HABITAT USE, FOOD HABITS AND THE INFLUENCE OF PREDATION ON SUBYEARLING CHINOOK SALMON IN LOWER GRANITE AND LITTLE GOOSE RESERVOIRS, WASHINGTON

College of Forestry, Wildlife and Range Sciences

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HABITAT USE, FOOD HABITS AND THE INFLUENCE OF PREDATION ON SUBYEARLING CHINOOK SALMON IN LOWER GRANITE AND LITTLE GOOSE RESERVOIRS, WASHINGTON

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Thomas S. Curet

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Authorization to Submit Thesis

This thesis of Thomas S. Curet, submitted for the degree of Master of Science with a major in Fisheries Resources and titled "HABITAT USE, FOOD HABITS AND THE INFLUENCE OF PREDATION ON SUBYEARLING CHINOOK SALMON IN LOWER GRANITE RESERVOIR, WASHINGTON", has been reviewed in final form, as indicated by the signatures and dates given below. Permission is now granted to submit final copies to the College of Graduate Studies for approval.

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ABSTRACT

A majority of the subyearling chinook salmon *Oncorhynchus tshawytscha* that occur along the shorelines of the lower Snake River reservoirs are believed to be progeny of adult fall chinook salmon which spawn in the free flowing portion of the Snake and Clearwater rivers or possibly in tailwaters of impoundments on the lower Snake River. An understanding of the basic life history of this population is required if recovery and enhancement efforts for fall chinook are to be successful. Subyearling chinook salmon were sampled primarily by beach seining and open water trawling. Subyearling chinook salmon appear to be distributed primarily along the shoreline of the reservoir over sand substrate during their early rearing period in the reservoirs and pelagically orientated once shoreline temperatures exceed 18-20° C. Temperature appears to control the duration of shoreline residence and downstream movement by increasing the metabolic activity of the fish beyond tolerant physiological levels.

Food habits and the caloric importance of prey were assessed for four length groups (40-50 mm, 56-70 mm, 71-85 mm and > 86 mm) of subyearling chinook salmon collected in Lower Granite and Little Goose reservoirs, Washington, during 1991-1992. Ephemeropterans and Cladocerans were the most important prey item for the 40-50 mm size class. Ephemeropterans and Dipterans were the most important prey items for the 56-70 and 71-85 mm size classes and larval fish were the most important prey item (72%) in the diet of fish > 86 mm. Application of a bioenergetics model estimated that subyearling chinook salmon were feeding at 27% of their maximum ration during the time interval modeled (April-July). The observed proportion of maximum ration was only 7% greater than the estimated maintenance ration (zero growth) modeled for the same time interval suggesting either forage limitations, competition or other abiotic and biotic factors may be influencing subyearling growth in the reservoir.

Mean daily consumption rates of subyearling chinook salmon were estimated for three length groups of smallmouth bass *Micropterus dolomieui* (<250 mm, 250-389 mm and >389) collected in May 1992 and two length groups of northern squawfish *Ptychocheilus oregonensis* (250-349 mm and >349 mm) collected during the smolt outmigration period (April through June) in 1987-1991. Daily consumption rates of subyearling chinook salmon by smallmouth bass were similar between the <250 mm and 250-389 length groups at 0.06 and 0.09 prey/predator/day, respectively. No consumption was noted by the >389 mm length group although low numbers of smallmouth bass were examined. Consumption of subyearling chinook by northern squawfish was detected only in April. Daily consumption rates of subyearling chinook salmon by northern squawfish ranged from 0.01 to 0.06 prey/predator/day for the 250-349 mm and >349 length groups, respectively.

The results of my research indicate Lower Granite and Little Goose reservoirs provide suitable rearing habitats for subyearling chinook salmon. The quantity of food ingested is limited either due to food limitations, competitive interactions or the influence of other biotic and abiotic factors. Temperatures appear to control both duration of shoreline residence and the duration of open water rearing for subyearling chinook salmon. Smallmouth bass and northern squawfish are both predators of subyearling chinook salmon with smallmouth bass being the most serious predator, particularly along the shoreline of Lower Granite Reservoir. These predators may consume up to 6% of the wild subyearling fall chinook salmon population as they rear and migrate through Lower Granite Reservoir.

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INTRODUCTION

Listing of several stocks of Snake River chinook salmon *Oncorhynchus tshawytscha* under the Endangered Species Act has elevated concern for all chinook salmon in the Columbia River Basin. The Columbia River watershed historically produced more chinook salmon than any other river system in the world, with the majority of the spring and summer chinook salmon coming from the Snake River system (Williams 1989). Recovery efforts to date have been primarily focused on spring and summer chinook stocks such as water budgeting, artificial rearing of fry, modification and the use of spillways, construction of collection, transportation and by-pass facilities. Recently, however, attention has been focused on the recovery of fall chinook salmon although these efforts are impaired because little is known about the life history of Snake River fall chinook salmon (Howell et al. 1985).

Subyearling chinook salmon that occur in Lower Granite Reservoir could be either progeny of adult fall chinook which spawn upstream from Lower Granite in the free flowing portion of the Snake and Clearwater rivers, or subyearling spring chinook of either hatchery or natural origin. Most of the subyearlings that occur along the shoreline of the reservoir are believed to be of fall chinook offspring. Electrophoretic analyses of subyearlings captured upriver from Lower Granite Reservoir indicate that subyearlings captured along the shoreline of the Snake River are primarily fall chinook offspring (Connor et al. 1992) whereas subyearlings collected in open water at the smolt collection trap operated by the Idaho Department of Fish and Game (IDFG) at Lewiston, Idaho were predominantly spring chinook progeny (Edwin Buettner, IDFG, Lewiston, Idaho, personal communication). Hatchery released subyearling chinook in the Hanford Reach of the Columbia River were less abundant in near-shore areas than wild subyearling chinook (Dauble et al. 1989). Therefore, subyearling fall and spring chinook may be spatially separated in the spring with subyearling fall chinook exhibiting a fidelity for the shoreline of the river and reservoir and subyearling spring chinook being more pelagically orientated.

Historically, Snake River fall chinook salmon occurred in the mainstem Snake River from its mouth to Shoshone Falls in southcentral Idaho (Haas 1965). With the completion of Hells Canyon Dam and the four lower Snake River dams between 1958 and 1975 the most productive spawning and rearing areas in the Snake River were inundated or inaccessible (Figure 1), leaving approximately 166 km of habitat in the main stem Snake River (Connor et al. 1992). The middle Snake River reservoirs now confine fall chinook salmon to the mainstem from the base of Hell's Canyon Dam to the headwaters of Lower Granite Reservoir.

Life History

Snake River fall chinook salmon enter the Columbia River in August, September and early October (Bjornn 1960). Redds are constructed in the mainstem Snake River from October until December (Waples et al. 1991), with a majority of redds appearing in 1991 at river km (Rkm) 260.8 (William Connor, U.S. Fish and Wildlife Service, Ahsahka, Idaho, personal communication).

The number of fall chinook salmon adults returning to the Snake River has dramatically declined in recent years (Figure 2), from an estimated annual mean of 72,000 over the period of 1938-1949 (Waples et al. 1991) to only 1,027 fish passing Lower Granite Dam in 1991 (Annual Fish Passage Report, U.S. Army Corps of Engineers, 1991).

Little is known about timing of emergence for Snake River fall chinook salmon (Howell et al. 1985). However, Bennett et al. (1986, 1988, 1990a, 1990b , 1993a, 1993b) have captured small (<50mm) subyearling chinook salmon in Lower Granite Reservoir in April which suggests emergence probably occurred in March to early April. Most juvenile fall chinook salmon from the Snake River migrate to the ocean as subyearlings (Bjornn 1960).

Bennett et al. (1986, 1988, 1990a, 1990b , 1993a, 1993b) captured subyearling chinook salmon over low gradient, low velocity, sandy substrates in Lower Granite Reservoir. Available evidence indicates that subyearling chinook salmon utilize relatively slow moving waters near the shorelines or below islands of the central Columbia River for resting and

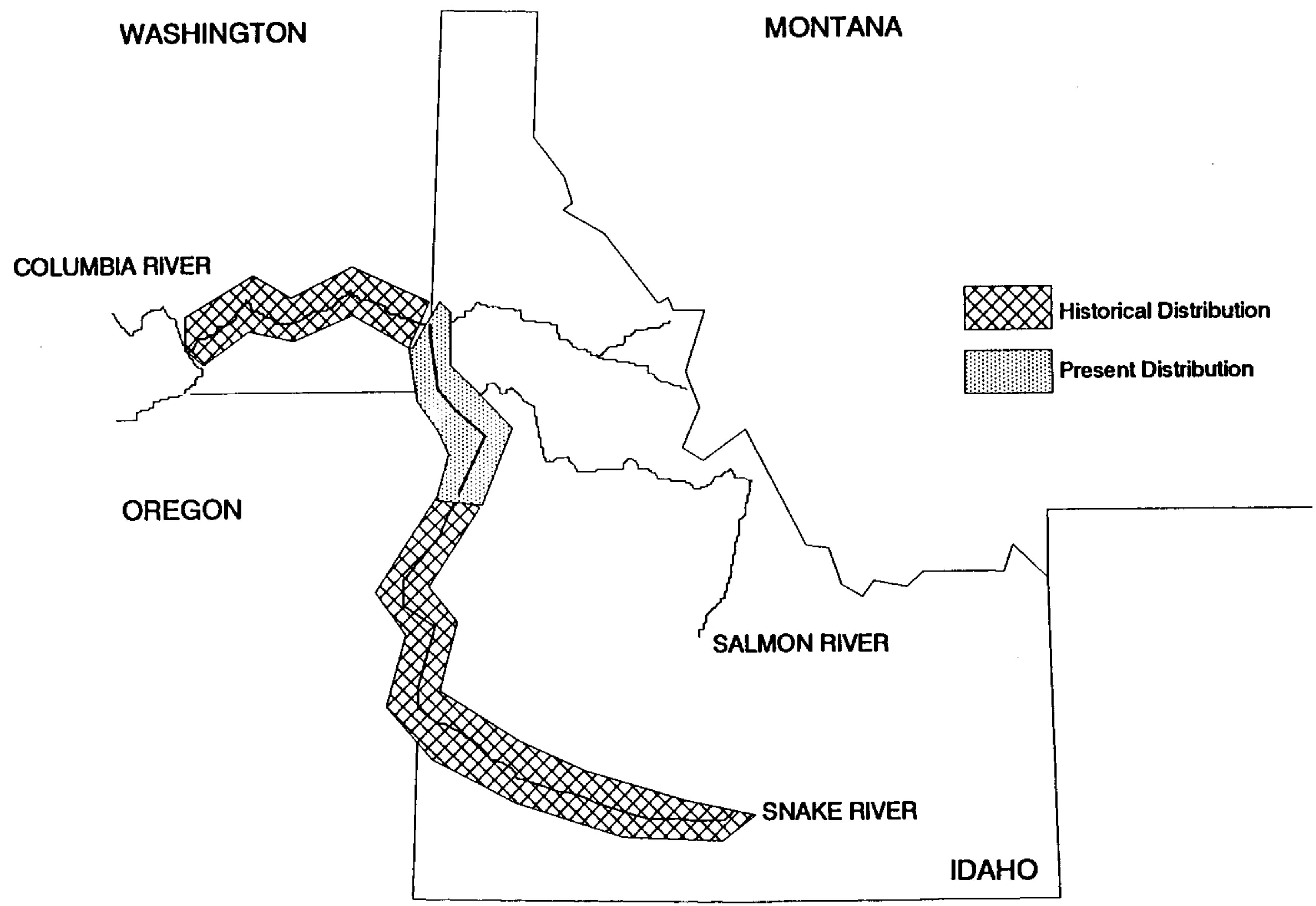

Figure 1. Historic and current distribution of Snake River fall chinook salmon.

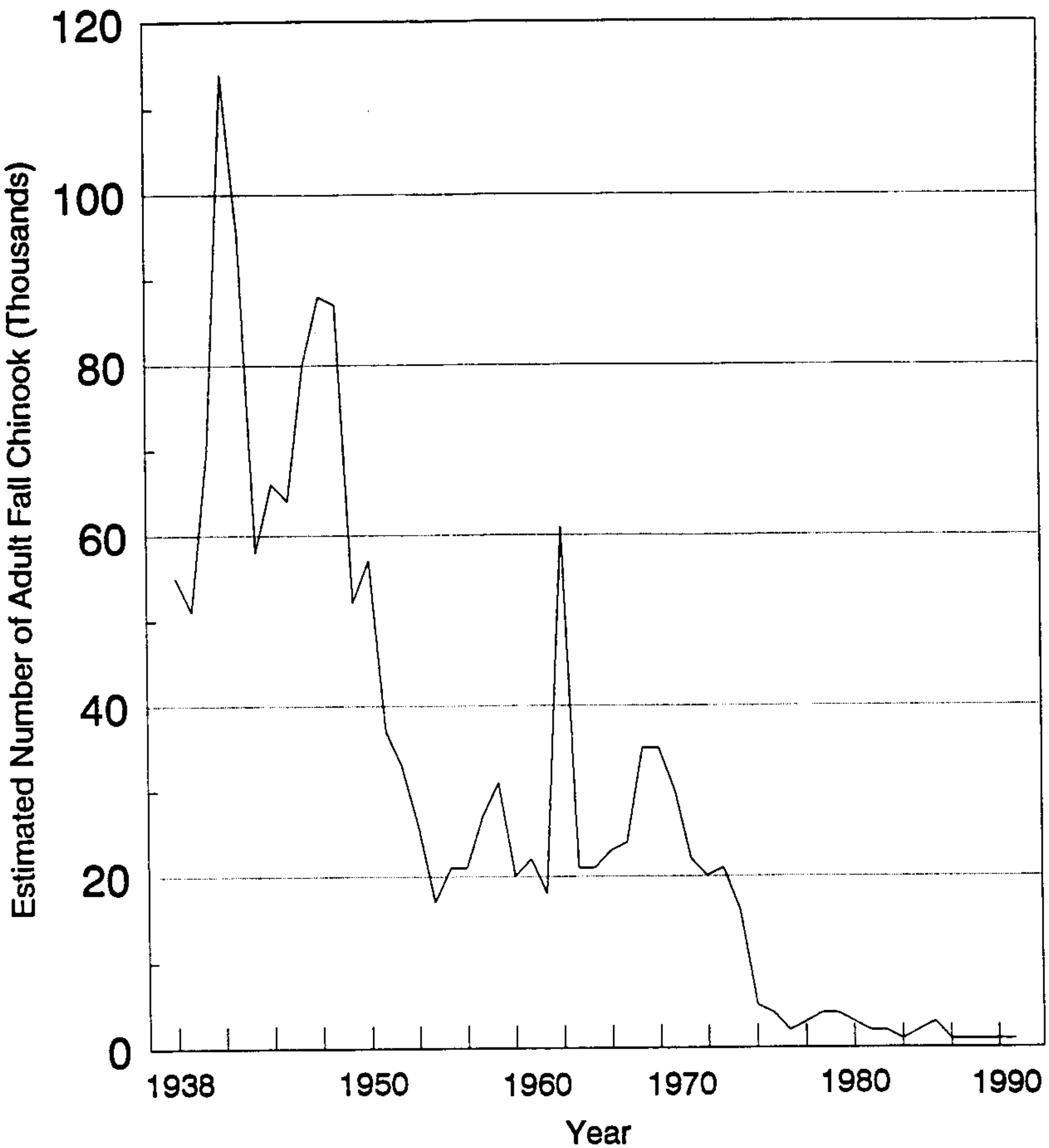

Figure 2. Estimated number of fall chinook salmon entering the Snake River, 1938-1991.

feeding (Becker 1970). After emergence and initial dispersal, fall chinook salmon exhibit a high fidelity for lower velocity backwater areas for rearing (William Connor, U.S. Fish and wildlife Service, Ahsahka, Idaho, personal communication).

Impoundments on the lower Snake and Columbia rivers have delayed passage of all chinook salmon (Raymond 1988). For subyearling chinook salmon, this delay may have deleterious consequences. Raymond (1988) believed that subyearling chinook salmon may have higher mortality than yearling outmigrants because subyearlings migrate in July and August when river flows and dam spills are reduced and water temperatures are higher than during April and May when yearling fish emigrate. Subyearling chinook salmon migrate through reservoirs more slowly than do yearling smolts and probably spend more time in reservoir habitats (Rondorf et al. 1990).

The basic life history of subyearling Snake River fall chinook salmon and the impact that the lower Snake River reservoirs have on the early rearing and migration period of these fish is poorly understood. This study was initiated to provide information regarding these questions.

The specific objectives of this research were to:

1. Identify factors related to distribution, abundance and rearing of subyearling chinook salmon in Lower Granite Reservoir;
2. Determine food habits of subyearling chinook salmon in Lower Granite and Little Goose reservoirs;
3. Assess the influence of predation on subyearling chinook salmon consumption by potential predators in Lower Granite Reservoir.

STUDY AREAS

Lower Granite Reservoir, the first reservoir encountered by downstream migrating Snake River fall chinook salmon (Figure 3), provides flood control, recreation, navigation and electrical power generation (Bennett et al. 1986). Total surface area of the reservoir is 3,602 ha with a mean and maximum depth of 16.6 and 42.1 m, respectively. Substrata vary along the shoreline from rip-rap, mud-sand beaches to steep basalt cliffs. Some upper-reservoir areas and alluvial fans support a majority of the riparian vegetation found along the reservoir, which consists of short grasses, shrubs and some cattails. Riparian vegetation is sparse as a result of the 1.52 m water level fluctuation from reservoir operations.

Little Goose Reservoir, the next reservoir downstream of Lower Granite Dam, was formed in 1970 with the completion of Little Goose Dam (Figure 4). Total surface area of the reservoir is 4,057 ha and width varies from about 0.3 to 1.3 km. Bennett et al. (1983) classified habitat in Little Goose Reservoir into five general habitat types: embayments, rip-rap shorelines, sandy shorelines, talus slopes, and tailwater. Total length of the reservoir is 60 km with approximately 142 km of shoreline.

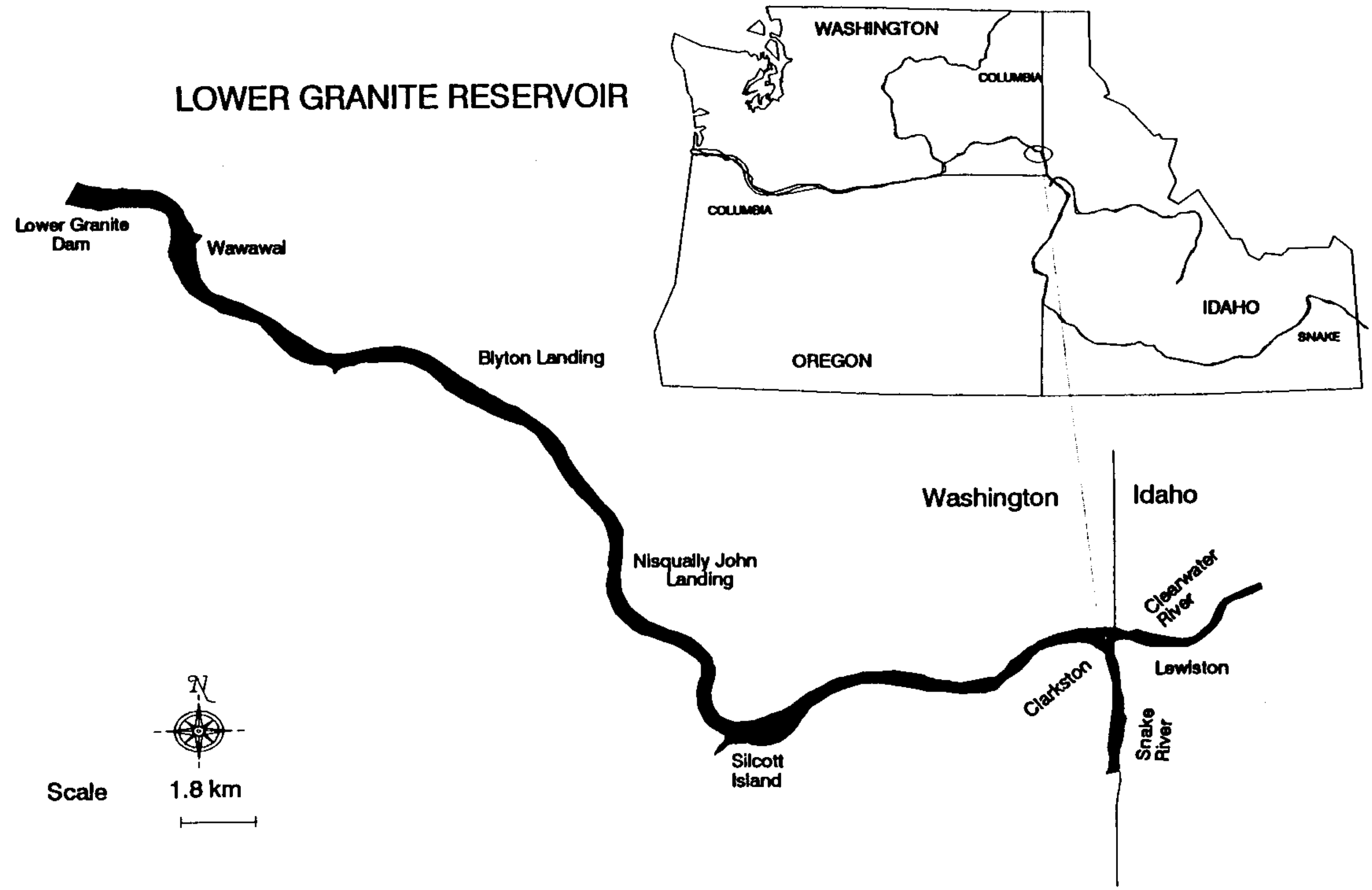

Figure 3. Map of Lower Granite Reservoir, near Clarkston, Washington and Lewiston, Idaho.

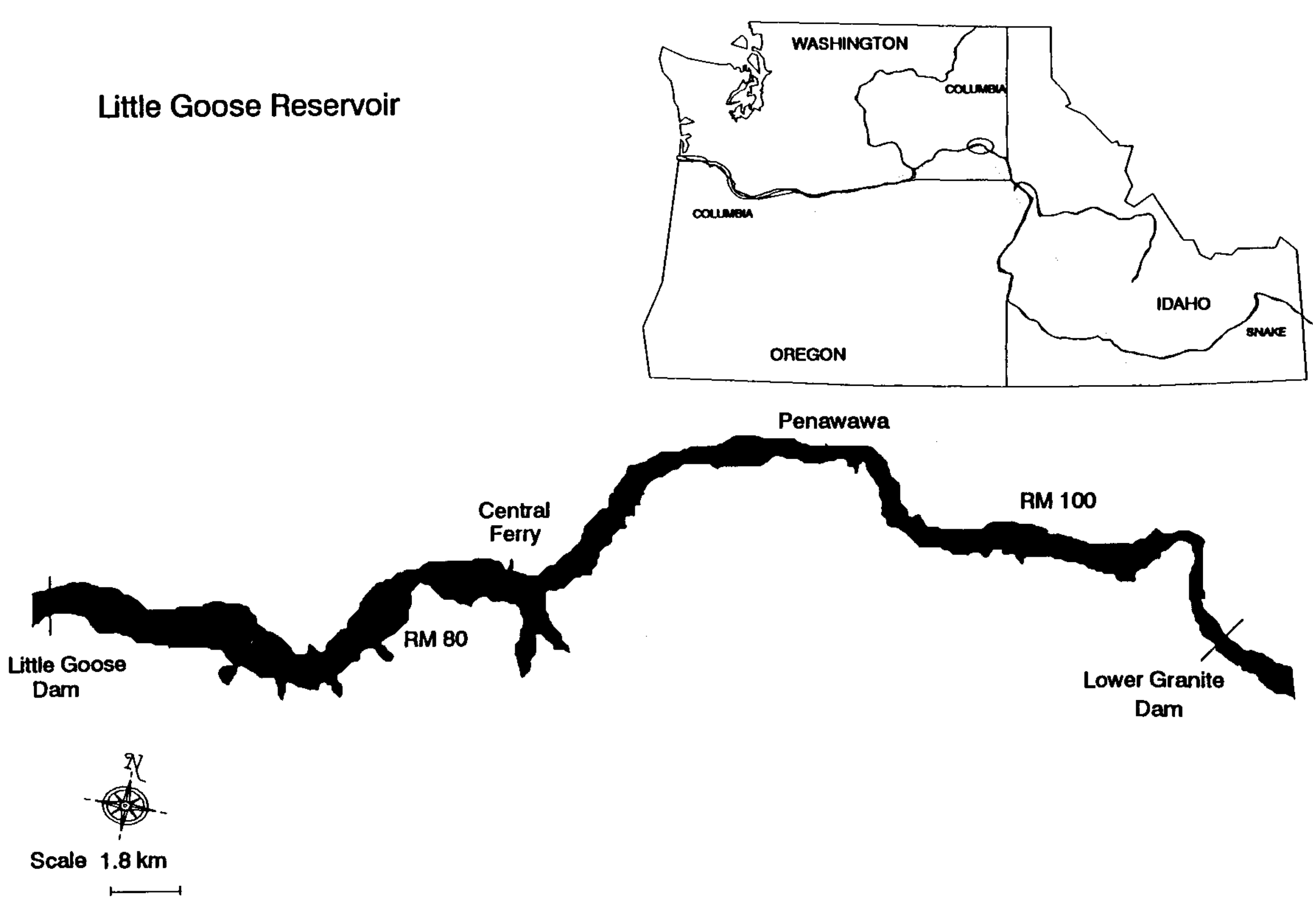

Figure 4. Map of Little Goose Reservoir, immediately downstream of Lower Granite Reservoir on the Snake River.

Chapter 1. To identify factors related to distribution, abundance, rearing and migration of subyearling chinook salmon in Lower Granite and Little Goose Reservoirs.

INTRODUCTION

Research on subyearling chinook salmon in the Snake River has been restricted to the Clearwater River, Lower Granite and Little Goose reservoirs (Bennett et al. 1992, 1993a, 1993b), and the flowing portions of the Snake River downstream of Hells Canyon Dam (Connor et al. 1991). Subyearling chinook salmon were first reported rearing in Little Goose Reservoir in 1980 (Bennett et al. 1983) and Lower Granite Reservoir in 1985 (Bennett and Shrier 1986). More intensive subyearling chinook abundance monitoring has since been conducted (Bennett et al. 1993a, 1993b). Subyearling chinook salmon in Lower Granite Reservoir are believed to be progeny of adult fall chinook salmon that spawned upstream of the reservoir in the Snake and lower Clearwater rivers.

Data collections in Lower Granite Reservoir from 1988 through 1991 (Bennett et al. 1990a, 1990b, 1993a, 1993b) indicate subyearling chinook salmon are no longer present in shallow water habitats after late May to late June, possibly in response to increasing water temperatures. However, numerous subyearling chinook salmon continue to be collected at the collection facility at Lower Granite Dam through October, though peak collections occur in June and July (Tim Wik, U.S. Army Corps of Engineers, Dayton, Washington, personal communication).

METHODS

Fish Collections

Synoptic beach seine surveys were conducted throughout Lower Granite and Little Goose reservoirs during April, May, June, and July to assess the abundance of subyearling chinook salmon in littoral areas. Sampling continued until no subyearling chinook salmon were collected on two consecutive beach seining efforts.

We commenced beach seining with a 15.25 m x 2.4 m beach seine consisting of 0.32 cm knotless nylon. An area approximately 227 m^3 was sampled with this smaller meshed seine prior to 15 May to ensure smaller subyearling chinook salmon did not escape through the net. Thereafter, a 30.5 m x 2.4 m beach seine consisting of 0.64 cm knotless nylon was fished. An area approximately 454 m^3 was sampled using the larger seine. The seines were set parallel to and approximately 15.2 m from the shoreline with attachment lines that were drawn in perpendicular to the shoreline. Each beach seining sample consisted of 60-65 randomly selected beach seine hauls based on a stratified design for each reservoir.

In 1992 Lower Granite Reservoir was stratified by habitat type and beach seining efforts were allocated over these habitat types. Habitats were classified as sand, sand-cobble, sand-talus and rip-rap. Beach seining allocation was based on the proportional area of different habitats available in Lower Granite Reservoir and on the variance of previous subyearling collections. The total shoreline area of each habitat was estimated and then beach seining samples were then allocated using the Neyman Allocation (Scheaffer et al. 1979):

$$n_i = n\ (N_i s_i / \Sigma N_i s_i)$$

Where: n_i = Number of seine hauls within each habitat

n = Total possible 30.5 m sampling stations in Lower Granite Reservoir

N_i = Total number of sampling stations for strata

s_i = Stratum standard deviation from previous subyearling catches

Of the habitat samples allocated, each 30.5 m sample location was randomly selected for beach seining within each respective stratum. In Lower Granite Reservoir one standardized beach seine haul was made at each sampling station. In 1987-1991 beach seining was conducted at standardized shallow water stations throughout Lower Granite Reservoir (Bennett et al., 1988, 1990a, 1990b, 1993a, 1993b).

In Little Goose Reservoir, initial field surveys and collections of subyearling chinook salmon indicated that the reservoir would be best divided into three strata. Collectively, the three strata comprised the entire 60.4 km of shoreline. The upstream end of Little Goose Reservoir or tailwater stratum extended from Lower Granite Dam (Rkm 173.1) downstream to Almota (Rkm 167.4). This stratum was characterized by higher velocities from Lower Granite Dam with a substrate consisting primarily of rip-rap and cobble on the northern shoreline to sand and gravel on the southern shoreline. Mid (Rkm 166.6-Rkm 134.4) and lower strata (Rkm 133.6-Rkm 112.7) have a combination of four general habitat types: embayments; rip-rap shorelines; sandy shorelines; and talus slopes (Bennett et al. 1983). The northern shoreline in both the mid and lower region was principally railroad rip-rap. Embayments are more common in the lower region. A total of 21 transects was selected in Little Goose Reservoir during each beach seine effort, 7 from each reach in which 3 beach seine hauls were conducted at each transect.

Open water, surface, mid and bottom trawling were conducted in June 1992 in Lower Granite Reservoir to assess the presence of subyearling chinook salmon in open water, three weeks after subyearlings disappeared from the shoreline of the reservoir. Sampling was conducted during day and night hours to record diel distribution.

Size was the principal criterion used to identify subyearling chinook salmon from yearling chinook salmon in the reservoir. Reviewing length frequency distributions for spring and summer chinook from tributaries throughout Idaho suggested that the minimum size of yearling chinook migrating through the lower Snake River reservoirs in the early spring is about 80 mm. To ensure that yearling chinook were not included in the samples, a conservative maximum length of 75 mm was used during April and May and 85 mm during June.

All subyearling chinook encountered were measured for total length (mm) and interrogated for the presence of a passive integrated transponder (PIT) tag.

Abundance

Abundance of subyearling chinook salmon was estimated in each habitat stratum and expanded for all available habitats in Lower Granite and Little Goose reservoirs. Methods presented by Scheaffer et al. (1979) were used to estimate the mean number of subyearling chinook salmon by:

$$\bar{y} = \sum_{i=1}^{n} \frac{y_i}{n}$$

where:

y_i = total subyearling chinook salmon in the ith haul and,

n = total number of hauls in each reservoir stratum.

The variance associated with this estimate was calculated as:

$$V(\bar{y}) = ((N-n)/N)(\frac{s^2}{n})$$

where:

$$s^2 = \sum_{i=1}^{n} (y_i - \bar{y})^2/n-1$$

N = total number of possible sampling units in each stratum, and

n = number of samples (hauls) taken.

A 90% bound (B) ($\alpha = 0.10$) was placed on this estimate by:

$$B = 1.645 \sqrt{V(y)}$$

A total reservoir subyearling chinook salmon population estimate was calculated by summing each of the reservoir stratum estimates (Scheaffer et al. 1979):

$$\hat{T} = \sum_{i=1}^{L} (N_i y_i)$$

where: $N_i y_i$ = the population estimates for each reservoir stratum.

The associated variance (V(T)) of this total population estimate was calculated by:

$$V(T) = \sum_{i=1}^{L} N_i^2 \frac{(Ni-ni)}{Ni} (s_i^2 / n_i)$$

A 90% bound (B) ($\alpha = 0.10$) was placed on this estimate by:

$$B = 1.645 \sqrt{V(T)}$$

Distribution and Preferred Habitat

Densities of subyearling chinook salmon collected from Lower Granite Reservoir (1990, 1991 and 1992) by beach seining were compared spatially by habitats using the Jacobs Utilization Index and a chi square test of homogeneity ($P = 0.05$) to determine the distribution and preferred habitat of subyearling chinook. The Jacobs index takes a value of zero under random distribution and deviates symmetrically from zero between plus and minus one for preferred and avoided habitats, respectively (Lechowicz 1982). Using the Jacobs Utilization

Index, comparisons were made to determine if differences in densities occurred between habitat types.

Rearing and Migration Timing

To estimate the duration of rearing in Lower Granite Reservoir for years 1991 and 1992, rearing was divided into three categories: overall, littoral, and open water. Overall reservoir rearing period was estimated as the number of days between the initial collection of subyearlings in Lower Granite Reservoir compared to peak arrivals of subyearlings at the smolt collection facility at Lower Granite Dam. Littoral rearing was estimated as the number of days between the initial dates of collection of subyearlings along the shoreline until subyearlings were no longer present in littoral areas. Open water rearing was estimated as the number of days between the migration of subyearlings from the shoreline of the reservoir and peak arrivals of subyearlings at the smolt collection facility at Lower Granite Dam.

Physico-Chemical Variables

Water temperatures (°C) and dissolved oxygen (DO, in mg/l) concentrations were monitored at shoreline and open water sampling areas and related to fish abundance in Lower Granite Reservoir. Water temperature and DO were measured at each sampling location with a Y.S.I. probe. Measurements were taken at the shoreline, and at 7.5 and 15 m from the shoreline after beach seining immediately below the surface, mid-depth and off the bottom approximately where beach seining was conducted. Pearson's correlation coefficients (r) were used to determine whether the abundance of subyearlings was associated with water temperature and dissolved oxygen values.

Habitat surveys were conducted during the March 1992 drawdown of Lower Granite Reservoir. An overall description of the substrate size, embeddedness, cover type, cover size, slope and percent area covered by dominant substrate was recorded at 0.80 km intervals during the drawdown. Habitat evaluations were used to quantify and stratify potential rearing habitats in the littoral zone.

RESULTS

Abundance

Lower Granite

The estimated population size of subyearling chinook along the shoreline of the reservoir peaked on 10 May, 1992 at 4,460 fish (Figure 5) and declined throughout the month of May. Catches along the shoreline of the reservoir peaked on 14 May in 1992 (Figure 6). In 1987 peak catches along the shoreline occurred on 16 May similar to 1992. In 1990 and 1991, peak catches occurred on 29 May and 3 June, respectively. The duration of subyearling chinook rearing along the shoreline of the reservoir also differed between the 4 years. In 1987 and 1992 subyearlings disappeared from the shoreline by late May whereas in 1990 and 1991 subyearlings remained along the shoreline until late June.

Little Goose

In 1992 the estimated peak population size of subyearling chinook occurred along the shoreline of Little Goose on 11 - 12 May (Figure 7). No subyearling chinook were collected after mid-May. Population estimates by stratum indicated that the highest numbers of subyearling chinook were rearing in stratum 2 followed by strata 3 and 1, respectively.

In 1991, the highest abundance of subyearling chinook salmon occurred on 4 June in Little Goose Reservoir (Figure 8). No subyearling chinook were collected after mid-July, 1991. Catches by Rkm indicated that most subyearling chinook salmon were rearing within the mid reservoir area, more specifically between Rkm 136.8 and Rkm 168.4 (Figure 9).

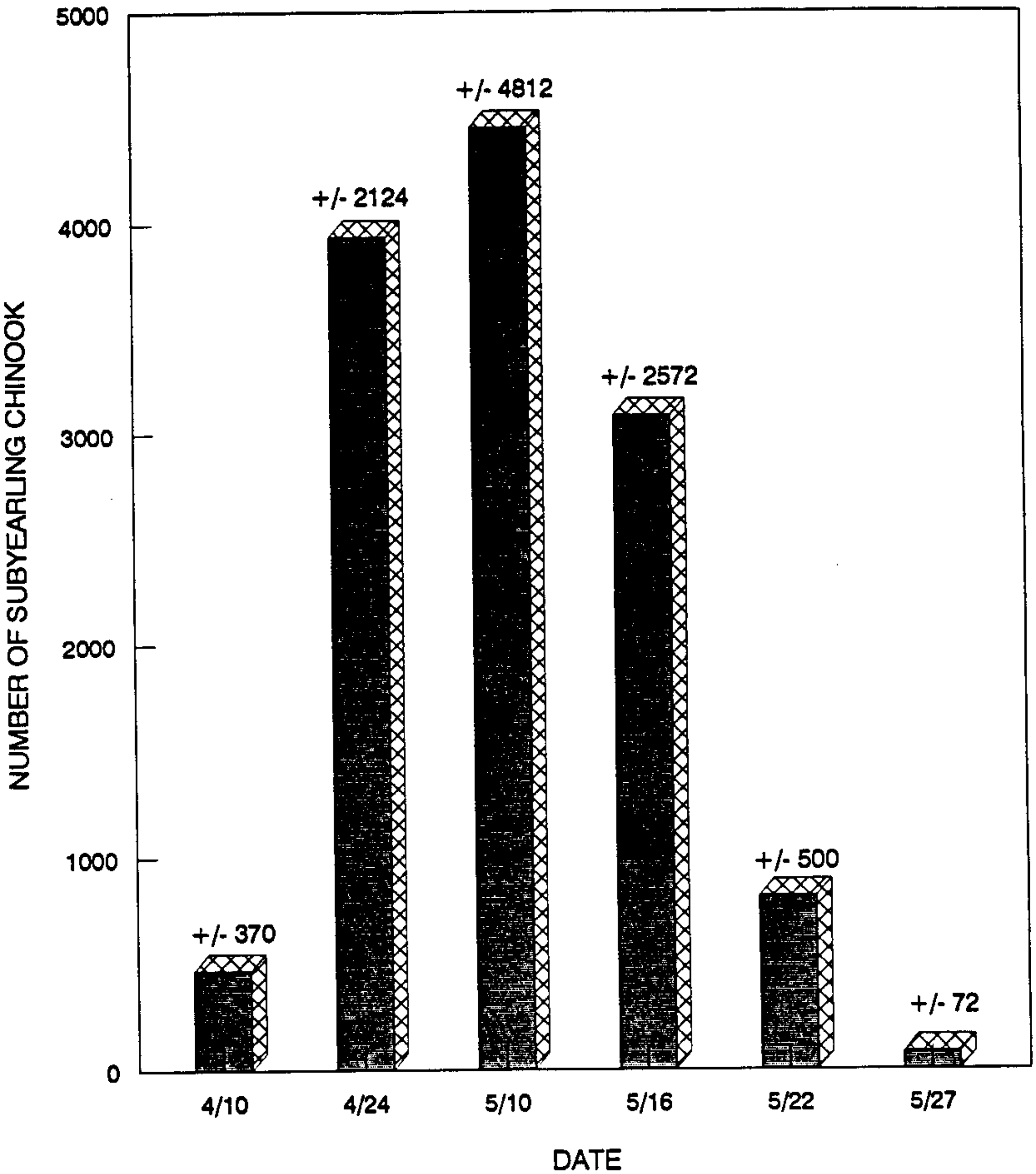

Figure 5. Population estimates of subyearling chinook salmon by date using stratified random samples (4/10 and 5/10 estimated using simple random samples) in Lower Granite Reservoir, Washington 1992.

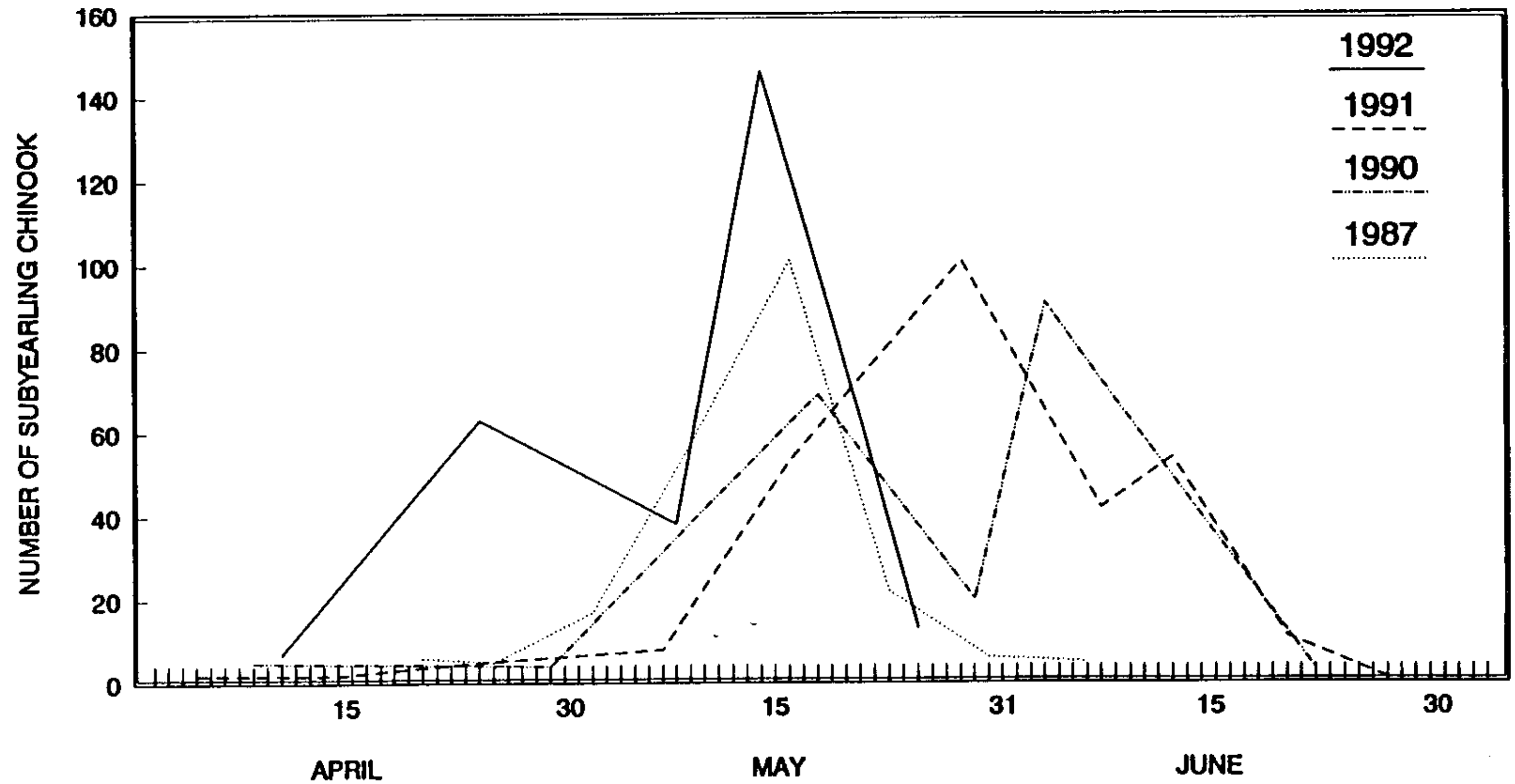

Figure 6. Annual comparisons of shoreline abundance of subyearling chinook salmon in Lower Granite Reservoir, Washington.

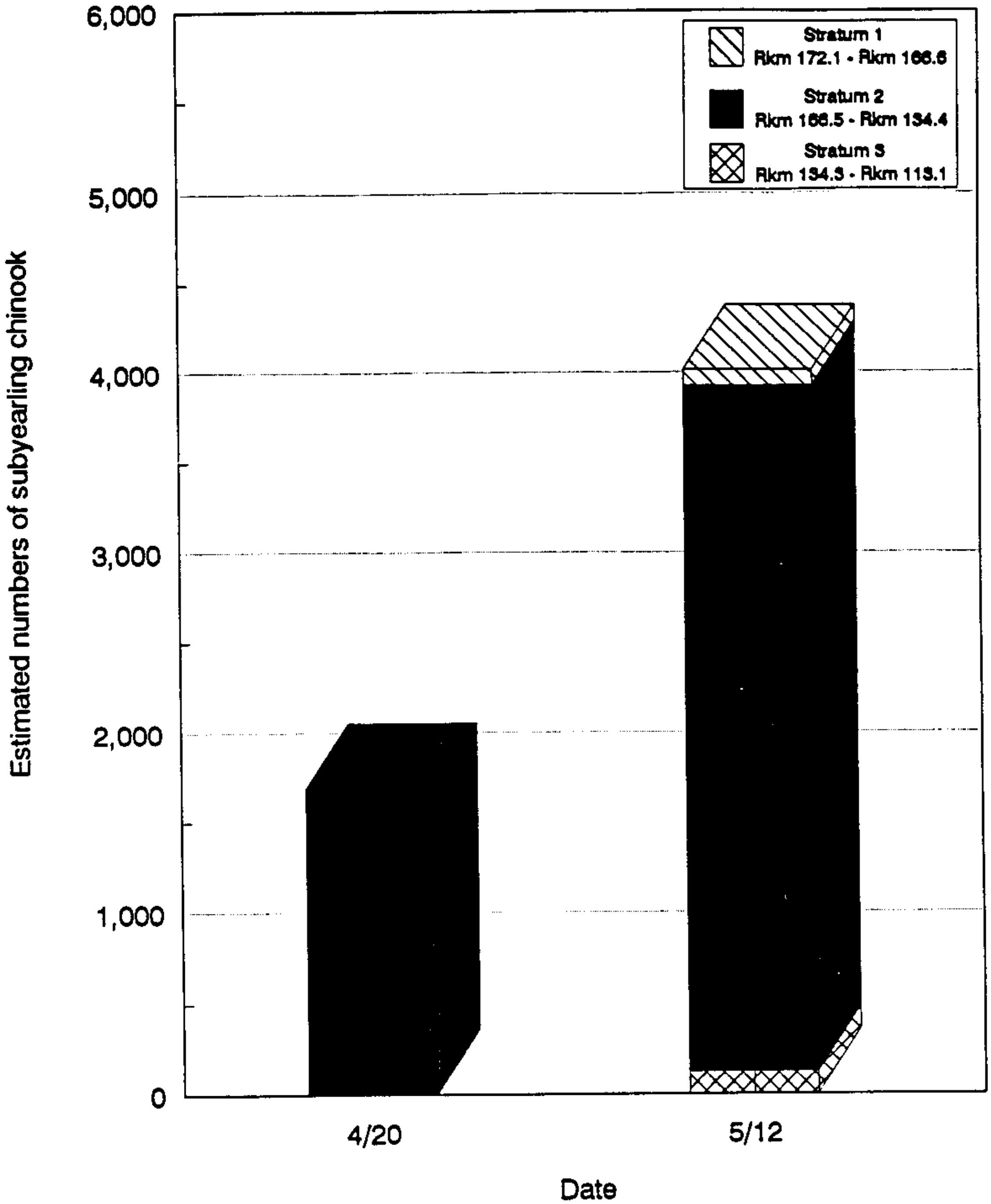

Figure 7. Population estimates of subyearling chinook salmon by stratum using simple random samples in Little Goose Reservoir, Washington,1992.

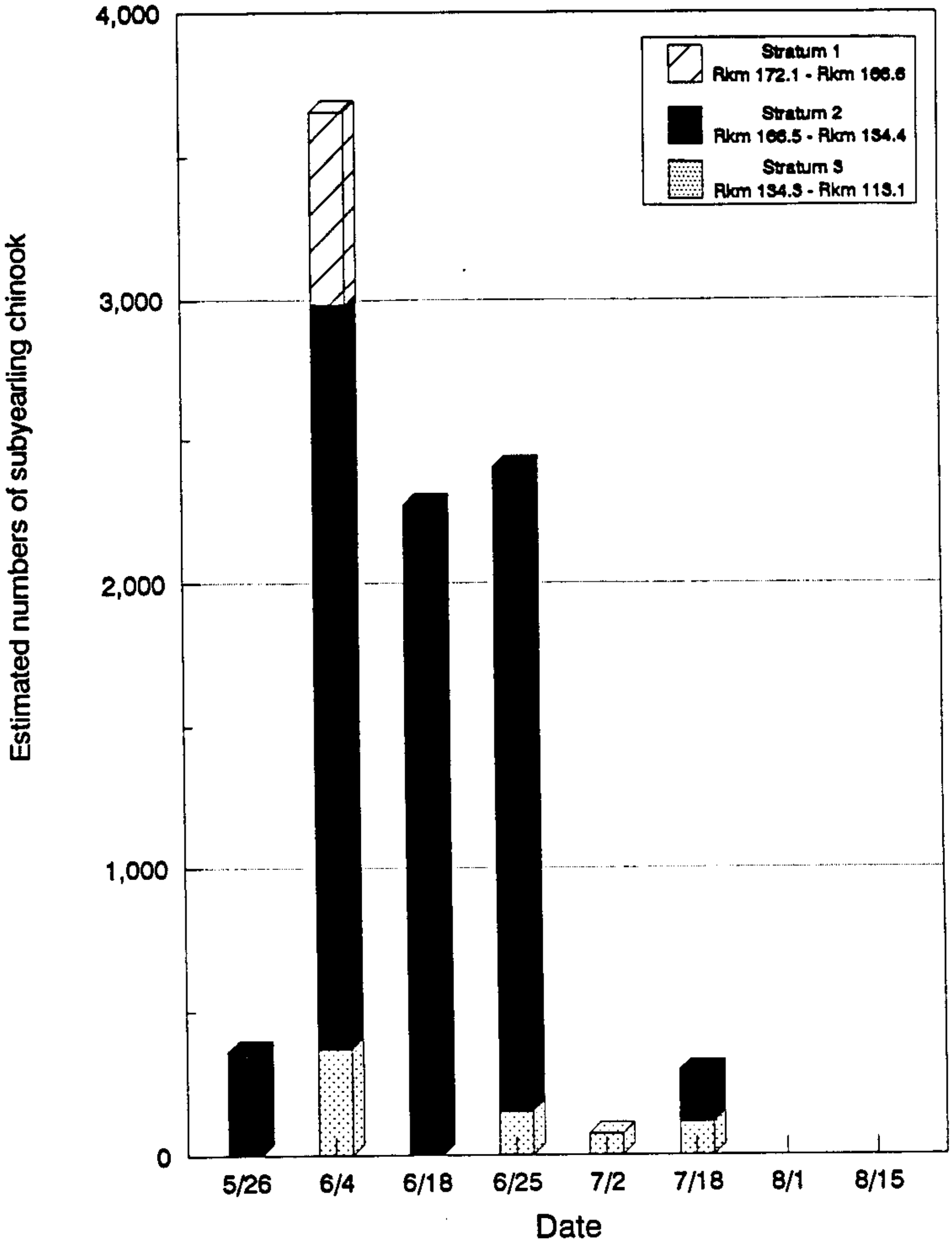

Figure 8. Population estimates of subyearling chinook salmon by stratum using simple random samples in Little Goose Reservoir, Washington, 1991.

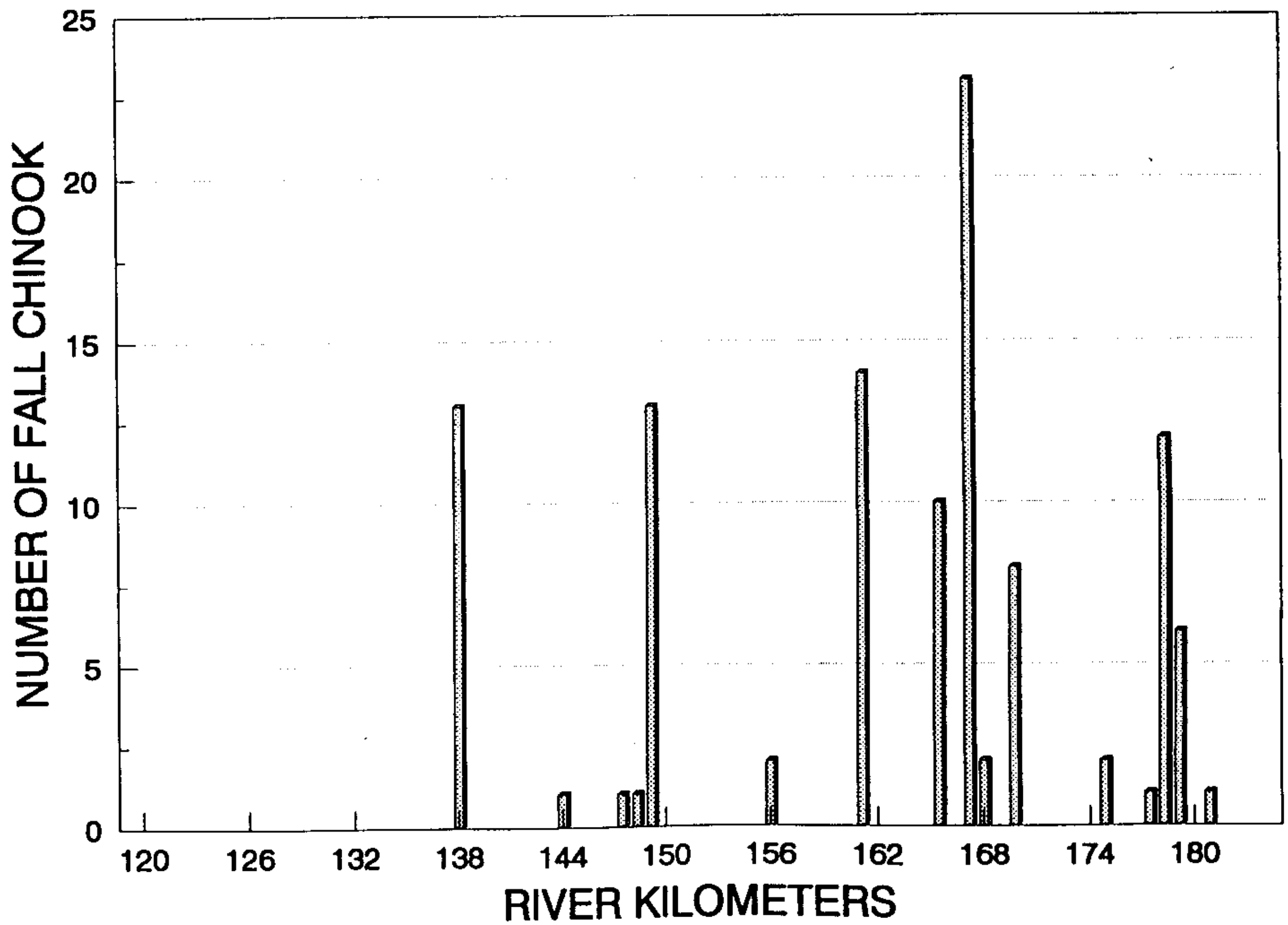

Figure 9. Estimated number of subyearling chinook salmon by river kilometer in Little Goose Reservoir, 1991.

Distribution and Preferred Habitat

Subyearling chinook rearing along the shoreline of Lower Granite Reservoir during the spring exhibit a strong selection for substrata consisting primarily of sand and a moderate avoidance of cobble/sand and talus/sand (Figure 10). I found a strong avoidance of rip-rap habitat consistent for all years analyzed (years 1990-1992) ($P < 0.001$).

Rearing and Migration Timing

The overall rearing period of subyearling chinook in Lower Granite Reservoir varied from 75 days in 1992 to 112 days in 1991. Littoral rearing differed from 48 days in 1992 to 84 days in 1991. The open water rearing period was most similar between the two years at 27 and 28 days, for 1992 and 1991 respectively (Figure 11). Mid-water and bottom trawl collections conducted in Lower Granite during June 1992 indicated that after the subyearlings migrate from the shoreline of the reservoir in late spring the fish appeared to be pelagically orientated in mid and deep water areas before beginning their downstream migration.

Physico-Chemical Variables

Neither shoreline temperature nor dissolved oxygen were correlated with subyearling chinook abundance ($r^2 = 0.292$).

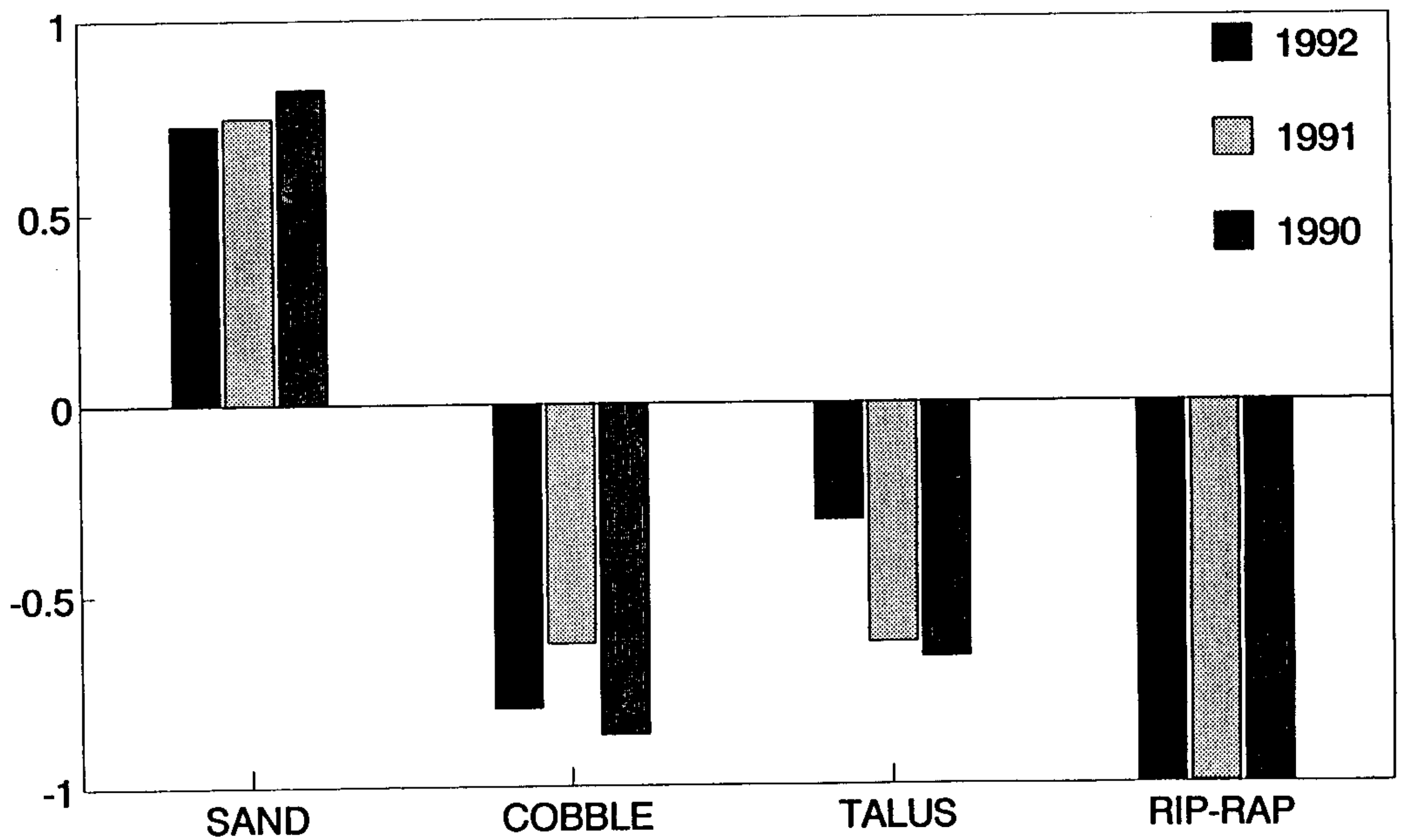

Figure 10. Selectivity of habitats by subyearling chinook salmon in Lower Granite Reservoir as determined by Jacobs utilization index.

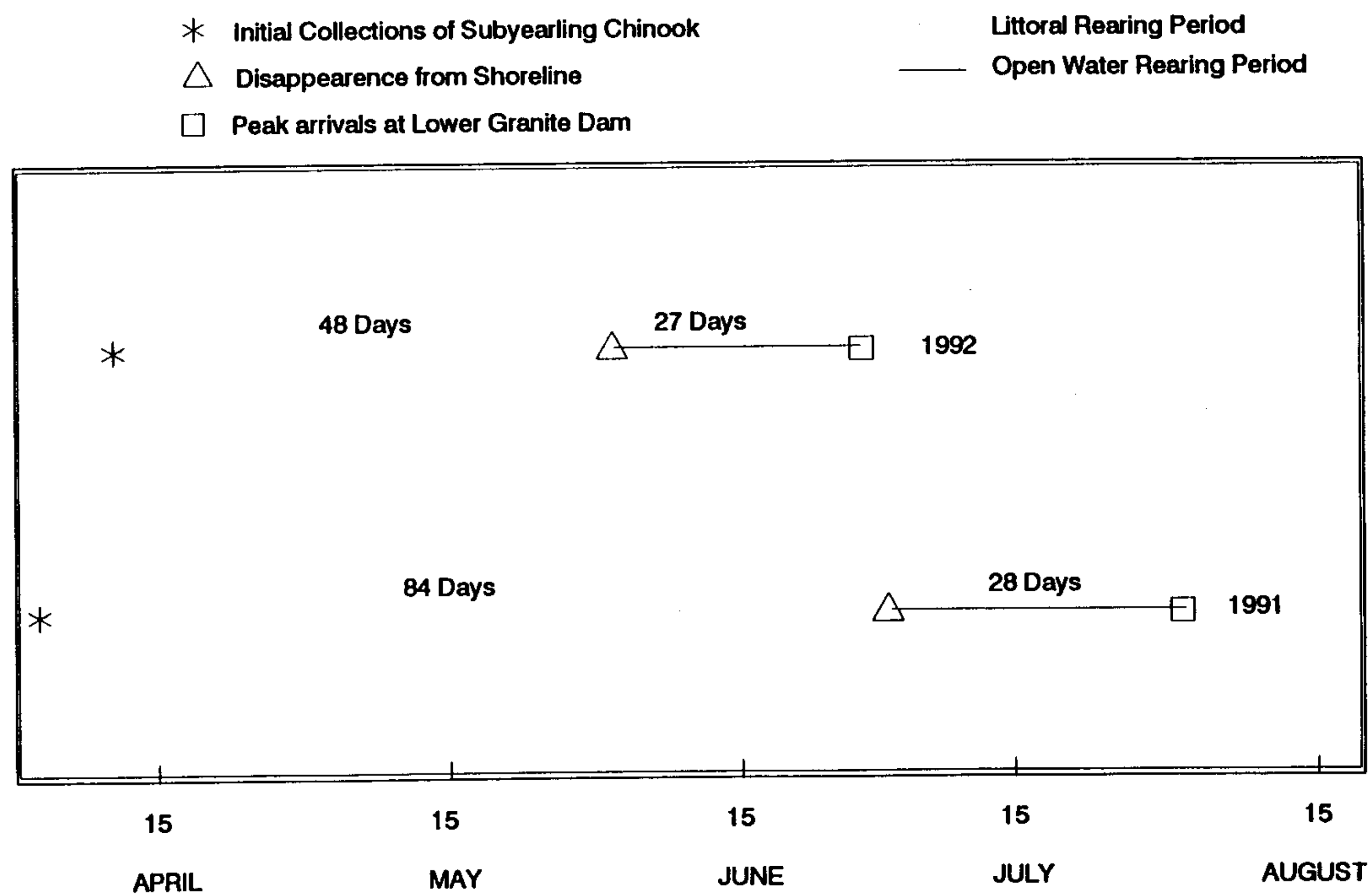

Figure 11. Estimated overall, littoral, and open water rearing periods of subyearling chinook salmon in Lower Granite Reservoir, Washington. 1991 and 1992.

DISCUSSION

Abundance

Lower Granite

The peak abundance and duration of rearing of subyearling chinook salmon along the shoreline of Lower Granite Reservoir appears to be related to both water temperature and discharges from the Snake and Clearwater rivers and to shoreline temperatures in the reservoir. During 1987 and 1992, years of low river discharge and higher water temperatures (Figure 12), earlier peaks in shoreline abundance and an earlier movement of subyearlings offshore occurred, possibly a result of excessively warm rearing conditions along the shoreline. During 1990 and 1991, years of higher river discharge and lower water temperatures, rearing conditions along the shoreline appeared suitable until mid to late June (Figure 12). Except for 1992, subyearlings migrated from the shoreline once shoreline reservoir temperatures approached and remained above 18 °C (Figure 13). In 1992, subyearlings left the shoreline of the reservoir at 17 °C although temperatures declined to 16 °C for a short period after their disappearance.

Collections of subyearling chinook in 1991 upriver from Lower Granite in the free flowing portion of the Snake River continued until mid July (Connor et al. 1992) although temperatures in this area approached 22 °C prior to the disappearance of subyearlings. Peak abundance of subyearlings in this reach occurred 22 days after peak abundance in the reservoir. Rearing conditions in the free flowing portion of the Snake River are likely more suitable for subyearling chinook than the reservoirs possibly explaining the protracted rearing period of the subyearlings in the free flowing river.

The early movement of subyearlings offshore in Lower Granite Reservoir does not appear to be size related (Figure 14). During the 4 years of collections, lengths of subyearlings captured along the shoreline of the reservoir were similar although migration times were different, which suggests that size does not dictate or initiate movement.

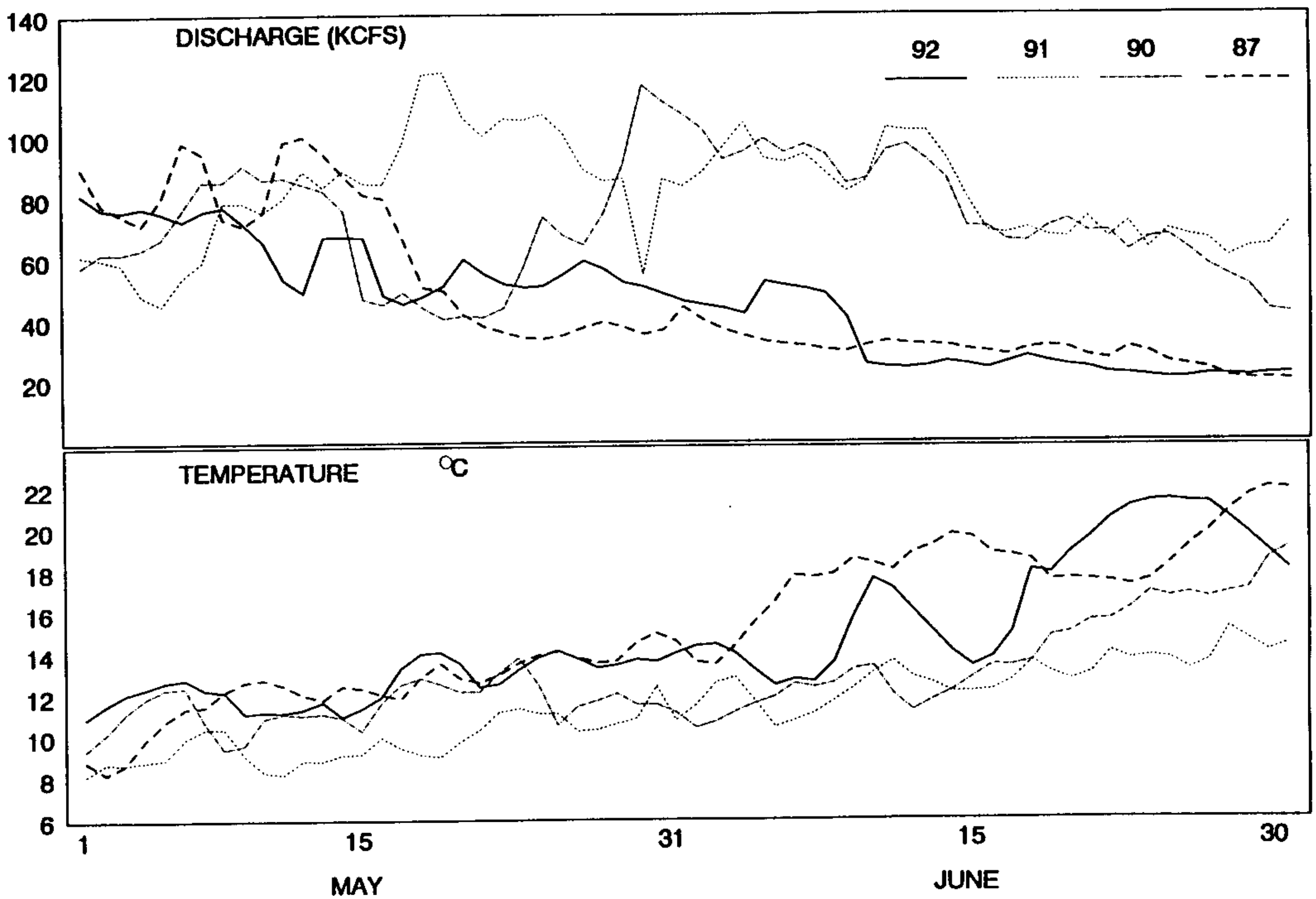

Figure 12. Weighted mean temperatures and discharges from the Snake and Clearwater rivers, years 1987, 1990, 1991, and 1992.

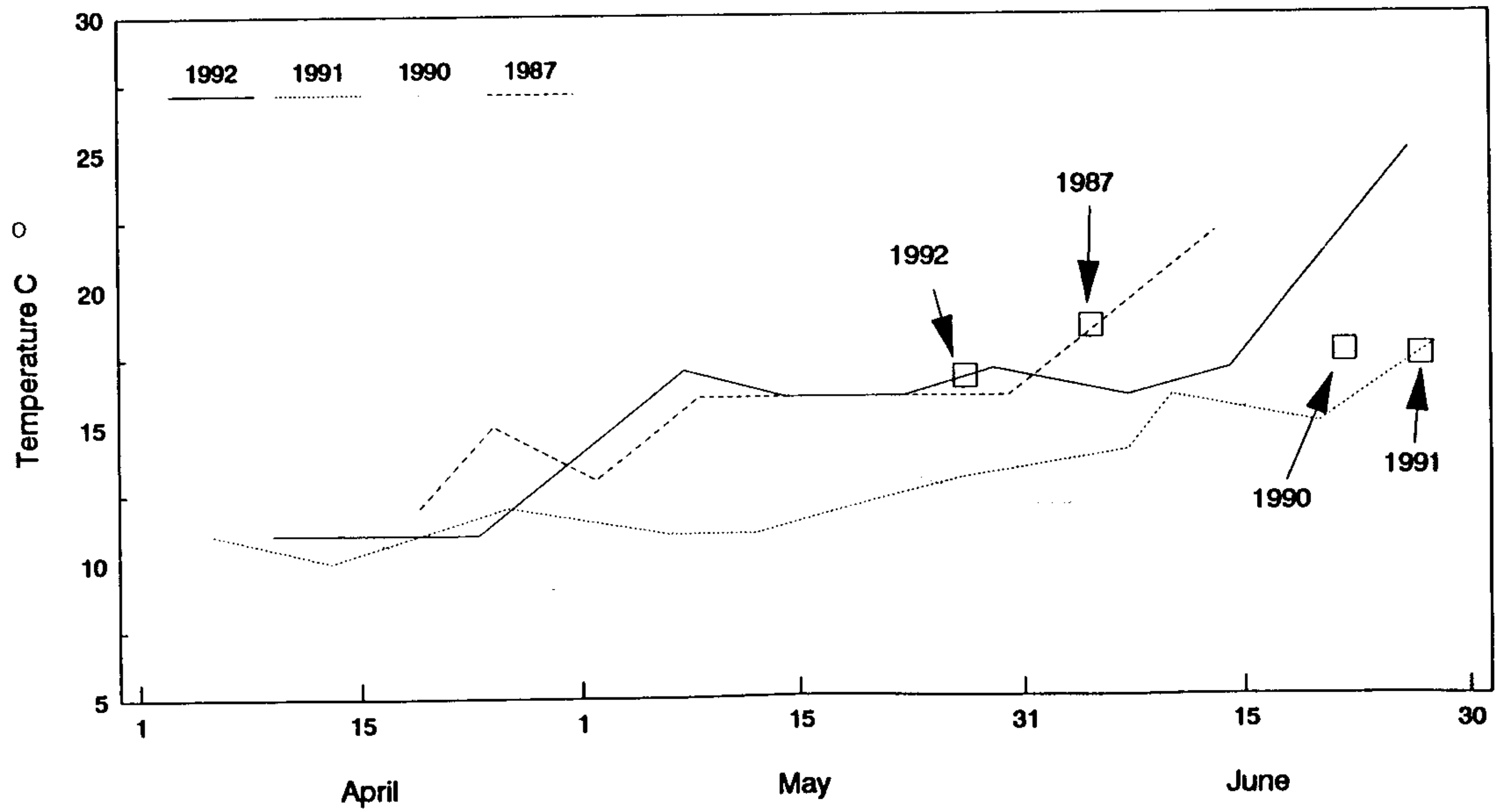

Figure 13. Mean shoreline temperatures in Lower Granite Reservoir, years 1987, 1990, 1991, and 1992. Dates and arrows depict disappearance of subyearling chinook salmon from shoreline of reservoir.

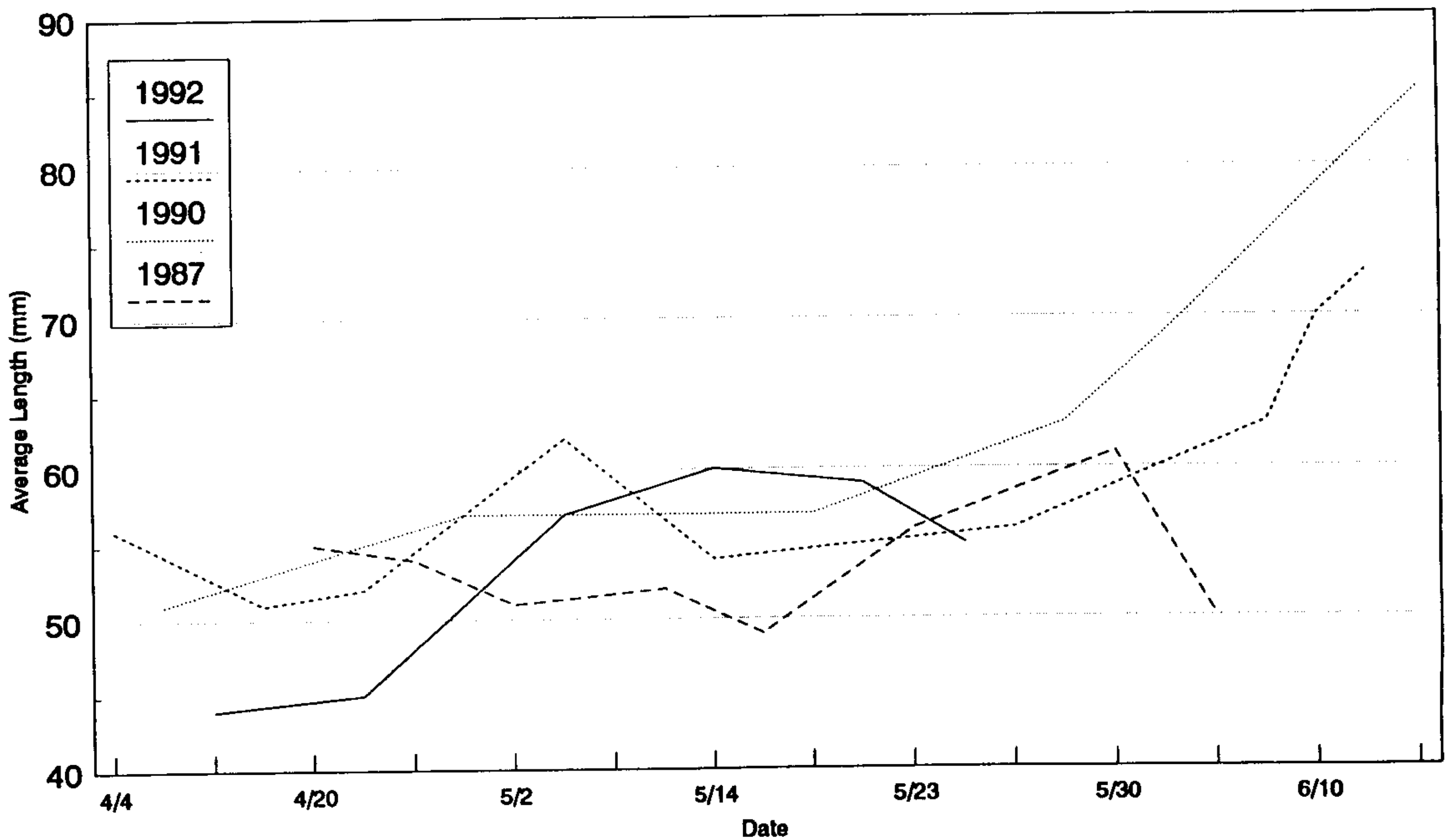

Figure 14. Average lengths of subyearling chinook salmon in Lower Granite Reservoir for years 1992, 1991, 1990 and 1987.

Little Goose

The abundance of subyearling chinook salmon in Little Goose also appears to be related to shoreline temperatures in the reservoir. In 1991, the rearing period of subyearlings continued into July when shoreline temperatures remained substantially cooler (Figure 15) than in 1992 (Figure 16). In 1992, as in Lower Granite Reservoir, subyearlings in Little Goose Reservoir were no longer present along the shoreline of the reservoir after late May once temperatures exceeded 18 °C. Compared to 1992, shoreline water temperatures in Little Goose Reservoir in 1991 did not exceed 18 °C until mid July, the last date when subyearlings were captured (Figure 15). Although some subyearlings in 1991 were captured in water temperatures of 21 °C, the fish were captured in the upper portion of the reservoir, where the coolest water temperatures occurred (Figure 15). One explanation for the collection of subyearlings at water temperatures exceeding 18 °C may be the collection of these fish coincided with the peak outmigration of subyearlings at Lower Granite Dam in 1991 (Connor et al. 1992). That is, the collection of these fish may have been a function of the abundance of subyearlings migrating through the reservoir in mid July.

Distribution and Preferred Habitat

Subyearling chinook salmon in both Lower Granite and Little Goose reservoirs are consistently collected over sand substrate and in areas of reduced velocity. These findings are consistent with subyearling collections in the Hanford reach of the Columbia River where subyearlings utilize shoreline areas of reduced current velocity for resting and feeding (Dauble et al. 1989). The reason for higher abundance of subyearling chinook salmon over sand substrate is not clear. Low velocities may be more important in influencing rearing potential than the prevailing substrate (Bennett et al. 1992).

Habitat selection studies, conducted for many salmonid species, generally suggest that larger fish inhabit deeper and faster water (Dauble et al. 1989). As increasing water

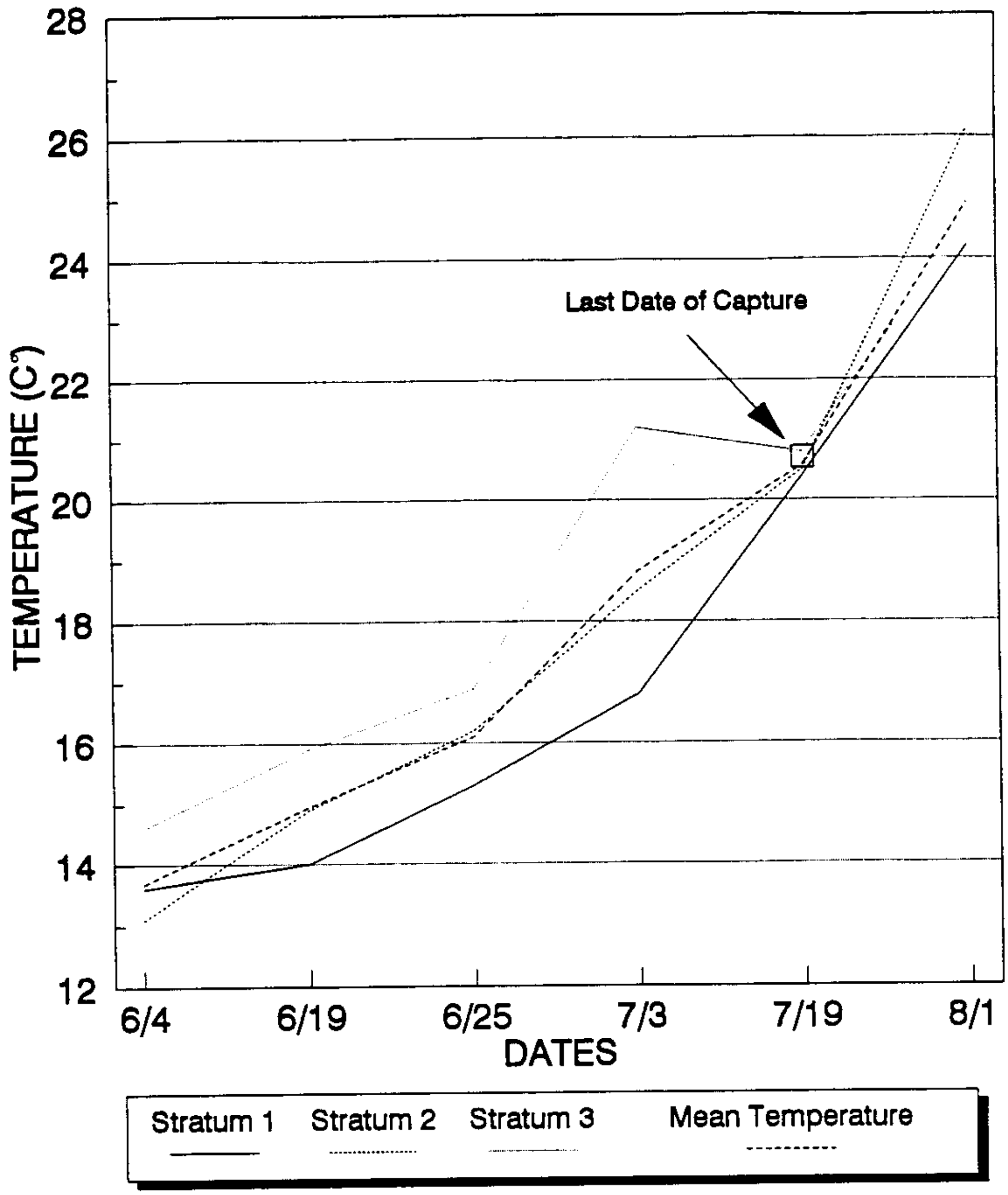

Figure 15. Mean shoreline temperatures by stratum from June to August 1991, in Little Goose Reservoir, Washington.

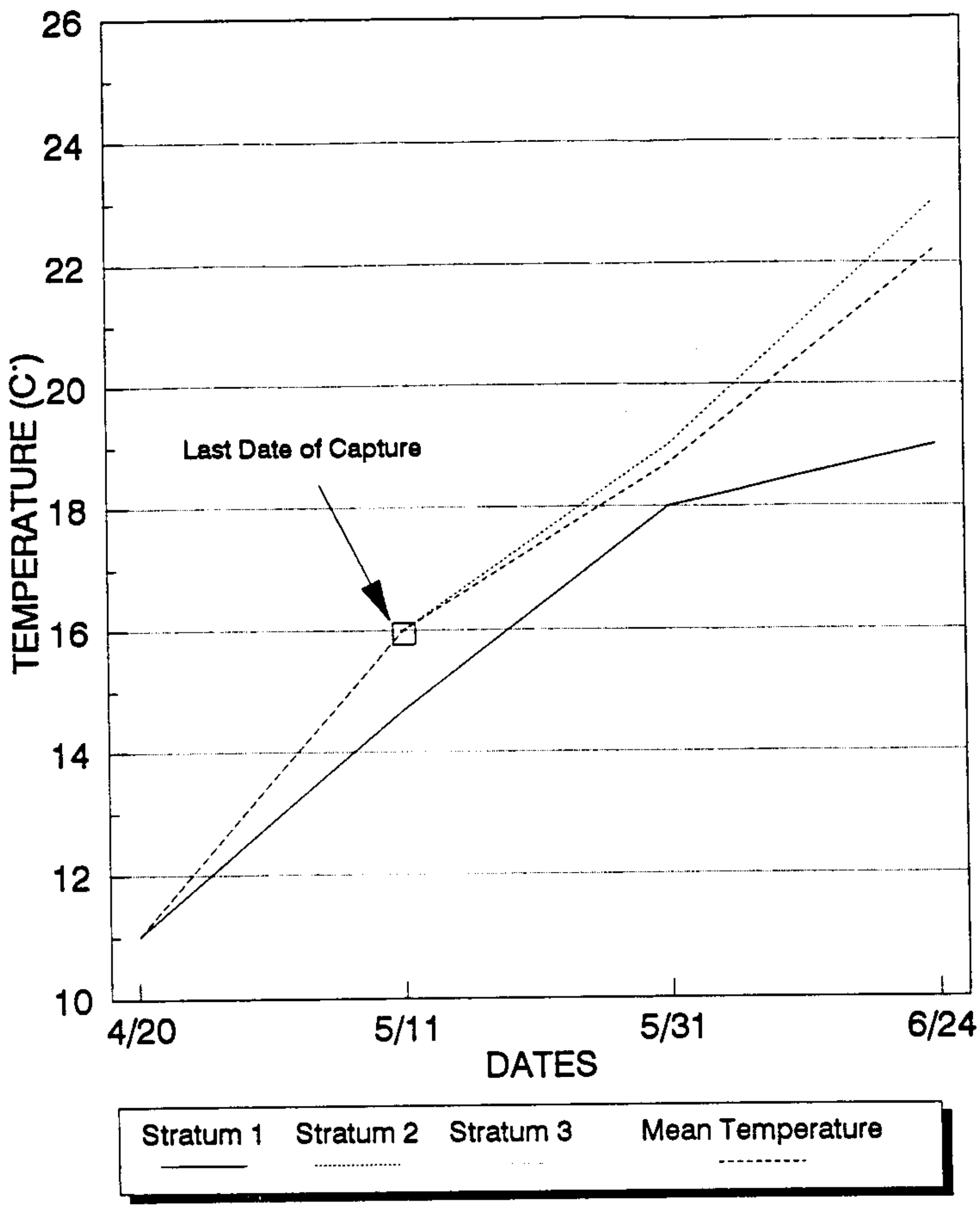

Figure 16. Mean shoreline temperatures from April to May 1992 by stratum, in Little Goose Reservoir, Washington.

temperatures result in water too warm for shoreline rearing, subyearlings may move offshore into deeper, faster areas where they rear until commencing their downstream migration. The fidelity exhibited by subyearlings for shoreline rearing in the reservoir and the free flowing Snake River may however compromise survival since these areas are shared with a number of predators (Connor et al. 1992;Bennett et al. 1988). Results of my predation effort in Lower Granite Reservoir appear to corroborate this hypothesis (Chapter 3).

Rearing and Migration Timing

Subyearling chinook appear to not just pass quickly through, but to utilize the shoreline and open water areas of Lower Granite and Little Goose reservoirs as rearing areas before migrating down river. The overall rearing period for subyearling chinook in Lower Granite Reservoir was 75 days in 1992 and 112 days in 1991, in both cases less than in John Day Reservoir on the Columbia River (>160 days) (Sims and Miller 1981).

Based on results from 1987, 1990, 1991 and 1992, duration of littoral rearing was longer in the cooler years. In 1990 and 1991, when shoreline temperatures remained below 18 °C until mid to late June, subyearlings remained along the shoreline of the reservoir until late June and peak abundance along the shoreline of the reservoir occurred in late May to early June, 2 weeks later than in 1987 and 1992, years of warmer shoreline temperatures. The 27 - 28 day open water rearing period observed for subyearlings in Lower Granite closely coincides to results from subyearling collections in the free flowing Snake River. Connor et al. (1992) noted an approximate 30 day difference between peak shoreline abundance and peak arrivals of subyearlings at Lower Granite Dam. Duration of open water rearing appeared to be related to temperature and was similar for both 1991 and 1992.

Application of a bioenergetics model, used in analysis of stomach contents of subyearling chinook salmon (Objective 2), further suggests temperatures may dictate shoreline distribution and downstream migration. Both specific growth rates (calories/gram predator/day) and daily weight increments for subyearling chinook salmon declined once water temperatures exceeded 13 °C (Figures 17 and 18). Brett (1952) found that chinook fingerlings preferred temperatures ranging from 12 °C to 14 °C. At temperatures exceeding this preferred range, the metabolic demands of subyearling chinook begin to exceed the fish's ability to consume adequate forage to maintain optimal growth. Migration from the shoreline of Lower Granite Reservoir (Figure 13) occurred once water temperatures exceeded 18 °C coinciding with the models predicted cessation and reduction of weight gain and growth rates (Figures 17 and 18). My results suggest reservoir and shoreline temperatures greatly influence the duration of shoreline and open water rearing period of subyearling chinook salmon.

Based on data from John Day Reservoir, neither rate of downstream movement or residence time of subyearling fall chinook is influenced by river velocities (Sims and Miller 1981). My data suggests reservoir temperatures strongly influence the residence time of subyearling chinook salmon in the lower Snake River reservoirs.

Physico-Chemical Variables

The lack of a large sample size may account for the lack of correlation between either dissolved oxygen or temperatures and abundance of subyearling chinook salmon. Although 376 beach seine hauls were conducted in Lower Granite Reservoir during spring 1992, subyearling chinook salmon were collected in only 46 hauls. My findings indicate that subyearling distribution is clumped. I believe that subyearlings are concentrated over suitable micro-habitats where conditions such as temperatures and dissolved oxygen levels remain at levels conducive for rearing.

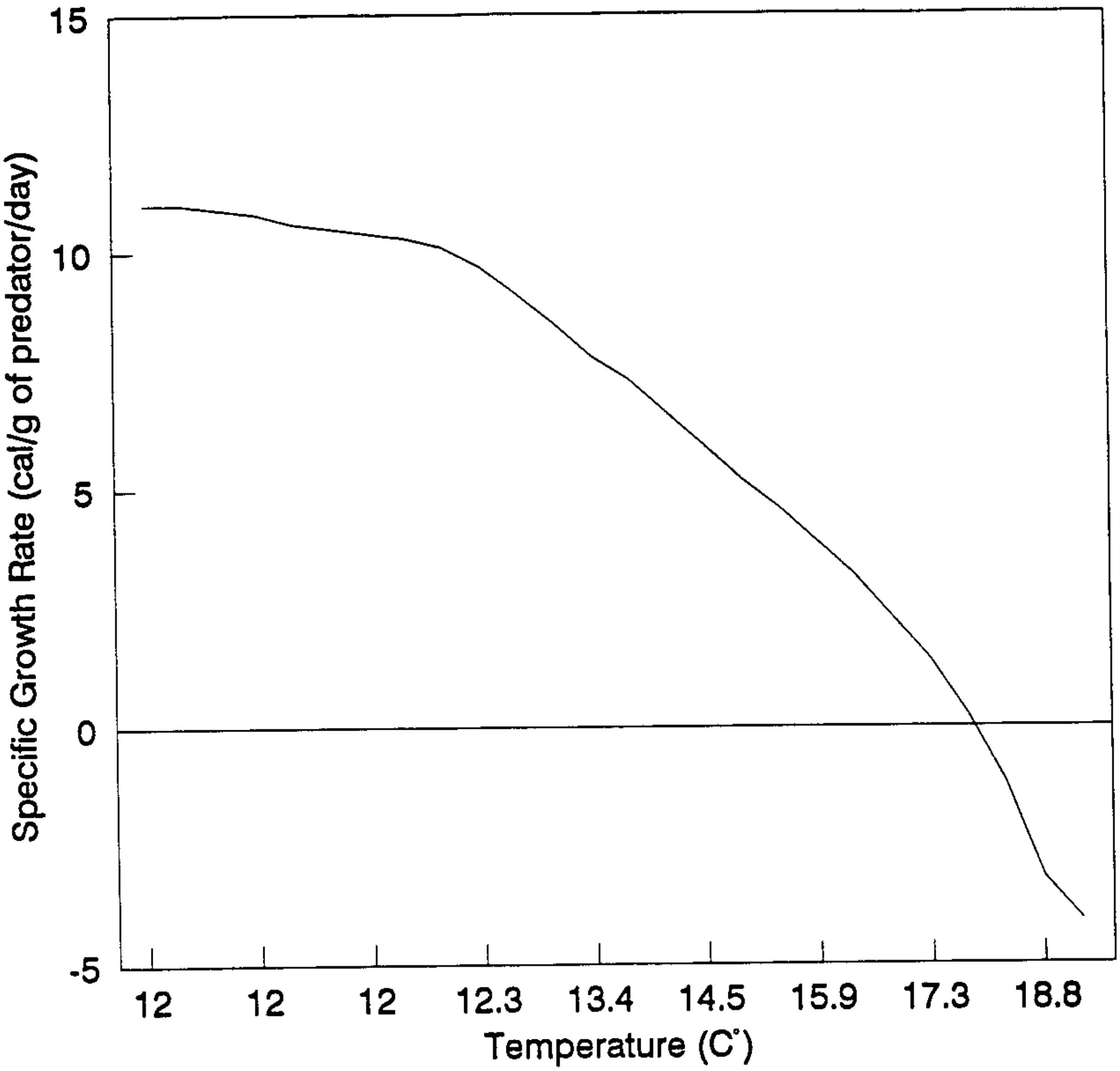

Figure 17. Estimated specific growth rates for subyearling chinook salmon in Lower Granite Reservoir, Washington, 1991-1992.

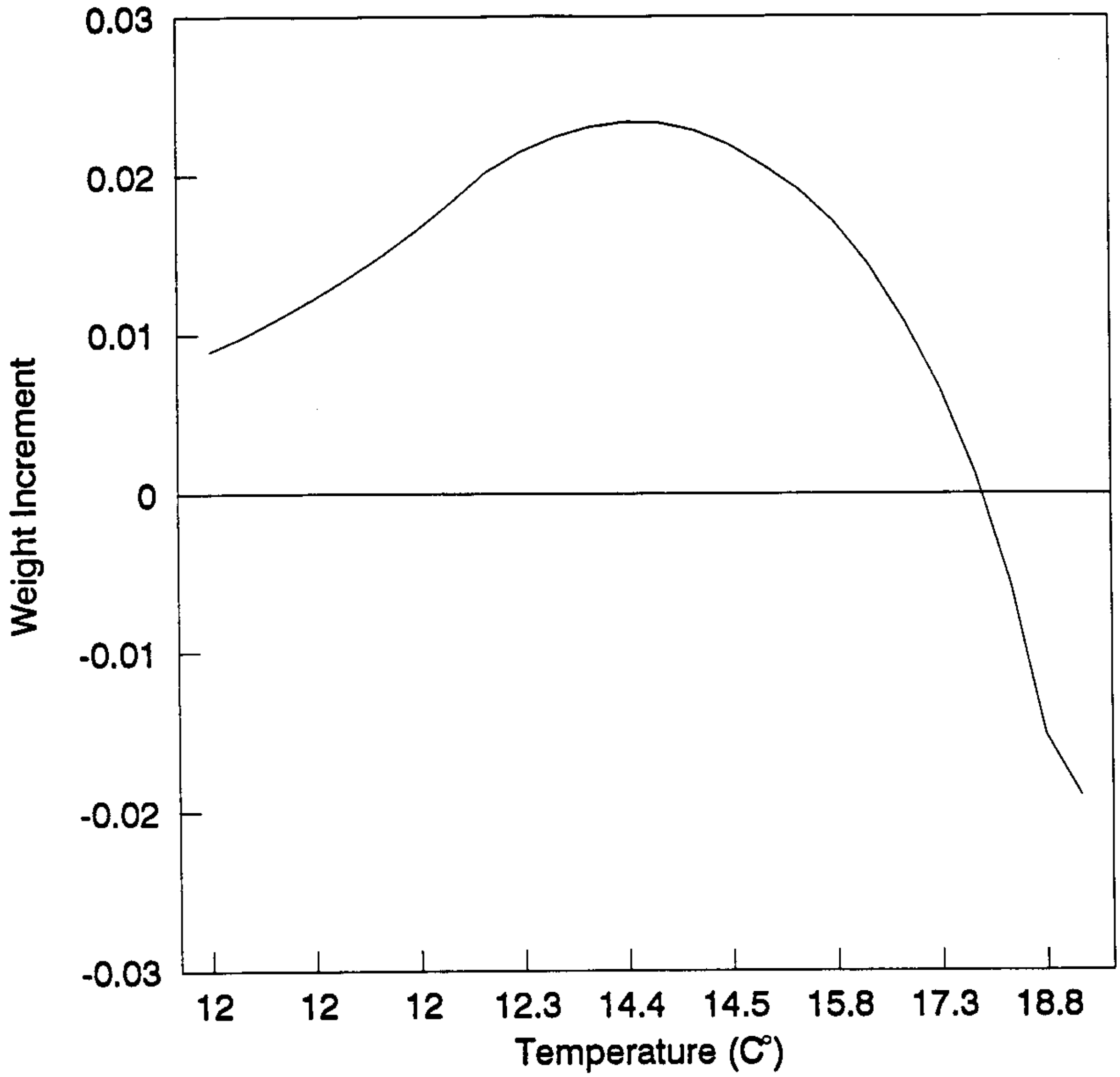

Figure 18. Estimates daily weight increments for subyearling chinook salmon in Lower Granite Reservoir, Washington, 1991-1992.

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Chapter 2: To determine food habits of subyearling chinook salmon in Lower Granite and Little Goose Reservoirs.

INTRODUCTION

Several studies have addressed the feeding ecology of subyearling chinook salmon in the free flowing (Dauble et al. 1980; Becker 1970) and impoundment areas on the Columbia River (Rondorf et al. 1990) although the feeding ecology of subyearling chinook in the lower Snake River has not been evaluated. Changes in the benthic community have occurred as a result of impoundment, including a decrease in diversity and abundance (Bennett and Shrier 1986; Bennett et al. 1988, 1990, 1991). These changes, combined with the large number of salmonids released above Lower Granite (21,000,000 in 1990) and the prolonged migration period of hatchery released salmonids through the reservoir (3-4 weeks for yearling releases from Dworshak National Fish Hatchery), have elevated concerns that the abundance of potential food items may not be adequate to maintain the outmigrating yearling chinook and steelhead (Poe 1992) and subyearling chinook rearing along the shoreline of Lower Granite Reservoir.

Some evidence suggests the benthic community in the reservoir may not sustain all the emigrants in the reservoir during the spring. Yearling smolts collected at Lower Granite Dam in 1987, 1989, and 1991 had high percentages of empty stomachs in contrast to migrants collected at other dams (Poe 1992). Because of the prolonged rearing period of subyearlings in the Lower Granite pool, the feeding ecology of subyearling chinook in the reservoir environment may provide valuable insight into the availability of food items to the fish. Also, if the reservoir environment were incapable of supporting the energy needs of emigrating salmonids during the spring, food habits of subyearling chinook may reflect such a paucity of food.

METHODS

Subyearling chinook salmon were collected during synoptic beach seine surveys conducted throughout Lower Granite and Little Goose reservoirs during April, May, June, and July 1991 and April and May 1992 (Objective 1). Stomach contents were evacuated from subyearling chinook salmon >40 mm using a modified gastric lavage (Foster 1977; Dunsmoor 1990) following anesthetization with M.S. 222. A 5cc syringe with a protected hypodermic needle was inserted through the mouth, down the esophagus to the fish's stomach. Distilled water was then pumped into the stomach flushing the stomach contents out through the mouth where food items were collected in a plankton mesh funnel. The technique enabled collection of food items without sacrificing the fish. All prey items were preserved in 10% buffered formalin.

Prey items were identified to the lowest practical taxonomic level and classified according to their developmental stage. Prey items were enumerated and individual weights for organisms determined using length-weight relationships (Dunsmoor 1990) or estimates of mean weight per individual (Gains et al. 1992; Hall et al. 1970). Live weight estimates were adjusted for ash and water content and estimates of calories/g ash free dry weight for individual prey items were used to determine caloric values for food items (Cummins and Wuycheck 1971).

Stomach items were analyzed using an index of caloric importance (ICI) developed by Dunsmoor (1990). The ICI is calculated as follows:

ICI = C x F, where:

C = the percentage that a food category contributed to the total calories of food items in all stomachs,

F = frequency of occurrence

Estimates of caloric importance were calculated for all taxonomic groups identified when analyzing stomach contents and for consolidated prey groups. Consolidated prey groups were Diptera, Cladocera, larval fish, Ephemeroptera, other insects, and other items.

A bioenergetics model (Hewett and Johnson 1987) was used to estimate the proportion of maximum ration consumed by the fish over the sample season (P-value). If the P-value is 1, the fish is feeding at its maximum rate based on its size and the water temperature (Hewett and Johnson 1987). Average monthly total length (mm), weights (g), prey caloric values, and water temperatures (°C) were used in the model.

RESULTS

A total of 292 subyearling chinook salmon stomachs were examined during this study. Thirty one different prey items were identified (Table 1).

All Taxonomic Groups

Four prey items numerically accounted for 96% of all the prey items occurring in the stomachs. Cladocera, primarily Daphnia, were the dominant food items (46%) ingested, occurring in 43% of the stomachs followed by Diptera, primarily Chironomidae and Simulidae, which accounted for 38% of the prey items occurring in 84% of the stomachs. Ephemeroptera, primarily Baetidae, and Homoptera, primarily Aphididae, accounted for 7% and 4% of the ingested prey items occurring in 35% and 33% of the stomachs, respectively (Table 1).

Four prey items accounted for 87% of all prey items occurring in the stomachs by weight (dry weight, mg). Ephemeroptera and Diptera accounted for 33% and 25% of the prey items, respectively. Larval fish accounted for 21% of the prey items by weight occurring in 4% and of the stomachs, while Cladocera accounted for 11% of all prey items (Table 1).

Table 1. Stomach contents of 292 subyearling chinook salmon collected during the spring 1991-1992, Lower Granite and Little Goose Reservoirs, Washington.

Prey Group	Number	Frequency	% Number	Dry Weight (mg)	% Dry Weight	Calories	% Calories
Collembola	6	5	0.0005	1.0635	0.0012	6.1	0.1200
Chironomidae/Simuliidae	4,516	246	0.3841	232.8146	0.2523	1,190.1	24.280
Cecidomyiidae	46	19	0.0039	0.5260	0.0006	2.5	0.0500
Ceratopogonidae	3	1	0.0003	0.0210	0.0000	0.1	0.0000
Coleoptera	1	1	0.0001	0.4700	0.0005	2.2	0.0400
Drosophilidae	2	1	0.0002	0.0400	0.0000	0.2	0.0000
Empididae	1	1	0.0001	0.0100	0.0000	0.0	0.0000
Sciaridae	1	1	0.0001	0.0050	0.0000	0.0	0.0000
Ephemeroptera	858	101	0.0730	307.3716	0.3331	1,849.2	37.730
Homoptera	482	97	0.0410	31.3587	0.0340	159.9	3.2600
Cicadellidae	12	8	0.0010	0.6620	0.0007	3.4	0.0700
Isoperla	4	4	0.0003	0.2500	0.0003	1.3	0.0300
Hodotermitidae	1	1	0.0001	0.0100	0.0000	0.1	0.0000
Odonata	1	1	0.0001	0.8500	0.0009	4.7	0.0900
Hymenoptera	22	18	0.0019	4.2996	0.0047	24.4	0.5000
Plecoptera	3	3	0.0003	1.8800	0.0020	9.6	0.2000
Psocoptera	1	1	0.0001	0.0200	0.0000	0.1	0.0000
Thysanoptera	16	8	0.0014	0.3110	0.0003	1.6	0.0300
Thripidae	4	4	0.0003	0.0290	0.0000	0.1	0.0000
Trichoptera	20	14	0.0017	6.3380	0.0069	30.4	0.6200
Uknown Insects	38	11	0.0032	1.1174	0.0012	5.6	0.1100
Insect Parts	72	65	0.0061	14.8000	0.0160	74.6	1.5200
Amphipoda	10	6	0.0009	3.4296	0.0037	13.4	0.2700
Annelida	10	6	0.0009	3.0600	0.0033	14.2	0.2900
Araneae	5	4	0.0004	0.5700	0.0006	2.7	0.0500
Copepoda	11	9	0.0009	1.1650	0.0013	6.4	0.1300
Cladocera	5,426	126	0.4616	102.3934	0.1110	503.9	10.280
Hirudinea	1	1	0.0001	3.7800	0.0041	18.5	0.3800
Hydracarina	66	36	0.0056	0.2343	0.0003	1.2	0.0200
Isopoda	76	35	0.0065	31.7780	0.0344	90.1	1.8400
Larval Fish	41	11	0.0035	172.2000	0.1866	884.6	18.050
Total				922.8575		4,901.4	

Four pey items accounted for 89% of the total calories ingested by subyearling chinook. Ephemeroptera, Diptera, Cladocera, and larval fish provided 37%, 24%, 10%, and 18% of the total calories ingested, respectively. Estimates of caloric importance indicate that Chironomidae/Simulidae, Ephemeroptera, and Cladocera are the most important contributors to the subyearlings diet (Table 2). The mean value of caloric intake exhibited by subyearling chinook increased substantially over the course of the sample period (April-July) (Figure 19).

Consolidated Prey Groups

Estimates of caloric relative importance by group indicated that Dipterans, Ephemeropterans, and the Other Insects were the most important prey items (Table 3). Monthly comparisons of percent caloric contribution of prey items to subyearling diets indicated Dipterans contributed substantially to subyearling diets in April and became less important during the summer months. Ephemeropterans increased in importance from April to June and constituted about half of the total ingested calories by June. Their importance decreased substantially in July, however, when larval fish constituted 89% of the total calories ingested. Before July, larval fish had contributed little to the total number of calories ingested. Cladocera was the dominant prey item present in stomachs in May, although they contributed only a small portion of the ingested calories during April, June, and July. Dipterans were the most numerous prey item eaten during April, June, and July (Figure 20).

Comparisons of percent caloric and numeric contribution of prey items to subyearling diets for four size classes of subyearling chinook salmon indicated that for 40-55 mm fish Ephemeropterans were calorically the most important food item (43%) followed by Cladocera (28%). Ephemeropterans were important to subyearling diets for all size classes, although less for the largest subyearlings (<30%). Dipterans contributed substantially to the caloric intake of 56-70 and 71-85 mm size classes (27% and 39%, respectively), however contributed to

Table 2. Food habits and resulting index calculations from 292 subyearling chinook salmon stomachs collected in Lower Granite and Little Goose Reservoirs, Washington, spring 1991-1992.

Prey Group	Frequency	% Number	% Frequency	% Dry Weight	% Calories	I.C.I.	% I.C.I.
Collembola	5	0.0005	0.0059	0.0012	0.0012	7.39500E-06	0.0100
Chironomidae/Simuliidae	246	0.3841	0.2911	0.2523	0.2428	0.07069	50.660
Cecidomyiidae	19	0.0039	0.0225	0.0006	0.0005	1.16860E-05	0.0100
Ceratopogonidae	1	0.0003	0.0012	0.0000	0.0000	2.50000E-08	0.0000
Coleoptera	1	0.0001	0.0012	0.0005	0.0004	5.20000E-07	0.0000
Drosophilidae	1	0.0002	0.0012	0.0000	0.0000	4.70000E-08	0.0000
Empididae	1	0.0001	0.0012	0.0000	0.0000	1.20000E-08	0.0000
Sciaridae	1	0.0001	0.0012	0.0000	0.0000	6.00000E-09	0.0000
Ephemeroptera	101	0.0730	0.1195	0.3331	0.3773	0.04510	32.330
Homoptera	97	0.0410	0.1148	0.0340	0.0326	0.00378	2.6900
Cicadellidae	8	0.0010	0.0095	0.0007	0.0007	6.52100E-08	0.0000
Isoperla	4	0.0003	0.0047	0.0003	0.0003	1.23100E-08	0.0000
Hodotermitidae	1	0.0001	0.0012	0.0000	0.0000	1.20000E-08	0.0000
Odonate	1	0.0001	0.0012	0.0009	0.0009	1.12400E-06	0.0000
Hymenoptera	18	0.0019	0.0213	0.0047	0.0050	0.00011	0.0800
Plecoptera	3	0.0003	0.0036	0.0020	0.0020	6.94400E-08	0.0000
Psocoptera	1	0.0001	0.0012	0.0000	0.0000	2.50000E-08	0.0000
Thysanoptera	8	0.0014	0.0095	0.0003	0.0003	3.06300E-08	0.0000
Thripidae	4	0.0003	0.0047	0.0000	0.0000	1.43000E-07	0.0000
Trichoptera	14	0.0017	0.0166	0.0069	0.0062	0.00010	0.0700
Uknown Insects	11	0.0032	0.0130	0.0012	0.0011	1.49660E-05	0.0100
Insect Parts	65	0.0061	0.0769	0.0160	0.0152	0.00117	0.8400
Amphipoda	6	0.0009	0.0071	0.0037	0.0027	1.93690E-05	0.0100
Annelida	6	0.0009	0.0071	0.0033	0.0029	2.06030E-05	0.0100
Araneae	4	0.0004	0.0047	0.0006	0.0005	2.56800E-06	0.0000
Copepoda	9	0.0009	0.0107	0.0013	0.0013	1.40000E-05	0.0100
Cladocera	126	0.4616	0.1491	0.1110	0.1026	0.01533	10.990
Hirudinea	1	0.0001	0.0012	0.0041	0.0036	4.46100E-06	0.0000
Hydracarina	36	0.0056	0.0426	0.0003	0.0002	1.01370E-06	0.0100
Isopoda	35	0.0065	0.0414	0.0344	0.0184	0.00076	0.5500
Larval Fish	11	0.0035	0.0130	0.1866	0.1605	0.00236	1.6800

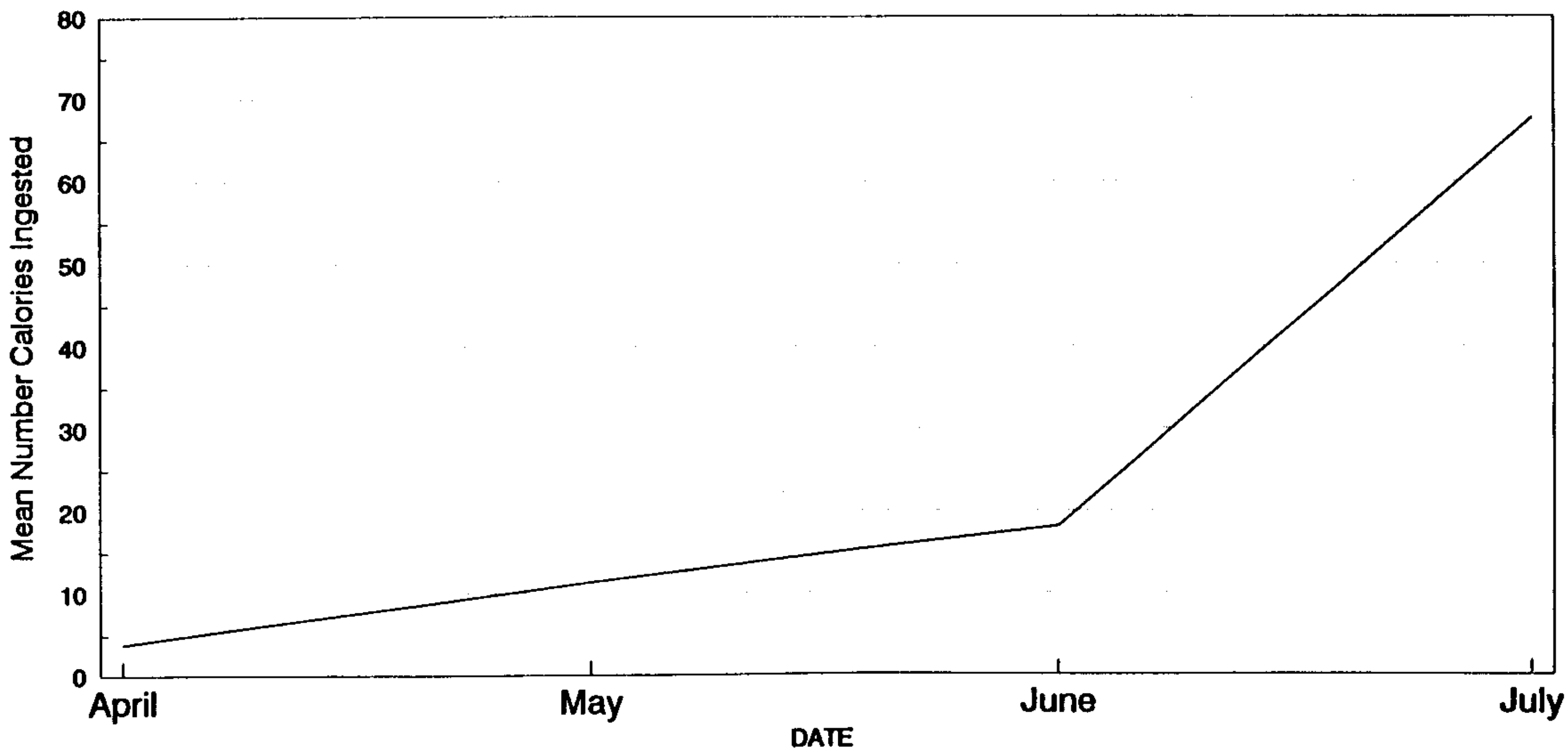

Figure 19. Mean monthly calories ingested by subyearling chinook salmon in Lower Granite and Little Goose Reservoirs, Washington, spring 1991-1992.

Table 3. Food habits and resulting index calculations after prey group consolidation from 292 subyearling chinook salmon collected in Lower Granite and Little Goose Reservoirs, Washington, spring 1991-1992.

	Number	Frequency	% Number	% Frequency	% Dry Weight	% Calories	I.C.I.	% I.C.I.
Diptera	4,569	269	0.3885	0.3168	0.2528	0.2433	0.0771	47.61
Ephemeroptera	858	101	0.0730	0.1190	0.3329	0.3771	0.0449	27.71
Larval Fish	41	11	0.0035	0.0130	0.1665	0.1804	0.0023	1.440
Other [a]	184	101	0.0158	0.1190	0.0483	0.0304	0.0036	2.240
Other Insects [a]	683	241	0.0581	0.2839	0.0687	0.0661	0.0188	11.59
Cladocera	5,426	128	0.4614	0.1484	0.1109	0.1028	0.0153	9.420
Totals	11,761	849						

[a] Other items were Amphipoda, Annelida, Araneae, Copepoda, Cladocera, Hirudinea, Hydracarina, and Isopoda. Other Insects were Hemiptera, Isoperla, Coleoptera, Odonata, Hymenoptera, Plecoptera, Psocoptera, Thysanoptera, Collembola, Trichoptera, Unknown Insects, and Insect Parts.

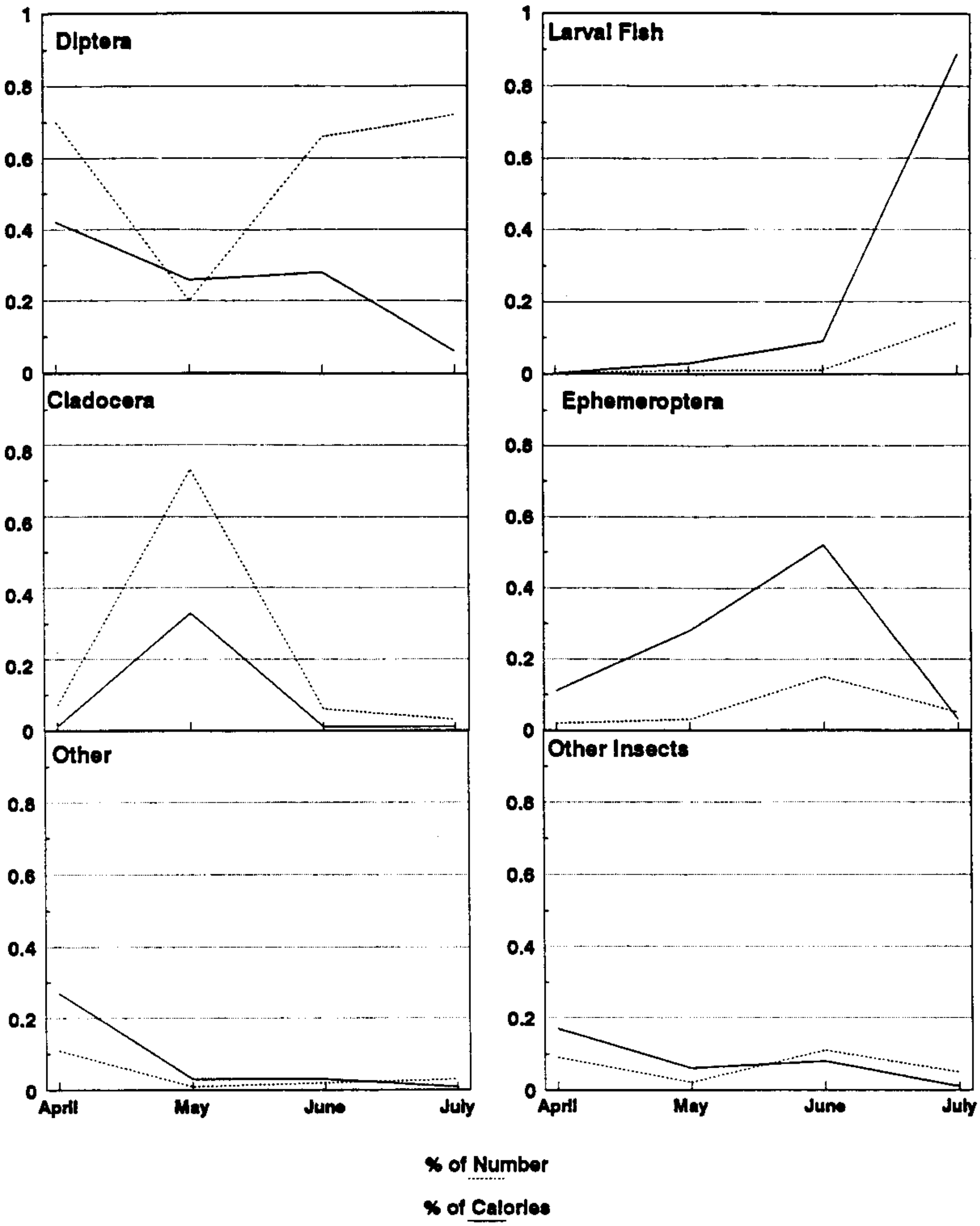

Figure 20. Relative caloric importance of major food items by mouth of subyearling chinook salmon collected in Lower Granite and Little Goose Reservoirs, Washington, April-July, 1991-1992.

>3% of the diets of 40-55 and >86 mm size classes. Calorically, larval fish were the most important prey item in the diet of fish >86 mm constituting 72% of the diet. Cladocera contributed primarily to the diets of the 40-55 mm size class and their caloric importance consistently decreased for each of the larger size classes. Cladocera were the most numerically abundant prey item present in stomachs of 40-55 and 56-70 mm fish (Figure 21).

Bioenergetics Model

The estimated average proportion of maximum consumption (P-value) fitted to observed monthly growth was 0.274 for the combined April to July 1991-1992 samples. The P-value for a maintenance ration (zero growth) was estimated at .20 using the same prey caloric values and water temperatures.

DISCUSSION

I found differences in the utilization of prey items by month and size of subyearling chinook. These differences may be attributed to the abundance and availability of prey items, the size of prey items, and the size of the fish, all of which may have been affected as the lower Snake River changed from a lotic to a lentic environment. Before impoundment the benthic community in the area now inundated by Lower Granite Dam consisted mainly of ephemeropterans and trichopterans (Edwards and Funk 1974). However, Bennett and Shrier (1986), Bennett et al. (1988, 1990, 1991), and Dorband (1980) reported numerous alterations in benthos density and standing crop in Lower Granite Reservoir after impoundment. Rondorf et al. (1990) determined discrete differences in the diets of subyearling chinook and in the availability of prey items in the Columbia River between lotic and lentic systems.

Availability of alternative prey items to subyearling chinook may be responsible for shifts in diet composition by month and among size classes. Availability has been suggested as an important factor in determining the utilization of specific prey items (Dauble et al.1980).

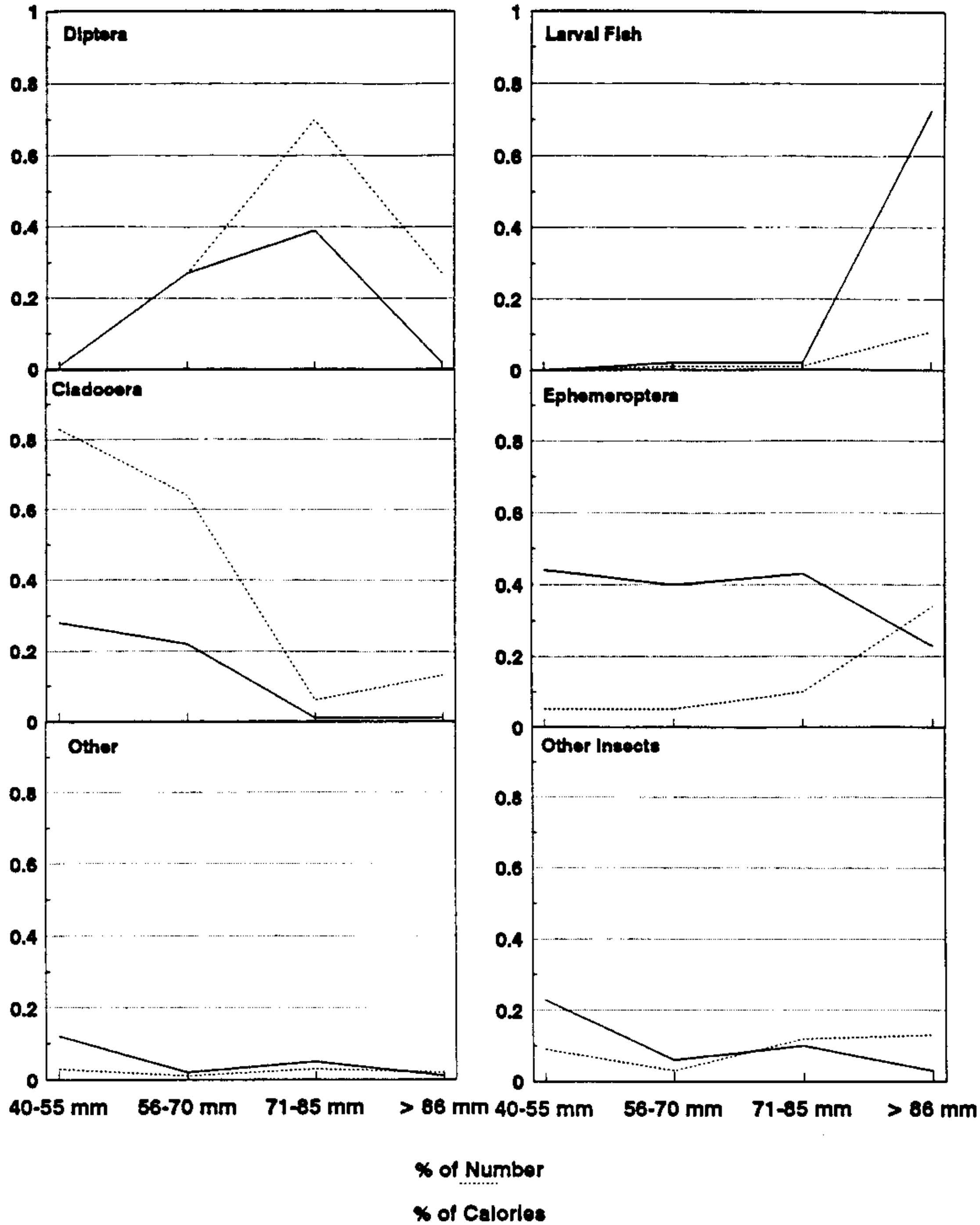

Figure 21. Relative caloric importance of major food items by size class of chinook salmon collected in Lower Granite and Little Goose Reservoirs, Washington, April-July, 1991-1992.

Rondorf et al. (1990) indicated the shift in diet by subyearlings to smaller, less preferred Daphnia species in embayments on Lake Wallula may be a result of the Cladocerans' higher densities and ease of capture in embayments. In the lower Snake River reservoirs, the importance of Cladocera to subyearling diets was most apparent in May and in the 40-55 mm length class. The almost complete absence of Cladocera in the diets of subyearlings in April may be a result of their reduced availability. In early spring relatively few cladocerans are found in lakes and ponds, but as temperatures increase more reproduction occurs and larger populations result (Pennak 1978). Furthermore, the turbulence of water movement and grinding effect of suspended material generally precludes high zooplankton densities in free-flowing rivers (Funk et al. 1979), a situation that could occur in Lower Granite Reservoir during spring runoff. Although conclusive evidence is lacking on the timing and abundance of zooplankton in the spring in Lower Granite Reservoir, recent sampling efforts (Bennett et al. 1993, unpublished data) indicate an increase in zooplankton abundance during the spring and summer, coinciding with importance of cladocera to subyearling diets in May.

The reduced importance of Cladocerans to subyearling diets in June and July may be related to the size of subyearling chinook. The maximum size a food particle consumed by a fish generally increases as the size of the fish grows (Becker 1970), so as the length of subyearlings during the spring increases, the larger migrants may consume larger prey with higher energy content.

The availability of the most important insects (chironomids and ephemeropterans) and larval fish to the diets of subyearling chinook generally coincided with the peak seasonal abundance of insects (Dorband 1980) and larval fish (Bennett et al. 1993). Chironomid species in Lower Granite Reservoir generally peak in the late spring or early summer with notable declines occurring between early May or June (Dorband 1980). Baetis, the most abundant ephemeropteran ingested by subyearlings, were most abundant in Dorband's (1980) samples during the spring and mainly in the upper portion of Lower Granite Reservoir where most of my stomach samples were collected. Peak abundance of larval fish, primarily cyprinids, occurred during July in Lower Granite in 1990 (Bennett et al. 1993) the same month larval fish were an important food item to subyearlings. The importance of these organisms to subyearlings may partially be explained by their seasonal abundance.

Using the same prey grouping strategy as Rondorf et al. (1990), subyearlings in the lower Snake River reservoirs ingest prey items that differ in composition compared to diets of subyearlings in the Columbia River. Numerically, Dipterans contributed substantially to the diet (38%) of subyearlings in the lower Snake whereas in the Columbia River Dipterans constituted <15% of the diet. The difference probably reflects differences in the diversity and availability of potential prey in the two systems. The more predominant terrestrial insects ingested as food items in the Columbia River (Homopterans and Hymenopterans) could result from the higher riparian vegetation there, which is lacking along the Lower Granite pool. This hypothesis is supported by the higher frequency of Homopterans ingested (65%) in Little Goose than in Lower Granite (35%). Little Goose Reservoir visually supports a more diverse and abundant riparian community than Lower Granite Reservoir.

The proportion of maximum consumption (P-value) for subyearling chinook was low (0.274) suggesting prey availability may be limiting as Poe (1992) suggested. P-values <1 may also suggest competition, predator avoidance, disease (Hewett and Johnson 1987) or the influence of other biotic and abiotic factors. To determine the difference between my estimated P-value and the maintenance ration (zero growth) for subyearling chinook, I estimated the P-value for the maintenance ration by setting the ending weight equal to the initial weight for subyearling chinook. The estimated maintenance ration P-value for subyearling chinook was 0.2 suggesting subyearlings are feeding at less than optimal levels. P-values reported for sockeye salmon *Oncorhynchus nerka* for the approximate temperature values used in my estimates ranged from 0.85 to 0.98 (Beauchamp et al. 1989).

The overall impact of the altered river environment to a lentic environment on fish communities and their associated prey bases cannot be adequately addressed when observing the food habits of a single group of fish. My results suggest however, that the nutritional need of subyearling chinook is probably not being satisfied during their brief migratory and rearing period in the reservoir.

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Chapter 3. To assess the influence of predation on subyearling chinook by potential predators in Lower Granite Reservoir.

INTRODUCTION

The number of potential salmonid predators in the Columbia River system has increased due to introductions of walleye *Stizostedion vitreum*, channel catfish *Ictalurus punctatus*, and smallmouth bass *Micropterus dolomieui* and also from increasing populations of native northern squawfish *Ptychocheilus oregonensis* in response to increased limnetic and littoral habitat (Poe et al. 1988). Yellow perch *Perca flavescens* also inhabit Lower Granite Reservoir. Smaller fish may comprise 30% of the diet (by volume) of yellow perch by the end of their first year (Scott and Crossman 1979). Two other potential predators, white crappie *Pomoxis annularis* and black crappie *Pomoxis nigromaculatus* may also contribute to subyearling chinook salmon predation. White crappie eat aquatic insects, some crustaceans, and a large number of small fishes; black crappie >160 mm also include fishes into their diet (Scott and Crossman 1979). No known information exists relevant to predation of subyearling chinook salmon on the lower Snake River reservoirs. Consumption estimates by northern squawfish have been developed for juvenile chinook and steelhead (Chandler 1993) in Lower Granite Reservoir, but have not been specifically for subyearlings. Northern squawfish in John Day Reservoir utilized subyearling chinook salmon heavily during their July migratory peak; 82% of the diet was subyearling chinook (Poe et al. 1988). During the peak migration of subyearling chinook in John Day Reservoir in July, salmonids also accounted for about 35% of the diet of channel catfish (Poe et al. 1988). Preliminary surveys conducted on the Hanford Reach of the Columbia River indicated smallmouth bass selected juvenile chinook during the chinook's early migration through the Hanford Reach (Dennis Rondorf, U.S.F.W.S., personal communication).

METHODS

Predators Collections and Laboratory Analysis

Areas of concentrations of subyearling chinook salmon were identified primarily in the upper portion of the reservoir (Objective 1). Potential predators were collected in these areas in May 1992 during the period of peak abundance of subyearling chinook salmon (Figure 22). Sampling was typically conducted over 24 hour periods using electrofishing, gillnetting, and beach seining. Electrofishing using a constant output of 400 volts at 3-5 amps to stun predators was used to sample the shoreline where subyearlings were previously sampled. Four multifilament gill nets (68.6 m x 1.2 m) consisting of three graded panels (3.1, 4.1 and 5.1 cm) were set perpendicular to the shoreline and fished continuously during the 24 hour sampling period. Nets were checked as often as possible, ideally at <1 hour intervals and reset. Sampling was conducted on a continuous basis since natural digestive processes would probably render the consumed prey fish unidentifiable soon after consumption, due to the small size of a subyearling chinook salmon. Beach seining was conducted with a 30.5 m x 2.4 m beach seine consisting of 0.64 cm knotless sampling an approximate 454 m^3 area. The seine was set parallel to and approximately 15.2 m from the shoreline with attachment lines then drawn in perpendicular to the shoreline, similar to the method described under fish collections (Objective 1).

Northern squawfish were collected from 1987 through 1991 using horizontal bottom, mid-water and surface gill nets (both monofilament and multifilament), vertical multifilament gill nets, shoreline boat electrofishing, beach seining, open water purse seining, bottom trawling and surface trawling (Chandler 1993). Horizontal bottom gill nets 69 m long X 1.8 m deep, with 3.2, 4.4, and 5.1 cm bar mesh, proved to be the most effective sampling technique for predator sized northern squawfish (> 250 mm)(Arthaud 1992). Eight nets were fished either during day and night hours at each station for 7 to 8 hours (1987) or nets fished starting 3 hours before dark for 6 to 8 hours (1988-1991). Sampling locations for northern squawfish ranged from Rkm 215.8 to 175.5 (Figure 23) during the 5 years of study (Chandler 1993).

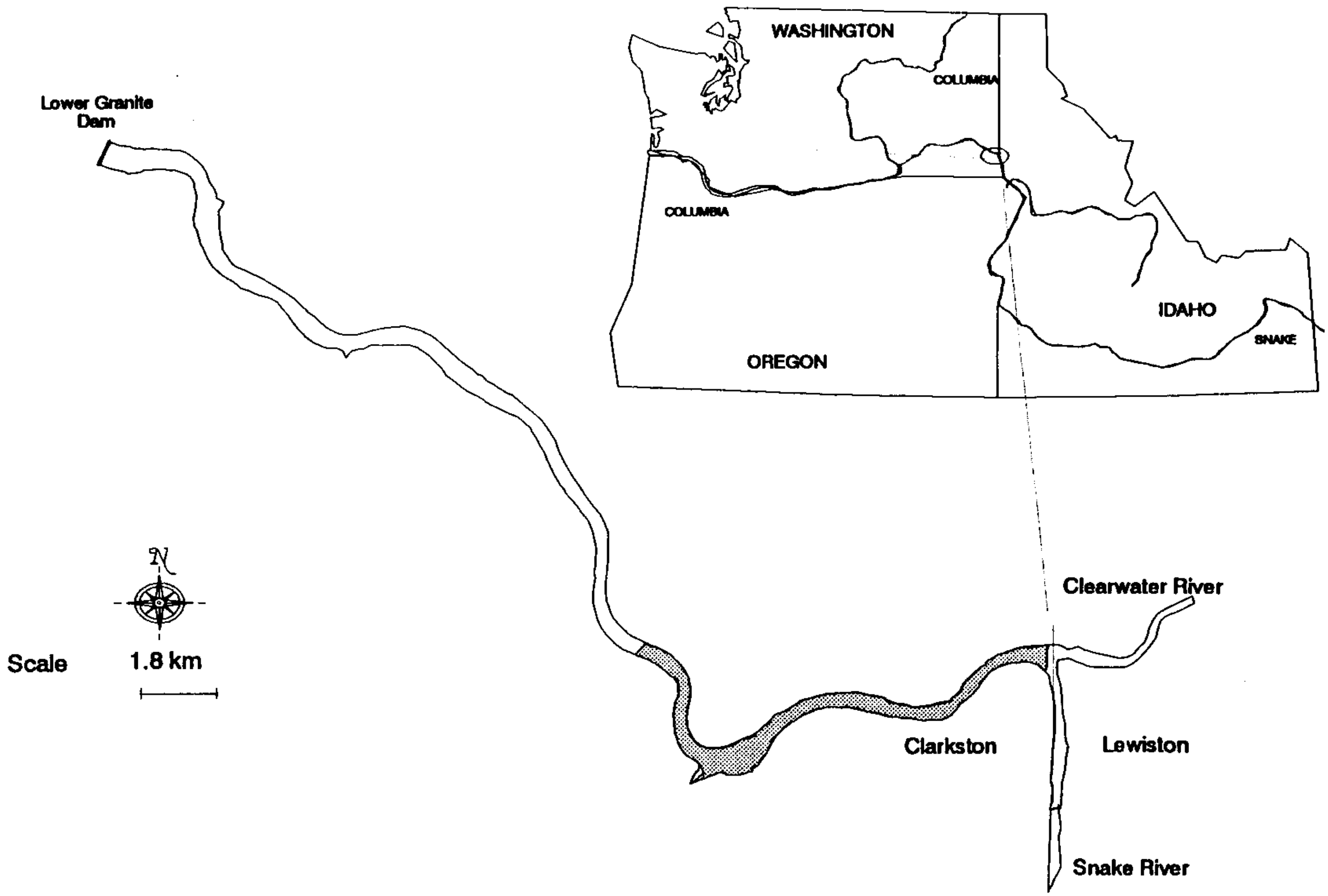

Figure 22. Proximity of potential predator study area in Lower GraniteReservoir, Washington. 1992

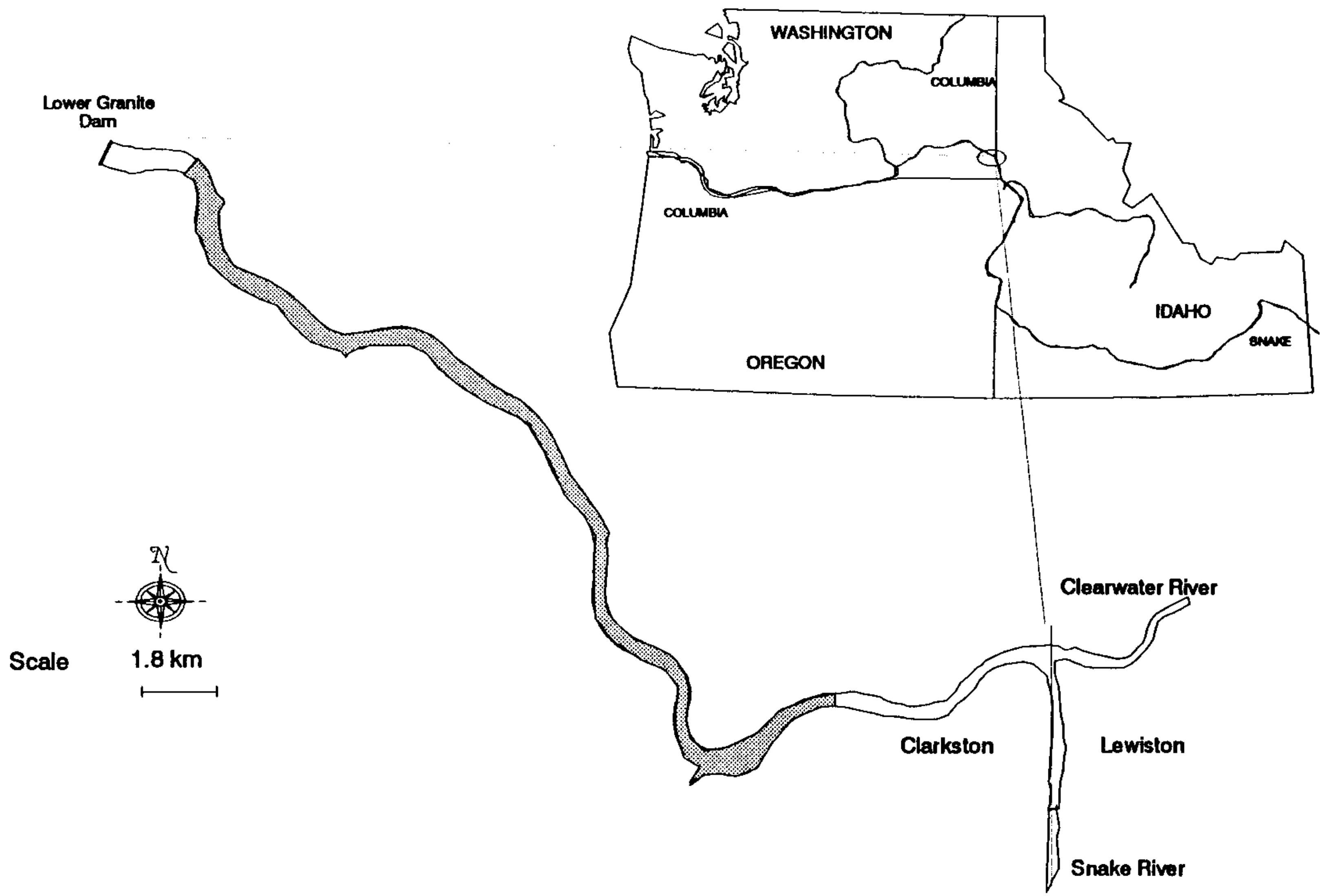

Figure 23. Sampling locations of northern squawfish study area (shaded area) in Lower Granite Reservoir.

All potential predators captured were measured to total length (TL) to the nearest millimeter. Weights of individual predators were estimated using previously developed length-weight regressions (Bennett et al. 1983). Stomach contents from all potential predators were collected; northern squawfish > 250 mm and channel catfish >100 mm were sacrificed and their entire digestive tract removed. All other potential predator stomachs (smallmouth bass >50 mm, yellow perch >70 mm, black and white crappie >75 mm) were evacuated using the lavage technique (Chapter 2). Digestive tracts from northern squawfish were preserved in a 10% formalin solution (1987) or frozen after removal (1988-1991). Stomach contents flushed from all other predators were preserved in 10 % buffered formalin.

Stomachs samples were examined in the laboratory and food items were identified to the lowest practical taxon. Diagnostic bones were used to identify prey fishes in the latter stages of digestion and to determine live fork lengths (Hansel et al. 1988). Prey items were divided into prey taxa, enumerated, blotted dry for a standard 60 s and weighed to the nearest 0.01 g.

Consumption

Daily consumption of subyearling chinook salmon was estimated for smallmouth bass and northern squawfish. Consumption rates were also estimated for three length groups of smallmouth bass (< 250 mm, 250-389 mm and > 390 mm) and two length groups of northern squawfish (250-349 mm and >350 mm) for purposes of determining size related differences in consumption rates. Estimates of daily consumption rates of subyearling chinook were derived using methods developed by Vigg et al. (1991) who modified the original method developed by Swenson (1972) and Smith (1973). Consumption rates were summarized by the following equation (Vigg et al. 1991):

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

Where C is the daily consumption (g) by an average predator; *Wij* is the undigested weight of prey fish of a given size category (j) during a given diel time interval (i), and *Fij* is 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 time period i (i.e. a squawfish/bass was considered part of the sample for all time intervals from the time of capture back to the limits of time when ingested food would have been detectable; Wahl and Nielson 1985). Consumption estimates of subyearling chinook salmon by northern squawfish were made by pooling all 5 years of predator collections (1987-1991).

Bounds (95% C.I.) on consumption estimates were derived using bootstrapping estimates from the original consumption data set. Calculations of standard deviation from bootstrapping distribution were used as the standard error of the original consumption estimate (Efron and Tibshirani 1986).

Abundance of Predators

Abundances of smallmouth bass (> 200 mm) and northern squawfish (> 250 mm) were calculated using density estimates of 1.8 smallmouth bass/ha and 4.4 northern squawfish/ha based on data from John Day Reservoir on the Columbia River (Beamesderfer and Rieman 1991). Mortality estimates from beach seining catch per unit effort data were used to include smaller size classes of bass to correct the bass population estimate (Bennett et al. 1991, unpublished data). The corrected population estimate of smallmouth bass using mortality estimates is 13 smallmouth bass/ha > age 0.

The density of each respective predator population was multiplied by the total surface area of Lower Granite Reservoir (3602 ha). The proportion of smallmouth bass within each of the three size classes was estimated from length frequencies of smallmouth bass collected within each size group during spring 1992. The proportion of squawfish > 349 mm in the population of squawfish > 250 mm was estimated from pooled length frequencies of squawfish from 1985-1990 (Chandler 1993).

Estimated Loss of Subyearling Chinook Salmon

Estimated loss of subyearlings was calculated using daily consumption rates of subyearling chinook derived from the Vigg et al. (1991) technique and expanded for each respective predator population. Loss of subyearling chinook can be described by the equation developed by Rieman et al. (1991):

$$L_{hij} = PS_iC_{ij}D_jG_{hij}\ ;$$

where L_{hij} is the loss of subyearling chinook $_h$lost to predators (smallmouth bass or squawfish) in size group $_i$ during month $_j$, P is the population of predators >71 mm (age 1 and larger), >250 mm (smallmouth bass and squawfish, respectively), S_i is the proportion of each predator population within size group $_i$, C_{ij} is consumption of predator size group $_i$ during month *j*, D*j* is the number of days in month $_j$ and G_{hij} is the proportion of subyearlings $_h$ in predator size group i during month $_j$. Northern squawfish mean daily consumption per average predator per day estimates for each month and each predator size group from the pooled data (1987-1991) were used for C_{ij} (Chandler 1993).

To estimate the percent of the naturally produced fall chinook outmigrants consumed in 1992, I assessed the possible population size of the subyearling chinook salmon migrating through the Lower Granite pool in 1992. The estimate is based on the 630 adult fall chinook which crossed Lower Granite Dam in 1991 (Annual Fish Passage Report, U.S. Army Corps of Engineers, 1992), of which half were assumed to be females, with an average fecundity of 4300 eggs (Priest Rapids Hatchery personnel, personal communication), and a 62% survival rate from embryo to emergence (Fast et al. 1986).

RESULTS

A total of 891 smallmouth bass, 32 black crappie, 28 yellow perch, 26 white crappie, 17 channel catfish and 6 largemouth bass collected in spring 1992 were analyzed for the presence of subyearling chinook salmon. Subyearling chinook were observed only in smallmouth bass stomachs. A total of 892 squawfish (> 250 mm) were collected during the spring months of 1987-1991 and examined for the presence of subyearling chinook.

Consumption

Based on comparisons of numerical consumption (subyearling/predator/day) of subyearling chinook by smallmouth bass and northern squawfish, smallmouth bass are the most serious predator of subyearling chinook. Overall consumption estimates for all length groups combined for each respective predator population were 0.06 and 0.03 subyearling/predator/day for smallmouth bass and northern squawfish, respectively. Most smallmouth bass samples were collected during May, when daily consumption rates ranged among the three length groups from 0.06 (+/- .03, 95% C.I.) (< 250 mm) to 0.09 (+/- .10, 95% C.I.) subyearling/predator/day (250-389 mm) (Figure 24). No consumption of subyearlings was noted by smallmouth bass > 389 mm. Consumption of subyearling chinook by northern squawfish was noted only in April. Consumption between the two size groups ranged from 0.01 (+/- .02, 95% C.I.) subyearling/predator/day (250-349 mm) to 0.06 (+/- .06, 95% C.I.) subyearling/predator/day for the > 349 length group (Figure 25).

Abundance of Predators

Using corrected density estimates for smallmouth bass and density estimates for northern squawfish, I estimated 46,962 smallmouth bass (age 1 and larger) and 15,850 northern squawfish > 250 mm in Lower Granite Reservoir. The proportion of smallmouth bass within each respective size group (< 250 mm, 250-389 mm and > 390 mm) are 83%,

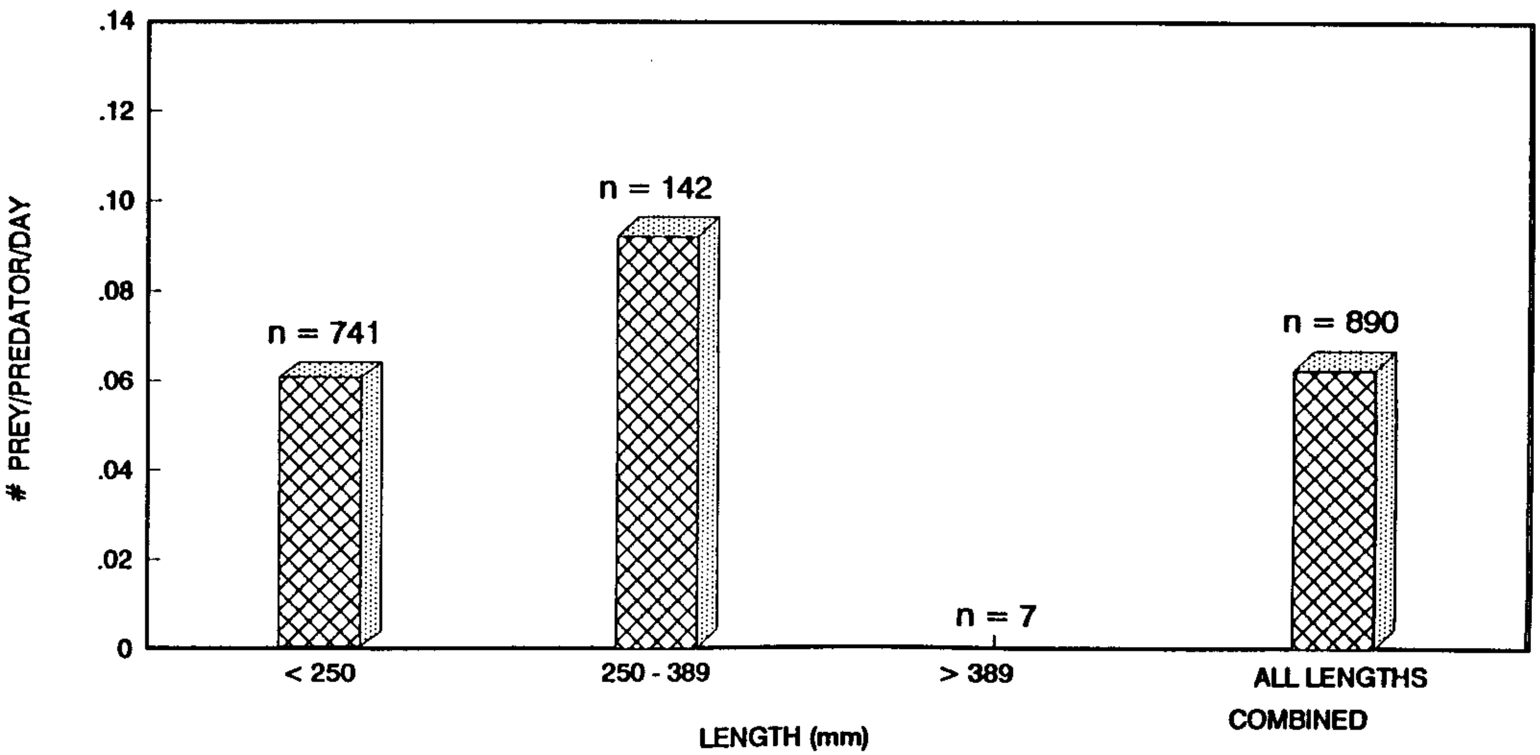

Figure 24. Consumption (prey/predator/day) of subyearlings chinook for smallmouth bass during May 1992, Lower Granite Reservoir, Washington.

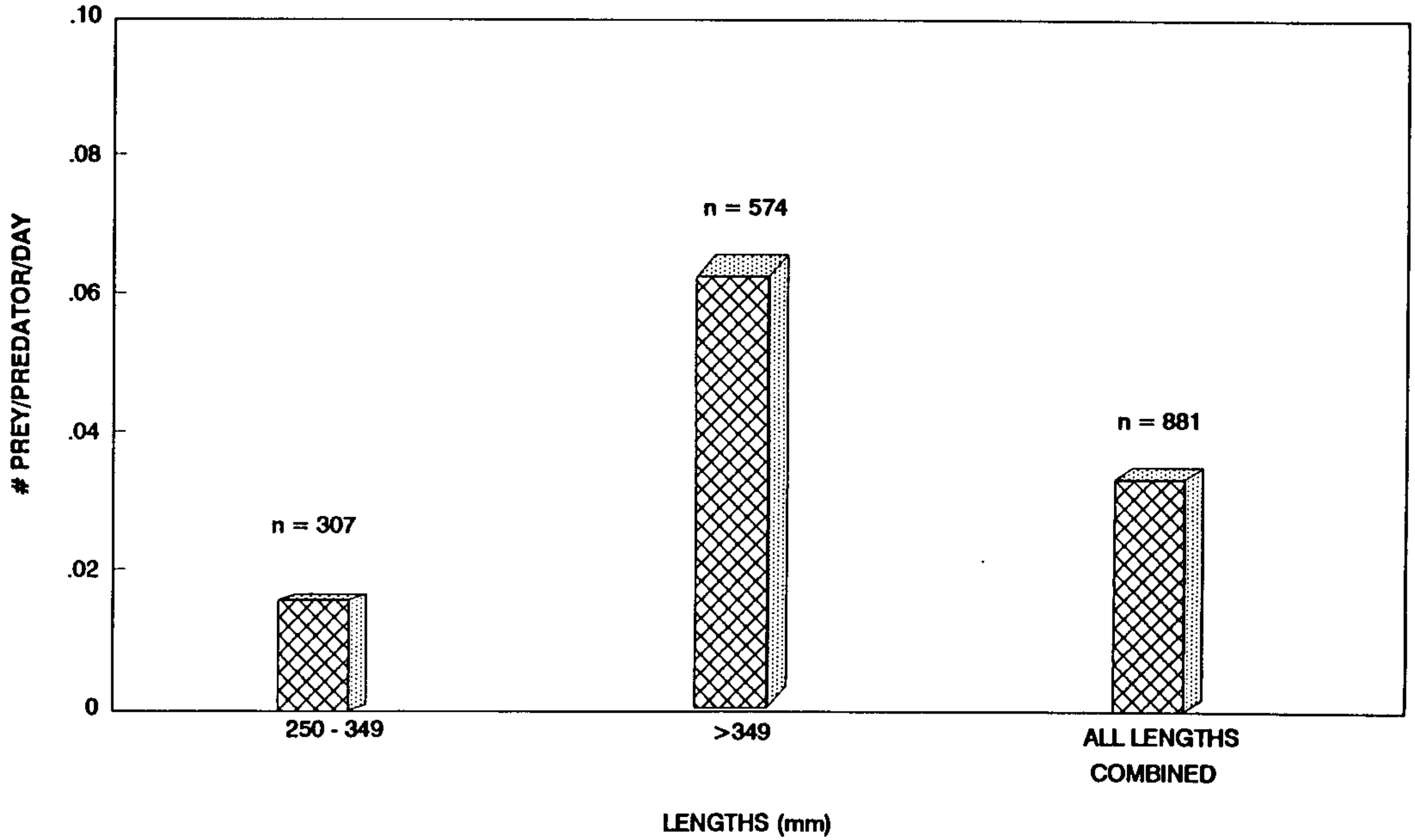

Figure 25. Consumption (prey/predator/day) of subyearlings chinook for northern squawfish during 1987-1991, Lower Granite Reservoir, Washington.

16% and 1%, respectively. The proportion of northern squawfish > 349 mm from the population of all squawfish > 250 mm was estimated to be 44% (Chandler 1993).

Estimated Loss of Subyearling Chinook Salmon

Loss estimates of subyearling chinook between the two predator populations are 31,512 and 17,092 subyearlings for smallmouth bass and northern squawfish, respectively. The total loss estimate of subyearling chinook to smallmouth bass was estimated for the upper portion of the reservoir (rkm 205-224) where a majority of the samples were collected. Combining the total loss estimates from both smallmouth bass and northern squawfish, an estimated 48,600 subyearling chinook salmon are consumed annually in the Lower Granite pool, approximately 6% of the estimated 786,470 naturally produced subyearling fall chinook that migrated through Lower Granite Reservoir in 1992.

DISCUSSION

Consumption

Consumption of salmonids by smallmouth bass in John Day Reservoir peaked in July which coincides with the peak abundance of subyearling chinook through McNary Dam (Vigg et al. 1991; Poe et al. 1991). During peak abundance of subyearling chinook in Lower Granite Reservoir, consumption estimates for smallmouth bass were lower (0.06 subyearlings/predator/day) than reported in July in John Day Reservoir (0.118 salmonids/predator/day). In John Day Reservoir the rate of consumption of salmonids by smallmouth bass was low (Vigg et al. 1991) in comparison to northern squawfish, channel catfish and walleye. This may be related to the distribution of subyearling chinook as they migrate through John Day Reservoir in July. In Lower Granite, subyearlings appear to move offshore between late May and late June (Objective 1). If subyearlings were pelagically oriented in July during their peak migration through John Day Reservoir, subyearling chinook and smallmouth bass may be spatially separated. The disparity in consumption rates between smallmouth bass in Lower Granite and John Day Reservoirs may be attributed to the apparent difference in abundance or timing of subyearling chinook migrating through each reservoir. Based on fish passage indices, in 1992 an estimated 543,500 subyearling chinook were collected at John Day Dam compared to 6,000 subyearlings collected at Lower Granite Dam (Fish Passage Center 1993). The increased availability of subyearlings in John Day Reservoir may account for the higher consumption rates.

Consumption estimates by small and large smallmouth bass were comparable. However, the reason for no consumption in the > 389 length group may be explained by either the small sample size (n=7), reduced foraging activity of male centrarchids during the spawning season (Vigg et al. 1991; Pflieger 1966), or the larger adults initiating spawning earlier than smaller sexually mature smallmouth bass (Hubert and Mitchell 1979).

In Lower Granite Reservoir, northern squawfish accounted for only 35% of the loss of subyearling chinook. Consumption estimates for salmonids by northern squawfish in John Day Reservoir peaked in July which coincides with the peak abundance of subyearling chinook through McNary Dam (Vigg et al. 1991; Poe et al. 1991). In John Day Reservoir, reduced salmonid consumption (Vigg et al. 1991) was found for northern squawfish in June (Rieman et al. 1991), although no appreciable difference exists in the estimated number of salmonids entering the reservoir.

Periodic collections of northern squawfish on the St. Joe River in northern Idaho illustrate that most squawfish spawned between mid-June and mid-July (Reid 1971). Jeppson and Platt (1959), Jeppson (1960), Keating (1958), Casey (1962), Hill (1962) and Patten and Rodman (1969) showed squawfish in Idaho, Montana and Washington spawn at the same time. Reduced salmonid consumption in John Day Reservoir by northern squawfish during June may be attributed to spawning activity. The reduced consumption of subyearling chinook in Lower Granite Reservoir may also be related to the spawning activity of northern squawfish. During the spring months larger northern squawfish are believed to migrate to areas in the upper reservoir and free flowing sections of the Snake River for spawning (Chandler 1993). Subyearlings in Lower Granite appear to move offshore between late May and late June (Objective 1) and become pelagically oriented, possibly after the larger squawfish move upriver thus reducing the chance of interaction between the two species. These movements may spatially separate the subyearling chinook and northern squawfish.

Estimated Loss of Subyearling Chinook Salmon

In Lower Granite Reservoir, smallmouth bass are the most serious predator of subyearling chinook salmon. Unlike the squawfish, which begin augmenting their diets with prey fishes once they enter the larger size class (> 350 mm), smallmouth bass begin incorporating subyearling chinook into their diet at relatively small sizes. Predation of subyearlings by smallmouth bass 105 mm has been noted in the field during previous years collections (Bennett et al. 1992, unpublished data).

My estimates of total loss of subyearling chinook in Lower Granite Reservoir to smallmouth bass are underestimated because my estimates were for only the upper 1/3 of the reservoir. Although subyearling chinook are most abundant in the upper portion of Lower Granite Reservoir, predation by smallmouth bass probably occurs in the remaining portion of the reservoir. Predation on subyearling chinook by smallmouth bass has been noted during field collections upstream of the forebay in Lower Granite in 1991 (Bennett et al. 1992, unpublished data) which suggests that predation is also occurring in the lower reservoir areas, although the quantity is unknown.

Although my loss estimates were estimated only for May, I believe the estimates represent a majority of the loss of subyearling chinook to smallmouth bass. During April, water temperatures remain cold due to spring runoff probably inhibiting the foraging activity of the smallmouth bass. By June, subyearlings begin to migrate from the shoreline of the reservoir which spatially separates the subyearling chinook from the smallmouth bass, therefore reducing interaction between these fish.

Northern squawfish accounted for 75% of the estimated 968,000 chinook salmon consumed in the John Day Pool during the July peak migration of subyearling chinook (Rieman et al. 1991). Although predation on subyearling chinook was not the specific focus of that study, according to the relative abundance of salmonids through McNary Dam reported by Poe et al. (1991), a majority of the chinook consumed were subyearlings. In Lower Granite Reservoir squawfish account for 35% of the total loss of subyearling chinook. The difference between squawfish predation in Lower Granite Reservoir compared to John Day, as addressed earlier, may be explained by the distribution of northern squawfish and the distribution and timing of subyearling chinook in Lower Granite during the spring.

Loss estimates of subyearling chinook to northern squawfish also may be underestimated because they are based on the estimated population of northern squawfish in the main Lower Granite pool, excluding the forebay and uppermost portion of the reservoir. In John Day Reservoir, the forebay and tailrace areas accounted for 26% of the 1,100,320 salmon and steelhead consumed during April to June (Rieman et al. 1991). Higher densities of squawfish probably occur in the forebay area of Lower Granite Dam, as well as the extreme upper end of the reservoir, which would notably increase estimated losses (Chandler 1993).

Based on observed growth rates of >1 mm day and incubation timing studies for fall chinook (968 Celsius temperature units to emergence) in the Snake and Clearwater rivers, Snake River fall chinook could exceed 120 mm by mid-July when migrating through Lower Granite Dam (Arnsberg et al. 1992). Using the conservative cutoff length of <85 mm for subyearlings during this study, subyearling chinook could have been eliminated from analysis ultimately underestimating the impact of predators on the subyearling chinook salmon migrating through the reservoir.

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