptera
Ephemeridae	Ephemeroptera
Heptageniidae	Ephemeroptera
Leptophlebiidae	Ephemeroptera
Siphlonuridae	Ephemeroptera
Tricorythidae	Ephemeroptera
Exuviae	Nonfood
Odonata	
Zygoptera (damselfly)	Misc. aquatics
Anisoptera (dragonfly)	Misc. aquatics
Plecoptera (adult, nymph, exuviae)	Plecoptera

Table 21. Continued.

Food item	Category
Aquatic insects (continued)	
Hemiptera	Misc. aquatics
Trichoptera (adult, UID)	Trichoptera
Brachycentridae	Trichoptera
Hydropsychidae	Trichoptera
Hydroptilidae	Trichoptera
Polycentropidae	Trichoptera
Exuviae	Nonfood
Lepidoptera	Misc. aquatics
Coleoptera (beetle)	Misc. aquatics
Diptera	
Chironomidae (adult, larvae, pupae)	Diptera
Other Diptera (adult, larvae, pupae)	Diptera
Exuviae	Nonfood
Molluscs	
Gastropoda	Crustaceans/molluscs
Pelecypoda	Crustaceans/molluscs
Terrestrial insects	
Dermaptera (earwigs)	Tterrestrial insects
Hydracarina (water mites)	Terrestrial insects
Homoptera	Terrestrial insects
Aphididae	Terrestrial insects
Hymenoptera	Terrestrial insects
Orthoptera (grasshopper)	Terrestrial insects
Insecta misc. (i.e. Isoptera)	Terrestrial insects
Insect parts (UID)	Insect parts/UID food
Fishes (larval, UID whole and parts)	Non-Salmonidae
Salmonid (UID)	Salmonidae
Chinook	Salmonidae
Steelhead (rainbow trout)	Salmonidae
Whitefish	Salmonidae
Nonsalmonid (UID)	Non-Salmonidae
Catostomidae	Non-Salmonidae
Centrarchidae (UID)	Non-Salmonidae
Bluegill	Non-Salmonidae
Crappie	Non-Salmonidae
Green sunfish	Non-Salmonidae
Largemouth bass	Non-Salmonidae
Pumpkinseed	Non-Salmonidae
Smallmouth bass	Non-Salmonidae

Table 21. Continued.

Food item	Category
Fishes	
Cottidae	Non-Salmonidae
Clupeidae	Non-Salmonidae
Ictaluridae	Non-Salmonidae
Percidae	Non-Salmonidae
Cyprinidae (UID)	Non-Salmonidae
Carp	Non-Salmonidae
Chiselmouth	Non-Salmonidae
Peamouth	Non-Salmonidae
Redside shiner	Non-Salmonidae
Northern squawfish	Non-Salmonidae
Misc. food item (i.e. fish eggs)	Insect parts/UID food
Misc. nonfood item (i.e. plastic)	Nonfood
UID material	Insect parts/UID food
Exuviae UID	Nonfood

[a] UID = unrecognizable items

foods were weighed as a group. Digested weights were obtained by blotting prey items dry and weighing to the nearest milligram.

When prey fish were found in a stomach sample, fork length (nearest mm) was measured and weights were obtained to the nearest milligram. When prey fish were too digested to properly identify, diagnostic bones from cleitherum, opercle, dentary, hypural bones, and vertebrae were used to distinguish between salmonid and nonsalmonid prey (Hansel et al. 1988). Species identification was further determined using a key to bones to aid in specific bone morphological traits.

Dietary Consumption Frequencies

Seasonal changes in diets of salmonids and resident fishes were determined using percent frequency of occurrence for each prey item category. Values of frequency of occurrence were determined for specific prey types by groups (Table 21). Prey items were consolidated from prior identification to lower taxon prior to calculating occurrence frequencies.

To test for dietary overlap, we used the Statistical Analysis System Proc Freq and conducted a comparison of proportions of food items in stomachs. A non-zero correlation (alternative hypotheses) was examined and dietary overlap was considered significant if $P < 0.05$.

RESULTS

We found 93 different items in the stomachs of resident and juvenile anadromous fishes and consolidated the items into 11 categories (Table 21). The frequency of occurrence of these food items in wild and hatchery chinook salmon and steelhead and six resident fishes were examined.

Hatchery Chinook Salmon

In fall 1994, we sampled the stomach contents from nine hatchery chinook salmon that ranged in length from 279 to 393 mm (Figure 39). Crustaceans/molluscs, diptera, insect parts, and nonfood items accounted for the majority of food items in the samples (Figure 40). The remaining items accounted for less than 7% of the stomach contents.

In spring 1995, we sampled food items from 208 hatchery chinook salmon that ranged in length from 74 to 229 mm (Figure 39). The majority of the fish sampled ranged from 110 to 144 mm. Hatchery chinook salmon consumed mainly nonfood items, diptera, and insect parts (Figure 40). Other items of lesser importance were terrestrial insects and ephemeroptera (mayflies).

In summer 1995, we sampled three hatchery chinook salmon that ranged in length from 100 to 179 mm (Figure 39). Few items were found in the stomachs of hatchery chinook salmon during summer (Figure 40). Terrestrial insects and miscellaneous aquatics were the most important dietary items, although five items composed most of the food items.

Two hatchery chinook salmon (203 mm and 233 mm in length) were sampled for stomach contents in fall 1995 (Figure 39). Diptera was the most common item found in the stomach samples and was followed by nonfood items and terrestrial insects, which were similar in abundance (Figure 40). Miscellaneous aquatics and crustaceans/molluscs were found in less abundance and were equally present.

Wild Chinook Salmon

In fall 1994, three wild chinook salmon were sampled for stomach contents, and their lengths ranged from 283 to 307 mm (Figure 41). Crustaceans/molluscs were the most common food item found (Figure 42). Insect parts and diptera were next in abundance, in about equal proportions, followed by nonfood items.

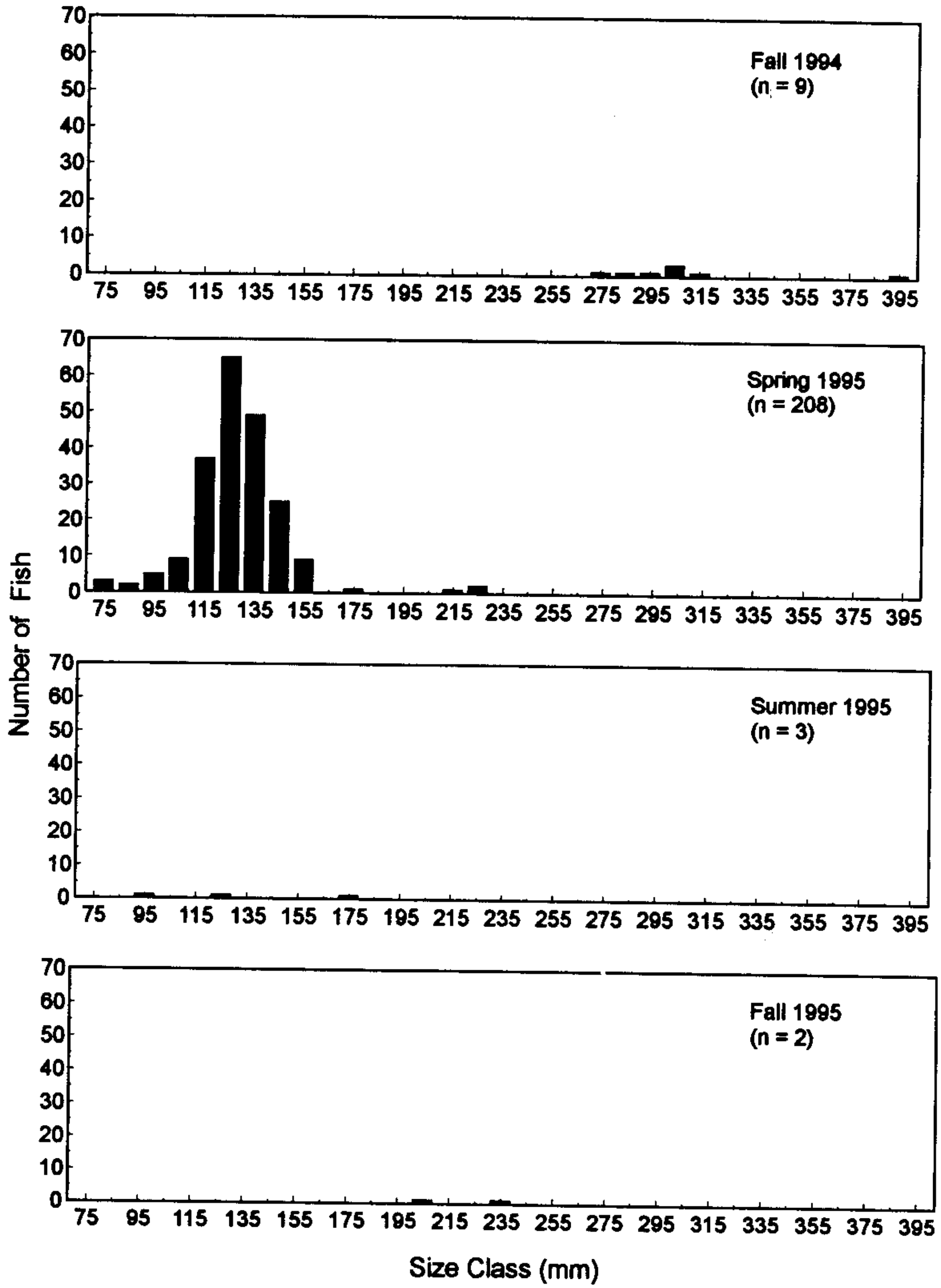

Figure 39. Length distributions of hatchery chinook salmon sampled for stomach contents in fall 1994, spring 1995, summer 1995, and fall 1995 from Lower Granite Reservoir.

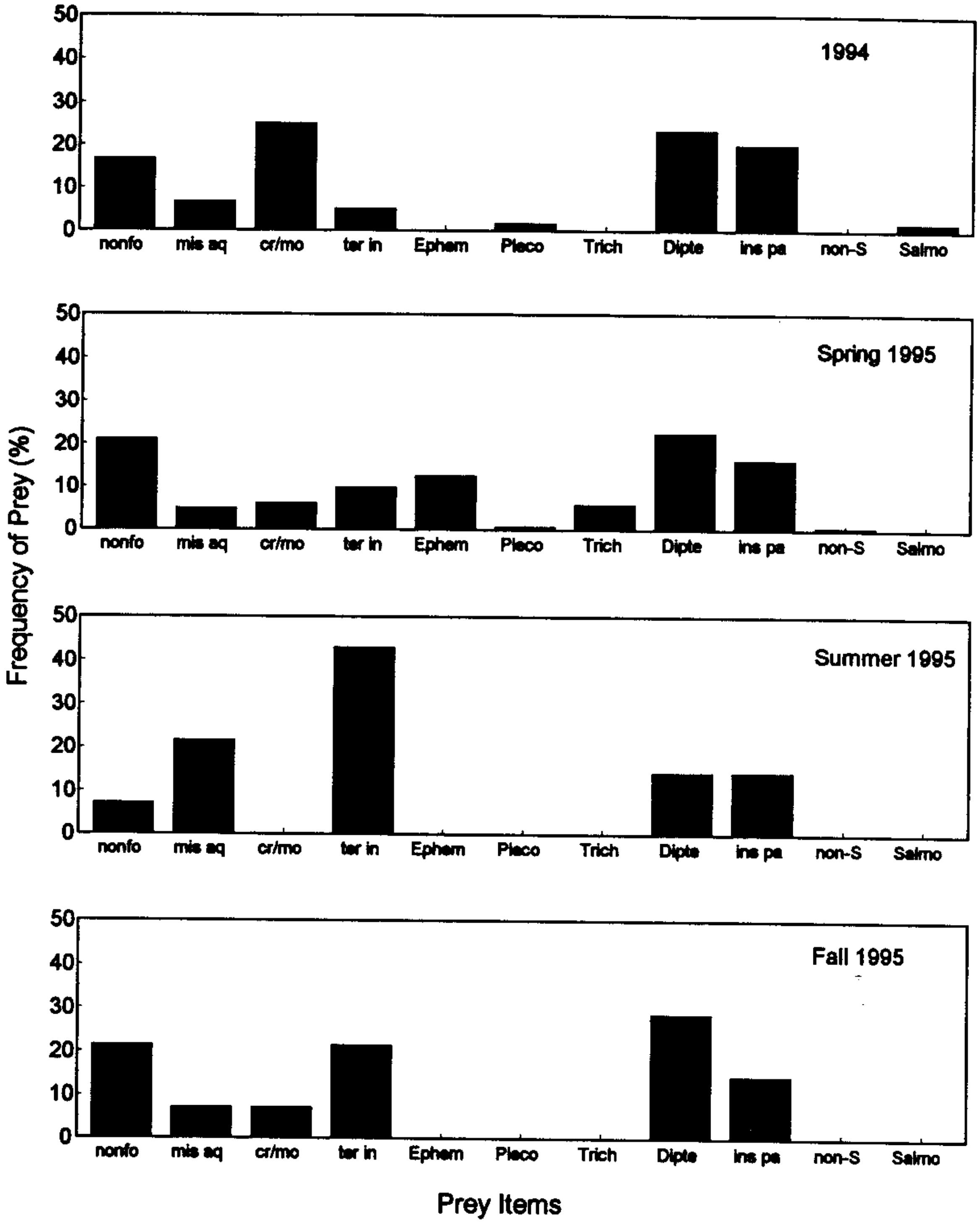

Figure 40. Prey items found in stomachs of hatchery chinook salmon sampled in 1994, spring 1995, summer 1995, and fall 1995 at Lower Granite Reservoir. Nonfood items - nonfo, misc. aquatics - mis aq, crustaceans/molluscs - cr/mo, terrestrial insects - ter in, Ephemeroptera - Ephem, Plecoptera - Pleco, Trichoptera - Trich, Diptera - Dipte, insect parts - ins pa, non-Salmonidae - non-S, Salmonidae - Salmo.

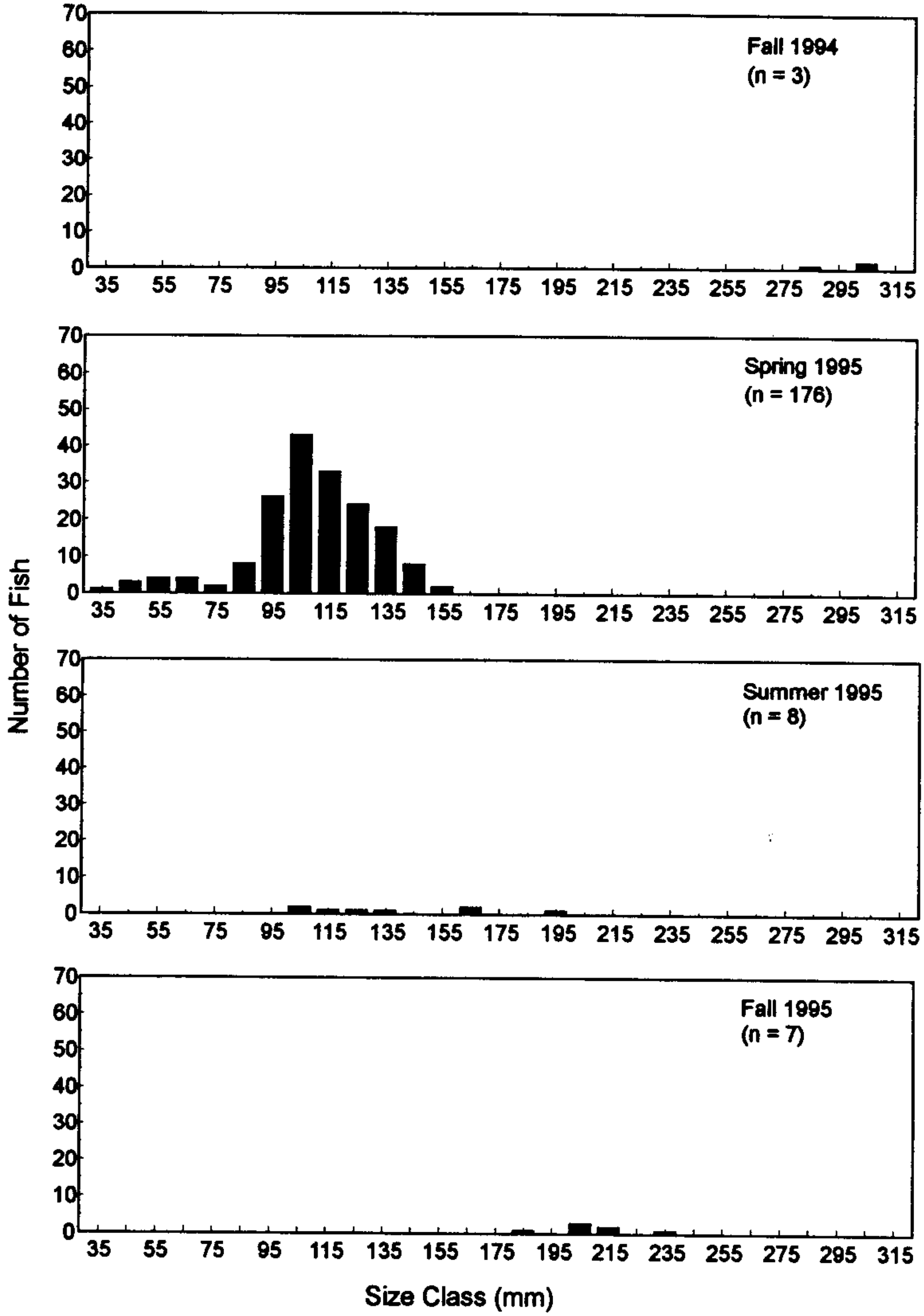

Figure 41. Length distributions of wild chinook salmon sampled for stomach contents in fall 1994, spring 1995, summer 1995, and fall 1995 from Lower Granite Reservoir.

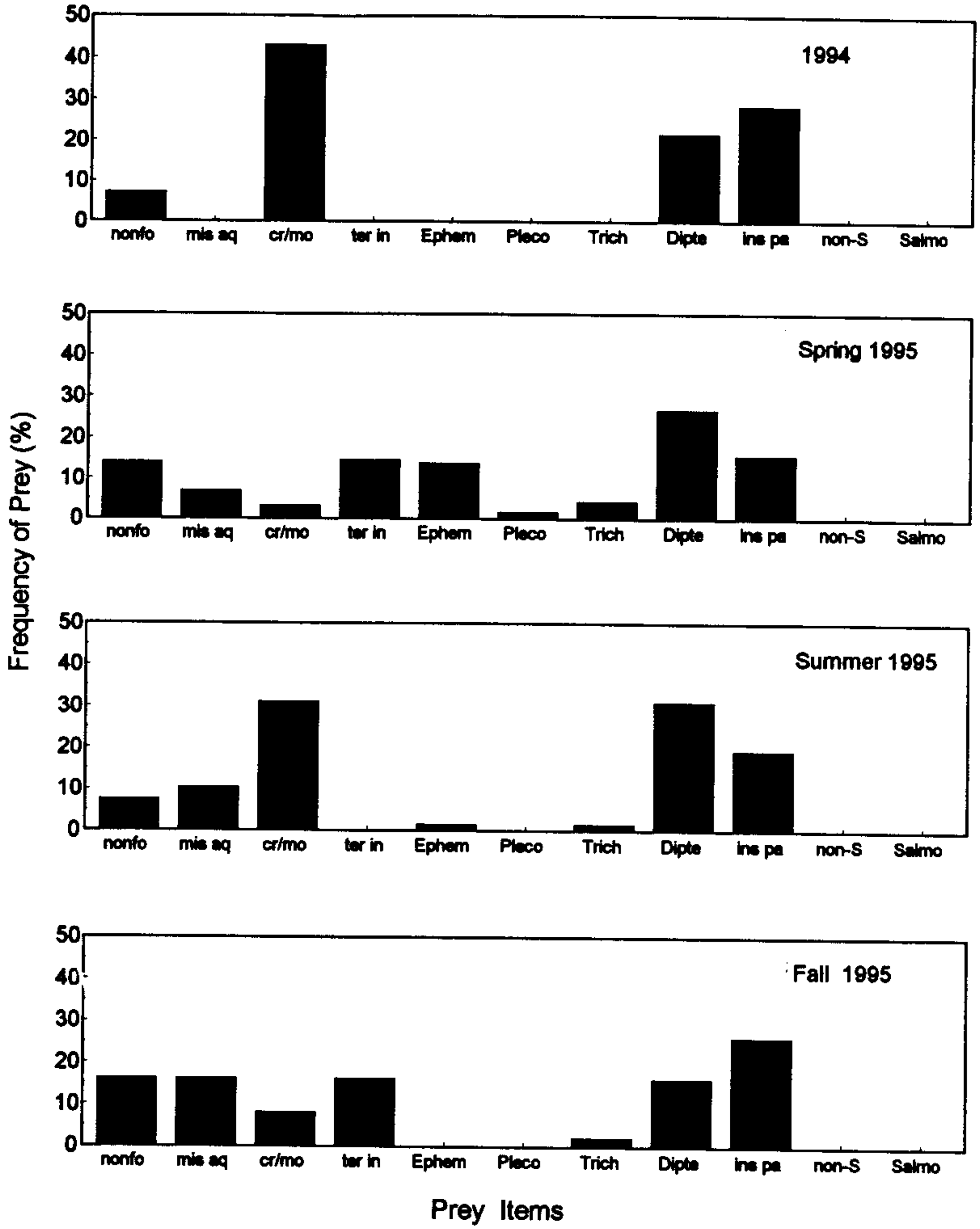

Figure 42. Prey items found in stomachs of wild chinook salmon sampled in 1994, spring 1995, summer 1995, and fall 1995 at Lower Granite Reservoir. Nonfood items - nonfo, misc. aquatics - mis aq, crustaceans/molluscs - cr/mo, terrestrial insects - ter in, Ephemeroptera - Ephem, Plecoptera - Pleco, Trichoptera - Trich, Diptera - Dipte, insect parts - ins pa, non-Salmonidae - non-S, Salmonidae - Salmo.

In spring 1995, we sampled 176 wild chinook salmon for stomach contents. These fish ranged in length from 33 to 157 mm, although most of the fish ranged from 90 and 130 mm (Figure 41). Stomach items from these samples were comprised of mostly diptera followed by insect parts, terrestrial insects, nonfood items, and emphemeroptera (Figure 42). Miscellaneous aquatics, tricopotera, and crustaceans/molluscs were present in less abundance.

In summer 1995, eight wild chinook salmon ranging in length from 101 mm to 192 mm were sampled for stomach contents (Figure 41). These stomach samples contained mostly crustaceans/molluscs, diptera, and insect parts (Figure 42). Other items accounted for less than 10% of the total food items.

Seven wild chinook salmon, ranging in length from 183 to 236 mm, were sampled for stomach contents (Figure 41). Insect parts were the most common items found, followed in equal proportions by nonfood items, miscellaneous aquatics, terrestrial insects, and diptera (Figure 42). Tricoptera (caddisflies) were the least common items consumed.

Hatchery Steelhead

In 1994, 35 hatchery steelhead, ranging in length from 204 to 330 mm, were examined for food items (Figure 43). These fish consumed mainly crustaceans/molluscs, although diptera and insect parts were present in nearly 20% of the samples (Figure 44).

In spring 1995, 127 hatchery steelhead stomachs were examined for food items. These fish ranged in length from 110 to 295 mm (Figure 43). Diptera, nonfood items, and insect parts comprised most of the food items and were found in generally equal abundance (Figure 44). Terrestrial insects were present in about 12% of the stomach samples whereas other items were present in less than 10%.

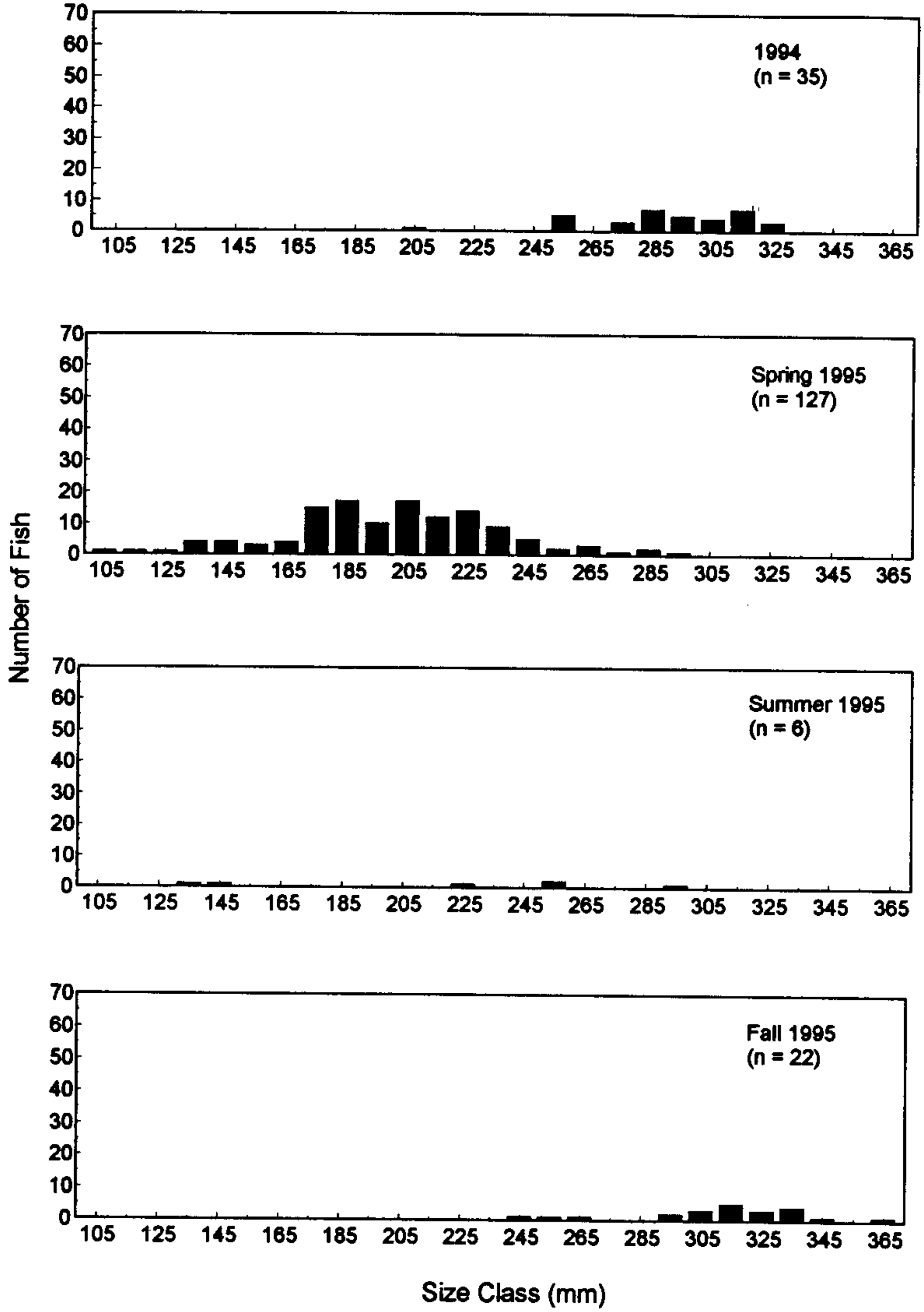

Figure 43. Length distributions of hatchery steelhead sampled for stomach contents in 1994, spring 1995, summer 1995, and fall 1995 from Lower Granite Reservoir.

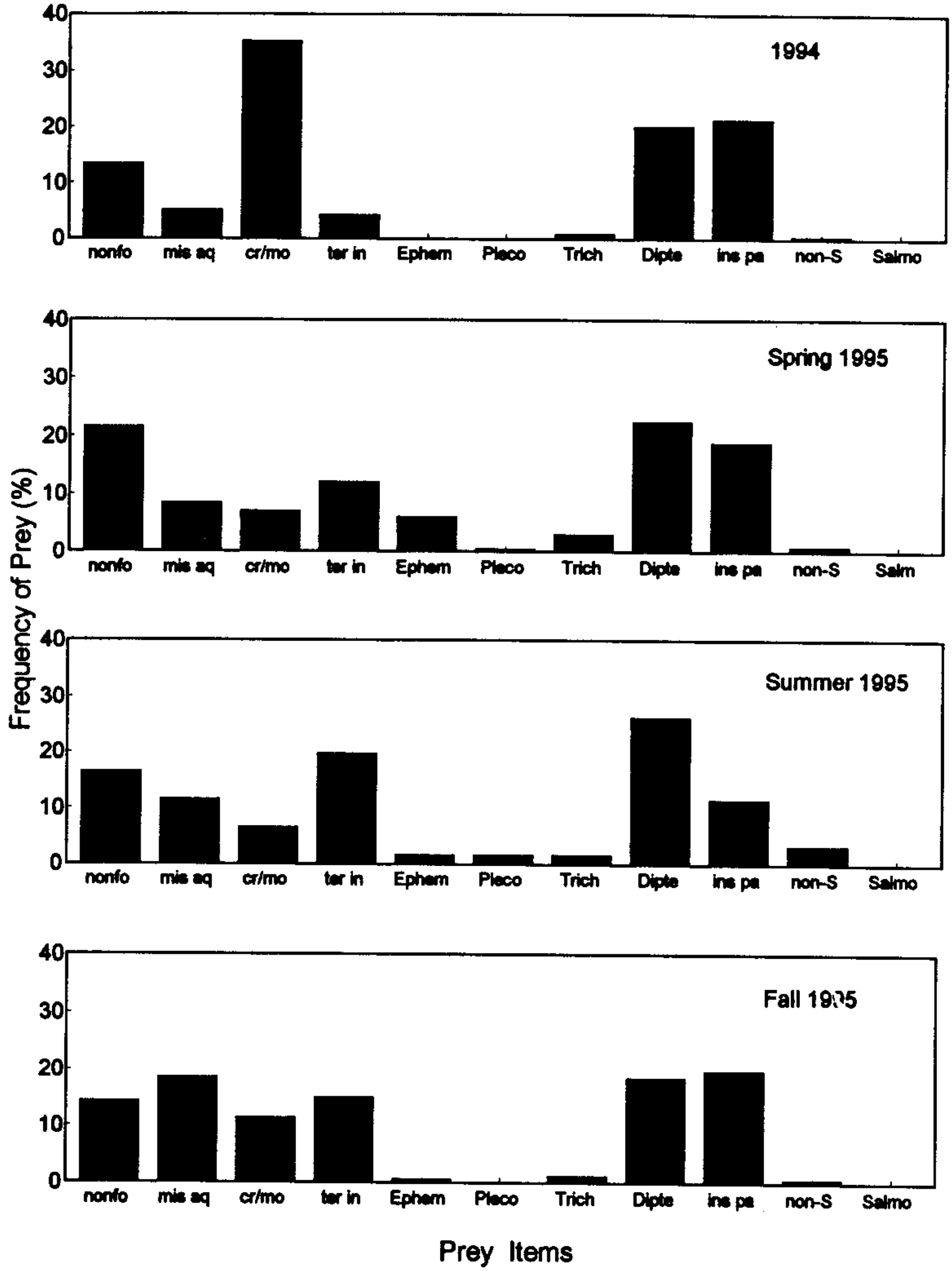

Figure 44. Prey items found in stomachs of hatchery steelhead sampled in 1994, spring 1995, summer 1995, and fall 1995 at Lower Granite Reservoir. Nonfood items - nonfo, misc. aquatics - mis aq, crustaceans/molluscs - cr/mo, terrestrial insects - ter in, Ephemeroptera - Ephem, Plecoptera - Pleco, Trichoptera - Trich, Diptera - Dipte, insect parts - ins pa, non-Salmonidae - non-S, Salmonidae - Salmo.

Six hatchery steelhead, ranging in length from 130 to 299 mm, were sampled for stomach contents in summer 1995 (Figure 43). Diptera, terrestrial insects, and nonfood items were the most common items found (Figure 44). Insect parts and miscellaneous aquatics were also present in about 12% of the samples.

In fall 1995, 22 hatchery steelhead, ranging in length from 250 to 362 mm, were sampled for stomach contents (Figure 43). Six items were commonly present: insect parts, diptera, miscellaneous aquatics, terrestrial insects, and nonfood items (Figure 44). Crustaceans/molluscs were found in about 10% of the samples.

Wild Steelhead

In 1994, we analyzed stomach items from 14 wild steelhead. These fish ranged in length from 151 to 292 mm (Figure 45). Crustaceans/molluscs, insect parts, and diptera were more commonly present in stomachs samples (Figure 46). Nonfood items, miscellaneous aquatics, and terrestrial insects were lower in abundance.

In spring 1995, wild steelhead sampled for stomach items were predominantly 100 to 150 mm and ranged from 86 to 252 mm (Figure 45). Out of 74 stomach samples, diptera and insect parts were found in about 20% of all stomachs while terrestrial insects, nonfood items, and miscellaneous aquatics were found in 10% to 12% (Figure 46).

Seventeen wild steelhead, most ranging in length from 137 to 140 mm, were sampled for stomach contents in summer 1995 (Figure 45). The largest steelhead was 201 mm. Terrestrial insects were found in more than 25% of the stomachs (Figure 46). The only other items found in more than 10% of the samples were diptera and miscellaneous aquatics.

In fall 1995, 45 wild steelhead were sampled for stomach samples. These fish ranged from 90 to 302 mm, although most ranged from 120 to 190 mm (Figure 45).

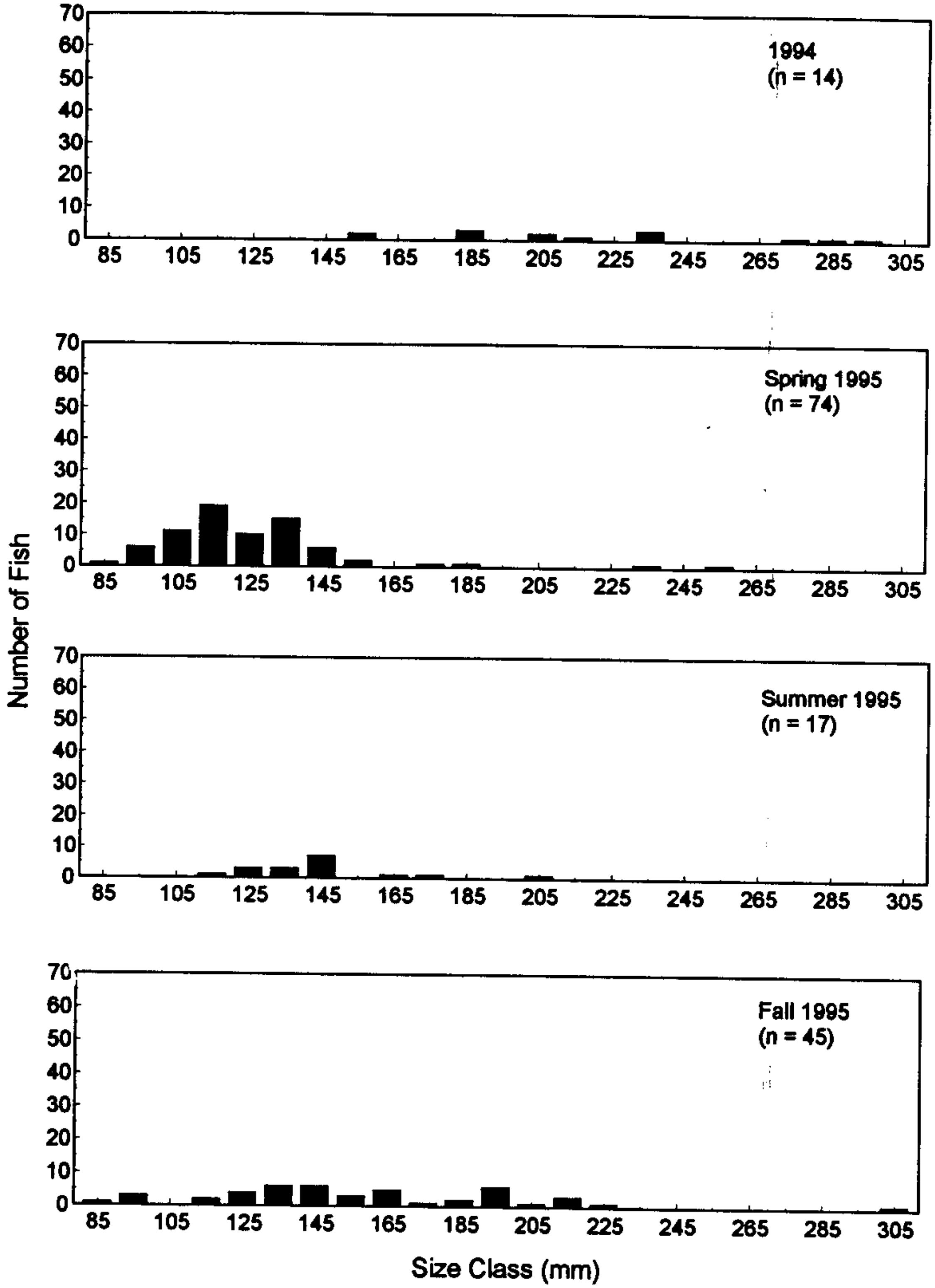

Figure 45. Length distributions of wild steelhead sampled for stomach contents in 1994, spring 1995, summer 1995, and fall 1995 from Lower Granite Reservoir.

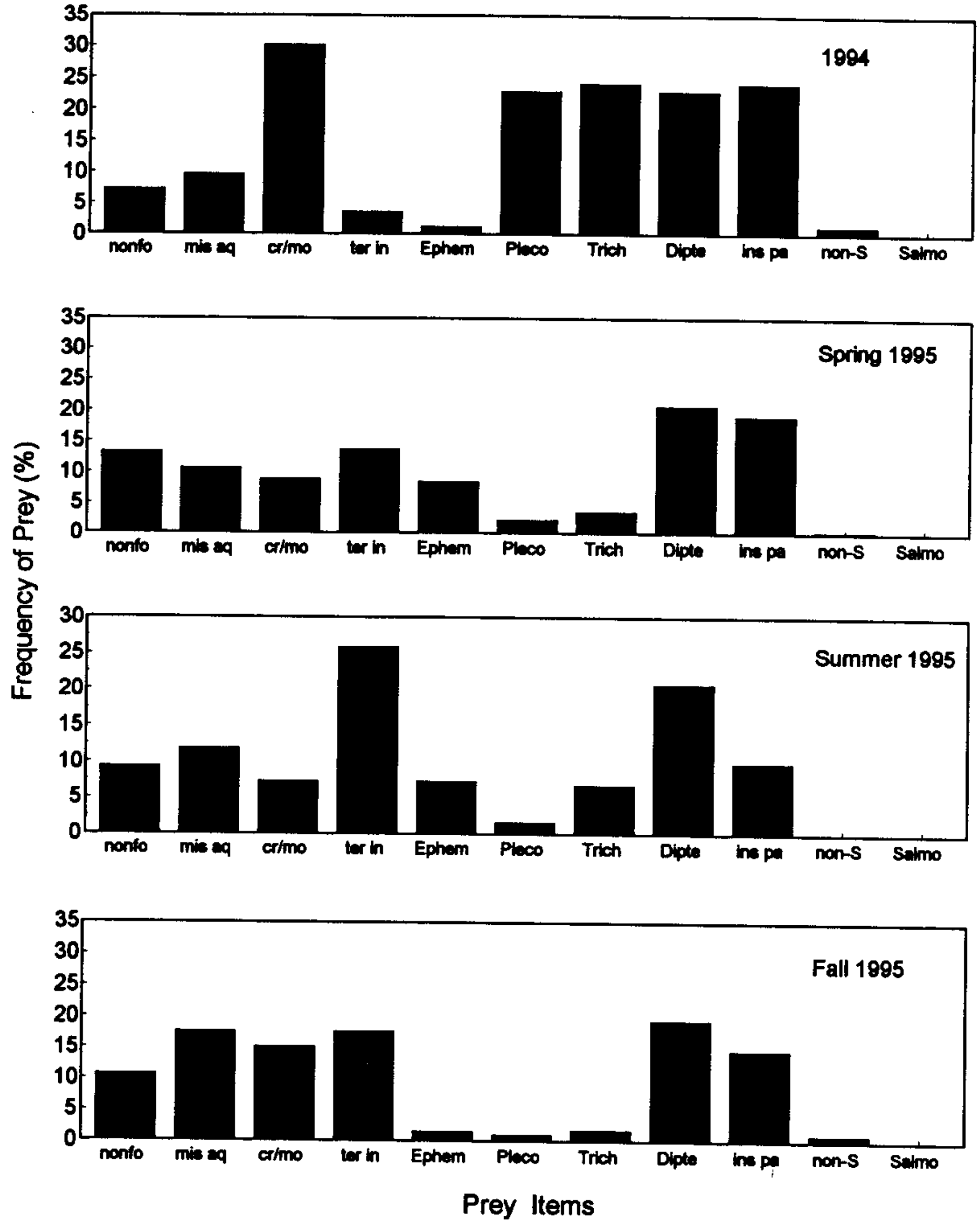

Figure 46. Prey items found in stomachs of wild steelhead sampled in 1994, spring 1995, summer 1995, and fall 1995 at Lower Granite Reservoir. Nonfood items - nonfo, misc. aquatics - mis aq, crustaceans/molluscs - cr/mo, terrestrial insects - ter in, Ephemeroptera - Ephem, Plecoptera - Pleco, Trichoptera - Trich, Diptera - Dipte, insect parts - ins pa, non-Salmonidae - non-S, Salmonidae - Salmo.

Six food items occurred in similar frequency (Figure 46). Diptera was the most common item followed by miscellaneous aquatics, terrestrial insects, insect parts, and crustaceans/molluscs. Nonfood items were present in about 11% of the samples.

Pumpkinseed

In 1994, lengths of pumpkinseed sampled for stomach contents were principally 100 mm with the largest at 167 mm (Figure 47). Samples from 59 pumpkinseed mostly contained diptera and insect parts followed by crustaceans/molluscs (Figure 48). Other items were found in less than 5% of the samples.

In spring 1995, 67 pumpkinseed ranging in length from 70 mm to 190 mm were sampled for stomach samples (Figure 47). The majority of these fish ranged from 80 to 181 mm in length. Six dietary items were most commonly found: diptera, insect parts, crustaceans/molluscs, miscellaneous aquatics, emphemeroptera, and nonfood items (Figure 48). These items individually were found in more than 10% of the samples, and diptera was the most abundant item found in nearly 25%.

In summer 1995, 141 pumpkinseed were sampled for stomachs contents. These fish were largely 120 to 160 mm and ranged from 78 to 175 mm (Figure 47). Crustaceans/molluscs and diptera were the most abundant items followed by insect parts (Figure 48). Nonfood items and miscellaneous aquatics were also present in more than 10% of the samples.

In the fall 1995, we sampled the stomach contents from five pumpkinseed, which ranged in length from 100 to 194 mm (Figure 47). These samples contained mostly crustaceans/molluscs followed by insect parts and diptera (Figure 48). No other items were present in more than 8% of the samples.

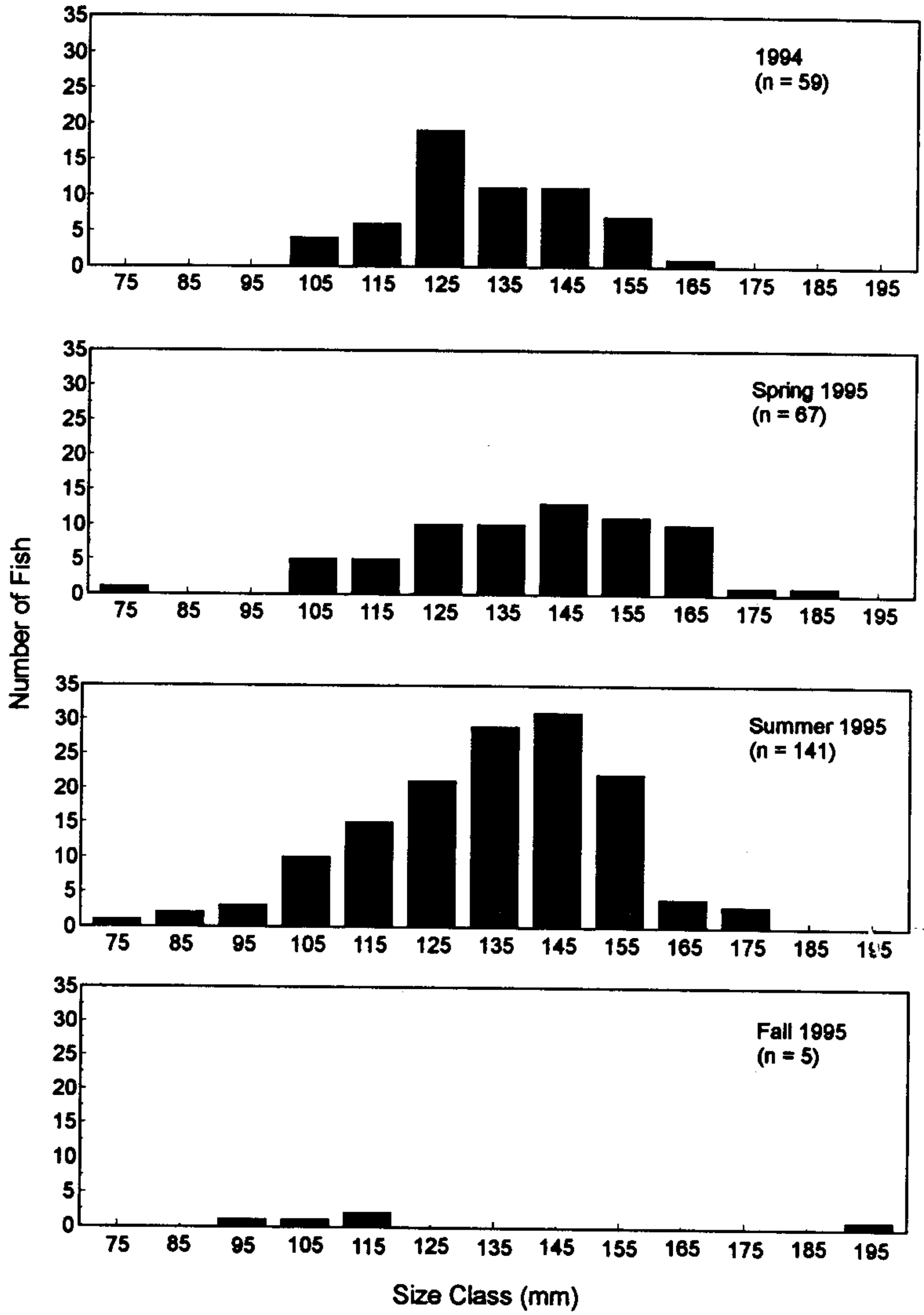

Figure 47. Length distributions of pumpkinseed sampled for stomach contents in 1994, spring 1995, summer 1995, and fall 1995 from Lower Granite Reservoir.

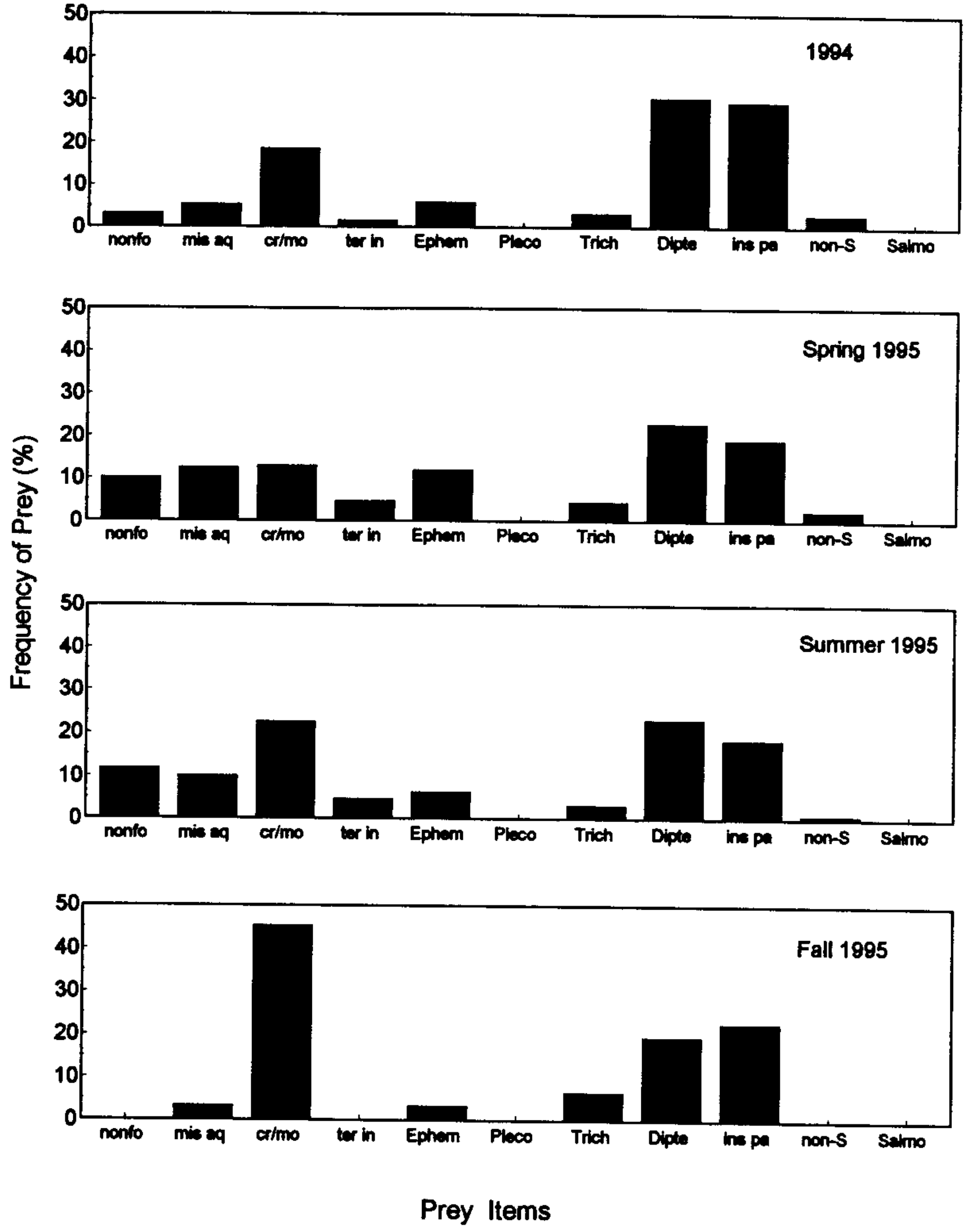

Figure 48. Prey items found in stomachs of pumpkinseed sampled in 1994, spring 1995, summer 1995, and fall 1995 at Lower Granite Reservoir. Nonfood items - nonfo, misc. aquatics - mis aq, crustaceans/molluscs - cr/mo, terrestrial insects - ter in, Ephemeroptera - Ephem, Plecoptera - Pleco, Trichoptera - Trich, Diptera - Dipte, insect parts - ins pa, non-Salmonidae - non-S, Salmonidae - Salmo.

Bluegill

In 1994, we examined the stomach contents of 14 bluegill. These fish ranged from 145 to 214 mm (Figure 49). Crustaceans/molluscs followed by diptera and insect parts were present in more than 25% of the samples (Figure 50). Other items were present in less than 5% of the stomachs.

Sixteen bluegill ranging in length from 111 to 188 mm were sampled in spring 1995 (Figure 49). Diptera was the most important item found in the samples followed by crustaceans/molluscs and insect parts (Figure 50). Terrestrial insects, miscellaneous aquatics, and nonfood items were found in more than 10% of the stomachs examined.

In summer 1995, 16 bluegill were sampled for stomach contents. These fish ranged in length from 94 to 190 mm with the majority ranging from 120 to 181 mm (Figure 49). Diptera was the most abundant item found followed by insect parts, crustaceans/molluscs, nonfood items, and emphemeroptera (Figure 50). Miscellaneous aquatics and terrestrial insects were present in more than 10% of the stomachs.

Two bluegill, 93 mm and 141 mm in length, were sampled from stomach contents in fall 1995 (Figure 49). Crustaceans/molluscs were the most abundant item followed equally by nonfood items, diptera, and insect parts (Figure 50). Ephemeroptera were present but in only 10% of the samples.

Black Crappie

Ten black crappie, ranging in length from 80 mm to 240 mm, were sampled for stomach contents in 1994 (Figure 51). Crustaceans/molluscs were the modal items, based on stomach samples, followed by diptera and insect parts (Figure 52). Miscellaneous aquatics and non-Salmonidae were next in frequency and appeared in about 5% of the samples.

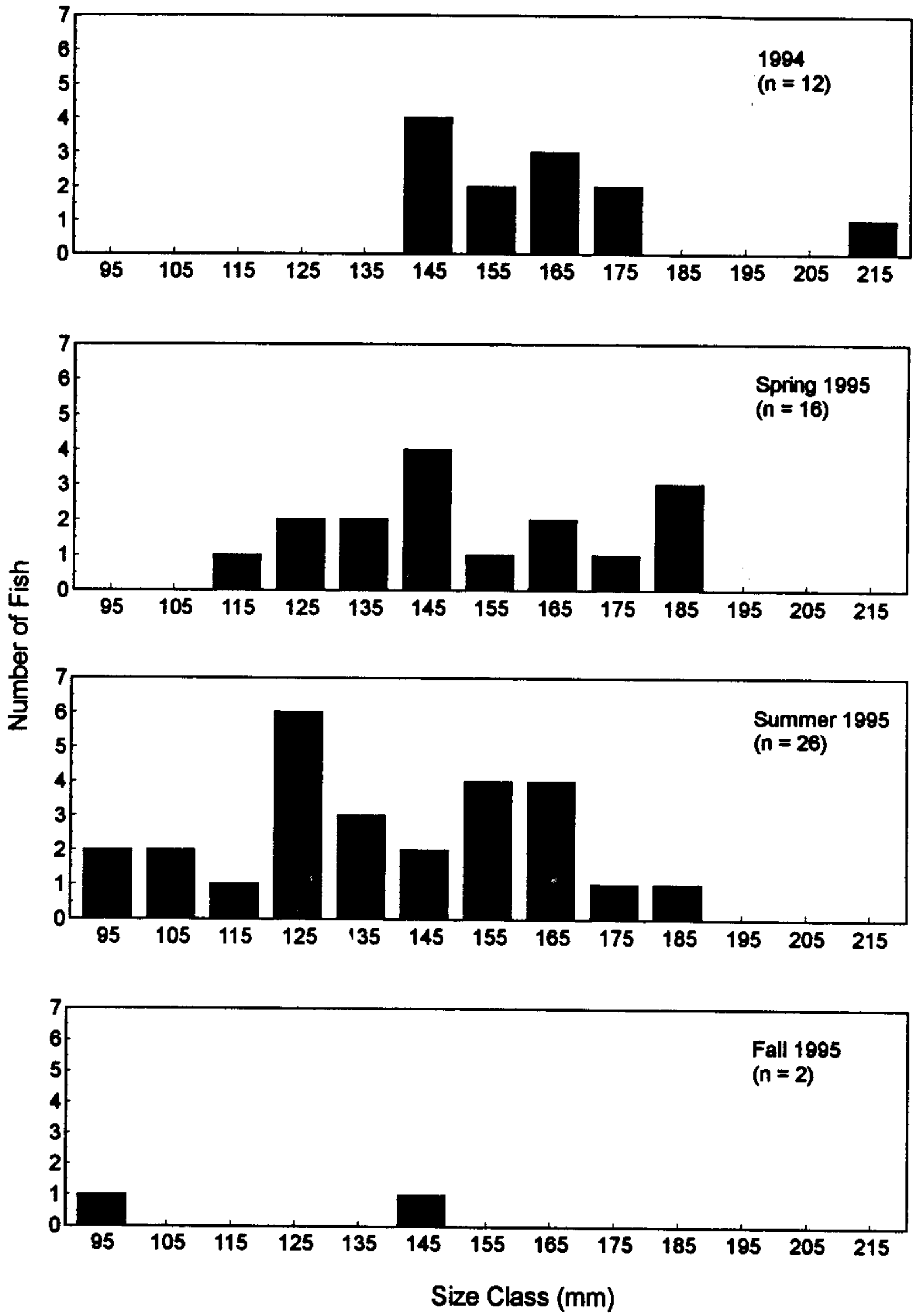

Figure 49. Length distributions of bluegill sampled for stomach contents in 1994, spring 1995, summer 1995, and fall 1995 from Lower Granite Reservoir.

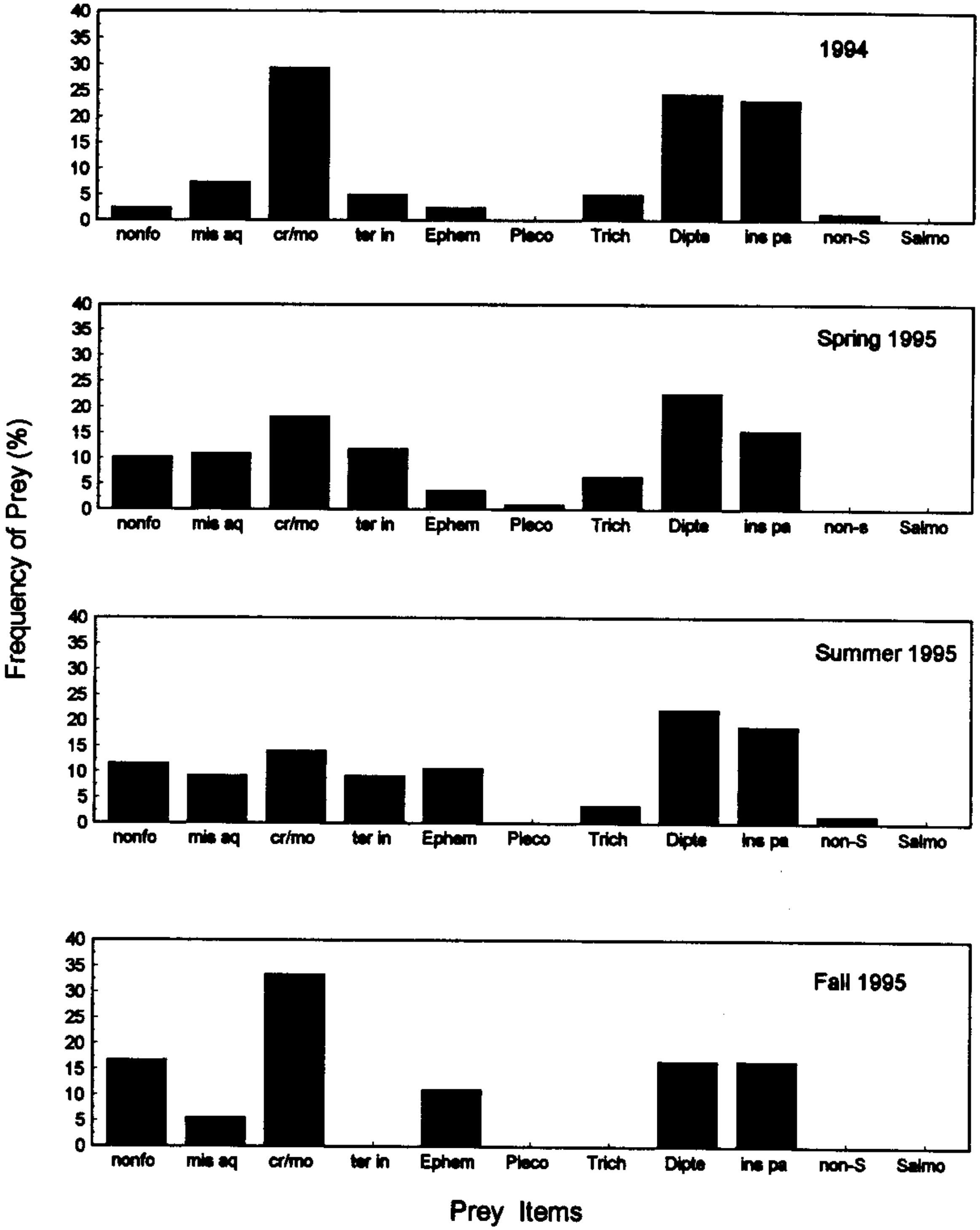

Figure 50. Prey items found in stomachs of bluegill sampled in 1994, spring 1995, summer 1995, and fall 1995 at Lower Granite Reservoir. Nonfood items - nonfo, misc. aquatics - mis aq, crustaceans/molluscs - cr/mo, terrestrial insects - ter in, Ephemeroptera - Ephem, Plecoptera - Pleco, Trichoptera - Trich, Diptera - Dipte, insect parts - ins pa, non-Salmonidae - non-S, Salmonidae - Salmo.

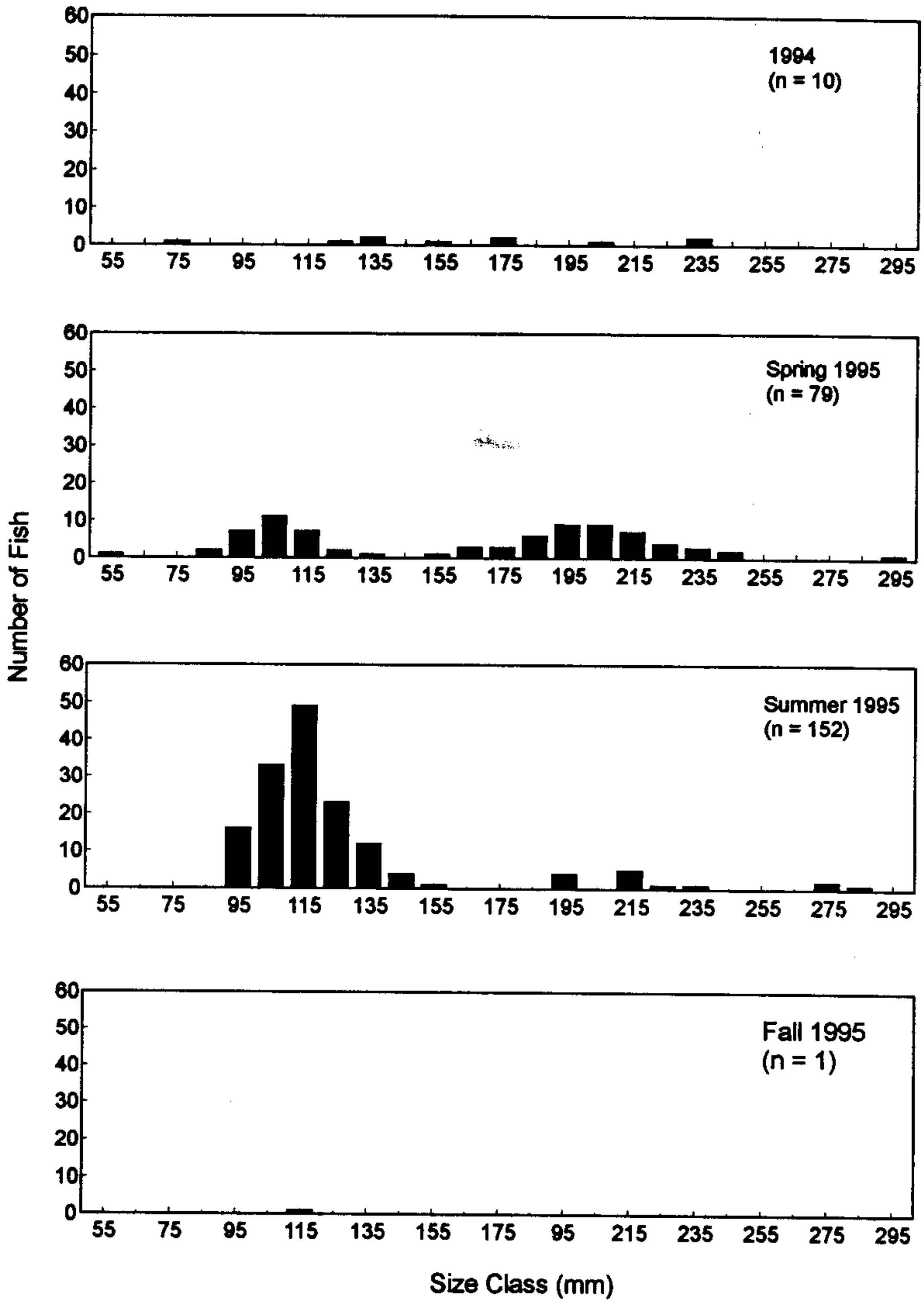

Figure 51. Length distributions of black crappie sampled for stomach contents in 1994, spring 1995, summer 1995, and fall 1995 from Lower Granite Reservoir.

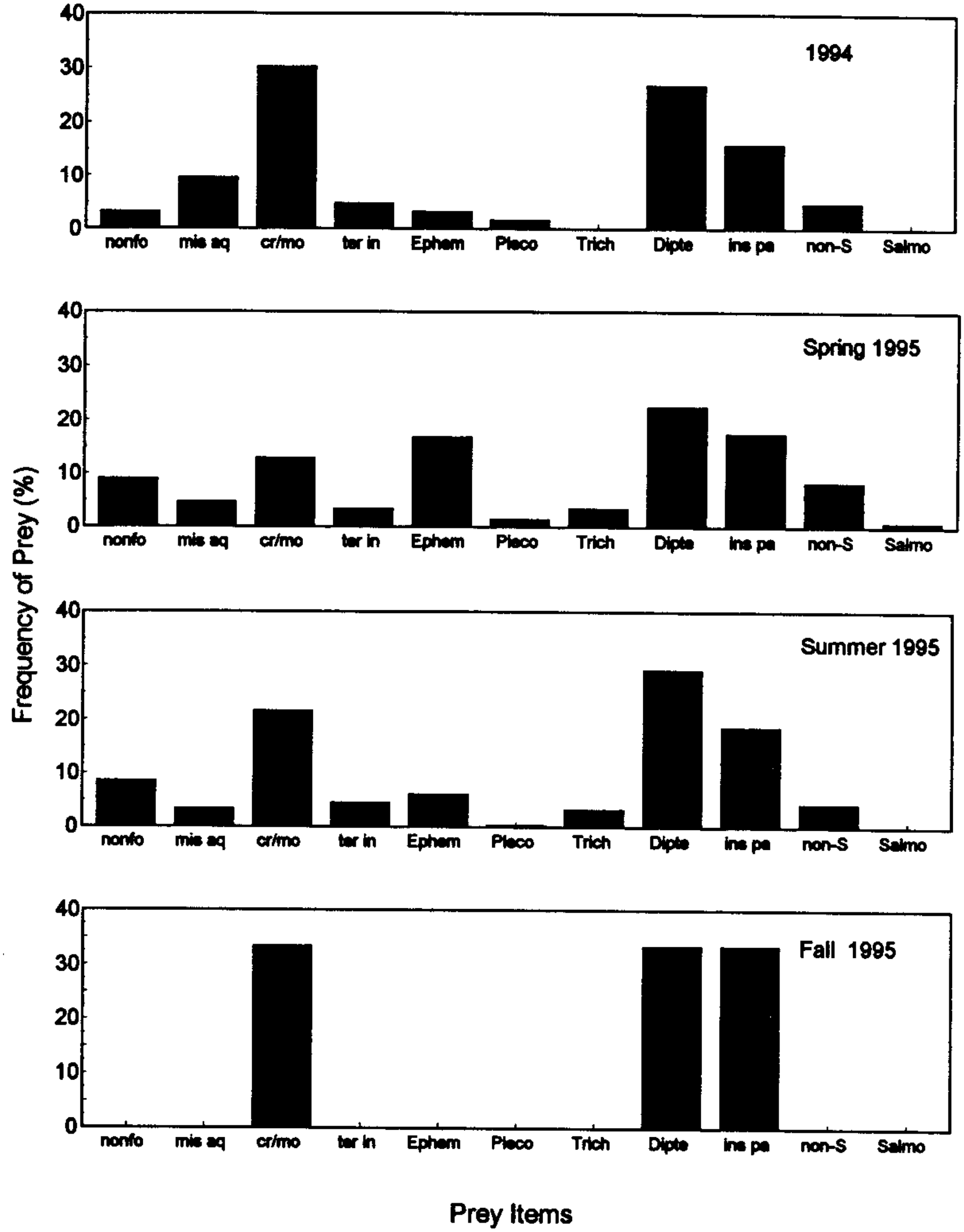

Figure 52. Prey items found in stomachs of black crappie sampled in 1994, spring 1995, summer 1995, and fall 1995 at Lower Granite Reservoir. Nonfood items - nonfo, misc. aquatics - mis aq, crustaceans/molluscs - cr/mo, terrestrial insects - ter in, Ephemeroptera - Ephem, Plecoptera - Pleco, Trichoptera - Trich, Diptera - Dipte, insect parts - ins pa, non-Salmonidae - non-S, Salmonidae - Salmo.

In spring 1995, 79 black crappies were sampled for stomach contents. These fish ranged in length from 55 to 296 mm; two modal size classes, 90 to 120 mm and 180 to 240 mm, were represented (Figure 51). The frequency of occurrence of food items was highest for diptera followed by insect parts and emphemeroptera (Figure 52). Crustaceans/molluscs were found in more than 12% of the samples while other items were less frequently present.

Black crappie sampled for stomach items in summer 1995 ranged from 98 mm to 140 mm, although the largest fish was 289 mm (Figure 51). In all, 152 samples were examined and were found to contain three major items: diptera, crustaceans/molluscs, and insect parts (Figure 52). Other items were found in less than 10% of the samples.

Crustaceans/molluscs, diptera, and insect parts were equally present in one stomach sample taken from a 113 mm black crappie in fall 1995 (Figures 51 and 52).

White Crappie

In 1994, we sampled stomach items from 14 white crappie. These fish ranged in length from 128 to 226 mm (Figure 53). Diptera were found in more than 35% of the samples (Figure 54). Insect parts, crustaceans/molluscs, and emphemeroptera were present in about 20% of the samples.

In spring 1995, 102 white crappie that ranged in length from 65 to 239 mm, primarily 90 to 105 mm, were sampled for stomach contents (Figure 53). Diptera, insect parts, and emphemeroptera were found in more than 20% of the stomachs (Figure 54).

Our summer 1995 sample of white crappie contained 171 individuals that ranged in length from 90 to 249 mm (Figure 53). Most of the stomachs samples came from white crappies 90 to 130 mm. Diptera was the most frequently found

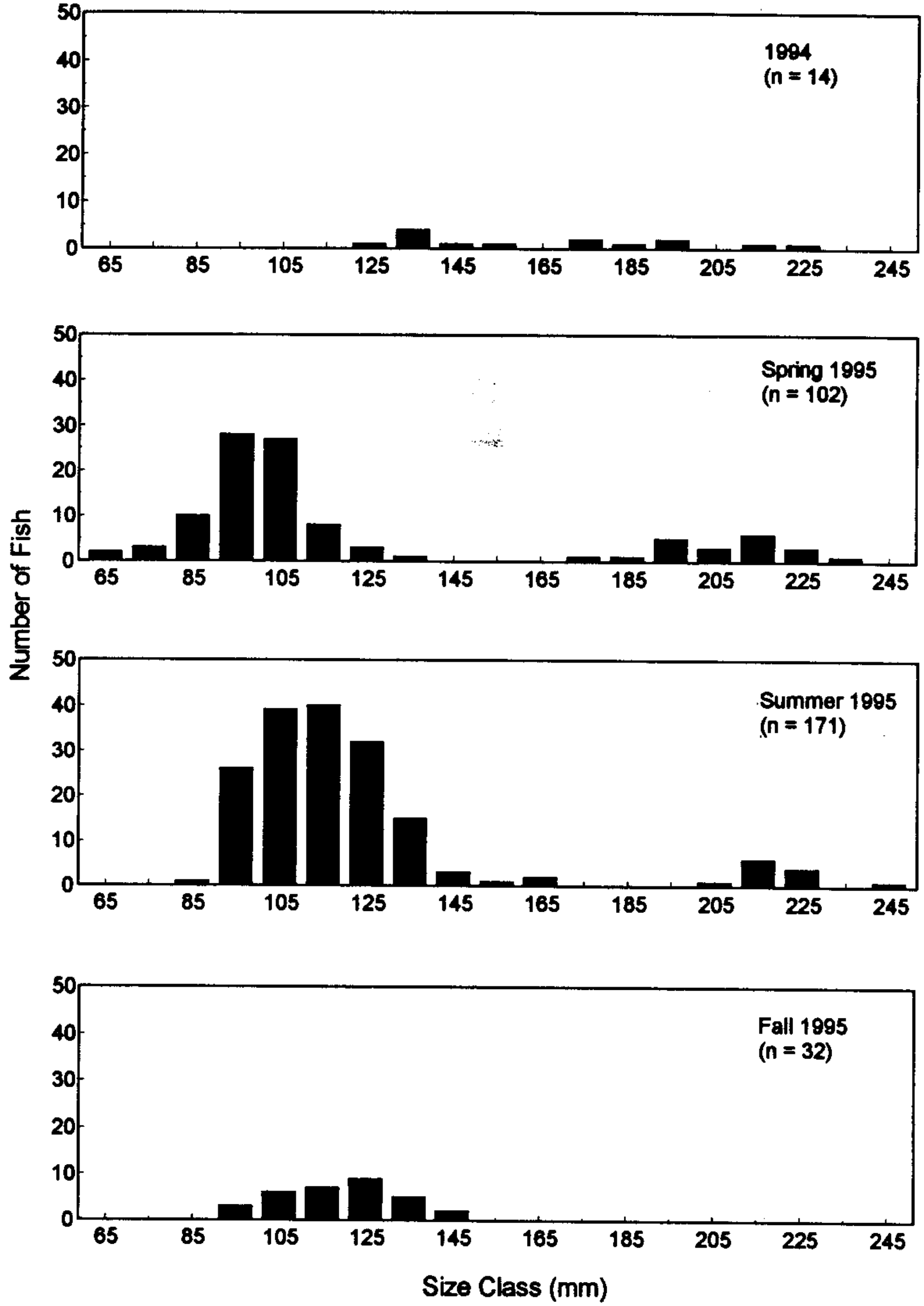

Figure 53. Length distributions of white crappie sampled for stomach contents in 1994, spring 1995, summer 1995, and fall 1995 from Lower Granite Reservoir.

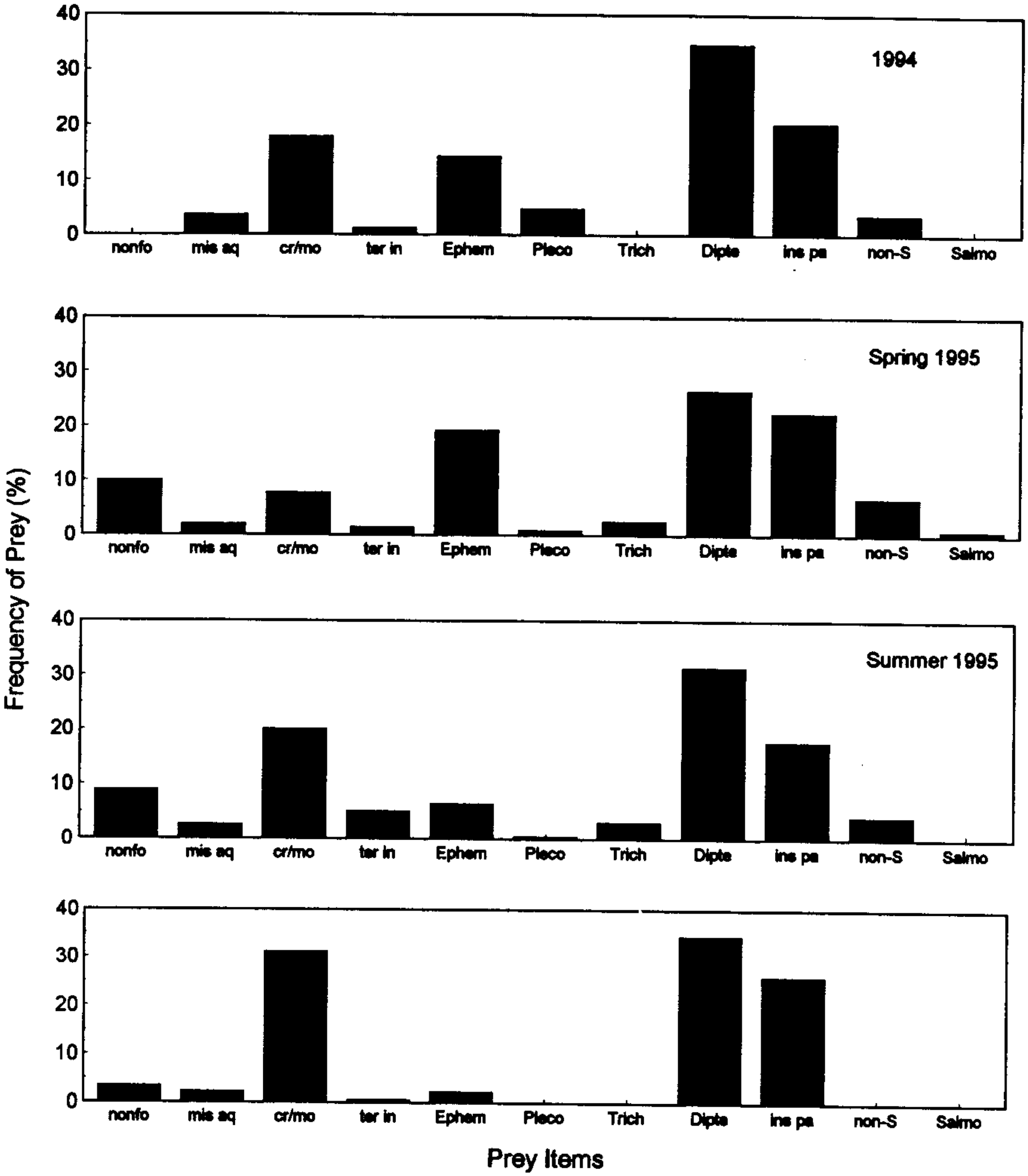

Figure 54. Prey items found in stomachs of white crappie sampled in 1994, spring 1995, summer 1995, and fall 1995 at Lower Granite Reservoir. Nonfood items - nonfo, misc. aquatics - mis aq, crustaceans/molluscs - cr/mo, terrestrial insects - ter in, Ephemeroptera - Ephem, Plecoptera - Pleco, Trichoptera - Trich, Diptera - Dipte, insect parts - ins pa, non-Salmonidae - non-S, Salmonidae - Salmo.

food item followed by crustaceans/molluscs and insect parts. No other items were found in more than 10% of the samples (Figure 54).

In fall 1995, 32 white crappie ranging in length from 94 to 150 mm were sampled for stomach contents (Figure 53). Diptera was the most common food item followed by crustaceans/molluscs and insect parts. No other items appeared in more than 5% of the samples (Figure 54).

Yellow Perch

Eight yellow perch were sampled for stomach contents in 1994. These fish ranged in length from 107 to 240 mm (Figure 55). Diptera and insect parts were present in nearly 30% of all samples and were followed by crustaceans/molluscs (Figure 56). Other items including nonfood items and non-Salmonidae were less frequently eaten.

In spring 1995, 37 yellow perch ranging in length from 96 to 282 mm were sampled for stomach contents, although most of the perch were 200 to 250 mm (Figure 55). Diptera and nonfood items occurred in about equal frequency followed by insect parts and emphemeroptera (Figure 56). Other food items were found in less than 5% of the samples.

Our sample of yellow perch collected in summer 1995 for stomach content analysis was evenly distributed from 115 to 252 mm (Figure 55). Nonfood items were most frequently found followed by diptera and insect parts (Figure 56). Other items were found in less than 10% of the samples.

In fall 1995, four yellow perch ranging in length from 108 mm to 200 mm were sampled for stomach contents (Figure 55). Diptera was the modal food item found in samples followed closely by insect parts and distantly by crustaceans/molluscs and nonfood items (Figure 56).

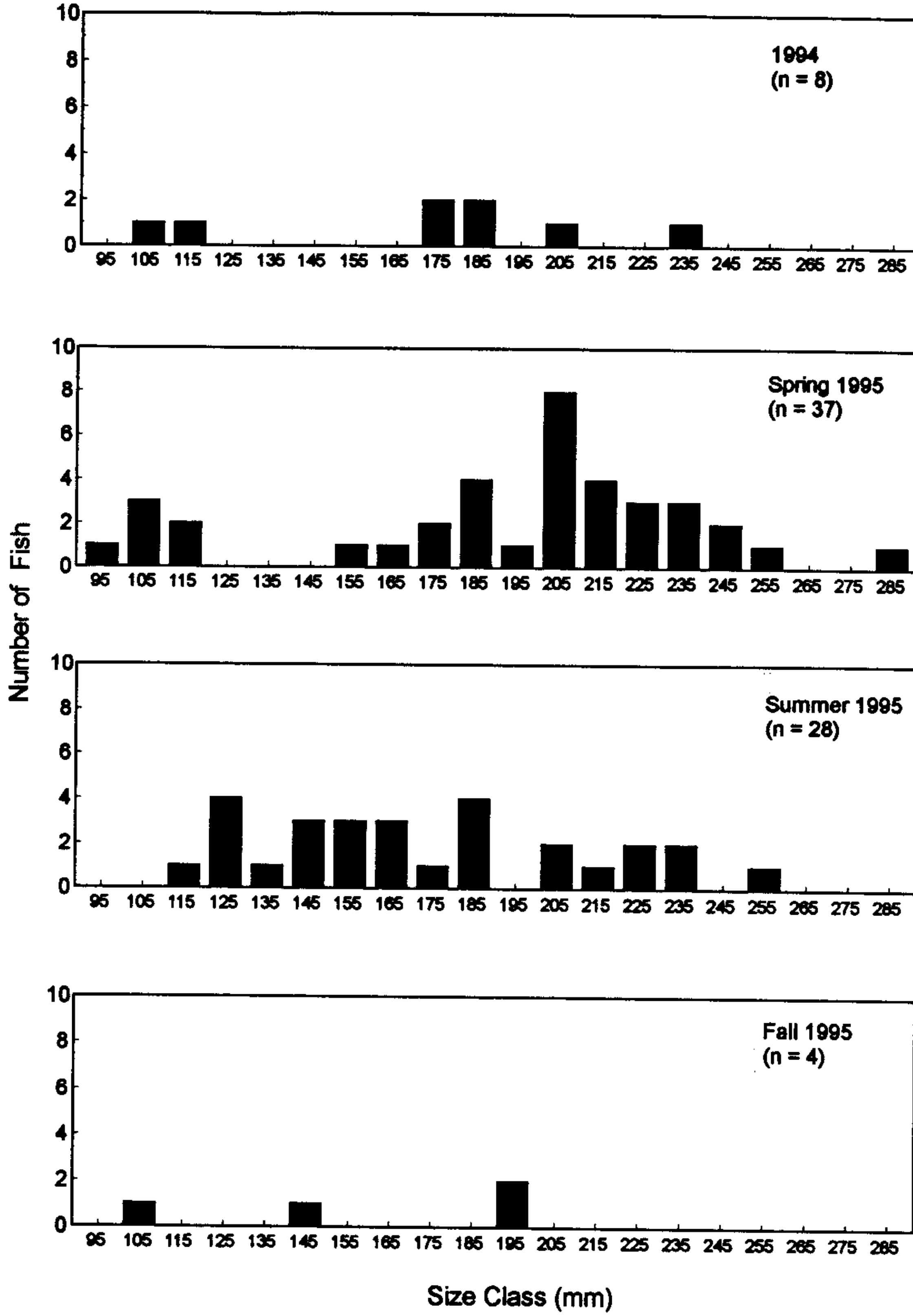

Figure 55. Length distributions of yellow perch sampled for stomach contents in 1994, spring 1995, summer 1995, and fall 1995 from Lower Granite Reservoir.

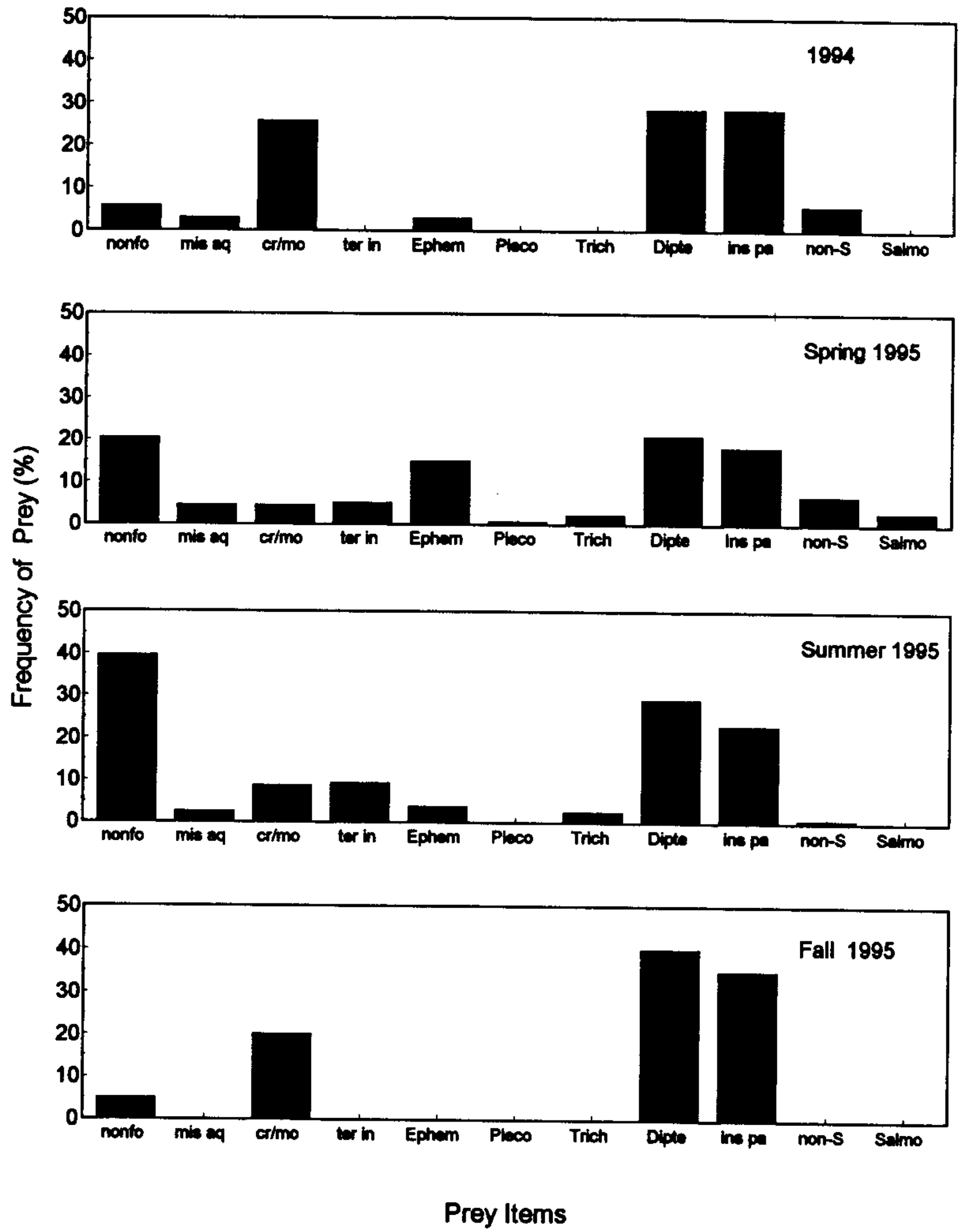

Figure 56. Prey items found in stomachs of yellow perch sampled in 1994, spring 1995, summer 1995, and fall 1995 at Lower Granite Reservoir. Nonfood items - nonfo, misc. aquatics - mis aq, crustaceans/molluscs - cr/mo, terrestrial insects - ter in, Ephemeroptera - Ephem, Plecoptera - Pleco, Trichoptera - Trich, Diptera - Dipte, insect parts - ins pa, non-Salmonidae - non-S, Salmonidae - Salmo.

Northern Squawfish

In 1994, 33 northern squawfish were sampled for stomach contents. . These fish ranged in length from 129 to 573 mm (Figure 57). Insect parts were the most important item found in samples followed by miscellaneous aquatics, diptera, and then crustaceans/molluscs (Figure 58). Other items were found in less than 5% of the samples.

In spring 1995, 76 northern squawfish were sampled for stomach contents. These fish ranged from 55 to 528 mm, although the majority were 75 to 225 mm (Figure 57). Insect parts were found in more than 35% of the samples followed by nonfood items and diptera (Figure 58). Miscellaneous aquatics were the only other items found in more than 10% of the samples.

One hundred and sixty-eight northern squawfish were sampled for stomach items in summer 1995. These northern squawfish were principally 76 to 131 mm with a few ranging from 160 to 437 mm (Figure 57). Insect parts were the most frequently identified food item (Figure 58). Other stomach items were present in about equal frequency, but other than insect parts, only nonfood items were present in more than 10% of the stomachs.

In fall 1995, 116 northern squawfish were sampled for stomach contents. Most of these fish were 100 to 125 mm in length, although a few were as large as 476 mm (Figure 57). Insect parts (50%) were the most important food item (Figure 58). Other important items included miscellaneous aquatics, crustaceans/molluscs, terrestrial insects, and nonfood items; all items were present in generally less than 10% of the samples.

Evidence of Dietary Overlap

We examined dietary overlap between hatchery and wild chinook salmon and steelhead. In 1994, hatchery and wild steelhead were not feeding proportionally on

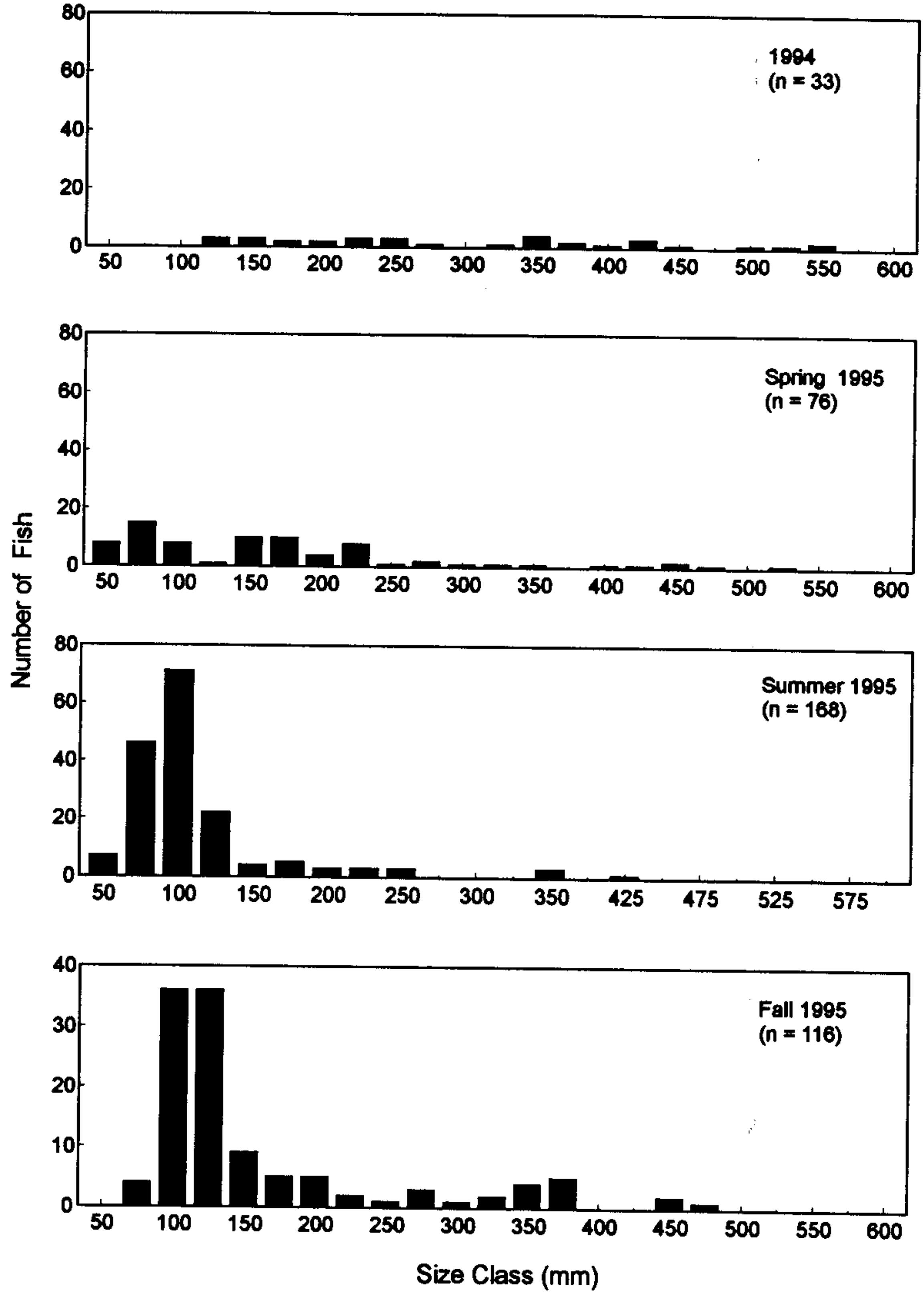

Figure 57. Length distributions of northern squawfish sampled for stomach contents in 1994, spring 1995, summer 1995, and fall 1995 from Lower Granite Reservoir.

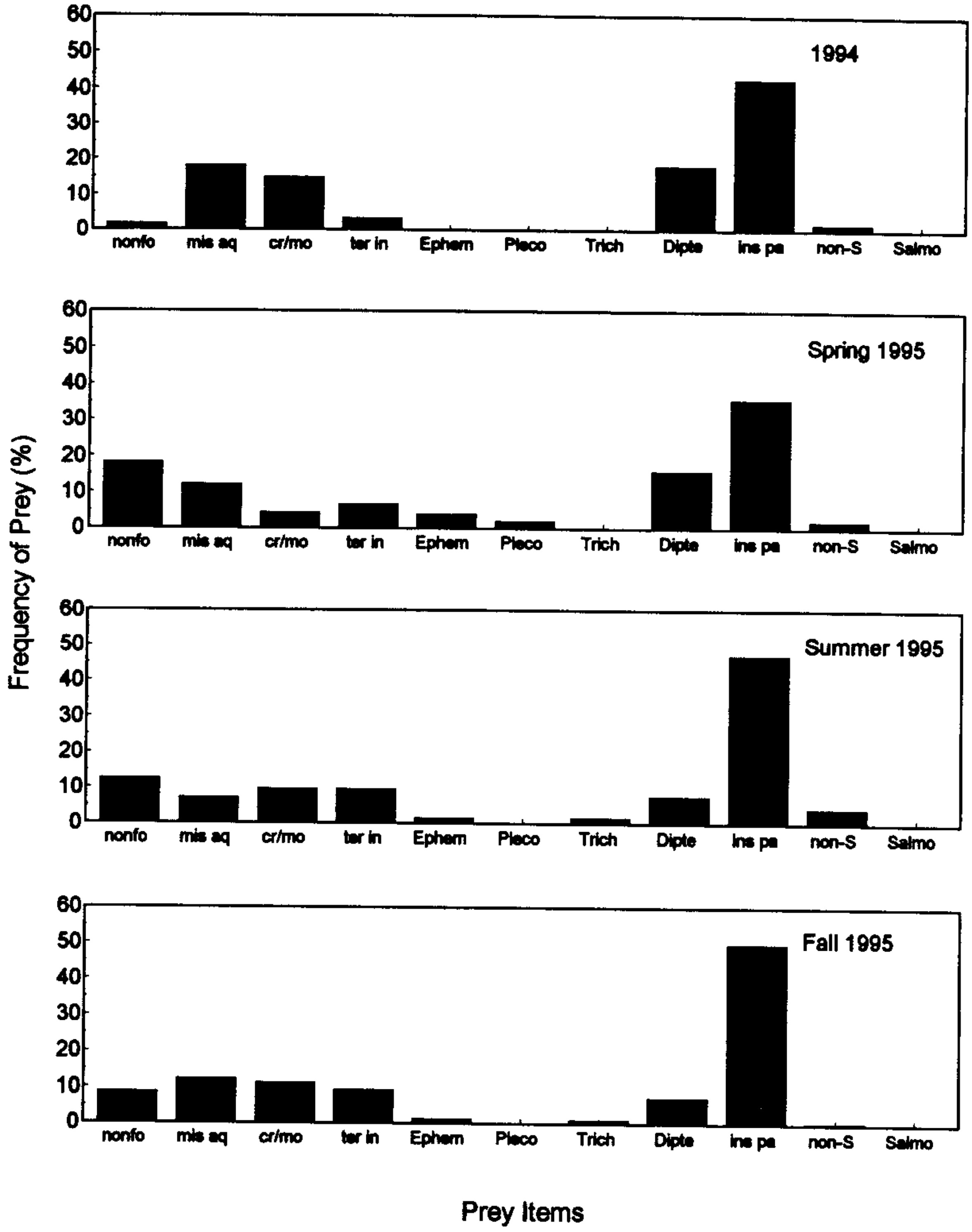

Figure 58. Prey items found in stomachs of northern squawfish sampled in 1994, spring 1995, summer 1995, and fall 1995 at Lower Granite Reservoir. Nonfood items - nonfo, misc. aquatics - mis aq, crustaceans/molluscs - cr/mo, terrestrial insects - ter in, Ephemeroptera - Ephem, Plecoptera - Pleco, Trichoptera - Trich, Diptera - Dipte, insect parts - ins pa, non-Salmonidae - non-S, Salmonidae - Salmo.

the same food items (P=0.818) and, therefore, had no dietary overlap. Also, in 1994, hatchery and wild chinook salmon were not feeding proportionally (P=0.289) on the same food items. In spring 1995, hatchery and wild steelhead (P=0.189) and hatchery and wild chinook salmon (P=0.247) also were not feeding proportionally on the same food items. We found that hatchery and wild steelhead in summer 1995 (P=0.380) and fall 1995 (P=0.724), and hatchery and wild chinook salmon in fall 1995 (P=0.588) fed on different food items.

We also examined similarity in diets between salmonids and resident fishes. In 1994, spring 1995, summer 1995, and fall 1995, we found dietary overlap between steelhead and northern squawfish < 250 mm (Table 22). In 1994, spring 1995, summer 1995, and fall 1995, we found no significant dietary overlap between steelhead and yellow perch, black crappie, and white crappie. We did find evidence of dietary overlap between steelhead and pumpkinseed in 1994 and summer 1995, although no overlap occurred in spring 1995 and fall 1995. We also found no significant overlap between steelhead and bluegill during 1994, summer 1995, and fall 1995, although dietary overlap occurred in spring 1995.

Although we found differences in the proportion of dietary components between wild and hatchery chinook salmon, all items were combined for comparison with resident species. Several more species had significant dietary overlap with chinook salmon. In 1994, spring 1995, and fall 1995, diets of chinook salmon and northern squawfish < 250 mm exhibited similar proportions of food items in their diet (Table 22). However in summer 1995, dietary overlap was not found between chinook salmon and northern squawfish < 250 mm. Diets of chinook salmon and yellow perch and black crappie had no significant overlap during 1994, spring 1995, and fall 1995, although overlap was found between chinook salmon and black crappie during summer 1995. Chinook salmon and white crappie had significant dietary overlap in spring 1995 and summer 1995 but not in 1994 and fall 1995.

Table 22. Matrix of statistical significance of dietary overlap between resident and juvenile anadromous fishes in Lower Granite Reservoir.

				P					
Resident species	n	Season	Year	Chinook salmon	n	Dietary overlap	Steelhead trout	n	Dietary overlap
Bluegill	82	All	1994	0.202	74	No	0.184	316	No
Bluegill	111	Spring	1995	0.033	2,462	Yes	0.026	1,204	Yes
Bluegill	208	Summer	1995	0.001	82	Yes	0.109	255	No
Bluegill	18	Fall	1995	0.276	64	No	0.325	560	No
Pumpkinseed	325	All	1994	0.003	74	Yes	0.001	316	Yes
Pumpkinseed	390	Spring	1995	0.202	2,462	No	0.121	1,204	No
Pumpkinseed	990	Summer	1995	0.001	82	Yes	0.001	255	Yes
Pumpkinseed	31	Fall	1995	0.264	64	No	0.337	560	No
White crappie	84	All	1994	0.163	74	No	0.165	316	No
White crappie	564	Spring	1995	0.036	2,462	Yes	0.180	1,204	No
White crappie	1,167	Summer	1995	0.001	82	Yes	0.067	255	No
White crappie	177	Fall	1995	0.603	64	No	0.999	560	No
Black crappie	63	All	1994	0.743	74	No	0.908	316	No
Black crappie	655	Spring	1995	0.628	2,462	No	0.352	1,204	No
Black crappie	1,059	Summer	1995	0.001	82	Yes	0.053	255	No
Black crappie	6	Fall	1995	0.824	64	No	0.666	560	No

Table 22. Continued

Resident species	n	Season	Year	P: Chinook salmon	n	Dietary overlap	P: Steelhead trout	n	Dietary overlap
Yellow perch	35	All	1994	0.325	74	No	0.371	316	No
Yellow perch	182	Spring	1995	0.352	2,462	No	0.243	1,204	No
Yellow perch	162	Summer	1995	0.070	82	No	0.768	255	No
Yellow perch	20	Fall	1995	0.531	64	No	0.281	560	No
Northern squawfish	24	All	1994	0.001	74	Yes	0.001	316	Yes
Northern squawfish	227	Spring	1995	0.001	2,462	Yes	0.001	1,204	Yes
Northern squawfish	521	Summer	1995	0.165	85	No	0.001	255	Yes
Northern squawfish	303	Fall	1995	0.001	64	Yes	0.001	560	Yes

Chinook salmon and pumpkinseed fed proportionally on similar food items during 1994 and summer 1995, whereas chinook salmon and bluegill had dietary overlap during spring 1995 and summer 1995 but not in 1994 and fall 1995.

DISCUSSION

Results from several studies suggested the need for a more thorough evaluation of food habits between hatchery and wild chinook salmon and steelhead and between resident and migrating juvenile salmonid fishes (Bennett and Shrier 1986; Curet 1994). One item to promote evaluation of food habitats was the number of smolts migrating through Lower Granite Reservoir in the late 1980s and early 1990s. Nearly 20 million smolts were migrating through and feeding in the reservoir and, thus, suggested the potential for food limitations. Curet (1994) reported that subyearling chinook salmon were consuming 27% of the optimum rate of food based on existing water temperatures and growth rates exhibited by subyearling chinook salmon during April and May 1992 in Lower Granite Reservoir. The potential for food limitations is probably greater during the latter part of the downstream migration because of the huge numbers of downstream migrating spring and summer chinook and steelhead. Also, the elevated water temperatures would be more conducive for resident fishes to be actively feeding in the reservoir. Many centrarchid fishes commence feeding around 10° C and northern squawfish at 8° C (Vigg and Burly 1991).

We found that diets of hatchery chinook salmon and hatchery steelhead trout did not include the same food items proportionally as those of wild fish. Thus, dietary overlap between wild and hatchery fish was not found in stomach samples collected during 1994, spring 1995, summer 1995, and fall 1995. We cannot explain why these differences occur. Regardless of these differences in diets, we combined the dietary items of hatchery and wild chinook salmon and steelhead to make comparisons with resident fishes. Diets of several species of resident fishes were similar to those of chinook salmon and steelhead suggesting that proportionally, similar food items are being consumed by both resident fishes and juvenile anadromous fishes in Lower Granite Reservoir.

The highest degree in overlap of food items was between juvenile chinook salmon and selected resident fishes (Table 22). Significant dietary overlap occurred during spring 1995 and summer 1995 between chinook salmon and bluegill, white crappie, and northern squawfish (spring only). Dietary items of pumpkinseed during 1994 and summer 1995 and those of black crappie during summer 1995 overlapped significantly with dietary items chosen by chinook salmon. In all cases of overlap, we often had sample sizes of more than 50 to 250 individuals. In general, seasons when sample sizes were smaller than 50 had fewer significant correlations of the quantity of dietary items than seasons with larger sample sizes.

The relative importance of specific food items in Lower Granite Reservoir was apparent from our sampling. Three or four items predominated the dietary items of both juvenile salmonids and resident fishes. Of these, crustaceans/molluscs were a large component especially in 1994 of both juvenile salmonids and resident fishes. Other items of importance were diptera and insect parts; miscellaneous aquatics and terrestrial insects were of lesser importance. We thoroughly recognize that some of the sample sizes for both juvenile salmonids and resident fishes were small in 1994 and especially during summer and fall 1995 for juvenile salmonids. Our presentation of results for those samples was meant to provide an overview of the dietary items and show variation among years. For example, 1994 was a low flow year compared to 1995, which was a much higher flow year. In 1994, crustaceans/molluscs were of higher in abundance in the diets of both juvenile salmonids and resident fishes. In 1995, the importance of diptera was considerably higher. Although these small samples sizes do not provide a definite analysis of dietary items and dietary overlap, they do show that a few food items are more prevalent in both resident and juvenile salmonids. Sample sizes for most resident and juvenile salmonid fishes are large in the spring of 1995 and these samples definitely demonstrate that dietary overlap occurs between resident fishes and downstream migrating salmonids. The more difficult interpretation is whether food items are limiting and then whether limited food is adversely affecting survival.

Our findings suggest that similar food items from chinook salmon and steelhead are being found in the stomachs of several resident fishes. Presently, we can not attest to food limitations in Lower Granite Reservoir. However, Curet's (1994) estimate of 27% feeding rate compared to optimum suggests that food limitations may be another stress affecting downstream migrating salmon and steelhead in the Snake River system. Preliminary analysis of potential food items in the drift and attached to hard substrates suggests that food abundance is highest in Lower Granite Reservoir and decreases downstream in Little Goose and Lower Monumental reservoirs. Thus, the potential for greater food limitations occur in downstream reservoirs.

Objective 6. To determine size composition and relative abundance of crayfish in Lower Granite Reservoir.

The crayfish *Pacifastacus leniusculus* of the family Astacidae is commonly found in Lower Granite Reservoir. This variety of crayfish is suited for lower temperature waters and is abundant in western lakes, streams, and reservoirs (Hogger 1988). Hogger (1988) related density and size distribution of crayfish to substrate quality, noting that areas of medium-sized rocks contained higher densities of medium-sized crayfish and areas with sandy substrate contained fewer but larger crayfish. Higher densities of *P. leniusculus* were observed in areas of the Sacramento-San Joaquin Delta protected by granite riprap compared to areas consisting primarily of mud-clay banks (Shimizu and Goldman 1983). Due to the nonburrowing nature of *P. leniusculus* (Hogger 1988), large decreases in water level may have a profound affect on crayfish abundance. When water levels decrease, crayfish are often stranded and become desiccated as was observed during the 1992 experimental drawdown. Relatively high fecundity (Lowery 1988) may allow crayfish populations to recover quickly from massive die-offs.

Crayfish are important energy transformers between trophic levels (Hogger 1988). In Lower Granite Reservoir crayfish are an important component in the diets and distributions of resident fishes, such as white sturgeon, smallmouth bas, and northern squawfish (Bennett and Shrier 1986; Curet 1994; Lepla 1994). Reduction in the availability of crayfish as a forage item for smallmouth bass and northern squawfish may lead to increases in smolt predation, as both smallmouth bass (Curet 1994) and northern squawfish (Chandler 1993) consume juvenile salmonids. Information on size composition, density, and distribution of crayfish will allow fisheries managers to predict effects that change in reservoir operations may have on the crayfish population and interaction among crayfish and resident fishes.

METHODS

Lower Granite Reservoir was divided into three strata: stratum 1 (RM 131.0-139.75, RKM 210.9 - 224.9), stratum 2 (RM 120.0-131.0, RKM 193.2 - 210.9), and stratum 3 (RM 107.8-120.0, RKM 173.6 - 193.2; Figure 2). Crayfish were sampled at randomly selected transects within each stratum. Fifty transects were sampled in stratum 1, 40 in stratum 2, and 30 in stratum 3 from June through October 1994 and 27 transects were sampled in stratum 1, 33 in stratum 2, and 15 in stratum 3 during June and July 1995.

Crayfish were collected using modified commercial GEE brand minnow traps. Trap entrances of 2-, 3-, and 4-cm were used to potentially trap a broader segment of the crayfish population. Stuecheli (1991) suggests that sampling efforts employing one size of trap entrance may bias results towards larger males. Large males, once trapped, have the ability to intimidate smaller males and females of equal or smaller size. If intimated, smaller crayfish may not enter the trap or be eaten, thus resulting in catches of predominately large male crayfish.

In 1994, five traplines were used to capture crayfish. Each trapline consisted of six traps individually attached at 3-m intervals. In 1995, six traplines with 15 traps at 3-m intervals were used to capture crayfish. Equal numbers of traps with 2-, 3-, and 4-cm entrance diameters were randomly attached to the traplines. Traplines were anchored on shore and deployed perpendicular to the shoreline with the first trap 3 to 5 m from shore. In 1995, traplines were also fished in pairs perpendicular to shore. Paired lines were separated by a segment of nylon line approximately 45 to 90 m long depending on the width of the channel. Paired traplines allowed both the shoreline and adjacent main channel area of a transect to be fished simultaneously. Depth range of each set was determined with an Eagle Model Mach 1 depth recorder. Traps were baited with herring *Clupea harangus* (about 180 mm) and fished for 48 to 72 hrs in 1994 and 24 hrs in 1995 at one location. Traplines were retrieved in the early morning to reduce crayfish escapement, as crayfish feed principally at night and retreat to crevices and holes during daylight hours (Abrahamsson 1983).

All crayfish captured by traps of similar entrance diameter were placed in a shallow basin containing water. Sex, carapace length (0.1 mm), rostral length (0.1 mm), weight (g), and number of crayfish caught per entrance size were recorded. Length of carapace (rostral tip to posteriomedian edge of carapace) and rostral length (tip of rostrum to posteriomedian edge of orbit) were measured with vernier calipers. Crayfish were released at the capture site after measurements were taken. Each trapline was retrieved, crayfish measurements were recorded, and trapline reset before the next trapline was checked.

Crayfish Length and Distribution Analysis

Differences in mean carapace lengths among trap entrance diameters were evaluated with the SAS (1995) general linear model procedure. The number of crayfish-per-trap-per-night (CPUE) at each transect was used as an expression of relative abundance. Abrahamsson and Goldman (1970) reported a sampling area of 13.0 m^2 for adult crayfish using cylindrical traps with funnel entrances at both ends when sampling *P. leniusculus* in Lake Tahoe, California-Nevada.

The spatial distribution of CPUE of crayfish was compared between years using a permutation distribution, generated in GAUSS, of the test statistic:

$$D = \sum | R_{94i} - R_{95i} |$$

where: D = the sum of the absolute difference between ranks,

R_{94} = the rank of the catch/effort at transect *i* in 1994, and

R_{95} = the rank of the catch/effort at transect *i* in 1995.

Values less than the test statistic indicate similar distributions of ranks between years. Student-Newman-Keuls multiple range test was performed to detect differences in CPUE among strata.

RESULTS

In all, 717 and 1958 crayfish were captured in 1994 and 1995, respectively. Each trap entrance size was fished for 510 trap-nights in 1994. In 1995 total trap-nights were 878 for 2-cm, 815 for 3-cm, and 883 for 4-cm trap entrance size. Mean depths of shoreline transects in 1995 were 9.0, 8.5, and 8.0 m, and mean depths of channel locations were 17.1, 22.0, and 23.2 m in strata 1, 2, and 3, respectively.

Length Distribution

Mean carapace length of crayfish captured in traps with 2-, 3-, or 4-cm entrances were significantly different ($P < 0.05$) in both years. Mean ($\pm$SE) carapace lengths (mm) in 1994 were 33.0 ± 0.7, 44.9 ± 0.5, and 51.3 ± 0.5 and similar in 1995 for traps with 2 (33.8 ± 0.6), 3 (43.5 ± 0.3), or 4 (48.8 ± 0.2) cm entrances, respectively (Figure 59). The range of carapace lengths (mm) of crayfish captured by traps with different entrance diameter were 20 to 58 mm (2-cm entrance), 8 to 62 mm (3-cm entrance), and 18 to 72 mm (4-cm entrance) in 1994 and 19.4 to 54 mm (2-cm entrance), 16.4 to 60 mm (3-cm entrance), and 13.3 to 79.7 mm (4-cm entrance) in 1995. Sixty-three percent of all crayfish captured in 1994 and 1995 were female.

In 1995, mean carapace lengths of crayfish captured in traps with 2-cm entrances did not differ significantly ($P>0.05$) between shoreline (33.9 mm) and channel (33.7 mm) areas (Figure 60). Mean carapace lengths of crayfish captured in traps with 3-cm entrances were significantly larger ($P < 0.05$) for shoreline (43.9 mm) locations compared to channel (42.8 mm) locations. Traps with 4-cm entrances

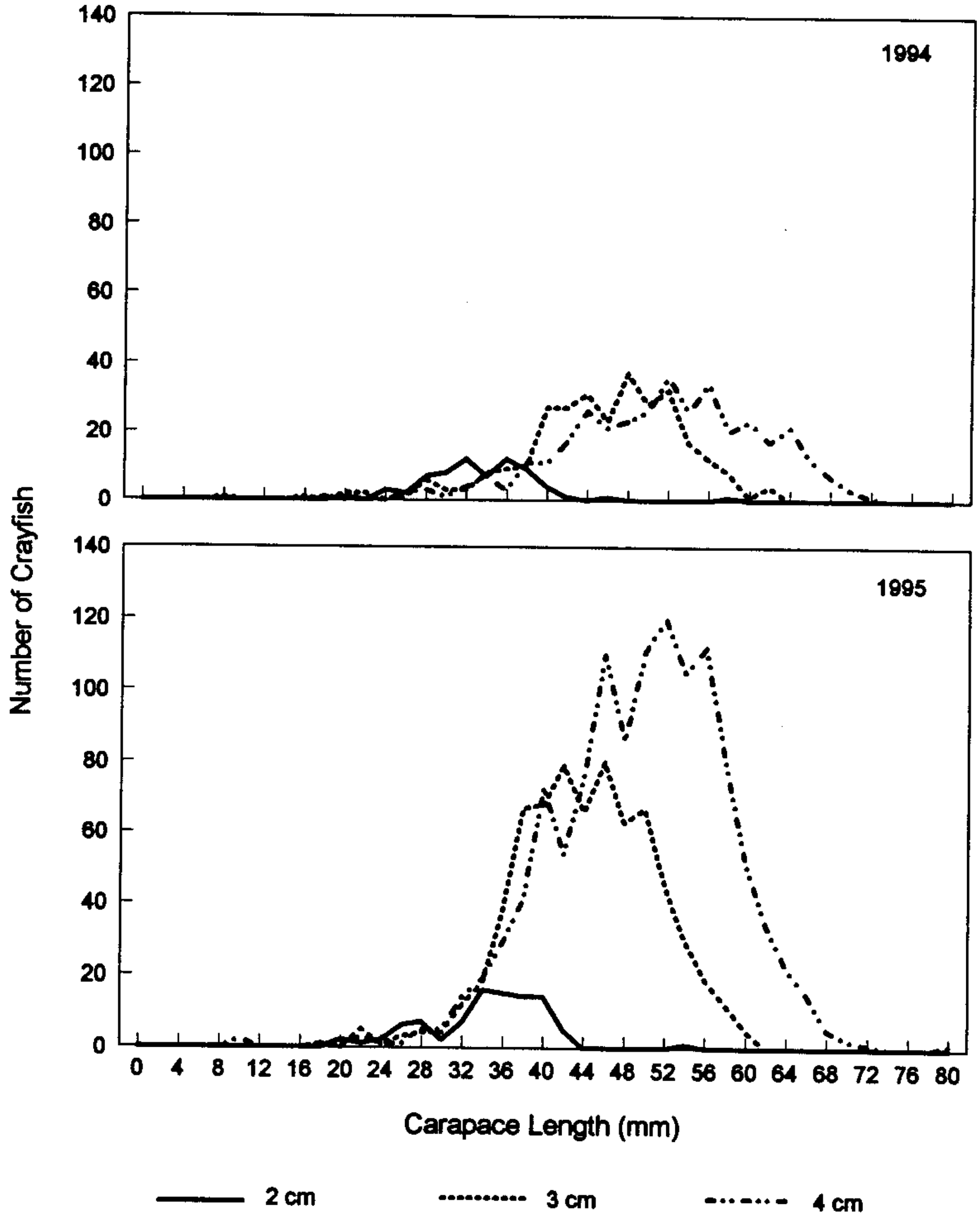

Figure 59. Carapace lengths of crayfish captured during 1994 and 1995 by one of three sizes (2, 3, or 4 cm) of trap entrances in Lower Granite Reservoir.

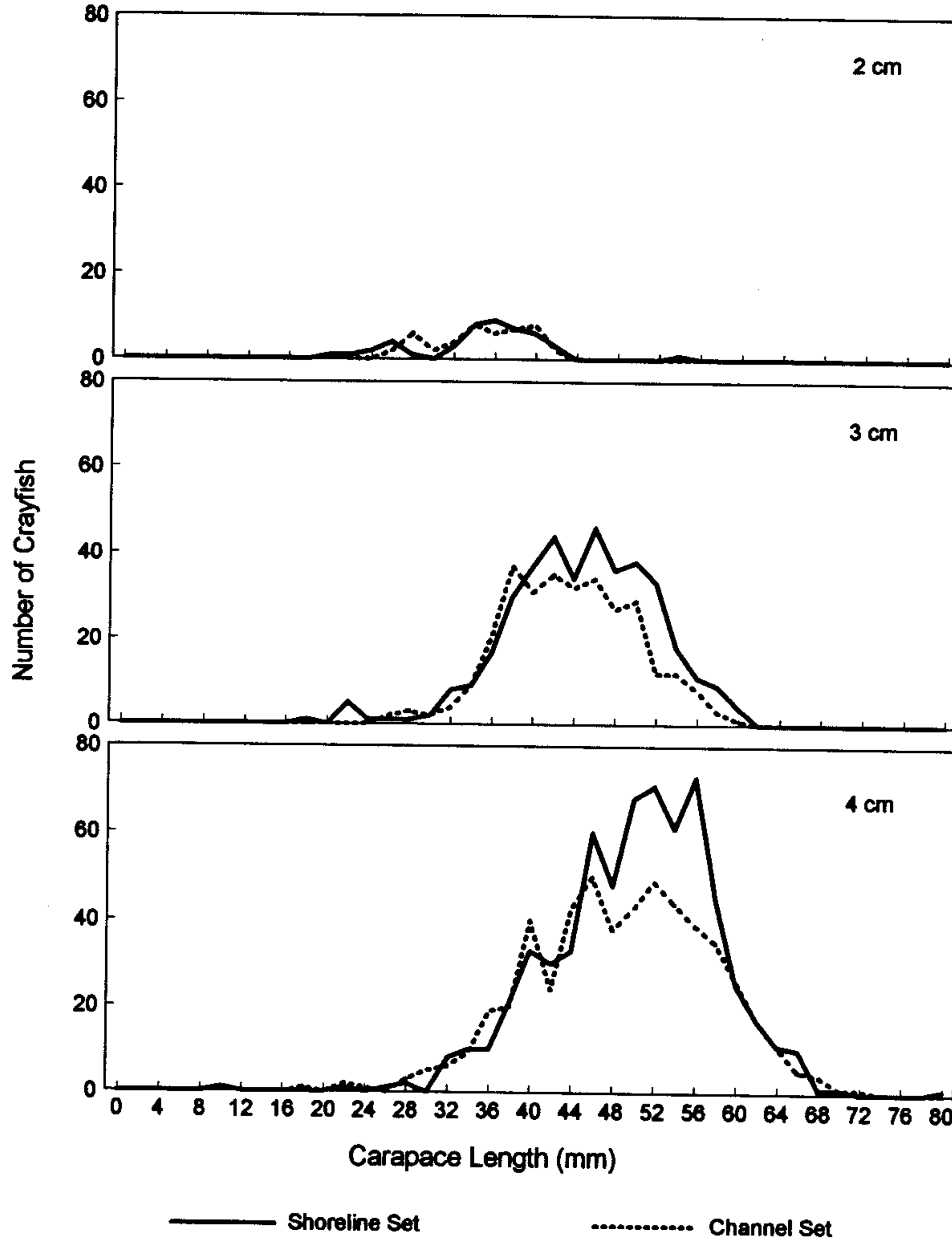

Figure 60. Comparison of number of crayfish and carapace length-frequency distributions sampled in shoreline and channel locations by traps with 2-, 3-, or 4-cm entrance diameters during 1995 in Lower Granite Reservoir.

captured significantly ($P < 0.05$) larger crayfish in shoreline (49.3 mm) and channel (48.1 mm) locations than traps with smaller entrances (Figure 60).

A significant positive relationship ($P < 0.05$; $r^2 = 0.84$) was demonstrated between carapace length and crayfish weight in 1995 (Figure 61). A linear model was used to describe the relationship ($P < 0.05$; $r^2 = 0.65$) between carapace and rostral lengths for crayfish captured in 1995 (Figure 62).

Crayfish Distribution

Crayfish distribution between 1994 and 1995 was similar between years (Figure 63). Densities of crayfish were similar in strata 1 and 2 ($P > 0.05$) but were significantly ($P < 0.05$) higher than those in stratum 3. No significant difference ($P > 0.05$) in CPUE between shoreline and channel locations was observed in 1995 (Figure 64). In 1995 density estimates of crayfish ranged from 0.03 fish/m^2 (0.80 g/m^2) in stratum 3 to 0.19 fish/m^2 (4.95 g/m^2) in stratum 1 (Table 23).

DISCUSSION

Length Distribution

Differences in mean carapace lengths of crayfish among traps with different entrance sizes are expected, as entrance size effectively limits the maximum size of crayfish able to enter a trap. Traps with 2-cm or 3-cm entrances captured fewer and smaller crayfish, resulting in lower density estimates for all strata. Small crayfish (< 40 mm carapace length) constituted the majority of crayfish captured in traps with 2-cm entrances (78%) and a small percentage in traps with 4-cm entrances (10%) in 1995. More crayfish < 40 mm carapace length were collected in traps with 4-cm entrances (n = 121) than in 2-cm entrances (n = 72 crayfish). Differential trapability may exist between entrance diameter based on percentages of size classes trapped. Conclusions based on numbers of trapped individuals of a particular size class

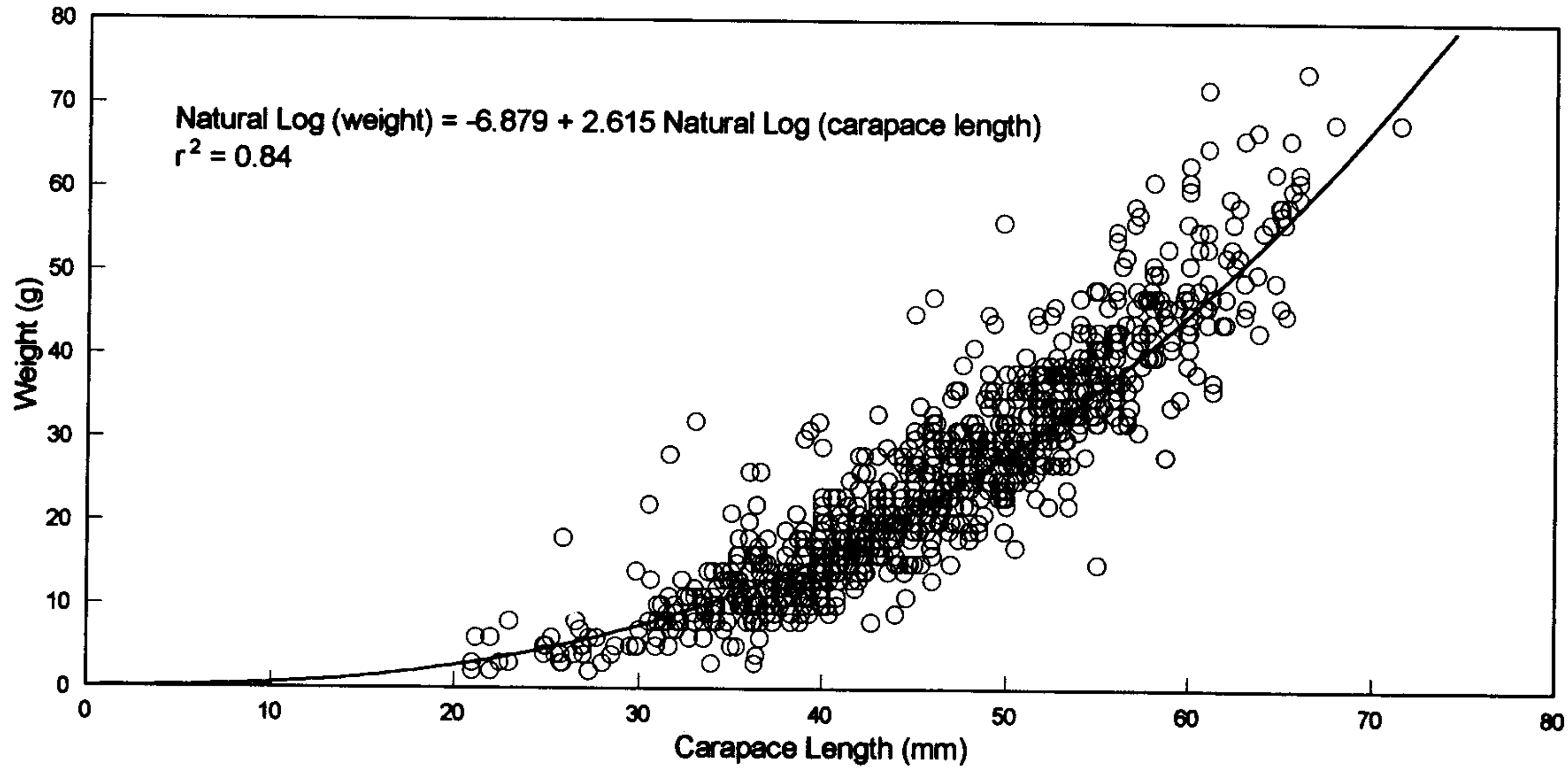

Figure 61. Relationship between carapace length and weight of crayfish collected during 1995 in Lower Granite Reservoir.

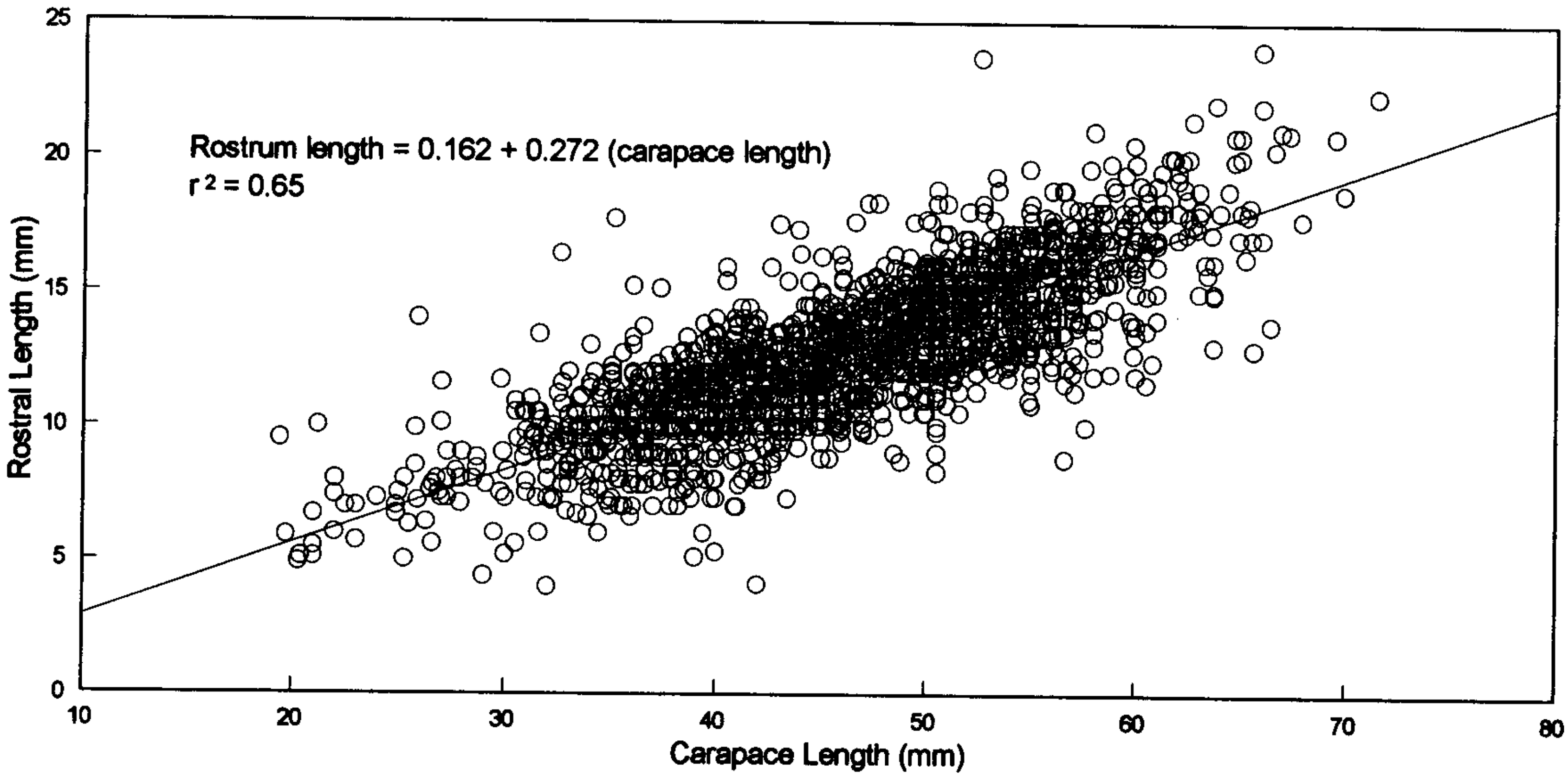

Figure 62. Relationship between carapace and rostral length of crayfish collected during 1995 in Lower Granite Reservoir.

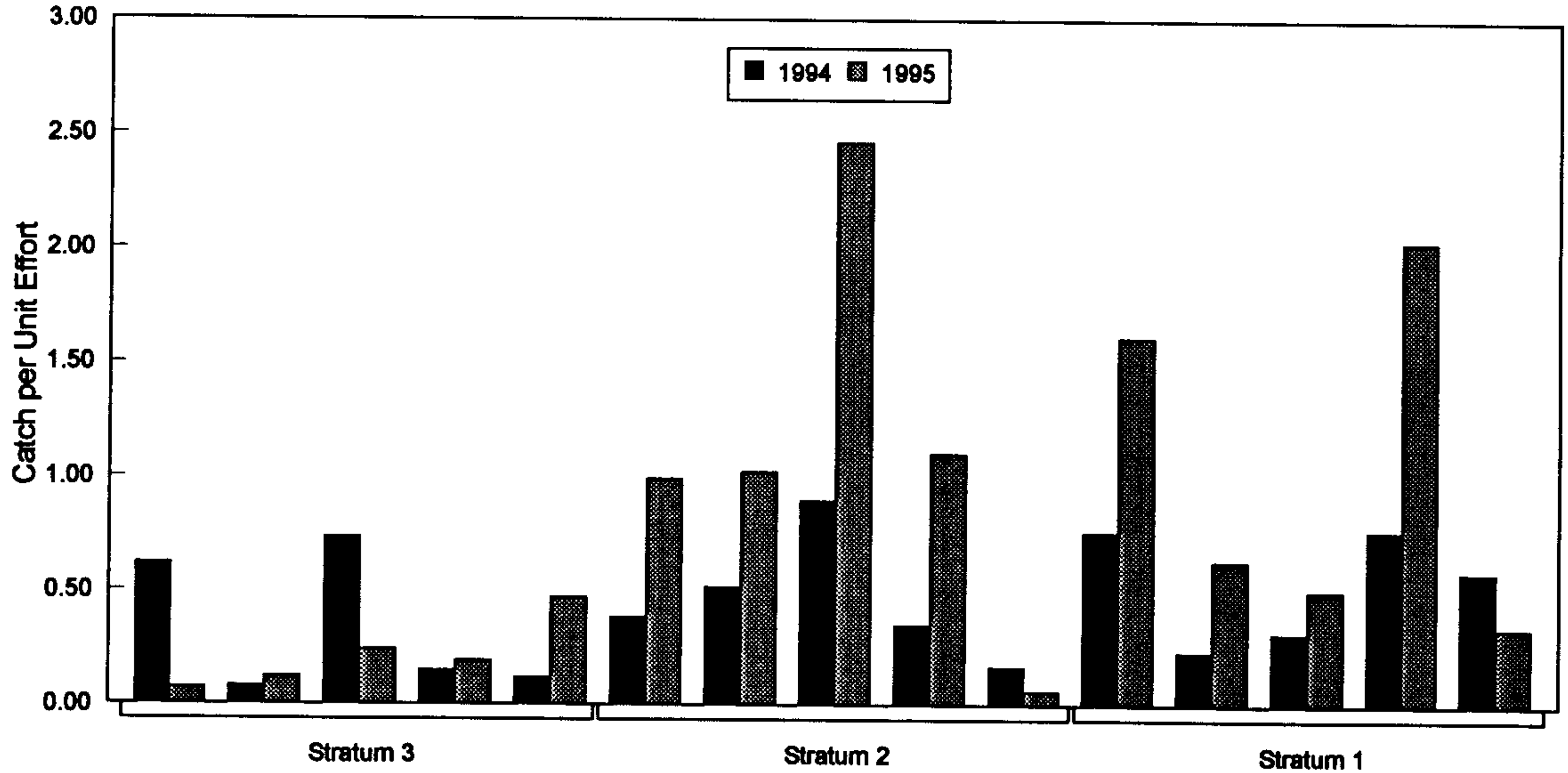

Figure 63. Catch per unit effort of crayfish collected during 1994 and 1995 in Lower Granite Reservoir. Stratum 1 - RM 131.0-139.75 (RKM 211.3 - 224.6), stratum 2- RM 120.0-131.0 (RKM 120.3 - 131.4), and stratum 3 - RM 107.5-120.0 (RKM 107.8 - 120.3).

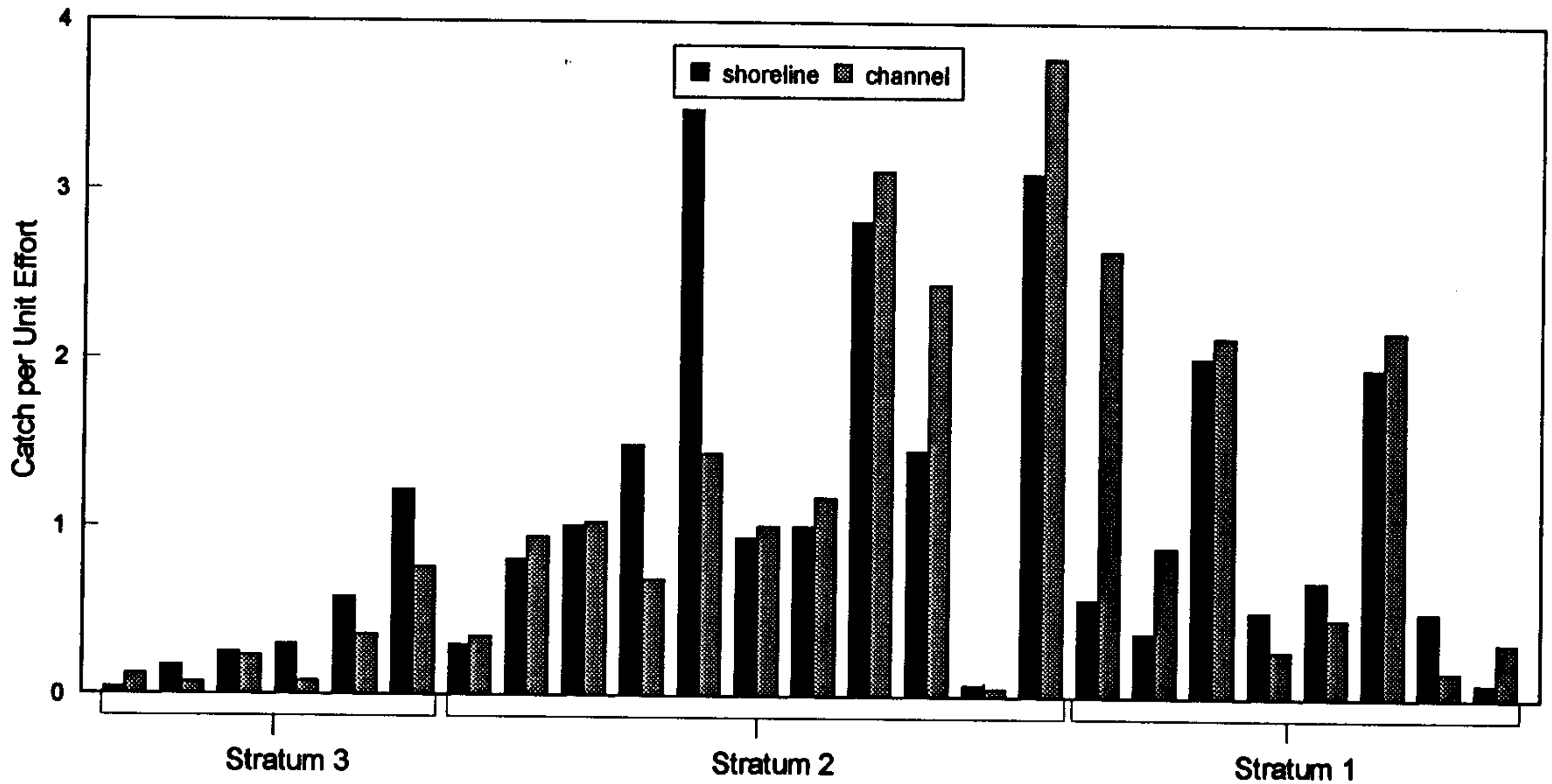

Figure 64. Catch per unit effort of crayfish collected during 1995 at shoreline and channel locations within each strata in Lower Granite Reservoir. Stratum 1 - RM 131.0-139.75 (RK 210.9 - 225.0); stratum 2 - RM 120.0 - 131.0 (RK 193.2 - 210.9); and stratum 3 - RM 107.5-120.0 (RK 173.1 - 193.2).

Table 23. Density (No./m^2) and biomass (g/m^2) of *P. leniusculus* sampled at three strata by traps with 2-, 3-, and 4-cm entrance diameter during 1995.

	Entrance diameter (cm)					
	2		3		4	
Strata[a]	Density	Biomass	Density	Biomass	Density	Biomass
1	0.01	0.12	0.10	1.90	0.19	4.95
2	0.01	0.13	0.13	2.54	0.16	4.19
3	0.01	0.10	0.01	0.27	0.03	0.80

[a] Stratum 1 - RM 131.0 - 139.75 (RKM 210.9 - 225), stratum 2 - RM 120.0 - 131.0 (RKM 193.2 - 210.9), stratum 3 - RM 107.5 - 120.0 (RKM 173.1 - 193.2). RM = river mile; RKM = river kilometer.

indicate no difference in trapability between entrance diameters. Our results differ from those of Stuecheli (1991) who reported a bias in crayfish size related to entrance diameter. The discrepancy in results may be related to his presentation of length-frequency distributions based on percent versus number of individuals within a particular size class. The dimorphic characteristic of male crayfish possessing larger chelipeds than females and male chelipeds becoming smaller during nonmating periods (Stein 1976) may explain the relatively high number of small individuals captured by traps with 3- and 4-cm entrance diameters. Male crayfish with large chelae can more effectively prevent other crayfish from entering a trap.

In 1995 few crayfish with carapace lengths from 28 to 32 cm were captured. Crayfish of this size are probably 3 to 4 years of age. Lowery (1988) identified four populations of *P. leniusculus* whose lengths at age 3+ ranged from 32 to 68 cm carapace length (tip of rostrum to the posterior margin at the dorsal midline). The smallest length at age 3+ was reported for crayfish sampled in Lake Tahoe, California-Nevada, where water temperatures range from 5.0 to 20° C. Water temperature has been identified as the single most influential environmental variable affecting crayfish growth and production (Shimizu and Goldman 1983; Lowery 1988). Water temperature has a positive influence on molt increment and the frequency of molting (Lowery 1988). In Lower Granite Reservoir, water temperatures can range annually from 4 to 23° C, thus growth rates may be on the lower end of reported values. Length-frequency and growth data suggest that the March 1992 test drawdown of Lower Granite Reservoir may have resulted in a partial elimination of the 1992 cohort. Juvenile crayfish generally hatch (release from females) between late March and April (Shimizu and Goldman 1983). Mortality of juveniles may have resulted from their being dislodged from the host female by desiccation or through entrainment into downstream reservoirs. The impact of the test drawdown is most dramatically depicted in the length-frequency distribution of crayfish captured in 1995 by traps with 2- or 4-cm entrances. Collections of the 1992 cohort in 1994 were most likely too few to yield the resolution required to identify age classes in the lower end of the length-frequency distribution.

Crayfish Distribution

The pattern of crayfish distribution in Lower Granite Reservoir observed in 1994 and 1995 was similar to that reported by Lepla (1994). Klosterman and Goldman (1983) suggest that *P. leniusculus* distribution is nonrandom and may be related to substrate quality. Abrahamsson and Goldman (1970) observed higher densities and production of *P. leniusculus* in areas of Lake Tahoe that were dominated by rocky substrate. Substrate at upstream main channel locations in Lower Granite Reservoir is characterized by sand, large cobble, and boulders, while main channel substrate in lower regions of the reservoir consists largely of silt (Lepla 1994). Difference in substrate quality between upstream and downstream reservoir areas may explain the pattern of crayfish density observed in Lower Granite Reservoir.

Substantial reductions in reservoir surface elevation during March 1992 may have led to the partial collapse of a year class. The reduction in number of crayfish may allow individuals to survive at higher rates, be more fecund, and repopulate the habitat quickly, given the frequency of drawdowns does not reduce the crayfish population to a level it is unable to recover. Crayfish are valuable to the Lower Granite Reservoir ecosystem not only as a food source for resident predatory fishes, but also for the role they may play in affecting the productivity of the reservoir. Hogger (1988) reported that crayfish can comprise 30% of the biomass in stream ecosystems. Flint and Goldman (1975) identified *P. leniusculus* as an important source of ammonia in Lake Tahoe and suggested the crayfish population influences the entire benthic community through its nutrient recycling. Crayfish may play a vital but unnoticed role in providing an adequate food source for juvenile anadromous salmonids that migrate through the reservoir system. Our detailed descriptions of crayfish size and density distributions in Lower Granite Reservoir will provide crucial information to monitor the influence of future reservoir management actions.

Objective 7. To monitor abundance and habitat use of white sturgeon in Lower Granite Reservoir.

Limited information has been collected on white sturgeon distribution, abundance, and habitat use in Lower Granite Reservoir (Lepla 1994). Bennett et al. conducted collections of white sturgeon in Lower Granite Reservoir with regards to in-water disposal and reference stations (Bennett et al. 1990, 1993b, 1995a, 1995b). Data from sturgeon collections conducted during this study will supplement previous efforts.

METHODS

Lower Granite Reservoir was divided into three strata (stratum 1 - RM 119.0 - 108.0, RKM 173.9 - 191.2; stratum 2 - RM 119.0 - 126.0, RKM 191.2 - 202.9; stratum 3 - RM 126.0 - 138.0, RKM 202.9 - 222.2; Figure 65). Gill nets were the primary gear used to capture and assess relative abundance of white sturgeon in deep water areas (> 15.2 m). Eight transects were sampled throughout the reservoir: four transects in stratum 1, two transects in stratum 2, and two transects in stratum 3. Sampling was conducted by fishing eight horizontal, multifilament experimental gill nets 76.2 m x 1.8 m with three graded panels and bar mesh ranging from 5.0 cm to 15.0 cm at each of the eight transects. Gill nets were fished on the bottom and perpendicular to the shoreline for a total of 6 hours. Nets were checked at 3-hour intervals to preclude destructive sampling to all fishes (Bennett et al. 1993b). During 1995, additional sampling with gill nets was conducted to capture northern squawfish; sturgeon were also captured during this effort. Two nets of different mesh size were used to capture northern squawfish (Objective 3).

Six sampling passes were conducted during 1994 in Lower Granite Reservoir from 23 May to 9 July and from 29 September to 2 December, although gill netting was suspended between 9 July and 29 September 1994 to satisfy ESA requirements

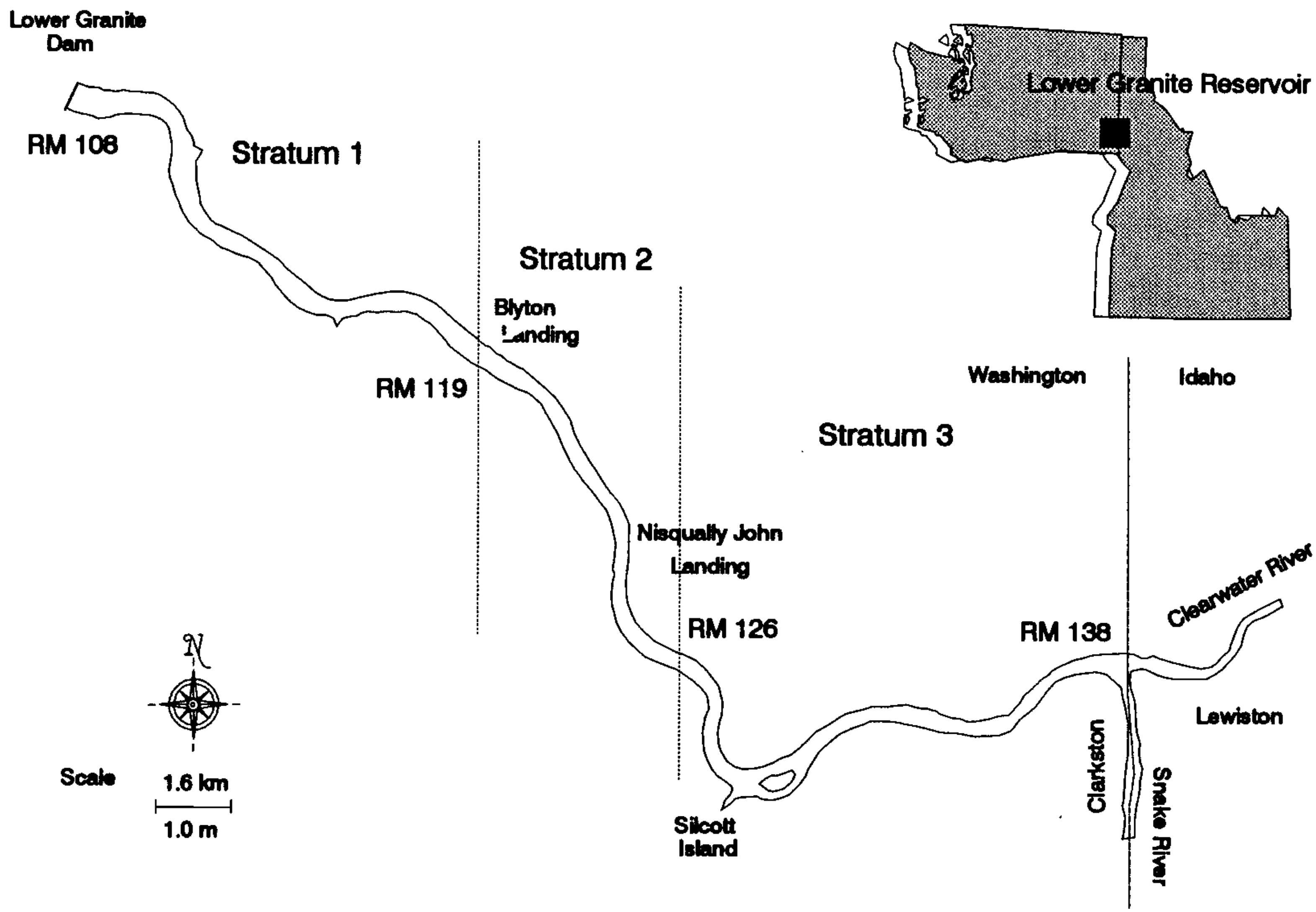

Figure 65. Map of three strata sampled for sturgeon in Lower Granite Reservoir during 1994 and 1995. Stratum 1 - RM 108-119 (RKM 67-192), stratum 2 - RM 119-126 (RKM 192-203.1), stratum 3 - RM 126-138 (RKM 203.1-222.4). RM indicates river mile and RKM indicates river kilometer.

over potential mortality to adult sockeye salmon *O. nerka* migrating through the Snake River system. In 1995 gill netting for salmonid predators was conducted from 17 June to 6 July and sampling for sturgeon was conducted from 28 October to 21 November, although gill netting was suspended from 7 July 1995 to 26 October 1995 to allow safe passage of upstream migrating adult sockeye salmon.

Set lines were used throughout Lower Granite Reservoir in 1994 to supplement gill net effort and reduce potential gear bias (Bennett et al. 1993a, 1993b). Set lines were fished for approximately 48 to 72 hours per transect. Set lines were not used in 1995. Set lines consisted of a 48-m mainline (1.28-cm cord rope) weighted on the bottom with Gamakatsu and Mustard hooks attached every 3 m for a total of 12 hooks. Gangen lines were constructed with a stainless steel halibut snap and 4/0 bearing swivel attached to a 0.04-cm leader. All hooks were size 9/0. Each gangen line measured approximately 7.1 cm from the mainline to hook and was rigged onto the mainline in random order. Hooks were baited primarily with largescale sucker and commercially processed herring. A 61.0-m, foam-filled rope coupled with an ultrasonic transmitter was attached and submerged with the mainline to prevent theft and facilitate locating the line. Set lines were retrieved by locating the sonic transmitter and intercepting the submerged float line with a grapple hook.

All captured sturgeon were measured, weighed, marked, and released. Each untagged sturgeon was marked with a passive integrated transponder (PIT) injected into the dorsal musculature midway between the leading edge of the dorsal fin and right lateral row of scutes. Sturgeon sampled in 1994 were also tagged with an external numbered aluminum lap seal tag crimped around the leading right pectoral fin ray for ease of identification. We did not use metal tags in 1995 due to possible infection that was observed in sturgeon that were tagged in previous years.

Movement of white sturgeon was assessed by recapturing marked sturgeon and comparing recapture location with previous capture records.

We calculated catch per hour (CPUE) of white sturgeon by dividing the catch by the total hours of gill netting effort. The values of CPUE were not normally distributed and, because means and variances were proportional, we transformed the CPUE by taking its square root. We ran analysis of variance on the transformed CPUE to make comparisons among years, and among seasons and years.

RESULTS

1994

Approximately 3,405 gill net and 2,750 set line hours of effort were expended to capture 805 white sturgeon from 23 May to 9 July and 29 September to 2 December 1994 in Lower Granite Reservoir. In all, 799 sturgeon were captured with gill nets and 6 were captured by set lines.

Total lengths of white sturgeon sampled by gill nets ranged from 10.0 cm to 200.2 cm with a mean of 56.9 cm (Figure 66). Total lengths of sturgeon sampled by set lines ranged from 114.6 to 150.2 cm with a mean of 129.5 cm. Ninety-four percent of the white sturgeon sampled were $<$ 122 cm and 0.5% were $>$ 168 cm (Figure 66).

Approximately 64% of white sturgeon ($n=511$) collected were located in stratum 3 between RMs 138 and 126 (RKM 222.2 - 202.9; Figures 67 and 68). These locations coincided with the highest catch rates during the spring (1.025 sturgeon/6 h) and fall (2.35 sturgeon/6 h) sampling efforts. Catch rates were low in strata 1 and 2 during spring and fall.

Thirteen white sturgeon initially marked were recaptured in 1994 (Table 24). Net movements of these fish ranged from 0 to 30.6 river kilometers with four fish traveling more than 16.1 river kilometers since their last recorded capture. Mean

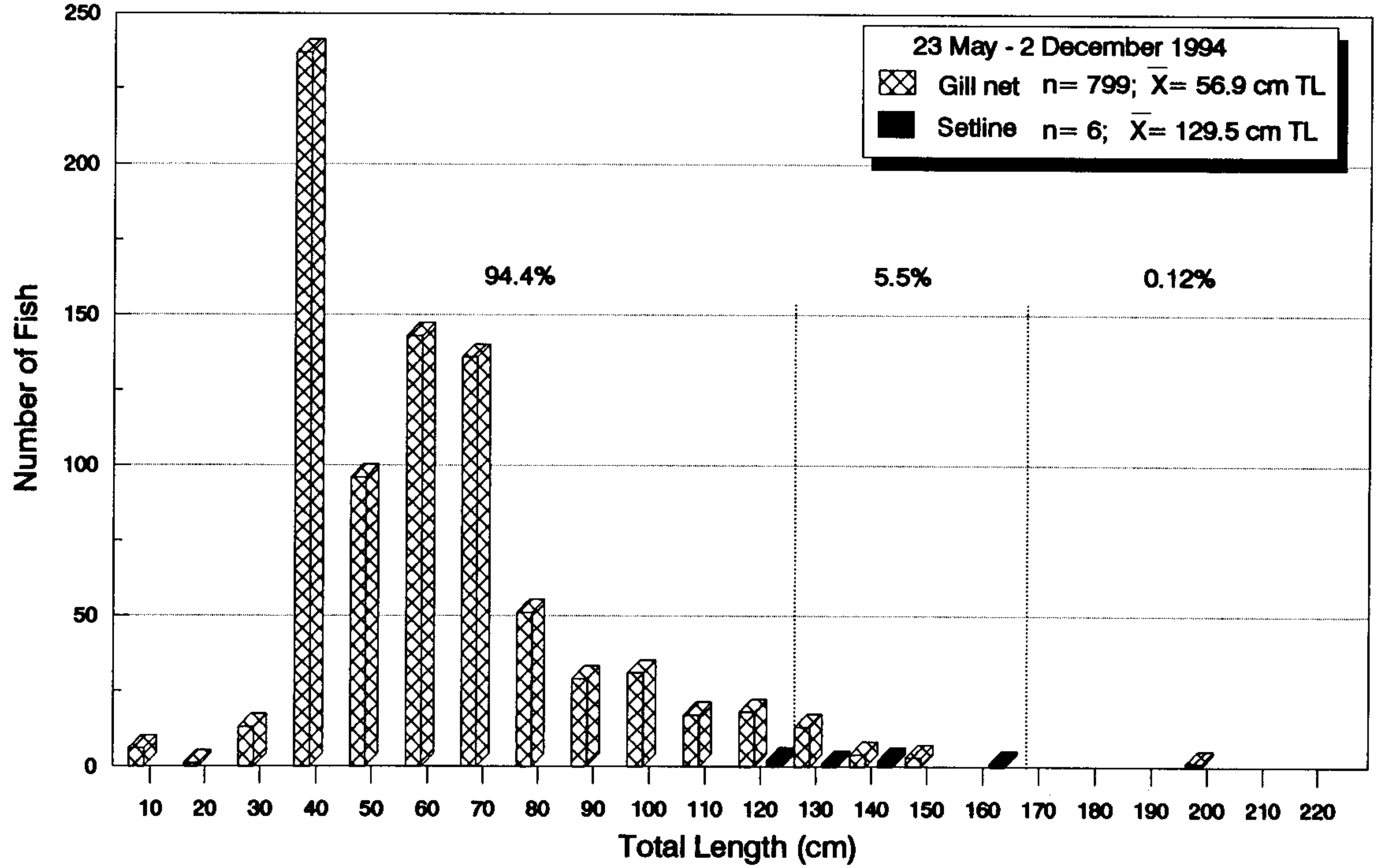

Figure 66. Length distributions of white sturgeon collected during 23 May to 9 July and 29 September to 2 December 1994 in Lower Granite Reservoir. TL indicates total length.

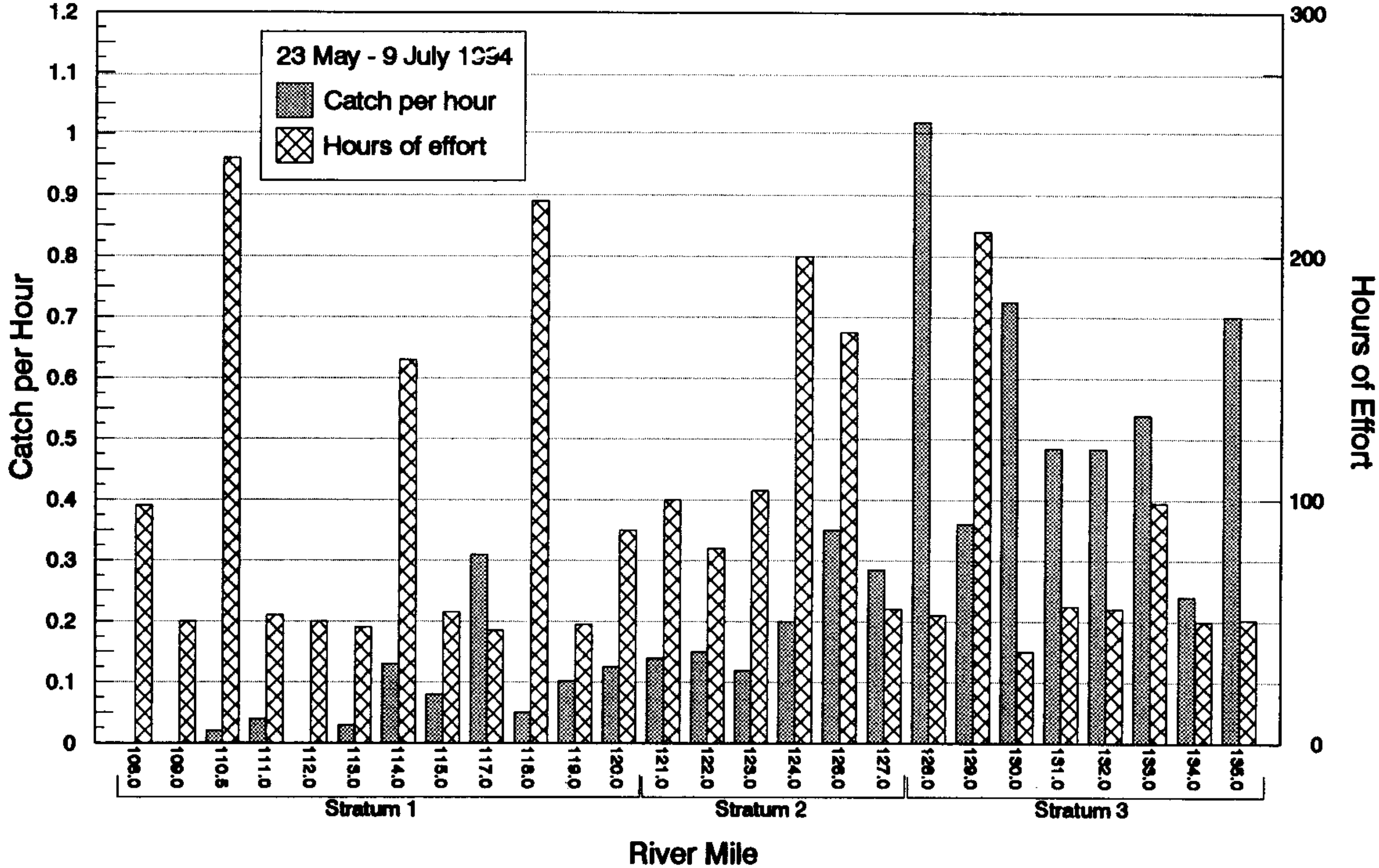

Figure 67. Catch per hour (CPUE) of white sturgeon captured by gill nets during spring sampling 23 May to 9 July 1994 in Lower Granite Reservoir.

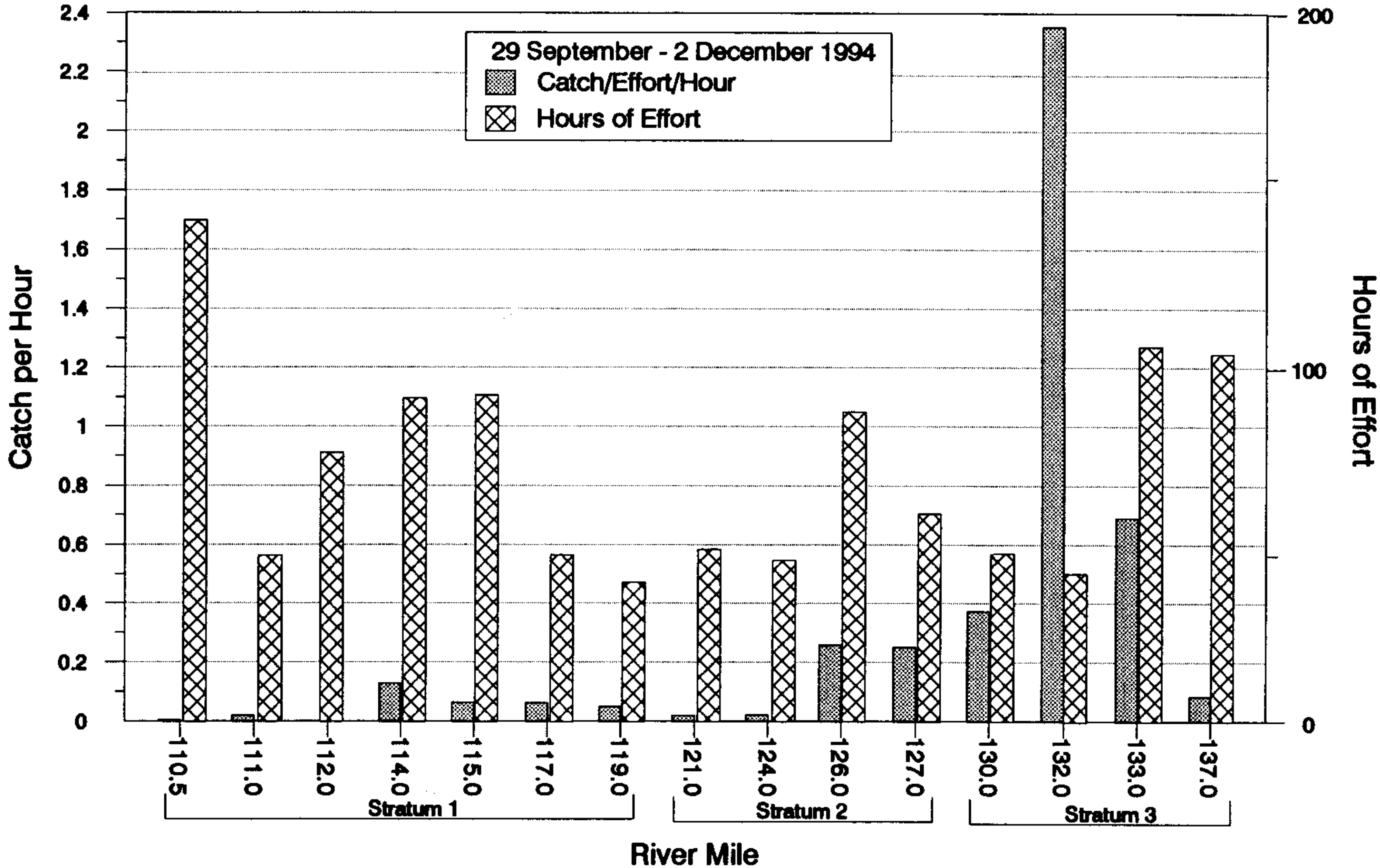

Figure 68. Catch per hour of white sturgeon captured by gill nets during fall (29 September to 2 December 1994) in Lower Granite Reservoir.

Table 24. Location and net movement of white sturgeon recaptured during spring (23 May - 9 July 1994) and fall (29 September - 2 December 1994) in Lower Granite Reservoir.

PIT[a] tag	Metal tag	Initial capture		Recapture		Recapture		Net
		Date	RM	Date	RM	Date	RM	movement (RM)[b]
-	420	1 Apr 91	134.5	18 Nov 94	133.0	-	-	1.5
-	916	20 May 92	119.9	18 Nov 94	133.0	-	-	13.1
-	106	11 Jun 90	137.1	18 Nov 94	133.0	-	-	4.1
7F7F76293D	783	30 Oct 91	137.1	8 Nov 94	137.0	-	-	0.1
-	31	28 May 90	115.8	12 Oct 90	120.5	27 Jun 94	129.0	13.2
-	155	1989	120.5	10 Jul 90	137.1	20 Jun 94	129.0	24.7
-	152	10 Jul 90	137.1	22 Jun 94	130.0	-	-	7.1
-	300	28 Jun 90	113.7	23 Apr 91	126.1	29 Jun 94	126.0	12.5
-	298	9 May 91	129.2	29 Jun 94	126.0	-	-	3.2
-	164	29 Aug 90	120.5	9 Jun 94	127.0	-	-	6.5
7F7F4E5C5A	2599	27 Jun 94	133.0	7 Nov 94	130.0	-	-	3.0
7F7B023C45	2669	25 Jun 94	113.9	1 Dec 94	126.0	-	-	12.1
7F7F774A2D	2721	9 Jul 94	118.0	30 Nov 94	133.0	-	-	15.0
7F7F774B06	2946	6 Jul 94	124.0	30 Nov 94	133.0	-	-	9.0
7F7F5A1F65	2971	5 Jul 94	119.0	30 Nov 94	133.0	-	-	14.0
7F7F50427E	2976	18 Nov 94	133.0	30 Nov 94	133.0	-	-	0
7F7D434B5F	1528	2 Jun 94	126.0	30 Nov 94	133.0	-	-	7.0
7F7D247354	1567	3 Jun 94	129.0	18 Nov 94	133.0	-	-	4.0
7F7D36467F	1594	2 Jun 94	126.0	2 Dec 94	132.0	-	-	6.0
7F7F5A3969	1649	14 Jun 94	114.0	30 Nov 94	133.0	-	-	19.0
7F7D371A56	1682	22 Oct 93	116.5	1 Dec 94	126.0	-	-	10.0
7F7B023407	1544	22 Sep 93	127.0	17 Jun 94	128.0	30 Nov 94	133.0	6.0

Table 24. Continued

PIT tag	Metal tag	Initial capture		Recapture		Recapture		Recapture		Net
		Date	RM	Date	RM	Date	RM	Date	RM	movement (RM)
-	160	10 Jul 90	137.1	6 Jun 94	131.0	-	-	-	-	6.1
-	364	21 Apr 91	122.6	18 Nov 94	133.0	-	-	-	-	10.4
-	168	14 Jul 90	117.7	6 Oct 91	116.5	22 May 92	129.7	27 Jun 94	133.0	17.7
7F7F7F0F59	-	29 May 91	116.5	30 Nov 94	133.0	-	-	-	-	16.5
-	167	12 Jul 90	113.6	21 Jun 94	135.0	-	-	-	-	21.4
7F7F4E5164	-	29 Jun 94	124.0	30 Nov 94	133.0	-	-	-	-	9.0
7F7B035674	-	18 Nov 94	133.0	30 Nov 94	133.0	-	-	-	-	0
7F7F5A3656	-	29 Jun 94	126.0	30 Nov 94	133.0	-	-	-	-	7.0
-	1369	18 Sep 93	116.5	29 Oct 94	127.0	-	-	-	-	10.5

[a] PIT = passive integrated transponder; [b] RM = river mile

distance traveled was 12.1 river kilometers upstream by sturgeon sampled in 1994, although three sturgeon showed no net movement from their original capture location. No net downstream movement was observed. Thirty-three white sturgeon captured and marked during previous sampling efforts were recaptured in 1994. Movement of 18 of these fish was similar to those marked in 1994 (Table 24). The remaining 15 recaptured sturgeon were untraceable due to tag loss.

Population abundance of sturgeon in Lower Granite Reservoir was estimated by a modified Schnabel estimator at 8,173 individuals and a 95% confidence interval of 5,281 to 14,401. Population abundance of sturgeon could not be estimated with a Jolly-Seber estimate because of the low number of recaptures.

1995

A total of 293 white sturgeon was sampled during 1995. Total lengths of sturgeon sampled ranged from 24.1 to 202 cm; mean length was 67 cm (Figure 69). The majority of sturgeon sampled (n=242, 82.5%) were captured in waters >18 m (Figure 70). No sturgeon were sampled in waters < 6 m deep. In summer and fall 1995, white sturgeon were predominantly collected in waters deeper than 18 m followed by collections from waters 6 to 18 m. Most sturgeon were sampled from stratum 3 (72.7%, n=213), followed by stratum 2 (26.6%, n=78), and stratum 1 (0.6%, n=2; Figure 71). Most sturgeon were sampled at RMs 133 (RKM 214.1; n=115) and 125 (RKM 201.3; n=32)

Twenty-two sturgeon that were captured and tagged in previous years were recaptured during the 1995 sampling effort (Table 25). Sixteen sturgeon moved upriver or maintained their position in the reservoir and six sturgeon moved down river. The largest net movement was 36.2 river kilometers from RM 110.5 (RKM 177.9) on 3 June 1991 to RM 133.0 (RKM 214.1) on 3 November 1995. The farthest downstream movement was 19.3 river kilometers from RM 133.0 (RKM 214.1) on

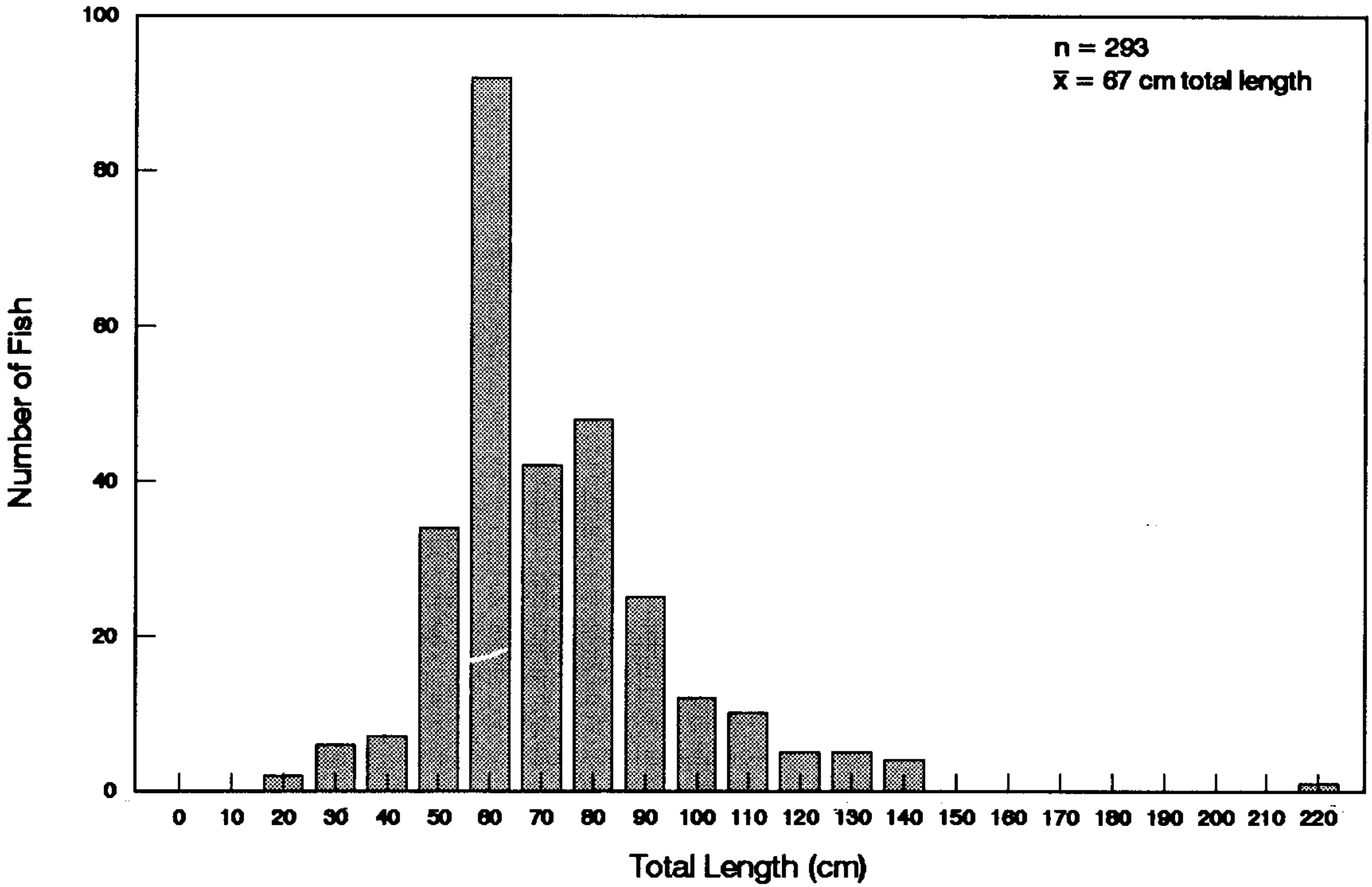

Figure 69. Length distribution of white sturgeon sampled by large and small gill nets during summer and fall 1995 in Lower Granite Reservoir.

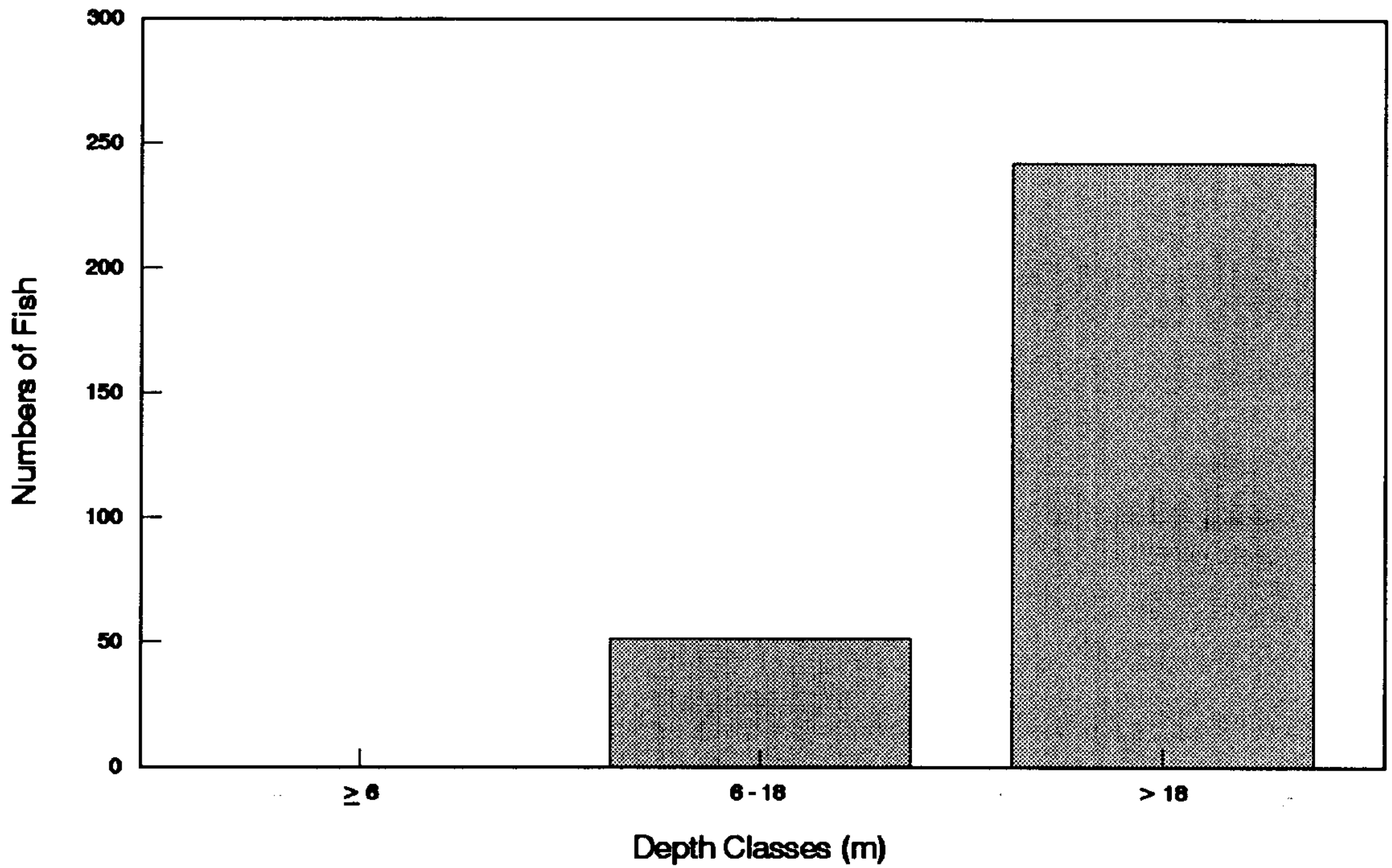

Figure 70. Relationship between depth and number of white sturgeon sampled by large and small gill nets during summer and fall 1995 in Lower Granite Reservoir.

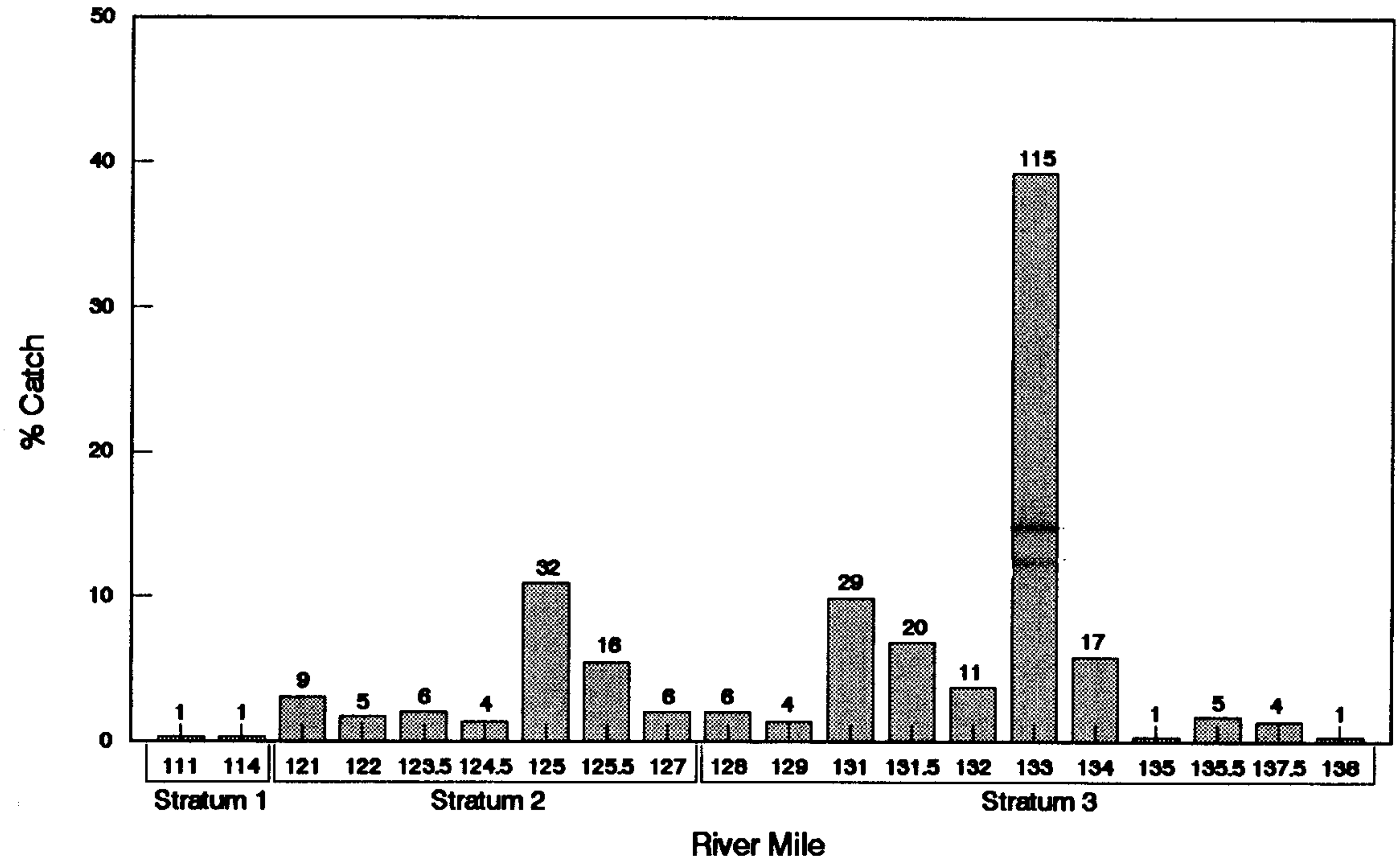

Figure 71. Percent catch of white sturgeon sampled by large and small mesh gill nets during summer and fall 1995 between river miles 111 and 138 in Lower Granite Reservoir.

Table 25. Location and net movement of white sturgeon recaptured from 1990 through 1995 in Lower Granite Reservoir.

		Initial capture		Recapture		Recapture		Recapture		Net
PIT[a] tag	Metal tag	Date	RM	Date	RM	Date	RM	Date	RM	movement (RM)[b]
7F7B015910	1633	7 Nov 94	130.0	21 Nov 95	133.0	-	-	-	-	3.0
7F7B01592A	2970	30 Nov 94	133.0	3 Nov 95	133.0	-	-	-	-	0
7F7B015D6D	2998	30 Nov 94	133.0	3 Nov 95	133.0	-	-	-	-	0
7F7B016D51	-	6 Jun 94	131.0	2 Nov 95	131.5	-	-	-	-	0.5
7F7B024C1C	-	15 Nov 94	126.0	17 Nov 95	129.0	-	-	-	-	3.0
7F7B03466F	2977	30 Nov 94	133.0	21 Nov 95	133.0	-	-	-	-	0
7F7B08B046	-	6 Jun 94	131.0	23 Jun 95	134.0	-	-	-	-	3.0
7F7F7D3110	2881	3 Jun 91	110.5	6 Sep 92	129.2	3 Nov 95	133.0	-	-	22.5
7F7D273F11	-	9 Jun 94	126.0	3 Nov 95	133.0	-	-	-	-	7.0
7F7D372A0D	-	2 Jun 94	126.0	21 Nov 95	133.0	-	-	-	-	7.0
7F7D401522	-	30 Nov 94	133.0	3 Nov 95	133.0	-	-	-	-	0
7F7D7C3326	2784	30 Nov 94	133.0	21 Nov 95	133.0	-	-	-	-	0
7F7F4E5219	-	6 Jul 94	117.0	16 Nov 95	125.0	-	-	-	-	8
7F7F5A3901	-	29 Jun 94	124.0	13 Nov 95	123.5	-	-	-	-	0.5
7F7F5D3151	1543	18 Nov 94	133.0	1 Dec 94	126.0	19 Jun 95	121.0	-	-	12.0
7F7F761A13	1028	15 Sep 92	118.6	3 Nov 95	133.0	-	-	-	-	14.4
7F7F4E5C5A	2599	27 Jun 94	133.0	7 Nov 94	130.0	18 Nov 94	133.0	3 Nov 95	133.0	3.0
221551604D	46	29 May 90	116.5	21 Nov 95	133.0	-	-	-	-	16.5
22153A5062	1342	7 Nov 93	133.7	2 Nov 95	131.5	-	-	-	-	2.2
22155E797E	2540	18 Nov 94	133.0	19 Nov 95	131.0	-	-	-	-	2.0
22154E2244	2949	1 Dec 94	127.0	19 Nov 95	131.0	-	-	-	-	4.0
7F7F5D250C	2983	30 Nov 94	133.0	20 Jun 95	125.0	-	-	-	-	8.0

[a] PIT = passive integrated transponder; [b] RM = river mile

18 November 1994 to RM 126.0 (RKM 202.9) on 19 June 1995. Five sturgeon showed no net movement from their initial capture location. We did not estimate population abundance for sturgeon captured in 1995.

Catch per Hour

Based on CPUE of white sturgeon from spring 1990 to 1994, highest catch rates of sturgeon were observed in spring 1994 (Figure 72). The highest CPUE occurred in stratum 3 in 1994, followed by that at stratum 3 in 1992 and stratum 2 in 1994. No sturgeon were sampled in stratum 1 in 1993. During fall 1990 to 1995, the highest CPUE occurred in stratum 3 in 1994, followed by that in stratum 3 in 1995 (Figure 73). Catches per hour were similar during fall from 1990 to 1993. No sturgeon were sampled in stratum 1 in 1995.

Catches per hour of white sturgeon by season indicate the highest CPUE occurred in stratum 3 in fall, followed by those during spring, summer and winter (Figure 74). Catches per hour for strata 2 and 3 were similar among seasons.

Highest CPUE varied among years between spring (1992), summer (1990), and fall (1991, 1994, and 1995) and often coincided with the highest variance. Highest number of sturgeon collected was not associated with the highest CPUE (Table 26). In fall 1994, CPUE averaged nearly one white sturgeon/hour of sampling. Statistically, when all years were pooled, significantly higher CPUE were found in stratum 1 during fall ($P=0.0001$), spring ($P=0.0001$), summer ($P=0.0001$), and winter ($P=0.0036$).

Within season and year comparisons of CPUE, significantly higher CPUE were found for stratum 1 in 1990, 1991, 1992, 1993 (fall only), 1994 (spring and fall; Table 26). In 1995, CPUE was significantly higher in stratum 1 than stratum 3 but no differences were found between stratum 2. Within season comparisons showed that CPUE were significantly higher in stratum 1 among 1990-1993 and 1995 with

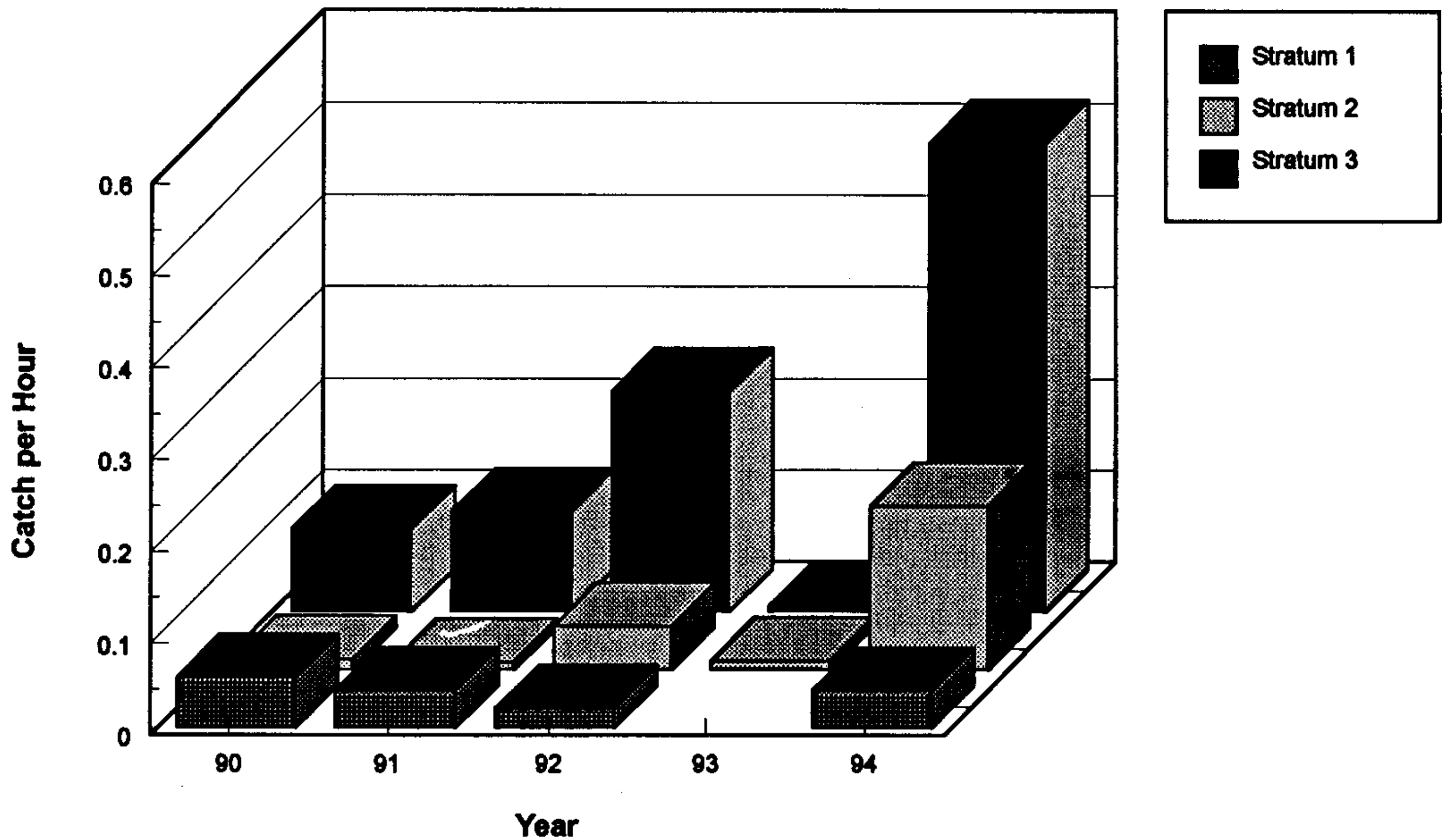

Figure 72. Comparison of catch per hour of white sturgeon sampled in spring from 1990 to 1995 in Lower Granite Reservoir.

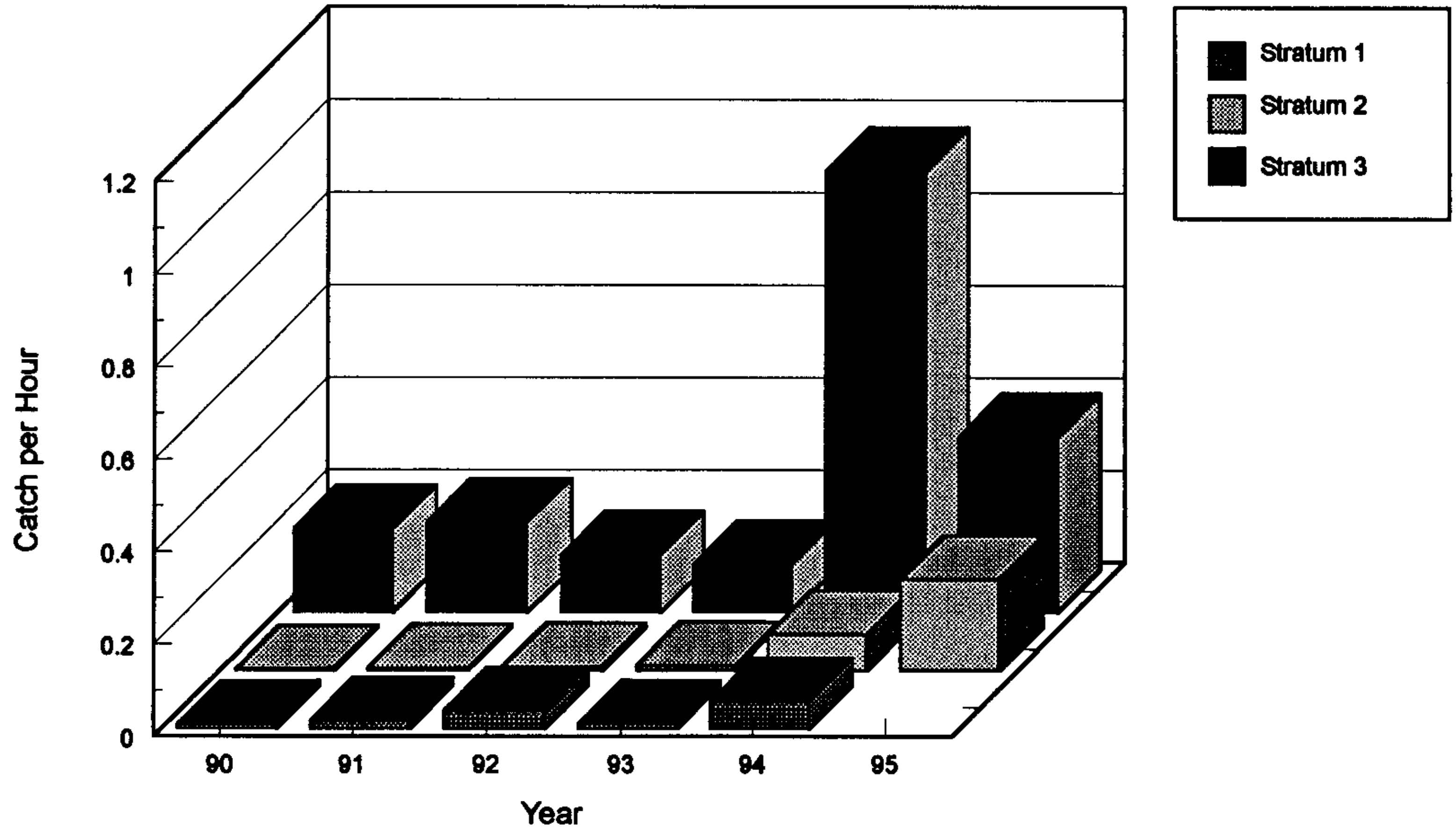

Figure 73. Comparison of catch per hour of white sturgeon sampled in fall from 1990 to 1995 in Lower Granite Reservoir.

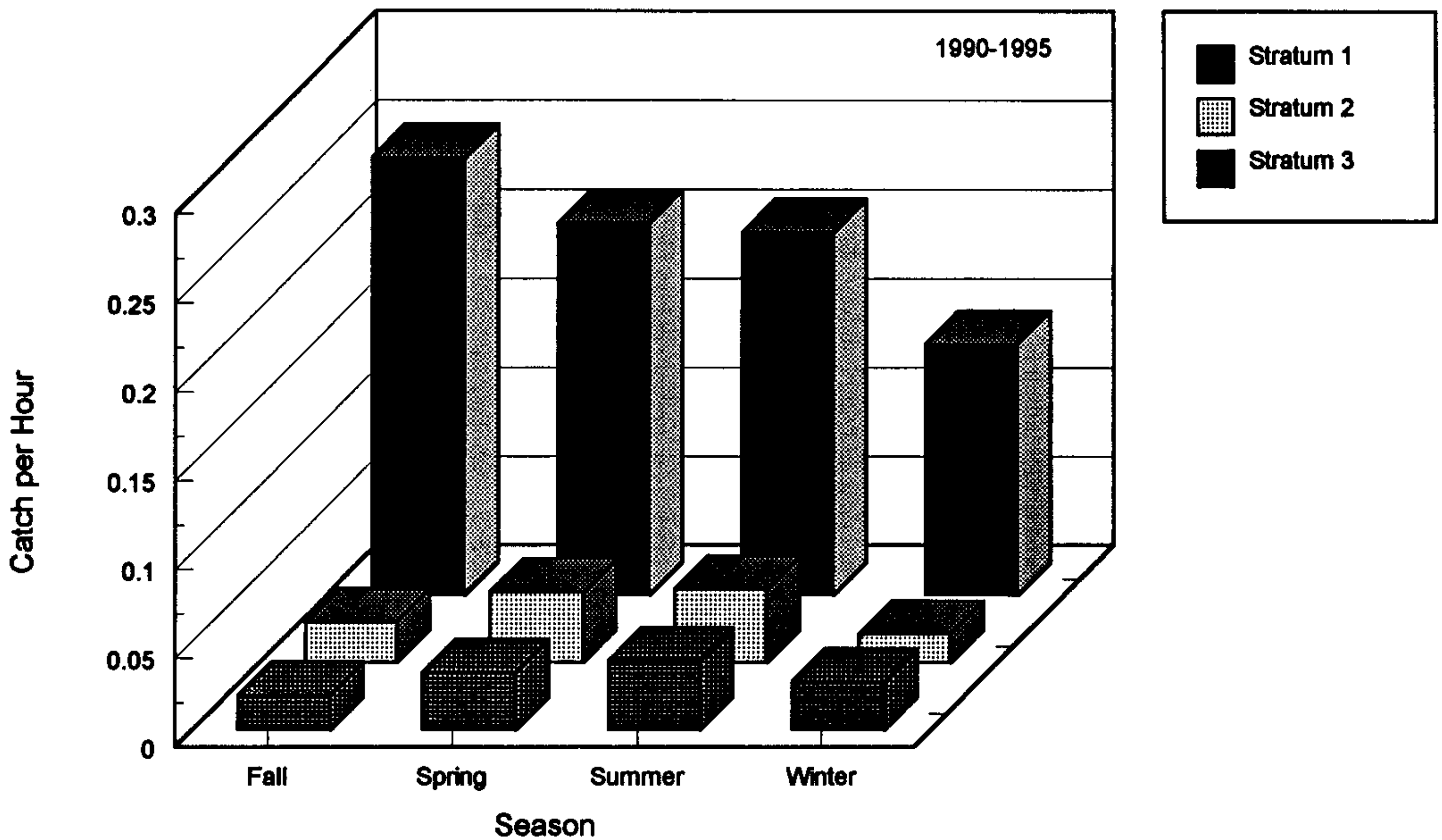

Figure 74. Comparision of catch per hour of white sturgeon sampled during fall, spring, summer, and winter from 1990 to 1995 in Lower Granite Reservoir.

Appendix Table 10. Continued

Variable	Winter non-MOP FB var.	Winter non-MOP FB level	Days≥20 kcfs	Days≥25 kcfs
Days ≥ 50 kcfs	-0.44	0.43	0.86*	0.87*
Days ≥ 75 kcfs	-0.40	0.31	0.78*	0.86*
Days ≥ 100 kcfs	-0.28	0.21	0.62	0.74*
MN ≥ 50 kcfs	-0.01	0.20	-0.41	-0.52
MN ≥ 75 kcfs	-0.28	0.44	-0.14	-0.31
MD ≥ 50 kcfs	-0.12	0.04	-0.00	0.02
MD ≥ 75 kcfs	-0.13	0.21	-0.15	-0.36
Days ≥ 20°C	-0.40	0.25	0.26	0.12
Days ≥ 15°C	0.41	-0.42	-0.69*	-0.67*
Days ≥ 10°C	0.40	-0.53	-0.51	-0.58
MN ≥ 20°C	-0.58	0.74*	0.56	0.11
MN ≥ 15°C	-0.85*	0.91*	0.57	0.27
MN ≥ 10°C	-0.90*	0.89*	0.56	0.32
MD ≥ 20°C	-0.71*	0.84*	0.47	0.40
MD ≥ 15°C	-0.84*	0.90*	0.58	0.43
MD ≥ 10°C	-0.85*	0.85*	0.38	0.20
MN secchi	0.54	-0.47	-0.91*	-0.89*
Days secchi ≥ 1.5 ft	-0.31	0.20	0.72*	0.86*
Days secchi ≥ 2 ft	-0.32	0.23	0.73*	0.83*
MOP forebay variance	-0.58	0.48	0.60	0.45
Forebay var. May	0.63	-0.60	-0.19	-0.11
Forebay var. Jun	0.37	-0.51	0.36	0.38
Forebay var. Jul	-0.36	0.28	0.58	0.48
Forebay var. Aug	-0.34	0.30	0.49	0.30
Forebay var. Sep	-0.26	0.38	0.49	0.34
Winter forebay var.	0.22	-0.38	-0.12	0.06
Winter forebay level	-0.01	0.24	-0.31	-0.46
Non-MOP forebay var.	1.00	-0.96*	-0.75	-0.60
Non-MOP forebay level		1.00	0.64	0.47
Days ≥ 20 kcfs			1.00	0.93*
Days ≥ 25 kcfs				1.00
Days ≥ 35 kcfs				
Winter days ≥ 10°C				
Sampling effort				
Instantaneous growth rate				

Appendix Table 10. Continued

Variables	Winter days≥35 kcfs	Winter D10°C	Sampling effort	Growth
Days ≥ 50 kcfs	0.60	0.20	0.49	0.49
Days ≥ 75 kcfs	0.58	0.20	0.47	0.57
Days ≥ 100 kcfs	0.49	0.14	0.70*	0.38
MN ≥ 50 kcfs	-0.39	0.14	0.10	-0.23
MN ≥ 75 kcfs	-0.32	0.18	0.19	-0.16
MD ≥ 50 kcfs	-0.14	0.30	0.10	-0.07
MD ≥ 75 kcfs	-0.33	0.35	-0.47	-0.15
Days ≥ 20°C	-0.30	0.57	-0.67	-0.78*
Days ≥ 15°C	-0.45	-0.29	0.17	-0.16
Days ≥ 10°C	-0.67*	-0.01	-0.42	-0.63
MN ≥ 20°C	0.39	-0.31	0.78*	0.45
MN ≥ 15°C	0.11	0.41	0.27	0.09
MN ≥ 10°C	0.06	0.61	0.07	-0.27
MD ≥ 20°C	0.23	0.14	0.68	0.16
MD ≥ 15°C	0.14	0.43	0.27	0.15
MD ≥ 10°C	-0.09	0.54	0.18	-0.31
MN secchi	-0.48	-0.32	-0.34	-0.38
Days secchi ≥ 1.5 ft	0.64	0.08	0.46	0.62
Days secchi ≥ 2 ft	0.53	0.09	0.55	0.52
MOP forebay variance	-0.15	0.69*	0.09	-0.57
Forebay var. May	-0.14	-0.24	0.32	-0.11
Forebay var. Jun	0.08	-0.05	-0.23	-0.29
Forebay var. Jul	0.06	0.49	0.06	-0.67
Forebay var. Aug	0.01	0.67*	-0.64	-0.28
Forebay var. Sep	-0.10	-0.01	0.67*	0.17
Winter forebay var.	-0.15	-0.06	-0.24	-0.43
Winter forebay level	-0.17	-0.37	0.88*	0.64
Non-MOP forebay var.	-0.19	-0.63	-0.22	0.05
Non-MOP forebay level	0.11	0.58	0.37	0.02
Days ≥ 20 kcfs	0.47	0.43	-0.48	0.03
Days ≥ 25 kcfs	0.71*	0.17	-0.21	0.29
Days ≥ 35 kcfs	1.00	-0.27	0.31	0.73
Winter days ≥ 10°C		1.00	-0.42	-0.48
Sampling effort			1.00	0.42
Instantaneous growth rate				1.00

* = significant correlation ($P < 0.05$); [a] MN = mean Julian date; [b] MD = median Julian date; [c] MOP = minimum operating pool; [d] FB = forebay

Table 26. Catch statistics for catch per hour of white sturgeon using gill nets in Lower Granite Reservoir from 1990 through 1995.

Year	Season	Strata[a]	n	Mean	Variance
1990	Fall	1	9	0.18266	0.096181
1990	Fall	2	23	0.00345	0.000131
1990	Fall	3	15	0.01021	0.000373
1990	Spring	1	13	0.09167	0.026796
1990	Spring	2	35	0.01223	0.000577
1990	Spring	3	21	0.05539	0.013277
1990	Summer	1	14	0.20887	0.053169
1990	Summer	2	23	0.02071	0.002329
1990	Summer	3	22	0.01629	0.001028
1990	Winter	1	3	0.03309	0.000539
1990	Winter	2	1	0.02083	-
1990	Winter	3	4	0.00000	0.000000
1991	Fall	1	23	0.19636	0.088860
1991	Fall	2	19	0.00622	0.000260
1991	Fall	3	15	0.01845	0.001260
1991	Spring	1	26	0.11001	0.023357
1991	Spring	2	21	0.00917	0.000546
1991	Spring	3	28	0.04162	0.007981
1991	Summer	1	7	0.19499	0.011296
1991	Summer	2	2	0.03687	0.002719
1991	Summer	3	5	0.06662	0.010332
1991	Winter	1	2	0.02147	0.000922
1992	Fall	1	16	0.12601	0.009671
1992	Fall	2	22	0.00924	0.000422
1992	Fall	3	10	0.04053	0.002696
1992	Spring	1	9	0.24180	0.065998
1992	Spring	2	27	0.04807	0.007448
1992	Spring	3	13	0.02241	0.001195
1992	Winter	1	7	0.16625	0.030854
1992	Winter	2	4	0.03572	0.001122
1992	Winter	3	10	0.02249	0.000664
1993	Fall	1	13	0.10527	0.007971
1993	Fall	2	22	0.01101	0.000400
1993	Fall	3	17	0.01145	0.000296
1993	Spring	1	5	0.00701	0.00010
1993	Spring	2	24	0.01041	0.00065
1993	Spring	3	4	0.00000	0.00000
1994	Fall	1	6	0.95659	1.57942
1994	Fall	2	3	0.0790	0.00562
1994	Fall	3	11	0.05966	0.00398
1994	Spring	1	16	0.51144	0.04784
1994	Spring	2	9	0.17972	0.01125

Table 26. Continued.

Year	Season	Strata	n	Mean	Variance
1994	Spring	3	15	0.04186	0.00429
1994	Summer	2	3	0.17958	0.00668
1994	Summer	3	4	0.15010	0.02172
1994	Winter	1	3	0.27292	0.01564
1994	Winter	2	1	0.00000	
1995	Fall	1	9	0.38166	0.13037
1995	Fall	2	5	0.19854	0.01244
1995	Fall	3	5	0.00000	0.00000

[a] Stratum 1 - RM 126 - 139.75 (RKM 202.9 - 225.0), stratum 2 - RM 119 - 126 (RKM 191.6 - 202.9), and stratum 3 - RM 108.0 - 119 (RKM 173.9 - 191.6). RM = river mile and RKM = river kilometer.

1994 in the fall and similar for stratum 2. In the spring season, CPUE was significantly higher in strata 1 and 2 in 1990, 1991, and 1993 than either 1992 and 1994. During both spring and fall seasons, fewer statistical differences among CPUE for years were found within stratum 3.

DISCUSSION

Sturgeon habitat use in Lower Granite Reservoir has changed little from year to year. In 1994 and 1995, the highest number of sturgeon were sampled in waters deeper than 18 m similar to that in 1993 when the mean depth of capture was 21 m. In 1990 to 1992, Lepla (1994) reported highest catches of white sturgeon at depths of 18 to 22 m. Size structure of sturgeon sampled in 1994 and 1995 was similar to previous years. In 1993, 96% of the sturgeon sampled from Lower Granite Reservoir were < 1.2 m (Bennett et al. 1995b) compared to 94% in 1994. Lepla (1994) reported a mean length of 62.3 cm compared to 63.1 cm in 1993 (Bennett et al. 1995b) and 56.9 cm in 1994 and 67 cm in 1995. The size structure of sturgeon inhabiting Lower Granite Reservoir has changed little in the 5 years of monitoring.

Movement information indicated that some sturgeon showed no net movement during both 1994 and 1995. The longest movement was downstream about 22.5 river miles in 1995 and 19.0 miles in 1994. Use of PIT tags has greatly improved the opportunity to collect movement information as tag loss was a problem prior to their use.

Discussion

Catches per hour of white sturgeon in Lower Granite Reservoir has shown few changes in abundance. Our comparisons consistently showed highest sturgeon abundance from 1990 to 1995 in stratum 3 with low catches in both strata 1 and 2. In 1993, we collected no sturgeon upstream of RM 137.1. We attributed the zero catches to the high velocities (Bennett et al. 1995b). However, 68% of the sturgeon collected in 1993 were collected from RM 127 to RM 137.1.

Seasonal comparisons of CPUE showed that during fall, CPUE was considerably higher in 1994 than other years of sampling. During spring, high CPUE also occurred in spring 1994 followed by spring 1992.

Differences in CPUE within seasons and among years are probably related to flow conditions. During both 1992 and 1994 spring flows were considerably lower than those in 1990, 1991 and 1993 that probably increased our collection efficiency. Those differences in CPUE were less obvious in the fall except in 1994. We do not know why our fall catches were so much higher in 1994 than other years.

Time of year, location, and discharge into Lower Granite Reservoir have a substantial effect on CPUE of white sturgeon. The influence of inflow on CPUE is unclear. The years 1990, 1991, 1993 and 1995 were higher inflow years whereas 1992 and 1994 were low inflow years. During lower flow years, our CPUE was high during the spring in stratum 1 whereas during the higher flow years they were lower probably because of the difficulty in sampling. One other possibility is that white sturgeon move downstream in Lower Granite Reservoir during years with higher inflows. Number of white sturgeon collected increased in downstream strata in years of higher inflows. Higher inflows may provide more favorable habitat in the mid and lower reaches of the reservoir.

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Appendix Table 1. Estimated mean catch per unit efforts (CPUEs) and sample variances (S^2) of smallmouth bass by length class (mm), month, and location during 1995 in Lower Granite Reservoir.

			70 - 174		175 - 249		250 - 389		>389	
Strata[a]	Month	Number of samples	CPUE	S^2	CPUE	S^2	CPUE	S^2	CPUE	S^2
1	April	16	0.01	0.002	0.01	0.002	0.03	0.006	0.00	0.000
	May	34	1.13	1.232	0.92	0.864	0.23	0.080	0.02	0.003
	June	31	3.11	8.313	1.03	0.622	0.08	0.011	0.00	0.001
	July	31	2.83	7.049	1.10	1.177	0.11	0.012	0.00	0.000
2	April	45	0.54	0.540	0.03	0.004	0.03	0.007	0.00	0.001
	May	61	0.40	0.453	0.73	0.360	0.19	0.030	0.01	0.001
	June	40	0.99	1.029	1.16	0.478	0.12	0.026	0.01	0.001
	July	48	1.79	1.634	1.09	0.726	0.20	0.038	0.00	0.000
3	April	24	0.05	0.007	0.14	0.069	0.03	0.002	0.00	0.000
	May	52	0.22	0.060	0.77	0.496	0.18	0.052	0.01	0.001
	June	58	0.71	0.709	1.45	2.809	0.24	0.339	0.01	0.001
	July	48	1.09	0.870	1.77	1.922	0.27	0.132	0.01	0.001

[a] Stratum1 - RM 131.0 - 139.25 (RKM 210.9 - 224.2), stratum 2 - RM 120.0 - 131.0 (RKM 193.2 - 210.9), stratum 3 - RM 107.5 - 120.0 (RKM 173.1 - 193.2). RM = river mile; RKM = river kilometer.

Appendix Table 2. River mile, slope, range of particle size, and substrate classification of sites sampled by electrofishing during summer (June - September) 1994, fall (October - November) 1994, and spring (April - May) 1995 in Lower Granite Reservoir.

RM[a] (RKM)[b]	Depth (m)	Slope (%)	Particle (mm)	Substrate
180.8 (174.9)	1.6	27	250 - 400	Riprap
109.3 (175.8)	2.1	36	>2000	Cliff
109.6 (176.2)	1.6	32	250 - 400	Riprap
110.1 (177.0)	0.9	6	2.0 - 250	Cob/rub[c]
110.3 (177.4)	1.5	90	>2000	Cliff
111.1 (178.6)	0.8	8	2.0 - 250	Cob/rub
111.3 (179.0)	2.0	28	250 - 400	Riprap
111.8 (179.8)	4.9	89	>2000	Cliff
112.6 (181.0)	2.6	32	250 - 400	Riprap
112.6 (181.0)	6.7	40	>2000	Cliff
113.1 (181.8)	0.9	8	2.0 - 250	Cob/rub
113.1 (181.8)	3.0	36	>2000	Cliff
113.3 (182.2)	0.5	8	2.0 - 250	Cob/rub
114.3 (183.8)	1.4	25	2.0 - 250	Cob/rub
114.3 (183.8)	2.4	29	250 - 400	Riprap
114.6 (184.2)	2.2	15	>2000	Cliff
115.3 (185.4)	2.2	34	250 - 400	Riprap
115.6 (185.8)	1.7	29	250 - 400	Riprap
115.8 (186.2)	0.7	8	<2.0	Sand
116.3 (187.0)	1.7	31	250 - 400	Riprap
116.6 (187.4)	0.5	9	2.0 - 250	Cob/rub
116.9 (187.9)	2.0	18	>2000	Cliff
117.6 (189.1)	1.4	25	250 - 400	Riprap
117.9 (189.5)	6.1	85	>2000	Cliff
118.9 (191.1)	0.5	20	250 - 400	Riprap
119.1 (191.5)	1.1	10	2.0 - 250	Cob/rub
119.6 (192.3)	0.6	9	<2.0	Sand
119.9 (192.7)	0.5	5	<2.0	Sand
120.1 (193.1)	0.5	10	<2.0	Sand
120.1 (193.1)	0.7	9	2.0 - 250	Cob/rub
120.1 (193.1)	0.6	10	2.0 - 250	Cob/rub
120.6 (193.9)	1.4	21	250 - 400	Riprap
120.9 (194.3)	1.8	23	250 - 400	Riprap
121.6 (195.5)	0.8	12	2.0 - 250	Cob/rub
121.6 (195.5)	1.0	34	250 - 400	Riprap
121.8 (195.9)	1.1	26	250 - 400	Riprap
121.8 (195.9)	2.8	10	>2000	Cliff
122.3 (196.7)	1.7	28	250 - 400	Riprap
122.6 (197.1)	1.2	45	>2000	Cliff

Appendix Table 2. Continued

RM (RKM)	Depth (m)	Slope (%)	Particle (mm)	Substrate
122.8 (197.5)	1.2	13	2.0 - 250	Cob/rub
123.1 (197.9)	1.1	13	2.0 - 250	Cob/rub
123.3 (198.3)	0.9	10	2.0 - 250	Cob/rub
124.1 (199.5)	0.7	15	>2000	Cliff
124.6 (200.3)	1.0	12	>2000	Cliff
124.8 (200.7)	1.3	29	250 - 400	Riprap
125.3 (201.5)	0.8	12	2.0 - 250	Cob/rub
125.6 (201.9)	1.1	13	2.0 - 250	Cob/rub
125.8 (202.3)	1.4	7	2.0 - 250	Cob/rub
125.8 (202.3)	1.3	45	>2000	Cliff
126.8 (203.9)	1.0	13	2.0 - 250	Cob/rub
127.3 (204.7)	1.1	8	2.0 - 250	Cob/rub
127.3 (204.7)	2.0	25	250 - 400	Riprap
127.6 (205.1)	0.6	9	2.0 - 250	Cob/rub
127.6 (205.1)	1.7	25	250 - 400	Riprap
128.1 (206.0)	1.2	4	2.0 - 250	Cob/rub
128.4 (206.4)	6.2	87	>2000	Cliff
128.6 (206.8)	1.4	33	250 - 400	Riprap
129.1 (207.6)	0.4	9	2.0 - 250	Cob/rub
129.6 (208.4)	5.0	91	>2000	Cliff
129.9 (208.8)	0.4	8	<2.0	Sand
129.9 (208.8)	3.7	88	>2000	Cliff
130.4 (209.6)	0.8	9	2.0 - 250	Cob/rub
130.6 (209.9)	2.4	27	250 - 400	Riprap
130.9 (210.4)	0.4	8	<2.0	Sand
131.4 (211.2)	1.5	32	250 - 400	Riprap
131.6 (211.6)	1.1	90	>2000	Cliff
131.6 (211.6)	0.4	8	<2.0	Sand
131.9 (212.0)	0.3	9	<2.0	Sand
132.1 (212.4)	1.3	23	250 - 400	Riprap
132.1 (212.4)	0.4	6	<2.0	Sand
132.6 (213.2)	1.2	21	250 - 400	Riprap
133.0 (213.9)	0.5	8	<2.0	Sand
133.4 (214.4)	0.6	9	2.0 - 250	Cob/rub
133.4 (214.4)	1.2	28	250 - 400	Riprap
133.6 (214.8)	0.8	9	2.0 - 250	Cobble
134.4 (216.0)	0.4	8	<2.0	Sand
134.6 (216.4)	0.4	8	<2.0	Sand
134.8 (216.8)	0.9	20	250 - 400	Riprap
135.6 (218.0)	1.7	25	250 - 400	Riprap
136.0 (219.6)	1.7	29	250 - 400	Riprap
136.8 (220.0)	1.9	26	250 - 400	Riprap
137.8 (221.6)	1.3	9	2.0 - 250	Cob/rub

Appendix Table 2. Continued

RM (RKM)	Depth (m)	Slope (%)	Particle (mm)	Substrate
138.1 (222.0)	1.9	25	250 - 400	Riprap
138.6 (222.8)	1.6	15	250 - 400	Riprap
138.8 (223.2)	0.9	10	2.0 - 250	Cob/rub
139.1 (223.7)	0.8	10	2.0 - 250	Cob/rub
139.1 (223.7)	1.6	22	250 - 400	Riprap

[a] RM = river mile
[b] RKM = river kilometer
[c] Cob/rub = cobble/rubble

Appendix Table 3. List of species codes, scientific names, and common names for fishes sampled by electrofishing during summer (June - September) 1994, fall (October - November) 1994, and spring (April - May) 1995 in Lower Granite Reservoir.

Codes	Scientific name	Common name
OTS	*Oncorhynchus tshawytscha*	Chinook salmon
OMY	*O. mykiss*	Steelhead trout
AAL	*Acrocheilus alutaceus*	Chiselmouth
POR	*Ptychocheilus oregonensis*	Northern squawfish
CCO	*Catostomus columbianus*	Bridgelip sucker
CMA	*C. macrocheilus*	Largescale sucker
Lepomis spp.	*Lepomis gibbosus*	Pumpkinseed
	L. macrochirus	Bluegill
Pomoxis spp.	*Pomoxis nigromaculatus*	Black crappie
PAN	*P. annularis*	White crappie
MDO	*Micropterus dolomieu*	Smallmouth bass
PFL	*Perca flavescens*	Yellow perch
COT	*Cottus spp.*	Sculpin

Appendix Table 4. Standardized canonical discriminant function coefficients for key species and species complexes during summer (June - September) 1994, fall (October - November) 1994, and spring (April - May) 1995 in Lower Granite Reservoir.

		Discriminant coefficients		
Species/Species complex	Variables	Summer 1994	Fall 1994	Spring 1995
Chinook salmon[a]	Velocity	_[b]	*[c]	0.79
	Water temperature	_	1.09	0.71
	Depth	_	-1.09	-0.85
	Slope	_	0.26	0.47
	Macrophyte	_	*	*
	Substrate	_	0.20	0.32
Steelhead[a]	Velocity	_	*	0.45
	Water temperature	_	0.90	0.87
	Depth	_	0.08	-0.07
	Slope	_	-0.16	-0.32
	Macrophyte	_	*	*
	Substrate	_	0.18	0.46
Northern squawfish	Velocity	0.27	*	0.33
	Water temperature	0.04	0.75	-0.48
	Depth	-1.73	-1.40	-0.09
	Slope	0.63	0.95	-0.73
	Macrophyte	0.53	*	*
	Substrate	2.14	0.57	0.84
Catostomus spp.	Velocity	-0.03	*	0.34
	Water temperature	0.38	-0.34	0.54
	Depth	0.34	-0.78	1.09
	Slope	0.13	1.46	0.19
	Macrophyte	-0.34	*	*
	Substrate	-1.63	-0.41	-1.01
Chiselmouth	Velocity	0.41	*	-0.50
	Water temperature	0.78	0.18	0.26
	Depth	0.58	1.30	-0.88
	Slope	-0.43	-1.48	0.01
	Macrophyte	0.13	*	*
	Substrate	-0.44	0.45	1.10

Appendix Table 4. Continued

Species/Species complex	Variables	Discriminant coefficients Summer 1994	Fall 1994	Spring 1995
Ictalurus spp.	Velocity	-0.31	–	–
	Water temperature	0.61	–	–
	Depth	-1.16	–	–
	Slope	0.25	–	–
	Macrophyte	0.30	–	–
	Substrate	1.83	–	–
Lepomis spp.	Velocity	-0.31	–	-0.47
	Water temperature	-0.03	–	-0.53
	Depth	-1.11	–	0.59
	Slope	0.44	–	0.17
	Macrophyte	0.50	–	*
	Substrate	0.03	–	0.28
Pomoxis spp.	Velocity	-0.27	–	-0.22
	Water temperature	0.38	–	0.61
	Depth	-0.82	–	0.52
	Slope	-0.51	–	-0.29
	Macrophyte	0.73	–	*
	Substrate	-0.78	–	0.55
Smallmouth bass	Velocity	0.38	*	0.59
	Water temperature	0.31	0.88	-0.62
	Depth	0.16	-0.32	-0.56
	Slope	-0.32	0.10	-0.09
	Macrophyte	-0.13	*	*
	Substrate	1.05	0.52	0.47

[a] Juvenile and subyearlings
[b] Species/species complexes were not sampled
[c] * = Independent variable not included in analysis

Appendix Table 5. Strata, location, shore, and habitat type of sites sampled in 1995 by electrofishing in Lower Granite Reservoir.

Stratum 1			Stratum 2			Stratum 3		
RM	Shore	Habitat	RM	Shore	Habitat	RM	Shore	Habitat
139.00	S[a]	Talus	130.75	S	Sand	120.00	S	Sand
139.00	N[b]	Riprap	130.50	N	Riprap	120.00	S	Talus
138.75	S	Talus	130.25	S	Cliff	120.00	S	Cobble
138.50	N	Riprap	129.75	N	Sand	118.75	N	Riprap
137.75	S	Talus	129.50	S	Cliff	117.75	S	Cliff
136.75	N	Riprap	129.00	N	Talus	117.50	N	Riprap
136.50	S	Riprap	128.50	N	Riprap	116.75	S	Talus
134.75	S	Riprap	128.25	S	Cliff	116.50	S	Cliff
134.50	N	Sand	127.75	N	Riprap	116.25	N	Riprap
134.25	N	Sand	126.25	S	Talus	115.75	S	Sand
133.50	S	Riprap	125.75	S	Cliff	115.50	N	Riprap
132.50	N	Riprap	125.75	N	Cobble	115.25	N	Riprap
132.25	N	Riprap	125.50	N	Cobble	114.50	S	Cliff
132.00	S	Sand	124.75	N	Riprap	114.25	N	Riprap
131.75	S	Sand	124.00	S	Cliff	114.25	S	Talus

Appendix Table 5. Continued

Stratum 1			Stratum 2			Stratum 3		
RM	Shore	Habitat	RM	Shore	Habitat	RM	Shore	Habitat
131.50	S	Cobble	123.00	S	Talus	113.00	N	Cobble
			122.25	N	Riprap	112.50	S	Cliff
			120.75	S	Cliff	111.75	S	Cliff
			121.75	N	Riprap	110.50	S	Cliff
			120.50	N	Riprap	110.00	S	Cobble
						109.25	N	Riprap
						109.25	S	Cliff
						108.00	S	Riprap
						107.50	N	Riprap

[a] S = south
[b] N = north

Appendix Table 6. Number of larval Cyprinidae collected during 1995 in Lower Granite Reservoir listed by river mile, shore orientation, and habitat.

Date	River mile	Shore	Habitat		Cyprinidae
May 30	126.0 - 126.25	N[a]	Cobble		0
	130.5 - 130.75	S[b]	Embayment		0
	130.75 - 131.0	N	Sand		0
	132.0 - 133.0	N	Riprap		0
	134.0 - 135.0	N	Sand		0
	138.0 - 139.0	N	Riprap		0
	138.0 - 139.0	S	Talus		0
				Total	0
Jun 13	126.0 - 126.25	N	Cobble		0
	130.5 - 130.75	S	Embayment		1
	131.0 - 132.0	S	Sand		4
	133.0 - 133.75	N	Riprap		2
	134.0 - 135.0	N	Sand		0
	134.0 - 135.0	S	Riprap		0
	137.0 - 138.0	S	Talus		0
				Total	7
Jun 28	125.25 - 126.0	N	Cobble		2
	126.25 - 127.0	N	Riprap		1
	130.5 - 130.75	S	Embayment		57
	132.0 - 133.0	S	Sand		12
	133.0 - 133.75	N	Riprap		3
	133.75 - 134.0	N	Talus		4
	134.0 - 135.0	N	Sand		4
				Total	83
Jul 11	126.0 - 126.25	N	Cobble		25
	127.0 - 127.75	S	Talus		24
	130.0 - 131.0	N	Riprap		4
	130.5 - 130.75	S	Embayment		4
	131.0 - 132.0	S	Sand		1
	134.0 - 135.0	N	Sand		98
	136.0 - 137.0	S	Riprap		3
				Total	159
Jul 25	125.0 - 125.25	N	Riprap		3
	126.0 - 126.25	N	Cobble		2
	128.75 - 129.0	N	Talus		3
	130.5 - 130.75	S	Embayment		3
	130.75 - 131.0	S	Sand		1
	132.0 - 133.0	N	Riprap		25

Appendix Table 6. Continued

Date	River mile	Shore	Habitat		Cyprinidae
Jul 25	134.0 - 135.0	N	Sand		126
	136.0 - 137.0	N	Riprap		5
	139.0 - 135.25	S	Talus		0
				Total	168
Aug 8	125.25 - 126.0	N	Cobble		1
	129.0 - 130.0	N	Talus		4
	130.5 - 130.75	S	Embayment		0
	130.75 - 131.0	S	Sand		0
	134.0 - 135.0	N	Sand		9
	136.0 - 137.0	N	Riprap		0
	138.0 - 138.75	N	Riprap		2
				Total	16
Aug 22	125.25 - 126.0	N	Cobble		0
	130.5 - 130.75	S	Embayment		0
	132.0 - 133.0	N	Riprap		0
	132.0 - 133.0	S	Sand		1
	134.0 - 135.0	N	Sand		1
	136.0 - 137.0	N	Riprap		1
	138.0 - 139.0	S	Talus		0
				Total	3
Sep 5	126.0 - 126.25	N	Cobble		0
	126.25 - 127.0	N	Riprap		0
	127.0 - 127.75	S	Talus		0
	128.0 - 128.75	N	Riprap		0
	130.5 - 130.75	S	Embayment		0
	130.75 - 131.0	N	Sand		0
	133.0 - 133.75	N	Riprap		0
	134.0 - 135.0	N	Sand		0
	139.0 - 139.25	S	Talus		0
				Total	0

[a] N = north
[b] S = south

Appendix Table 7. **Model significance and coefficient of variation of competing models for predicting abundance of larval northern squawfish. Model used: $CPUE_{n+1} = CPUE_n + variable$. CPUE indicates catch per unit effort.**

Location	Variable	Model significance	r^2	Period examined
Lower Granite	Days ≥ 50 kcfs	0.18	0.57	Annual
	Days ≥ 75 kcfs	0.21	0.54	Annual
	Days ≥ 100 kcfs	0.14	0.62	Annual
	MN[a] ≥ 50 kcfs	0.23	0.52	Annual
	MN ≥ 75 kcfs	0.21	0.54	Annual
	MD[b] ≥ 50 kcfs	0.13	0.64	Annual
	MD ≥ 75 kcfs	0.02	0.85	Annual
	Jun DD[c] ≥ 20C	0.23	0.52	Jun
	Jun DD ≥ 15C	0.23	0.52	Jun
	Jun DD ≥ 10C	0.22	0.53	Jun
	Jul DD ≥ 20C	0.21	0.54	Jul
	Jul DD ≥ 15C	0.19	0.57	Jul
	Jul DD ≥ 10C	0.19	0.57	Jul
	Aug DD ≥ 20C	0.20	0.56	Aug
	Aug DD ≥ 15C	0.20	0.55	Aug
	Aug DD ≥ 10C	0.20	0.55	Aug
	Sep DD ≥ 20C	0.16	0.60	Sep
	Sep DD ≥ 15C	0.12	0.65	Sep
	Sep DD ≥ 10C	0.12	0.65	Sep
	MN ≥ 20C	0.02	0.87	Mar 1 to Sep 15
	MN ≥ 15C	0.18	0.57	Mar 1 to Sep 15
	MN ≥ 10C	0.17	0.59	Mar 1 to Sep 15
	MD ≥ 20C	0.12	0.66	Mar 1 to Sep 15
	MD ≥ 15C	0.19	0.56	Mar 1 to Sep 15
	MD ≥ 10C	0.17	0.58	Mar 1 to Sep 15
	Mean secchi	0.20	0.56	Mar 1 to Jun 30
	Days secchi ≥ 1.5 ft	0.13	0.63	Mar 1 to Jun 30
	Days secchi ≥ 2.0 ft	0.15	0.61	Mar 1 to Jun 30
	MOP[d] forebay var.	0.06	0.75	Apr 15 to Sep 30
	Forebay var. May	0.12	0.65	May
	Forebay var. Jun	0.00	0.94	Jun
	Forebay var. Jul	0.03	0.81	Jul
	Forebay var. Aug	0.22	0.53	Aug
	Forebay var. Sep	0.22	0.53	Sep
Clearwater River	Days ≥ 20 kcfs	0.17	0.59	Annual
	Days ≥ 30 kcfs	0.23	0.53	Annual
	May DD ≥ 10C	0.16	0.60	May
	Jun DD ≥ 20C	0.16	0.59	Jun
	Jun DD ≥ 15C	0.21	0.54	Jun

Appendix Table 7. Continued

Location	Variable	Model significance	r^2	Period examined
	Jun DD ≥ 10°C	0.23	0.52	Jun
	Jul DD ≥ 20°C	0.22	0.53	Jul
	Jul DD ≥ 15°C	0.10	0.68	Jul
	Jul DD ≥ 10°C	0.04	0.81	Jul
	MN ≥ 20°C	0.82	0.13	Mar 1 to Sep 15
	MN ≥ 15°C	0.16	0.60	Mar 1 to Sep 15
	MN ≥ 10°C	0.22	0.53	Mar 1 to Sep 15
	MD ≥ 20°C	0.77	0.16	Mar 1 to Sep 15
	MD ≥ 15°C	0.17	0.59	Mar 1 to Sep 15
	MD ≥ 10°C	0.21	0.55	Mar 1 to Sep 15
Snake River	Days ≥ 50 kcfs	0.19	0.57	Annual
	Days ≥ 75 kcfs	0.15	0.61	Annual
	May DD ≥ 15°C	0.20	0.55	May
	May DD ≥ 10°C	0.23	0.52	May
	Jun DD ≥ 20°C	0.20	0.55	Jun
	Jun DD ≥ 15°C	0.23	0.52	Jun
	Jun DD ≥ 10°C	0.22	0.53	Jun
	Jul DD ≥ 20°C	0.17	0.59	Jul
	Jul DD ≥ 15°C	0.19	0.57	Jul
	Jul DD ≥ 10°C	0.19	0.57	Jul
	MN ≥ 20°C	0.23	0.52	Mar 1 to Sep 15
	MN ≥ 15°C	0.21	0.53	Mar 1 to Sep 15
	MN ≥ 10°C	0.18	0.57	Mar 1 to Sep 15
	MD ≥ 20°C	0.22	0.53	Mar 1 to Sep 15
	MD ≥ 15°C	0.22	0.53	Mar 1 to Sep 15
	MD ≥ 10°C	0.19	0.56	Mar 1 to Sep 15

[a] MN = mean Julian date
[b] MD = median Julian date
[c] DD = degree days
[d] MOP = minimum operating pool

Appendix Table 8. Model significance and coefficient of variation (r^2) of competing models for predicting survival of juvenile northern squawfish. Model used: $CPUE_{n+1} = CPUE_n + variable$. CPUE indicates catch per unit effort.

Variable	Model significance	r^2	Period examined
Days ≥ 20 kcfs	0.087	0.624	Jun 1 to May 31
Days ≥ 25 kcfs	0.086	0.625	Jun 1 to May 31
Days ≥ 35 kcfs	0.078	0.639	Jun 1 to May 31
Days ≥ 50 kcfs	0.042	0.718	Annual
Days ≥ 75 kcfs	0.047	0.706	Annual
Days ≥ 100 kcfs	0.070	0.654	Annual
MN[a] ≥ 50 kcfs	0.057	0.682	Annual
MN ≥ 75 kcfs	0.028	0.759	Annual
MD[b] ≥ 50 kcfs	0.071	0.652	Annual
MD ≥ 75 kcfs	0.065	0.665	Annual
Days ≥ 20°C	0.076	0.643	Annual
Days ≥ 15°C	0.030	0.754	Annual
Days ≥ 10°C	0.057	0.681	Annual
Winter days ≥ 10°C	0.040	0.723	Dec 1 to Feb 28
MN ≥ 20°C	0.033	0.744	Annual
MN ≥ 15°C	0.020	0.791	Annual
MN ≥ 10°C	0.021	0.786	Annual
MD ≥ 20°C	0.028	0.760	Annual
MD ≥ 15°C	0.020	0.791	Annual
MD ≥ 10°C	0.016	0.810	Annual
Mean secchi	0.045	0.712	Mar 1 to Jun 30
Days secchi ≥ 1.5 ft	0.052	0.694	Mar 1 to Jun 30
Days secchi ≥ 2.0 ft	0.068	0.660	Mar 1 to Jun 30
MOP[c] forebay var.	0.033	0.744	Apr 15 to Sep 30
Forebay var. May	0.051	0.696	May
Forebay var. Jun	0.053	0.691	Jun
Forebay var. Jul	0.055	0.686	Jul
Forebay var. Aug	0.067	0.660	Aug
Forebay var. Sep	0.075	0.645	Sep
Winter forebay var.	0.031	0.750	Dec 1 to Feb 28
Winter forebay level	0.081	0.634	Dec 1 to Feb 28
Non-MOP forebay var.	0.019	0.797	Oct 1 to Apr 14
Non-MOP forebay level	0.022	0.785	Oct 1 to Apr 14
Sampling effort	0.079	0.638	Annual
Instantaneous growth	0.029	0.757	Annual

[a] MN = mean Julian date
[b] MD = median Julian date
[c] MOP = minimum operating pool

Appendix Table 9. Coefficient of variation (r^2) between variables examined in predictive models of survival of larval northern squawfish.

Variable	D[a] 50 kcfs	D 75 kcfs	D 100 kcfs	MN[b] 50 kcfs	MN 75 kcfs
Lower Granite Reservoir					
Days ≥ 50 kcfs	1.00	0.92*	0.87*	-0.29	-0.00
Days ≥ 75 kcfs		1.00	0.95*	-0.50	-0.44
Days ≥ 100 kcfs			1.00	-0.46	-0.32
MN ≥ 50 kcfs				1.00	0.84*
MN ≥ 75 kcfs					1.00
MD[c] ≥ 50 kcfs					
MD ≥ 75 kcfs					
Jun DD[d] ≥ 20°C					
Jun DD ≥ 15°C					
Jun DD ≥ 10°C					
Jul DD ≥ 20°C					
Jul DD ≥ 15°C					
Jul DD ≥ 10°C					
Aug DD ≥ 20°C					
Aug DD ≥ 15°C					
Aug DD ≥ 10°C					
Sep DD ≥ 20°C					
Sep DD ≥ 15°C					
Sep DD ≥ 10°C					
MN ≥ 20°C					
MN ≥ 15°C					
MN ≥ 10°C					
MD ≥ 20°C					
MD ≥ 15°C					
MD ≥ 10°C					
Mean secchi					
Days secchi ≥ 1.5 ft					
Days secchi ≥ 2.0 ft					
MOP[e] forebay var.					
Forebay var. May					
Forebay var. Jun					
Forebay var. Jul					
Forebay var. Aug					
Forebay var. Sep					

Appendix Table 9. Continued

Variable	MD 50 kcfs	MD 75 kcfs	DD>20°C Jun	DD>15°C Jun	DD>10°C Jun
Lower Granite Reservoir					
Days ≥ 50 kcfs	0.16	-0.50	-0.72*	-0.60*	-0.49
Days ≥ 75 kcfs	0.33	-0.59	-0.64*	-0.33	-0.24
Days ≥ 100 kcfs	0.38	-0.73*	-0.50	-0.19	-0.09
MN ≥ 50 kcfs	0.03	0.62	-0.01	-0.41	-0.53
MN ≥ 75 kcfs	-0.26	0.42	-0.20	-0.63*	-0.67
MD ≥ 50 kcfs	1.00	0.02	-0.10	-0.01	-0.09
MD ≥ 75 kcfs		1.00	0.13	-0.26	-0.43
Jun DD ≥ 20°C			1.00	0.77*	0.67*
Jun DD ≥ 15°C				1.00	0.96*
Jun DD ≥ 10°C					1.00
Jul DD ≥ 20°C					
Jul DD ≥ 15°C					
Jul DD ≥ 10°C					
Aug DD ≥ 20°C					
Aug DD ≥ 15°C					
Aug DD ≥ 10°C					
Sep DD ≥ 20°C					
Sep DD ≥ 15°C					
Sep DD ≥ 10°C					
MN ≥ 20°C					
MN ≥ 15°C					
MN ≥ 10°C					
MD ≥ 20°C					
MD ≥ 15°C					
MD ≥ 10°C					
Mean secchi					
Days secchi ≥ 1.5 ft					
Days secchi ≥ 2.0 ft					
MOP forebay var.					
Forebay var. May					
Forebay var. Jun					
Forebay var. Jul					
Forebay var. Aug					
Forebay var. Sep					

Appendix Table 9. Continued

Variable	DD>20°C Jul	DD>15°C Jul	DD>10°C Jul	DD>20°C Aug	DD>15°C Aug
Lower Granite Reservoir					
Days ≥ 50 kcfs	-0.21	-0.20	-0.20	-0.17	-0.22
Days ≥ 75 kcfs	-0.14	-0.06	-0.06	-0.01	-0.05
Days ≥ 100 kcfs	-0.27	-0.18	-0.18	-0.13	-0.17
MN ≥ 50 kcfs	-0.15	-0.28	-0.28	0.10	0.02
MN ≥ 75 kcfs	-0.08	-0.17	-0.17	-0.05	-0.16
MD ≥ 50 kcfs	-0.37	-0.18	-0.18	0.54	0.46
MD ≥ 75 kcfs	0.30	0.15	0.15	0.48	0.51
Jun DD ≥ 20°C	0.17	0.27	0.27	-0.01	0.09
Jun DD ≥ 15°C	0.18	0.29	0.29	-0.02	0.07
Jun DD ≥ 10°C	0.02	0.14	0.14	-0.23	-0.14
Jul DD ≥ 20°C	1.00	0.88*	0.88*	0.45	0.57
Jul DD ≥ 15°C		1.00	1.00*	0.61	0.68
Jul DD ≥ 10°C			1.00	0.61	0.68
Aug DD ≥ 20°C				1.00	0.96
Aug DD ≥ 15°C					1.00
Aug DD ≥ 10°C					
Sep DD ≥ 20°C					
Sep DD ≥ 15°C					
Sep DD ≥ 10°C					
MN ≥ 20°C					
MN ≥ 15°C					
MN ≥ 10°C					
MD ≥ 20°C					
MD ≥ 15°C					
MD ≥ 10°C					
Mean secchi					
Days secchi ≥ 1.5 ft					
Days secchi ≥ 2.0 ft					
MOP forebay var.					
Forebay var. May					
Forebay var. Jun					
Forebay var. Jul					
Forebay var. Aug					
Forebay var. Sep					

Appendix Table 9. Continued

Variable	DD>10°C Aug	DD>20°C Sep	DD>15°C Sep	DD>10°C Sep	MN≥20°C
Lower Granite Reservoir					
Days ≥ 50 kcfs	-0.21	-0.20	-0.17	-0.17	-0.05
Days ≥ 75 kcfs	-0.05	0.03	-0.09	-0.09	-0.10
Days ≥ 100 kcfs	-0.17	0.05	-0.07	-0.07	-0.01
MN ≥ 50 kcfs	0.02	-0.03	0.19	0.19	0.24
MN ≥ 75 kcfs	-0.16	-0.20	0.18	0.18	0.14
MD ≥ 50 kcfs	0.46	0.65*	0.30	0.30	0.61
MD ≥ 75 kcfs	0.51	0.15	0.21	0.21	0.09
Jun DD ≥ 20°C	0.09	0.31	0.25	0.25	0.08
Jun DD ≥ 15°C	0.07	0.33	0.12	0.12	-0.11
Jun DD ≥ 10°C	-0.14	0.15	-0.04	-0.04	-0.09
Jul DD ≥ 20°C	0.57	0.23	0.20	0.17	-0.67
Jul DD ≥ 15°C	0.68*	0.46	0.32	0.32	-0.53
Jul DD ≥ 10°C	0.68*	0.46	0.31	0.31	-0.53
Aug DD ≥ 20°C	0.96*	0.78*	0.49	-0.01	0.10
Aug DD ≥ 15°C	1.00*	0.71*	0.36	0.36	-0.04
Aug DD ≥ 10°C	1.00	0.71*	0.36	0.36	-0.04
Sep DD ≥ 20°C		1.00	0.80*	0.80*	0.32
Sep DD ≥ 15°C			1.00	1.00*	0.31
Sep DD ≥ 10°C				1.00	0.31
MN ≥ 20°C					1.00
MN ≥ 15°C					
MN ≥ 10°C					
MD ≥ 20°C					
MD ≥ 15°C					
MD ≥ 10°C					
Mean secchi					
Days secchi ≥ 1.5 ft					
Days secchi ≥ 2.0 ft					
MOP forebay var.					
Forebay var. May					
Forebay var. Jun					
Forebay var. Jul					
Forebay var. Aug					
Forebay var. Sep					

Appendix Table 9. Continued

Variable	MN≥15°C	MN≥10°C	MD≥20°C	MD≥15°C	MD≥10°C
Lower Granite Reservoir					
Days ≥ 50 kcfs	0.48	0.46	0.38	0.49	0.34
Days ≥ 75 kcfs	0.35	0.34	0.29	0.42	0.22
Days ≥ 100 kcfs	0.18	0.23	0.22	0.25	0.12
MN ≥ 50 kcfs	0.33	0.22	0.28	0.30	0.09
MN ≥ 75 kcfs	0.45	0.39	0.24	0.34	0.25
MD ≥ 50 kcfs	0.18	0.13	0.26	0.26	0.03
MD ≥ 75 kcfs	0.45	0.29	0.34	0.40	0.32
Jun DD ≥ 20°C	-0.57	-0.26	-0.40	-0.68*	-0.08
Jun DD ≥ 15°C	-0.78*	-0.58	-0.54	-0.73*	-0.43
Jun DD ≥ 10°C	-0.88*	-0.64*	-0.59	-0.82*	-0.50
Jul DD ≥ 20°C	0.23	0.05	-0.05	0.24	0.20
Jul DD ≥ 15°C	0.12	0.00	-0.32	0.09	0.07
Jul DD ≥ 10°C	0.12	0.00	-0.33	0.09	0.07
Aug DD ≥ 20°C	0.43	0.16	0.06	0.46	0.11
Aug DD ≥ 15°C	0.36	0.10	0.04	0.42	0.13
Aug DD ≥ 10°C	0.36	0.10	0.04	0.42	0.13
Sep DD ≥ 20°C	0.17	0.21	0.05	0.14	0.18
Sep DD ≥ 15°C	0.34	0.51	0.27	0.20	0.47
Sep DD ≥ 10°C	0.34	0.51	0.27	0.20	0.47
MN ≥ 20°C	-0.01	0.15	0.22	-0.08	0.14
MN ≥ 15°C	1.00	0.83*	0.74*	0.94*	0.73*
MN ≥ 10°C		1.00	0.75*	0.66*	0.92*
MD ≥ 20°C			1.00	0.75*	0.77*
MD ≥ 15°C				1.00	0.56
MD ≥ 10°C					1.00
Mean secchi					
Days secchi ≥ 1.5 ft					
Days secchi ≥ 2.0 ft					
MOP forebay var.					
Forebay var. May					
Forebay var. Jun					
Forebay var. Jul					
Forebay var. Aug					
Forebay var. Sep					

Appendix Table 9. Continued

Variable	Mean secchi	Secchi ≥ 1.5 ft	Secchi ≥ 2.0 ft	FB[f] var. MOP	FB var. May
Lower Granite Reservoir					
Days ≥ 50 kcfs	-0.92*	0.86*	0.89*	0.55	0.11
Days ≥ 75 kcfs	-0.94*	0.97*	0.96*	0.60	0.19
Days ≥ 100 kcfs	-0.86*	0.95*	0.96*	0.66*	0.38
MN ≥ 50 kcfs	0.45	-0.57	-0.61*	-0.21	-0.51
MN ≥ 75 kcfs	0.18	-0.36	-0.37	-0.04	-0.30
MD ≥ 50 kcfs	-0.11	0.20	0.19	0.16	0.01
MD ≥ 75 kcfs	0.50	-0.74*	-0.75*	-0.43	-0.59
Jun DD ≥ 20°C	0.62*	-0.57	-0.53	-0.08	0.13
Jun DD ≥ 15°C	0.42	-0.18	-0.19	-0.05	0.41
Jun DD ≥ 10°C	0.31	-0.07	-0.06	-0.06	0.50
Jul DD ≥ 20°C	0.02	-0.11	-0.17	0.15	-0.19
Jul DD ≥ 15°C	0.00	-0.01	-0.09	0.26	-0.30
Jul DD ≥ 10°C	0.00	-0.01	-0.09	0.26	-0.30
Aug DD ≥ 20°C	0.10	-0.12	-0.20	0.07	-0.50
Aug DD ≥ 15°C	0.09	-0.16	-0.21	0.12	-0.37
Aug DD ≥ 10°C	0.09	-0.16	-0.21	0.12	-0.37
Sep DD ≥ 20°C	0.11	-0.01	-0.07	0.20	-0.30
Sep DD ≥ 15°C	0.17	-0.09	-0.16	0.03	-0.53
Sep DD ≥ 10°C	0.17	-0.09	-0.16	0.03	-0.53
MN ≥ 20°C	0.22	-0.22	-0.13	-0.20	-0.14
MN ≥ 15°C	-0.42	0.19	0.16	0.17	-0.59
MN ≥ 10°C	-0.43	0.20	0.22	0.26	-0.55
MD ≥ 20°C	-0.35	0.12	0.17	0.07	-0.19
MD ≥ 15°C	-0.48	0.26	0.23	0.23	-0.40
MD ≥ 10°C	-0.36	0.08	0.16	0.24	-0.42
Mean secchi	1.00	-0.89*	-0.93*	-0.70*	-0.18
Days secchi ≥ 1.5 ft		1.00	0.97*	0.59	0.27
Days secchi ≥ 2.0 ft			1.00	0.63*	0.35
MOP forebay var.				1.00	0.35
Forebay var. May					1.00
Forebay var. Jun					
Forebay var. Jul					
Forebay var. Aug					
Forebay var. Sep					

Appendix Table 9. Continued

Variable	FB var. Jun	FB var. Jul	FB var. Aug	FB var. Sep	CWR[g] D 20 kcfs
Lower Granite Reservoir					
Days ≥ 50 kcfs	0.28	0.43	-0.04	0.33	0.92*
Days ≥ 75 kcfs	0.37	0.35	-0.05	0.25	0.77*
Days ≥ 100 kcfs	0.42	0.40	-0.24	0.31	0.72*
MN ≥ 50 kcfs	-0.57	-0.24	0.38	-0.28	-0.10
MN ≥ 75 kcfs	-0.38	0.17	0.32	-0.06	0.19
MD ≥ 50 kcfs	-0.29	-0.27	0.17	0.09	0.17
MD ≥ 75 kcfs	-0.69*	-0.57	0.70*	-0.02	-0.41
Jun DD ≥ 20°C	-0.10	0.02	-0.23	-0.06	-0.84*
Jun DD ≥ 15°C	0.29	-0.04	-0.41	-0.16	-0.74*
Jun DD ≥ 10°C	0.38	0.01	-0.60*	-0.13	-0.62*
Jul DD ≥ 20°C	0.27	0.10	0.54	-0.14	-0.29
Jul DD ≥ 15°C	0.31	0.34	0.54	-0.44	-0.26
Jul DD ≥ 10°C	0.31	0.34	0.54	-0.44	-0.26
Aug DD ≥ 20°C	-0.21	-0.15	0.79*	-0.36	-0.09
Aug DD ≥ 15°C	-0.12	-0.21	0.79*	-0.26	-0.21
Aug DD ≥ 10°C	-0.12	-0.21	0.79*	-0.26	-0.21
Sep DD ≥ 20°C	-0.24	0.04	0.34	-0.18	-0.22
Sep DD ≥ 15°C	-0.47	0.16	0.22	-0.06	-0.14
Sep DD ≥ 10°C	-0.47	0.16	0.22	-0.06	-0.14
MN ≥ 20°C	-0.56	-0.21	-0.23	0.19	0.07
MN ≥ 15°C	-0.41	-0.02	0.70*	0.22	0.50
MN ≥ 10°C	-0.52	0.16	0.36	0.40	0.37
MD ≥ 20°C	-0.50	-0.37	0.22	0.74*	0.29
MD ≥ 15°C	-0.24	-0.16	0.70*	0.26	0.50
MD ≥ 10°C	-0.45	0.07	0.26	0.60	0.20
Mean secchi	-0.43	-0.40	-0.00	-0.37	-0.75*
Days secchi ≥ 1.5 ft	0.52	0.47	-0.18	0.15	0.73*
Days secchi ≥ 2.0 ft	0.52	0.45	-0.27	0.31	0.72*
MOP forebay var.	0.54	0.61*	0.07	0.27	0.33
Forebay var. May	0.64*	0.00	-0.60	0.39	-0.06
Forebay var. Jun	1.00	0.48	-0.26	-0.11	0.17
Forebay var. Jul		1.00	-0.14	-0.25	0.39
Forebay var. Aug			1.00	-0.29	0.04
Forebay var. Sep				1.00	0.10

Appendix Table 9. Continued

Variable	CWR D 30 kcfs	CWR DD>10°C May	CWR DD>20°C Jun	CWR DD>15°C Jun	CWR DD>10°C Jun
Lower Granite Reservoir					
Days ≥ 50 kcfs	0.74*	-0.67*	-0.51	-0.75*	-0.72*
Days ≥ 75 kcfs	0.73*	-0.57	-0.48	-0.60	-0.54
Days ≥ 100 kcfs	0.55	-0.42	-0.33	-0.43	-0.41
MN ≥ 50 kcfs	-0.09	-0.01	0.04	-0.17	-0.32
MN ≥ 75 kcfs	0.11	-0.09	-0.25	-0.39	-0.51
MD ≥ 50 kcfs	0.36	-0.12	-0.03	-0.07	-0.07
MD ≥ 75 kcfs	-0.05	0.01	-0.06	-0.08	-0.10
Jun DD ≥ 20°C	-0.87	0.86*	0.46	0.91*	0.88*
Jun DD ≥ 15°C	-0.72*	0.74*	0.50	0.90*	0.93*
Jun DD ≥ 10°C	-0.68*	0.68*	0.50	0.86*	0.91*
Jul DD ≥ 20°C	-0.05*	0.13	-0.13	0.05	0.08
Jul DD ≥ 15°C	0.01	0.25	-0.14	0.16	0.20
Jul DD ≥ 10°C	0.01	0.25	-0.14	0.16	0.20
Aug DD ≥ 20°C	0.37	-0.01	-0.20	-0.09	-0.06
Aug DD ≥ 15°C	0.26	0.06	-0.10	0.01	0.03
Aug DD ≥ 10°C	0.26	0.06	-0.10	0.01	0.03
Sep DD ≥ 20°C	0.09	0.34	-0.23	0.20	0.24
Sep DD ≥ 15°C	0.03	0.29	-0.51	0.01	0.05
Sep DD ≥ 10°C	0.03	0.29	-0.51	0.01	0.05
MN ≥ 20°C	0.06	0.15	-0.02	0.07	0.07
MN ≥ 15°C	0.71*	-0.59	-0.74*	-0.84*	-0.82*
MN ≥ 10°C	0.45	-0.30	-0.84*	-0.62*	-0.58
MD ≥ 20°C	0.40	-0.39	-0.60	-0.60*	-0.58
MD ≥ 15°C	0.77	-0.61*	-0.66*	-0.84*	-0.84*
MD ≥ 10°C	0.27	-0.13	-0.74*	-0.44	-0.39
Mean secchi	-0.69*	0.49	0.57	0.53*	0.59*
Days secchi ≥ 1.5 ft	0.60*	-0.48	-0.41	-0.48	-0.42
Days secchi ≥ 2.0 ft	0.57	-0.42	-0.40	-0.45	-0.39
MOP forebay var.	0.27	0.09	-0.28	-0.15	-0.22
Forebay var. May	-0.34	0.19	0.56	0.38	0.30
Forebay var. Jun	0.02	0.08	0.23	0.13	0.12
Forebay var. Jul	0.11	0.10	-0.26	-0.07	-0.10
Forebay var. Aug	0.44	-0.29	-0.29	-0.41	-0.43
Forebay var. Sep	-0.01	-0.03	-0.22	-0.16	-0.16

Appendix Table 9. Continued

Variable	CWR DD>20°C Jul	CWR DD>15°C Jul	CWR DD>10°C Jul	CWR MN≥20°C	CWR MN≥15°C
Lower Granite Reservoir					
Days ≥ 50 kcfs	-0.54	-0.43	-0.21	0.55	0.45
Days ≥ 75 kcfs	-0.55	-0.40	-0.19	0.50	0.29
Days ≥ 100 kcfs	-0.56	-0.47	-0.25	0.52	0.25
MN ≥ 50 kcfs	0.60	0.15	0.09	0.09	0.28
MN ≥ 75 kcfs	0.40	0.13	0.11	0.08	0.29
MD ≥ 50 kcfs	0.08	-0.11	-0.06	0.59	0.04
MD ≥ 75 kcfs	0.65	0.46	0.33	-0.17	0.09
Jun DD ≥ 20°C	0.24	0.39	0.29	-0.63	-0.66*
Jun DD ≥ 15°C	0.04	0.19	0.10	-0.49	-0.64*
Jun DD ≥ 10°C	-0.20	0.00	-0.07	-0.39	-0.56
Jul DD ≥ 20°C	0.53	0.73*	0.70*	-0.66*	-0.33
Jul DD ≥ 15°C	0.49	0.83*	0.80*	-0.69*	-0.67*
Jul DD ≥ 10°C	0.49	0.83*	0.80*	-0.69*	-0.67*
Aug DD ≥ 20°C	0.66*	0.65*	0.60	-0.06	-0.34
Aug DD ≥ 15°C	0.66*	0.73*	0.71*	-0.25	-0.37
Aug DD ≥ 10°C	0.66*	0.73*	0.71*	-0.25	-0.37
Sep DD ≥ 20°C	0.41	0.39	0.35	-0.04	-0.46
Sep DD ≥ 15°C	0.31	0.18	0.09	0.10	-0.22
Sep DD ≥ 10°C	0.31	0.18	0.09	0.10	-0.22
MN ≥ 20°C	-0.10	-0.32	-0.35	0.61	0.17
MN ≥ 15°C	0.20	0.07	0.13	0.36	0.46
MN ≥ 10°C	-0.10	-0.11	-0.04	0.32	0.35
MD ≥ 20°C	-0.07	-0.36	-0.28	0.67*	0.78*
MD ≥ 15°C	0.24	0.06	0.15	0.45	0.56
MD ≥ 10°C	-0.09	-0.05	0.03	0.23	0.35
Mean secchi	0.53	0.30	0.06	-0.39	-0.35
Days secchi ≥ 1.5 ft	-0.58	-0.40	-0.22	0.39	0.18
Days secchi ≥ 2.0 ft	-0.67*	-0.45	-0.23	0.44	0.24
MOP forebay var.	-0.07	0.19	0.43	-0.03	-0.09
Forebay var. May	-0.27	-0.27	-0.13	0.01	0.10
Forebay var. Jun	-0.17	0.14	0.27	-0.32	-0.24
Forebay var. Jul	-0.19	0.16	0.26	-0.47	-0.41
Forebay var. Aug	-0.70*	0.67*	0.65*	-0.19	-0.08
Forebay var. Sep	-0.35	-0.45	-0.30	0.46	0.66*

Appendix Table 9. Continued

Variables	CWR MN≥10°C	CWR MD≥20°C	CWR MD≥15°C	CWR MD≥10°C
Lower Granite Reservoir				
Days ≥ 50 kcfs	0.81*	0.52	0.63*	0.82*
Days ≥ 75 kcfs	0.70*	0.44	0.35	0.72*
Days ≥ 100 kcfs	0.55	0.45	0.22	0.62*
MN ≥ 50 kcfs	-0.21	0.20	0.35	-0.47
MN ≥ 75 kcfs	0.06	0.18	0.63*	-0.08
MD ≥ 50 kcfs	-0.08	0.50	-0.23	-0.19
MD ≥ 75 kcfs	-0.17	-0.08	0.14	-0.41
Jun DD ≥ 20°C	-0.71*	[illegible]	-0.70*	-0.52
Jun DD ≥ 15°C	-0.66*	-0.57	-0.91*	-0.45
Jun DD ≥ 10°C	-0.61*	-0.49	-0.87*	-0.36
Jul DD ≥ 20°C	0.13	-0.62	-0.01	0.22
Jul DD ≥ 15°C	0.01	-0.67*	-0.12	0.15
Jul DD ≥ 10°C	0.01	-0.67*	-0.12	0.15
Aug DD ≥ 20°C	-0.05	0.00	-0.10	-0.15
Aug DD ≥ 15°C	-0.09	-0.19	-0.13	-0.14
Aug DD ≥ 10°C	-0.09	-0.19	-0.13	-0.14
Sep DD ≥ 20°C	-0.21	0.01	-0.47	-0.20
Sep DD ≥ 15°C	0.00	0.09	-0.28	-0.05
Sep DD ≥ 10°C	0.00	0.09	-0.28	-0.05
MN ≥ 20°C	-0.25	0.56	-0.19	-0.29
MN ≥ 15°C	0.69*	0.41	0.68*	0.46
MN ≥ 10°C	0.59	0.29	0.49	0.45
MD ≥ 20°C	0.50	0.65*	0.24	0.30
MD ≥ 15°C	0.62*	0.51	0.66*	0.39
MD ≥ 10°C	0.52	0.17	0.37	0.47
Mean secchi	-0.70*	-0.33	-0.52	-0.78*
Days secchi ≥ 1.5 ft	-0.64*	0.34	0.25	0.72*
Days secchi ≥ 2.0 ft	0.61*	0.35	0.26	0.73*
MOP forebay var.	0.18	-0.10	0.28	0.39
Forebay var. May	-0.24	-0.05	-0.23	-0.03
Forebay var. Jun	0.03	-0.34	0.02	0.33
Forebay var. Jul	0.25	-0.53	0.24	0.49
Forebay var. Aug	0.19	-0.08	0.40	-0.01
Forebay var. Sep	0.24	0.36	0.15	0.27

Appendix Table 9. Continued

Variable	SR[b] D 50 kcfs	SR D 75 kcfs	SR DD>15°C May	SR DD>10°C May	SR DD>20°C Jun
Lower Granite Reservoir					
Days ≥ 50 kcfs	0.94*	0.79*	-0.53	-0.76*	-0.54
Days ≥ 75 kcfs	0.98*	0.90*	-0.48	-0.56	-0.38
Days ≥ 100 kcfs	0.96*	0.98*	-0.35	-0.43	-0.22
MN ≥ 50 kcfs	-0.48	-0.46	-0.00	-0.19	-0.22
MN ≥ 75 kcfs	-0.29	-0.38	-0.30	-0.49	-0.54
MD ≥ 50 kcfs	0.27	0.48	-0.14	-0.06	0.01
MD ≥ 75 kcfs	-0.63*	-0.[illegible]*	-0.08	-0.03	-0.20
Jun DD ≥ 20°C	-0.62*	-0.40	0.35	0.62	0.53
Jun DD ≥ 15°C	-0.34	-0.08	0.50	0.84*	0.74*
Jun DD ≥ 10°C	-0.22	0.01	0.53	0.79*	0.74*
Jul DD ≥ 20°C	-0.19	-0.33	-0.16	0.26	-0.01
Jul DD ≥ 15°C	-0.15	-0.21	-0.19	0.19	0.02
Jul DD ≥ 10°C	-0.15	-0.21	-0.19	0.19	0.02
Aug DD ≥ 20°C	-0.15	-0.11	-0.25	0.03	-0.13
Aug DD ≥ 15°C	-0.16	-0.16	-0.17	0.11	-0.02
Aug DD ≥ 10°C	-0.16	-0.16	-0.17	0.11	-0.02
Sep DD ≥ 20°C	-0.08	0.15	-0.33	0.18	-0.07
Sep DD ≥ 15°C	-0.18	-0.00	-0.56	-0.03	-0.41
Sep DD ≥ 10°C	-0.18	-0.00	-0.56	-0.03	-0.41
MN ≥ 20°C	-0.10	0.10	-0.36	-0.22	-0.46
MN ≥ 15°C	0.30	0.09	-0.76*	-0.75*	-0.85*
MN ≥ 10°C	0.32	0.18	-0.89*	-0.78*	-0.88*
MD ≥ 20°C	0.31	0.19	-0.59	-0.50	-0.65*
MD ≥ 15°C	0.38	0.16	-0.66*	-0.65*	-0.74*
MD ≥ 10°C	0.24	0.08	-0.81*	-0.60	-0.77*
Mean secchi	-0.95*	-0.77*	0.60	0.68*	0.51
Days secchi ≥ 1.5 ft	0.95*	0.91*	-0.38	-0.44	-0.26
Days secchi ≥ 2.0 ft	0.98*	0.91*	-0.40	-0.46	-0.28
MOP forebay var.	0.63*	0.61*	-0.43	-0.40	-0.23
Forebay var. May	0.30	0.42	0.53	0.38	0.61
Forebay var. Jun	0.41	0.37	0.26	0.21	0.38
Forebay var. Jul	0.35	0.37	-0.34	-0.36	-0.25
Forebay var. Aug	-0.14	-0.31	-0.33	-0.31	-0.36
Forebay var. Sep	0.37	0.31	-0.28	-0.22	-0.25

Appendix Table 9. Continued

Variable	SR DD>15°C Jun	SR DD>10°C Jun	SR DD>20°C Jul	SR DD>15°C Jul	SR DD>10°C Jul
Lower Granite Reservoir					
Days ≥ 50 kcfs	-0.60	-0.59	-0.35	-0.44	-0.44
Days ≥ 75 kcfs	-0.33	-0.30	-0.27	-0.28	-0.28
Days ≥ 100 kcfs	-0.23	-0.24	-0.46	-0.44	-0.44
MN ≥ 50 kcfs	-0.49	-0.54	-0.22	-0.30	-0.18
MN ≥ 75 kcfs	-0.74*	-0.79*	-0.20	-0.33	-0.30
MD ≥ 50 kcfs	0.07	0.10	-0.05	0.04	0.04
MD ≥ 75 kcfs	-0.17	-0.1[illegible]	0.37	0.32	0.32
Jun DD ≥ 20°C	0.67*	0.62	-0.04	0.15	0.15
Jun DD ≥ 15°C	0.92*	0.89*	0.04	0.25	0.25
Jun DD ≥ 10°C	0.88*	0.85*	0.01	0.19	0.19
Jul DD ≥ 20°C	0.31	-0.30	0.42	0.54	0.54
Jul DD ≥ 15°C	0.36	0.34	0.46	0.63*	0.63*
Jul DD ≥ 10°C	0.36	0.34	0.46	0.64*	0.64*
Aug DD ≥ 20°C	0.12	0.14	0.50	0.61	0.61
Aug DD ≥ 15°C	0.22	0.25	0.46	0.59	0.59
Aug DD ≥ 10°C	0.22	0.25	0.46	0.59	0.59
Sep DD ≥ 20°C	0.32	0.30	0.20	0.39	0.39
Sep DD ≥ 15°C	-0.01	-0.05	0.10	0.19	0.19
Sep DD ≥ 10°C	-0.01	-0.05	0.10	0.19	0.19
MN ≥ 20°C	-0.35	-0.29	-0.03	-0.18	-0.18
MN ≥ 15°C	-0.75*	-0.71*	0.04	-0.06	-0.06
MN ≥ 10°C	-0.69*	-0.66*	-0.19	-0.25	-0.25
MD ≥ 20°C	-0.57	-0.52	-0.28	-0.40	-0.40
MD ≥ 15°C	-0.69*	-0.64*	-0.01	-0.11	-0.11
MD ≥ 10°C	-0.51	-0.47	-0.16	-0.21	-0.21
Mean secchi	0.47	0.44	0.36	0.38	0.38
Days secchi ≥ 1.5 ft	-0.21	-0.22	-0.30	-0.29	-0.29
Days secchi ≥ 2.0 ft	-0.23	-0.22	-0.35	-0.36	-0.36
MOP forebay var.	-0.21	-0.27	-0.62	-0.48	-0.48
Forebay var. May	0.37	0.32	-0.60	-0.53	-0.53
Forebay var. Jun	0.30	0.25	-0.20	-0.11	-0.11
Forebay var. Jul	-0.20	-0.28	-0.26	-0.19	-0.19
Forebay var. Aug	-0.30	-0.27	0.37	0.39	0.39
Forebay var. Sep	-0.24	-0.21	-0.58	-0.64*	-0.64*

Appendix Table 9. Continued

Variables	SR MN≥20°C	SR MN≥15°C	SR MN≥10°C	SR MD≥20°C	SR MD≥15°C
Lower Granite Reservoir					
Days ≥ 50 kcfs	0.53	0.61	0.32	0.62	0.65*
Days ≥ 75 kcfs	0.30	0.36	0.16	0.39	0.38
Days ≥ 100 kcfs	0.31	0.34	0.11	0.37	0.36
MN ≥ 50 kcfs	0.45	0.51	0.33	0.35	0.32
MN ≥ 75 kcfs	0.67*	0.76*	0.54	0.58	0.54
MD ≥ 50 kcfs	-0.13	-0.04	-0.16	-0.10	-0.17
MD ≥ 75 kcfs	-0.01	-0.01	0.16	-0.03	-0.13
Jun DD ≥ 20°C	-0.46	-0.59	-0.14	-0.54	-0.69*
Jun DD ≥ 15°C	-0.66*	-0.80*	-0.47	-0.72*	-0.79*
Jun DD ≥ 10°C	-0.61	-0.78*	-0.46	-0.64*	-0.64*
Jul DD ≥ 20°C	-0.33	-0.24	-0.23	-0.36	-0.63
Jul DD ≥ 15°C	-0.44	-0.28	-0.21	-0.46	-0.71*
Jul DD ≥ 10°C	-0.44	-0.28	-0.21	-0.46	-0.71*
Aug DD ≥ 20°C	-0.32	-0.12	-0.19	-0.33	-0.52
Aug DD ≥ 15°C	-0.38	-0.24	-0.27	-0.36	-0.58
Aug DD ≥ 10°C	-0.38	-0.24	-0.27	-0.36	-0.58
Sep DD ≥ 20°C	-0.29	-0.18	-0.03	-0.39	-0.66*
Sep DD ≥ 15°C	0.07	0.17	0.40	-0.12	-0.36
Sep DD ≥ 10°C	0.07	0.17	0.40	-0.12	-0.36
MN ≥ 20°C	0.36	0.26	0.40	0.31	0.34
MN ≥ 15°C	0.53	0.68*	0.55	0.53	0.40
MN ≥ 10°C	0.62	0.64*	0.85*	0.57	0.39
MD ≥ 20°C	0.61	0.51	0.55	0.60	0.48
MD ≥ 15°C	0.53	0.63*	0.38	0.55	0.42
MD ≥ 10°C	0.53	0.46	0.73*	0.50	0.27
Mean secchi	-0.49	-0.47	-0.31	-0.59	-0.52
Days secchi ≥ 1.5 ft	0.23	0.30	0.09	0.30	0.32
Days secchi ≥ 2.0 ft	0.29	0.29	0.13	0.38	0.38
MOP forebay var.	0.42	0.38	0.22	0.46	0.18
Forebay var. May	-0.04	-0.22	-0.45	0.03	0.07
Forebay var. Jun	-0.13	-0.15	-0.49	-0.04	-0.06
Forebay var. Jul	0.24	0.38	0.27	0.20	0.10
Forebay var. Aug	0.01	0.21	0.08	0.02	-0.13
Forebay var. Sep	0.51	0.23	0.33	0.55	0.43

Appendix Table 9. Continued

Variables	SR MD≥10°C	Growth
Lower Granite Reservoir		
Days ≥ 50 kcfs	0.42	-0.69
Days ≥ 75 kcfs	0.28	-0.68
Days ≥ 100 kcfs	0.26	-0.50
MN ≥ 50 kcfs	0.17	0.69
MN ≥ 75 kcfs	0.10	-0.04
MD ≥ 50 kcfs	0.02	0.82*
MD ≥ 75 kcfs	0.11	0.54
Jun DD ≥ 20°C	-0.03	0.43
Jun DD ≥ 15°C	-0.36	0.36
Jun DD ≥ 10°C	-0.38	0.10
Jul DD ≥ 20°C	-0.03	0.09
Jul DD ≥ 15°C	-0.16	-0.05
Jul DD ≥ 10°C	-0.17	-0.05
Aug DD ≥ 20°C	-0.16	0.45
Aug DD ≥ 15°C	-0.15	0.48
Aug DD ≥ 10°C	-0.15	0.48
Sep DD ≥ 20°C	0.06	0.50
Sep DD ≥ 15°C	0.39	0.08
Sep DD ≥ 10°C	0.39	0.08
MN ≥ 20°C	0.51	0.17
MN ≥ 15°C	0.58	-0.06
MN ≥ 10°C	0.88*	-0.32
MD ≥ 20°C	0.75*	0.09
MD ≥ 15°C	0.41	0.14
MD ≥ 10°C	0.93*	-0.36
Mean secchi	-0.42	0.67
Days secchi ≥ 1.5 ft	0.18	-0.76*
Days secchi ≥ 2.0 ft	0.27	-0.77*
MOP forebay var.	0.32	-0.25
Forebay var. May	-0.20	0.17
Forebay var. Jun	-0.43	-0.31
Forebay var. Jul	0.16	-0.68
Forebay var. Aug	-0.00	0.36
Forebay var. Sep	0.71	-0.06

Appendix Table 9. Continued

Variable	CWR D 20 kcfs	CWR D 30 kcfs	CWR DD>10°C May	CWR DD>20°C Jun	CWR DD>15°C Jun
Clearwater River					
Days ≥ 20 kcfs	1.00	0.82*	-0.77*	-0.46	-0.82*
Days ≥ 30 kcfs		1.00	-0.73*	-0.64*	-0.88*
May DD ≥ 10°C			1.00	0.28	0.84*
Jun DD ≥ 20°C				1.00	0.68*
Jun DD ≥ 15°C					1.00
Jun DD ≥ 10°C					
Jul DD ≥ 15°C					
Jul DD ≥ 10°C					
MN ≥ 20°C					
MN ≥ 15°C					
MN ≥ 10°C					
MD ≥ 20°C					
MD ≥ 15°C					
MD ≥ 10°C					
Snake River					
Days ≥ 50 kcfs					
Days ≥ 75 kcfs					
May DD ≥ 20°C					
May DD ≥ 15°C					
May DD ≥ 10°C					
Jun DD ≥ 20°C					
Jun DD ≥ 15°C					
Jun DD ≥ 10°C					
Jul DD ≥ 20°C					
Jul DD ≥ 15°C					
Jul DD ≥ 10°C					
MN ≥ 20°C					
MN ≥ 15°C					
MN ≥ 10°C					
MD ≥ 20°C					
MD ≥ 15°C					
MD ≥ 10°C					
Growth					

Appendix Table 9. Continued

Variable	CWR DD>10°C Jun	CWR DD>20°C Jul	CWR DD>15°C Jul	CWR DD>10°C Jul	CWR MN≥20°C
Clearwater River					
Days ≥ 20 kcfs	-0.81*	-0.40	-0.42	-0.26	0.66*
Days ≥ 30 kcfs	-0.81*	-0.14	-0.14	-0.03	0.58
May DD ≥ 10°C	0.81	0.24	0.38	0.30	-0.45
Jun DD ≥ 20°C	0.58	0.20	0.13	0.09	-0.39
Jun DD ≥ 15°C	0.98	0.15	0.27	0.17	-0.56
Jun DD ≥ 10°C	1.00	0.05	0.22	0.11	-0.53
Jul DD ≥ 20°C		1.00	0.79*	0.70*	-0.39
Jul DD ≥ 15°C			1.00	0.96*	-0.73*
Jul DD ≥ 10°C				1.00	-0.65*
MN ≥ 20°C					1.00
MN ≥ 15°C					
MN ≥ 10°C					
MD ≥ 20°C					
MD ≥ 15°C					
MD ≥ 10°C					
Snake River					
Days ≥ 50 kcfs					
Days ≥ 75 kcfs					
May DD ≥ 20°C					
May DD ≥ 15°C					
May DD ≥ 10°C					
Jun DD ≥ 20°C					
Jun DD ≥ 15°C					
Jun DD ≥ 10°C					
Jul DD ≥ 20°C					
Jul DD ≥ 15°C					
Jul DD ≥ 10°C					
MN ≥ 20°C					
MN ≥ 15°C					
MN ≥ 10°C					
MD ≥ 20°C					
MD ≥ 15°C					
MD ≥ 10°C					
Growth					

Appendix Table 9. Continued

Variable	CWR MN≥15°C	CWR MN≥10°C	CWR MD≥20°C	CWR MD≥15°C	CWR MD≥10°C
Clearwater River					
Days ≥ 20 kcfs	0.47	0.79*	0.69*	0.69*	0.73*
Days ≥ 30 kcfs	0.40	0.69*	0.62	0.61*	0.55
May DD ≥ 10°C	-0.56	-0.81*	-0.53	-0.63*	-0.56
Jun DD ≥ 20°C	-0.32	-0.61*	-0.36	-0.43	-0.53
Jun DD ≥ 15°C	-0.65*	-0.83*	-0.62	-0.82*	-0.61*
Jun DD ≥ 10°C	-0.66*	-0.76*	-0.61	-0.89*	-0.54
Jul DD ≥ 20°C	-0.28	-0.36	-0.27	-0.01	-0.45
Jul DD ≥ 15°C	-0.64	-0.32	-0.67*	-0.03	-0.22
Jul DD ≥ 10°C	-0.55	-0.20	-0.61	0.11	-0.07
MN ≥ 20°C	0.74*	0.34	0.98*	0.22	0.18
MN ≥ 15°C	1.00	0.47	0.76*	0.53	0.27
MN ≥ 10°C		1.00	0.36	0.63*	0.90*
MD ≥ 20°C			1.00	0.30	0.16
MD ≥ 15°C				1.00	0.51
MD ≥ 10°C					1.00
Snake River					
Days ≥ 50 kcfs					
Days ≥ 75 kcfs					
May DD ≥ 20°C					
May DD ≥ 15°C					
May DD ≥ 10°C					
Jun DD ≥ 20°C					
Jun DD ≥ 15°C					
Jun DD ≥ 10°C					
Jul DD ≥ 20°C					
Jul DD ≥ 15°C					
Jul DD ≥ 10°C					
MN ≥ 20°C					
MN ≥ 15°C					
MN ≥ 10°C					
MD ≥ 20°C					
MD ≥ 15°C					
MD ≥ 10°C					
Growth					

Appendix Table 9. Continued

Variable	SR D 50 kcfs	SR D 75 kcfs	SR DD>15°C May	SR DD>10°C May	SR DD>20°C Jun
Clearwater River					
Days ≥ 20 kcfs	0.78*	0.65*	-0.44	-0.74	-0.56
Days ≥ 30 kcfs	0.66*	0.47	-0.60	-0.69*	-0.65*
May DD ≥ 10°C	-0.54	-0.33	0.19	0.58	0.39
Jun DD ≥ 20°C	-0.43	-0.26	0.97*	0.70*	0.93*
Jun DD ≥ 15°C	-0.57	-0.32	0.63*	0.84*	0.80*
Jun DD ≥ 10°C	-0.53	-0.29	0.56	0.84*	0.75*
Jul DD ≥ 20°C	-0.60*	-0.55	0.14	0.27	0.12
Jul DD ≥ 15°C	-0.45	-0.50	0.03	0.20	0.13
Jul DD ≥ 10°C	-0.22	-0.29	-0.06	0.05	0.07
MN ≥ 20°C	0.50	0.54	-0.39	-0.49	-0.50
MN ≥ 15°C	0.36	0.20	-0.24	-0.42	-0.45
MN ≥ 10°C	0.68*	0.45	-0.60	-0.73*	-0.68*
MD ≥ 20°C	0.44	0.46	-0.33	-0.47	-0.49
MD ≥ 15°C	0.38	0.08	-0.46	-0.86*	-0.68*
MD ≥ 10°C	0.74*	0.53*	-0.54	-0.59	-0.54
Snake River					
Days ≥ 50 kcfs	1.00	0.91*	-0.44	-0.56	-0.35
Days ≥ 75 kcfs		1.00	-0.29	-0.33	-0.14
May DD ≥ 15°C			1.00	0.75*	0.85*
May DD ≥ 10°C				1.00	0.93*
Jun DD ≥ 20°C					1.00
Jun DD ≥ 15°C					
Jun DD ≥ 10°C					
Jul DD ≥ 20°C					
Jul DD ≥ 15°C					
Jul DD ≥ 10°C					
MN ≥ 20°C					
MN ≥ 15°C					
MN ≥ 10°C					
MD ≥ 20°C					
MD ≥ 15°C					
MD ≥ 10°C					
Growth					

Appendix Table 9. Continued

Variable	SR DD>15°C Jun	SR DD>10°C Jun	SR DD>20°C Jul	SR DD>15°C Jul	SR DD>10°C Jul
Clearwater River					
Days ≥ 20 kcfs	-0.68*	-0.67*	-0.16	-0.30	-0.30
Days ≥ 30 kcfs	-0.61	-0.55	0.16	0.05	0.05
May DD ≥ 10°C	0.57	0.51	-0.12	0.06	0.06
Jun DD ≥ 20°C	0.62	0.58	-0.00	0.06	0.06
Jun DD ≥ 15°C	0.86*	0.81*	0.02	0.20	0.20
Jun DD ≥ 10°C	0.91*	0.88*	0.16	0.33	0.33
Jul DD ≥ 20°C	0.10	0.05	0.22	0.29	0.29
Jul DD ≥ 15°C	0.24	0.21	0.34	0.48	0.48
Jul DD ≥ 10°C	0.13	0.10	0.14	0.30	0.30
MN ≥ 20°C	-0.58	-0.56	-0.25	-0.44	-0.44
MN ≥ 15°C	-0.62	-0.57	-0.32	-0.54	-0.54
MN ≥ 10°C	-0.61	-0.58	0.00	-0.15	-0.15
MD ≥ 20°C	-0.62	-0.60	-0.16	-0.37	-0.37
MD ≥ 15°C	-0.92	-0.91*	-0.21	-0.39	-0.39
MD ≥ 10°C	-0.41	-0.39	-0.07	-0.16	-0.16
Snake River					
Days ≥ 50 kcfs	-0.35	-0.34	-0.39	-0.41	-0.41
Days ≥ 75 kcfs	-0.14	-0.15	-0.47	-0.43	-0.43
May DD ≥ 15°C	0.64*	0.61	0.10	0.13	0.13
May DD ≥ 10°C	0.91*	0.88*	0.26	0.38	0.38
Jun DD ≥ 20°C	0.84*	0.80*	0.05	0.18	0.18
Jun DD ≥ 15°C	1.00	0.99*	0.29	0.47	0.47
Jun DD ≥ 10°C		1.00	0.38	0.53	0.53
Jul DD ≥ 20°C			1.00	0.96*	0.96*
Jul DD ≥ 15°C				1.00	1.00*
Jul DD ≥ 10°C					1.00
MN ≥ 20°C					
MN ≥ 15°C					
MN ≥ 10°C					
MD ≥ 20°C					
MD ≥ 15°C					
MD ≥ 10°C					
Growth					

Appendix Table 9. Continued

Variable	SR MN≥20°C	SR MN≥15°C	SR MN≥10°C	SR MD≥20°C	SR MD≥15°C
Clearwater River					
Days ≥ 20 kcfs	0.49	0.68*	0.24	0.57	0.69*
Days ≥ 30 kcfs	0.35	0.52	0.20	0.44	0.44
May DD ≥ 10°C	-0.23	-0.45	-0.07	-0.32	-0.56
Jun DD ≥ 20°C	-0.58	-0.58	-0.75*	-0.53	-0.34
Jun DD ≥ 15°C	-0.62	-0.77*	-0.46	-0.67*	-0.72*
Jun DD ≥ 10°C	-0.70*	-0.86*	-0.45	-0.74*	-0.78*
Jul DD ≥ 20°C	-0.16	-0.00	-0.24	-0.23	-0.40
Jul DD ≥ 15°C	-0.32	-0.20	-0.24	-0.33	-0.57
Jul DD ≥ 10°C	-0.18	-0.08	-0.19	-0.15	-0.43
MN ≥ 20°C	0.60	0.61	0.29	0.61	0.74*
MN ≥ 15°C	0.66*	0.54	0.32	0.70*	0.79*
MN ≥ 10°C	0.40	0.58	0.36	0.44	0.52
MD ≥ 20°C	0.58	0.65	0.23	0.58	0.74*
MD ≥ 15°C	0.73*	0.83	0.47	0.81*	0.82*
MD ≥ 10°C	0.31	0.44	0.23	0.38	0.39
Snake River					
Days ≥ 50 kcfs	0.37	0.39	0.18	0.47	0.47
Days ≥ 75 kcfs	0.24	0.27	0.06	0.28	0.28
May DD ≥ 15°C	-0.61	-0.61	-0.77*	-0.58	-0.33
May DD ≥ 10°C	-0.74*	-0.82*	-0.74*	-0.79*	-0.73*
Jun DD ≥ 20°C	-0.73*	-0.77*	-0.80*	-0.70*	-0.56
Jun DD ≥ 15°C	-0.87*	-0.92*	-0.72*	-0.88*	-0.86*
Jun DD ≥ 10°C	-0.89*	-0.97*	-0.72*	-0.88*	-0.85*
Jul DD ≥ 20°C	-0.64*	-0.47	-0.38	-0.61	-0.49
Jul DD ≥ 15°C	-0.76*	-0.60	-0.44	-0.74*	-0.70*
Jul DD ≥ 10°C	-0.76*	-0.60	-0.44	-0.74*	-0.70*
MN ≥ 20°C	1.00	0.90*	0.76*	0.97*	0.85*
MN ≥ 15°C		1.00	0.67*	0.86*	0.79*
MN ≥ 10°C			1.00	0.68*	0.53
MD ≥ 20°C				1.00	0.90*
MD ≥ 15°C					1.00
MD ≥ 10°C					
Growth					

Appendix Table 9. Continued

Variable	SR MD≥10°C	Growth
Clearwater River		
Days ≥ 20 kcfs	0.22	-0.73
Days ≥ 30 kcfs	0.14	-0.33
May DD ≥ 10°C	-0.09	0.38
Jun DD ≥ 20°C	-0.65	0.46
Jun DD ≥ 15°C	-0.37	0.36
Jun DD ≥ 10°C	-0.35	0.23
Jul DD ≥ 20°C	-0.29	0.70
Jul DD ≥ 15°C	-0.27	0.27
Jul DD ≥ 10°C	-0.15	0.19
MN ≥ 20°C	0.30	-0.12
MN ≥ 15°C	0.40	0.02
MN ≥ 10°C	0.52	-0.72
MD ≥ 20°C	0.20	0.04
MD ≥ 15°C	0.34	-0.42
MD ≥ 10°C	0.48	-0.85*
Snake River		
Days ≥ 50 kcfs	0.34	-0.63
Days ≥ 75 kcfs	0.24	-0.41
May DD ≥ 15°C	-0.73*	0.46
May DD ≥ 10°C	-0.61	0.51
Jun DD ≥ 20°C	-0.68*	0.46
Jun DD ≥ 15°C	-0.52	0.37
Jun DD ≥ 10°C	-0.51	0.34
Jul DD ≥ 20°C	-0.45	-0.03
Jul DD ≥ 15°C	-0.49	0.05
Jul DD ≥ 10°C	-0.49	0.05
MN ≥ 20°C	0.63*	-0.28
MN ≥ 15°C	0.51	-0.28
MN ≥ 10°C	0.81*	-0.41
MD ≥ 20°C	0.59	-0.33
MD ≥ 15°C	0.40	-0.44
MD ≥ 10°C	1.00	-0.39
Growth		1.00

* = signficant correlations ($P < 0.05$)
[a] D = days
[b] MN = mean Julian date
[c] MD = median Julian date
[d] DD = degree days
[e] MOP = minimum operating pool
[f] FB = forebay
[g] CWR = Clearwater River
[h] SR = Snake River

Appendix Table 10. Coefficient of variation (r^2) between variables examined in predictive models of survival of juvenile northern squawfish.

Variable	D 50 kcfs	D 75 kcfs	D 100 kcfs	MN 50 kcfs	MN 75 kcfs
Days ≥ 50 kcfs	1.00	0.92*	0.87*	-0.29	-0.00
Days ≥ 75 kcfs		1.00	0.95*	-0.50	-0.44
Days ≥ 100 kcfs			1.00	-0.46	-0.32
MN[a] ≥ 50 kcfs				1.00	0.84*
MN ≥ 75 kcfs					1.00
MD[b] ≥ 50 kcfs					
MD ≥ 75 kcfs					
Days ≥ 20°C					
Days ≥ 15°C					
Days ≥ 10°C					
MN ≥ 20°C					
MN ≥ 15°C					
MN ≥ 10°C					
MD ≥ 20°C					
MD ≥ 15°C					
MD ≥ 10°C					
MN secchi					
Days secchi ≥ 1.5 ft					
Days secchi ≥ 2 ft					
MOP[c] forebay variance					
Forebay var. May					
Forebay var. Jun					
Forebay var. Jul					
Forebay var. Aug					
Forebay var. Sep					
Winter forebay var.					
Winter forebay level					
Non-MOP forebay var.					
Non-MOP forebay level					
Days ≥ 20 kcfs					
Days ≥ 25 kcfs					
Days ≥ 35 kcfs					
Winter days ≥ 10°C					
Sampling effort					
Instantaneous growth rate					

Appendix Table 10. Continued

Variable	MD 50 kcfs	MD 75 kcfs	D20°C	D15°C	D10°C
Days ≥ 50 kcfs	0.16	-0.50	-0.27	-0.56	-0.59
Days ≥ 75 kcfs	0.33	-0.59	-0.11	-0.48	-0.45
Days ≥ 100 kcfs	0.38	-0.73*	-0.12	-0.32	-0.33
MN ≥ 50 kcfs	0.03	0.62	-0.12	-0.23	-0.24
MN ≥ 75 kcfs	-0.26	0.42	-0.05	-0.34	-0.31
MD ≥ 50 kcfs	1.00	0.02	0.08	-0.05	0.05
MD ≥ 75 kcfs		1.00	0.10	-0.24	-0.19
Days ≥ 20°C			1.00	0.11	0.53
Days ≥ 15°C				1.00	0.75*
Days ≥ 10°C					1.00
MN ≥ 20°C					
MN ≥ 15°C					
MN ≥ 10°C					
MD ≥ 20°C					
MD ≥ 15°C					
MD ≥ 10°C					
MN secchi					
Days secchi ≥ 1.5 ft					
Days secchi ≥ 2 ft					
MOP forebay variance					
Forebay var. May					
Forebay var. Jun					
Forebay var. Jul					
Forebay var. Aug					
Forebay var. Sep					
Winter forebay var.					
Winter forebay level					
Non-MOP forebay var.					
Non-MOP forebay level					
Days ≥ 20 kcfs					
Days ≥ 25 kcfs					
Days ≥ 35 kcfs					
Winter days ≥ 10°C					
Sampling effort					
Instantaneous growth rate					

Appendix Table 10. Continued

Variable	MN20°C	MN15°C	MN10°C	MD20°C	MD15°C
Days ≥ 50 kcfs	0.26	0.41	0.24	0.49	0.57
Days ≥ 75 kcfs	0.11	0.19	0.16	0.29	0.36
Days ≥ 100 kcfs	0.10	0.07	0.06	0.27	0.22
MN ≥ 50 kcfs	0.35	0.31	0.10	0.38	0.31
MN ≥ 75 kcfs	0.42	0.54	0.31	0.51	0.54
MD ≥ 50 kcfs	0.11	0.17	0.03	0.15	0.24
MD ≥ 75 kcfs	0.20	0.51	0.37	0.27	0.45
Days ≥ 20°C	-0.37	0.16	0.56	-0.19	0.04
Days ≥ 15°C	-0.17	-0.32	-0.18	-0.39	-0.53
Days ≥ 10°C	-0.59	-0.40	-0.17	-0.65*	-0.56
MN ≥ 20°C	1.00	0.62	0.34	0.84*	0.61
MN ≥ 15°C		1.00	0.84*	0.79*	0.95*
MN ≥ 10°C			1.00	0.60	0.74*
MD ≥ 20°C				1.00	0.84*
MD ≥ 15°C					1.00
MD ≥ 10°C					
MN secchi					
Days secchi ≥ 1.5 ft					
Days secchi ≥ 2 ft					
MOP forebay variance					
Forebay var. May					
Forebay var. Jun					
Forebay var. Jul					
Forebay var. Aug					
Forebay var. Sep					
Winter forebay var.					
Winter forebay level					
Non-MOP forebay var.					
Non-MOP forebay level					
Days ≥ 20 kcfs					
Days ≥ 25 kcfs					
Days ≥ 35 kcfs					
Winter days ≥ 10°C					
Sampling effort					
Instantaneous growth rate					

Appendix Table 10. Continued

Variable	MD10°C	MN secchi	Secchi ≥ 1.5 ft	Secchi ≥ 2.0 ft
Days ≥ 50 kcfs	0.21	-0.92*	0.86*	0.89*
Days ≥ 75 kcfs	0.09	-0.94*	0.97*	0.96*
Days ≥ 100 kcfs	0.02	-0.86*	0.95*	0.96*
MN ≥ 50 kcfs	0.05	0.45	-0.57	-0.61*
MN ≥ 75 kcfs	0.28	0.18	-0.36	-0.37
MD ≥ 50 kcfs	0.02	-0.11	0.20	0.19
MD ≥ 75 kcfs	0.31	0.50	-0.74*	-0.75*
Days ≥ 20°C	0.53	0.11	-0.06	-0.13
Days ≥ 15°C	0.01	0.54	-0.41	-0.32
Days ≥ 10°C	-0.00	0.53	-0.37	-0.34
MN ≥ 20°C	0.31	-0.08	0.04	0.04
MN ≥ 15°C	0.82*	-0.27	0.03	0.05
MN ≥ 10°C	0.96*	-0.27	0.07	0.07
MD ≥ 20°C	0.59	-0.37	0.17	0.21
MD ≥ 15°C	0.70*	-0.45	0.18	0.21
MD ≥ 10°C	1.00	-0.21	-0.01	0.05
MN secchi		1.00	-0.89*	-0.93*
Days secchi ≥ 1.5 ft			1.00	0.97*
Days secchi ≥ 2 ft				1.00
MOP forebay variance				
Forebay var. May				
Forebay var. Jun				
Forebay var. Jul				
Forebay var. Aug				
Forebay var. Sep				
Winter forebay var.				
Winter forebay level				
Non-MOP forebay var.				
Non-MOP forebay level				
Days ≥ 20 kcfs				
Days ≥ 25 kcfs				
Days ≥ 35 kcfs				
Winter days ≥ 10°C				
Sampling effort				
Instantaneous growth rate				

Appendix Table 10. Continued

Variable	Aug FB var.	Sep FB var.	Winter FB var.	Winter FB level
Days ≥ 50 kcfs	-0.04	0.33	-0.08	0.38
Days ≥ 75 kcfs	-0.05	0.25	0.18	0.04
Days ≥ 100 kcfs	-0.24	0.31	0.29	0.10
MN ≥ 50 kcfs	0.38	-0.03	-0.43	0.45
MN ≥ 75 kcfs	0.32	-0.06	-0.39	0.56
MD ≥ 50 kcfs	0.17	0.09	0.06	-0.36
MD ≥ 75 kcfs	0.70*	-0.02	-0.64	-0.01
Days ≥ 20°C	0.41	-0.43	0.35	-0.80*
Days ≥ 15°C	-0.70*	-0.01	0.29	-0.20
Days ≥ 10°C	-0.26	-0.40	0.53	-0.66
MN ≥ 20°C	-0.13	0.46	-0.66	0.72*
MN ≥ 15°C	0.45	0.29	-0.72*	0.30
MN ≥ 10°C	0.44	0.20	-0.40	-0.06
MD ≥ 20°C	0.14	0.69*	-0.64	0.62
MD ≥ 15°C	0.51	0.37	-0.67	0.37
MD ≥ 10°C	0.28	0.31	-0.46	0.01
MN secchi	-0.00	-0.37	-0.11	-0.17
Days secchi ≥ 1.5 ft	-0.18	0.15	0.36	0.00
Days secchi ≥ 2 ft	-0.27	0.31	0.30	0.08
MOP forebay variance	0.07	0.27	0.54	-0.12
Forebay var. May	-0.60	0.39	0.41	0.18
Forebay var. Jun	-0.26	-0.11	0.76*	-0.23
Forebay var. Jul	-0.14	-0.25	0.40	-0.05
Forebay var. Aug	1.00	-0.29	-0.37	-0.31
Forebay var. Sep		1.00	-0.43	0.55
Winter forebay var.			1.00	-0.52
Winter forebay level				1.00
Non-MOP forebay var.				
Non-MOP forebay level				
Days ≥ 20 kcfs				
Days ≥ 25 kcfs				
Days ≥ 35 kcfs				
Winter days ≥ 10°C				
Sampling effort				
Instantaneous growth rate				

Appendix Table 10. Continued

Variable	MOP FB[d] var.	May FB var.	Jun FB var.	Jul FB var.
Days ≥ 50 kcfs	0.55	0.11	0.28	0.43
Days ≥ 75 kcfs	0.60	0.19	0.37	0.35
Days ≥ 100 kcfs	0.66*	0.38	0.42	0.40
MN ≥ 50 kcfs	-0.21	-0.30	-0.57	-0.24
MN ≥ 75 kcfs	-0.04	-0.43	-0.38	0.17
MD ≥ 50 kcfs	0.16	0.01	-0.29	-0.27
MD ≥ 75 kcfs	-0.43	-0.59	-0.69*	-0.57
Days ≥ 20°C	0.38	-0.36	0.08	0.81*
Days ≥ 15°C	-0.28	0.24	-0.08	0.04
Days ≥ 10°C	-0.03	0.16	0.23	0.40
MN ≥ 20°C	0.31	-0.34	-0.70	-0.38
MN ≥ 15°C	0.09	-0.69*	-0.66	0.19
MN ≥ 10°C	0.35	-0.60	-0.42	0.57
MD ≥ 20°C	0.18	-0.26	-0.53	-0.09
MD ≥ 15°C	0.22	-0.58	-0.53	0.10
MD ≥ 10°C	0.34	-0.49	-0.40	0.60
MN secchi	-0.70*	-0.18	-0.43	-0.40
Days secchi ≥ 1.5 ft	0.59	0.27	0.52	0.47
Days secchi ≥ 2 ft	0.63*	0.35	0.52	0.45
MOP forebay var.	1.00	0.35	0.54	0.61*
Forebay var. May		1.00	0.64*	0.00
Forebay var. Jun			1.00	0.48
Forebay var. Jul				1.00
Forebay var. Aug				
Forebay var. Sep				
Winter forebay var.				
Winter forebay level				
Non-MOP forebay var.				
Non-MOP forebay level				
Days ≥ 20 kcfs				
Days ≥ 25 kcfs				
Days ≥ 35 kcfs				
Winter days ≥ 10°C				
Sampling effort				
Instantaneous growth rate				