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FISHERIES DIVISION

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RELATIVE GROWTH AND SURVIVAL OF THREE STRAINS OF RAINBOW TROUT AND THREE STRAINS OF BROWN TROUT STOCKED INTO SMALL MICHIGAN INLAND LAKES

Andrew J. Nuhfer

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Diet of Chinook Salmon in Eastern Lake Michigan, 1991-93

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Abstract.–In recent years, a decline in chinook salmon *Oncorhyncus tshawytscha* abundance in Lake Michigan has been attributed to declining forage availability, increased incidence of bacterial kidney disease (BKD), as well as an interaction between these factors. Concern has also been expressed about the alewife *Alosa pseudoharengus* population's ability to support higher stocking levels of salmonines in the lake. Given these concerns, and the potential biases involved in evaluating chinook salmon diet using sport-caught fish, we conducted a study to evaluate the diet of chinook salmon in eastern Lake Michigan. Graded-mesh nylon gill nets were used to sample chinook salmon. Sampling was designed to determine the influence of chinook salmon size, season, and water depth on diet composition, and to evaluate the relationship between bacterial kidney disease and chinook salmon foraging. Small chinook salmon (≤ 37 cm total length) consumed a higher percentage of insects and other invertebrate food items (up to 26% of stomachs examined) than larger fish (maximum=8% of stomachs examined), but the majority of the diet of small chinook salmon was still fish (29-56% of stomachs). Large chinook salmon (≥58 cm) had a fish diet similar to that of small chinook salmon, while medium chinook salmon (38-57 cm) consumed more bloater *Coregonus hoyi* (58% of the diet by weight) than either of the other size groups. Size of prey fish consumed by chinook salmon was strongly dependent on predator size. Seasonal and year-to-year variation in diet was most pronounced for small and medium chinook salmon; diet diversity for these groups generally was highest in summer and increased from 1991 to 1993. Chinook salmon less than 58 cm in length also exhibited significant differences in the relative amounts of three forage fish they consumed, depending upon whether they were collected in water less than or greater than 45 m deep. Small and medium chinook salmon collected in water ≤ 45 m deep consumed more smelt and bloater, while fish collected in deeper water ate primarily alewife. Large chinook salmon in both shallow and deep water fed primarily on alewife. We observed an interaction among chinook salmon stomach fullness, BKD incidence, and season. BKD incidence was highest in May (24%) and declined to 6% by September. On average, BKD-infected fish had twice the percentage of empty stomachs when compared with healthy chinook salmon. Future diet studies of Great Lakes salmonines need to consider temporal and spatial variables, and should focus on the impacts of a shift in diet on growth and angler harvest of chinook salmon, as well as on the potential effects of changes in chinook salmon foraging on other Great Lakes species.

Introduction

Pacific salmon were introduced into Lake Michigan in 1966, in part, as an attempt to control the alewife *Alosa pseudoharengus* population which plagued the lake at that time (Tody and Tanner 1966). Ironically, the concern now expressed by some is that overstocking Lake Michigan with salmonine predators, especially chinook salmon *Oncorhyncus tshawytscha*, has depleted the alewife population (Jones et al. 1993). Concern has also been expressed that chinook salmon may not switch effectively to another food source in the event the alewife population collapses (Stewart et al. 1981, Jude et al. 1987), or if they do switch that other forage populations will not be capable of supporting predator demand (Jones et al. 1993). Concern about the alewife population's ability to support higher stocking levels of salmonines in the lake was expressed in the early 1980's (Stewart et al. 1981). This concern centered primarily on the potential instability of the alewife forage base (Jones et al. 1993). Hansen (1986) reported a decline in condition factor of chinook salmon in the southern basin of Lake Michigan and suggested a shortage of alewife as a possible cause. Questions exist, however, concerning the extent to which chinook salmon depend on alewife. Diet data collected by Wisconsin Department of Natural Resources personnel from their sport fishery for a number of years revealed that chinook salmon were feeding almost exclusively on alewife in western Lake Michigan (95% of the diet of all age classes), and did not switch to alternate food sources (Wisconsin Department of Natural Resources 1994). However, in eastern Lake Michigan, diet data collected from sport-caught chinook salmon during 1983-86 (Kogge 1985, Elliott 1993) showed that bloater *Coregonus hoyi* and smelt *Osmerus mordax* contributed significantly to salmon diets. The fish reported on in these studies tended to be larger salmon collected in near-shore areas, and it is not clear whether the diet of these sport-caught chinook salmon is representative of the entire population (Goyke and Brandt 1993).

Between 1987 and 1990, chinook salmon catch rates (number of chinook salmon caught per 100 hours of sport fishing) declined 54% in eastern Lake Michigan (Rakoczy and Svoboda 1995). Potential causes for this decline in chinook salmon abundance, in addition to declining forage availability, include increased incidence of bacterial kidney disease (BKD), as well as interaction between forage availability and disease. During 1986-87, there were unconfirmed reports of dead chinook salmon washing ashore in Lake Michigan. In 1988, an estimated 10,000-20,000 dead chinook salmon washed ashore in the southeastern part of the lake (Nelson and Hnath 1990, Johnson and Hnath 1991), but the number of beached chinook salmon has since declined. Bacterial kidney disease was found in numerous fish clinically examined in 1988, and, while declining, continued to be present in chinook salmon through 1993.

We began a study in 1991 to determine the diet of chinook salmon in eastern Lake Michigan. The objectives of this study were to determine the diet and forage-fish preference of chinook salmon by time of year, water depth, and size of chinook salmon. In addition, we compared diet of chinook salmon with and without clinical signs of BKD.

Methods

Study area

Central Lake Michigan between Big and Little Sable Points was chosen as the study area for several reasons: excellent harbor facilities were available; the area was small enough (approximately 1,300 km^2, 45 km shoreline length) to permit intensive sampling of near-shore (≤45 m) and offshore (>45 m) depth strata; forage-fish populations, such as alewife, bloater, smelt, yellow perch *Perca flavescens*, trout perch *Percopsis omiscomaycus*, and shiners *Notropis spp*. were abundant; and much of the lake bottom was suitable for trawling. Sampling was conducted from May through August in 1991, and from May through September in 1992 and 1993. The area strongly influenced by the reservoir discharge from the Ludington Pump Storage Facility was not sampled, because the abnormal, near-shore environment created by the facility (strong currents and warm water temperatures) serves to artificially attract both prey and predator.

Field sampling

Graded-mesh nylon gill nets were used to sample the chinook salmon population during 1991-93. A gill-net gang was 610 m long and 5 m deep. Individual panels were 30 m long and mesh sizes (stretch measure: 63.5-152.4 mm, 12.7 mm interval; 152.4-203.2 mm, 25.4 mm interval) were replicated sequentially (N=2 replicates per mesh size per gang). During the study, gill nets were set at the surface, suspended in the water column, and on the lake bottom. Suspended and bottom-set gill nets were usually set at dusk and lifted the following morning. Gill nets set at the surface were seldom fished for more than four hours, usually at night. In 1991-92, gill nets were fished suspended at a depth where water temperature was 11.1-13.9°C, within the range preferred by chinook salmon (Coutant 1977). Despite fishing in this temperature range, gill nets came up empty many times. In 1993, gill nets were set at the depth where forage fish were concentrated, and catch rates increased. Water temperatures at these depths were most often in the 8.3-10.0°C range.

Bottom-set gill nets caught no chinook salmon whether fished day or night. Gill nets set suspended in the water column failed to catch a single salmon during daylight, but were effective at night. Chinook salmon diet data reported in this study are primarily from fish captured in surface and suspended gill nets fished at night.

Bottom and mid-water trawls were used to sample forage fish potentially available to chinook salmon. The otter trawl used to sample at the bottom was 26.6 m in length, had a mouth opening of 22.0 m^2, and a codend lined with 12.7 mm mesh. The mid-water trawl was 13.3 m in length with a mouth opening of 7.0 m^2. Trawls were fished for 10-min (bottom) to 30-min (mid-water) at each sampling date and location. Both gill-net and trawl effort were equally divided between near-shore (≤45 m) and offshore (>45 m) areas. These divisions were selected because the sport fishery generally occurred in water depths less than 45 m. Gill netting and trawling were conducted on alternate weeks. Because chinook salmon catches were numerically small in 1991-92, trawling was discontinued in mid-June 1993 and all subsequent effort was directed into gill netting.

Whole-fish samples were iced immediately upon removal from gill nets. Length, weight, sex, finclip, and BKD status were recorded for each chinook salmon collected. A scale sample was also collected to determine age. Stomachs were removed aboard the research vessel and individually frozen in a sealed, coded freezer bag. Forage fish collected in trawl samples were sorted by species and a total weight was obtained for each species group. Individual fish lengths (total length in mm) were collected from a subsample (up to 2.3 kg) of all forage-fish species collected in a given trawl sample.

Sample processing

Stomach contents of chinook salmon were identified to species level only for adult fish food items. Larval fish, terrestrial insects, amphipods, zooplankton, and unidentified food items were recorded as present or absent. Overnight gill-net sets had little effect on the identification of food fish in stomachs. In most cases, more than 95% of fish remains could be identified from bone structure.

Total length and round dry weight of each identifiable fish removed from chinook salmon stomachs were reconstructed to approximate size at the time of ingestion. For each of the major forage species (alewife, bloater, smelt), a linear regression was derived for the relation between total length of fresh fish and the overall length of three vertebrae immediately posterior to the anal fin (Table 1). A micrometer was used to make the vertebral measurement (nearest 0.01 mm). The location posterior to the anal fin was selected because most forage fish are swallowed headfirst and these vertebrae are the last part to be digested. A second linear regression was developed for each species which established the relationship between observed or calculated total length and dry weight (Table 1). Specimens were oven-dried at 105°C (Bowen 1983); dry weight was determined when a constant weight was obtained for two consecutive measurements. Up to 96 hours were required to dry the largest bloater.

Data analysis

Analysis of diet data was conducted by chinook salmon length group (small, ≤37 cm; medium, 38-57 cm; and large, ≥58 cm), season (spring - May; summer - June through August; and fall - September), and water depth (≤45 m and >45 m). Data were described as percent frequency, percent by weight, and average dry weight of stomach contents (g) for each of these categories. Comparisons of reconstructed dry weights of forage fish per chinook salmon stomach among categories were based on a Kruskal-Wallis one-way ANOVA for k independent groups ($P \leq 0.05$).

An electivity index (Strauss 1979) was also used to examine forage-fish consumption by chinook salmon. The electivity index (L) is defined as $L = r_i - p_i$, where r_i is the proportion (by number) of forage fish in taxon i in the guts of the predators, and p_i is the proportion of the same taxon in trawl catches. The electivity index has these properties: 1) it ranges from -1 to +1, with positive values indicating preference and negative values indicating avoidance or inaccessibility; 2) its expected value for random, or opportunistic, feeding is zero under all conditions; and 3) it takes on extreme values only when a prey item is rare but consumed almost exclusively, or is very abundant but rarely consumed. When sample size of forage-fish species in the stomachs (n_r) and trawl catch (n_p) met the minimum number defined by

$$n_r \geq \frac{3}{r_i(1-r_i)} \quad \text{and} \quad n_p \geq \frac{3}{p_i(1-p_i)}$$

the null hypothesis tested was H_0: $L = 0$. When sample size was less than the required minimum, confidence limits were calculated by exact probability and the hypothesis tested was H_0: $r_i = p_i$. Diet data were stratified by season over years 1991-93, as were trawling data. Trawling was discontinued after mid-June 1993, so diet data collected only during May and June 1993 were included in the electivity index calculation. Trawl data used included only those length groups of each forage-fish species actually found in the diet of the chinook salmon length class for which the electivity index was calculated. A major assumption of the electivity index is that the species composition of forage fish in the trawl catch is proportional to that in the population, and representative of what is available to predators. Because chinook salmon are pelagic feeders (Olson et al. 1988), mid-water trawl samples probably best represent the forage population available to and fed upon by chinook salmon. Bottom trawls, on the other hand, sample the benthic zone where chinook salmon are not known to feed extensively. Bottom trawl catches were dominated in all years by bloater (63-99% across all samples). Alewife and smelt accounted for approximately equal, but smaller, portions of the bottom trawl catch (<1-23%) in all seasons and years. Only electivity indices calculated from mid-water trawl data are presented in this report.

Results

Forage availability

Forage availability varied across seasons and among years. Alewife were the most abundant forage in mid-water trawl samples in 1991, with peak numbers occurring in summer when alewife accounted for 76% of the fish sampled (Figure 1). Smelt were second in abundance to alewife, and bloater were least abundant, making up less than 1% of the mid-water trawl catch in all seasons. In 1992 and 1993, alewife were less abundant in trawl samples than in 1991, while percent frequency of smelt and bloater increased (Figure 1). Bloater abundance in trawl samples peaked in spring 1993 (61% of catch) whereas smelt abundance was highest in summer 1992 (54%).

General diet

Forage fish, including alewife, bloater, smelt, unidentified fish remains, and unidentified larval fish, were the most important food group numerically for all size classes of chinook salmon. Fish were observed in 29-59% of chinook salmon stomachs examined (Figure 2); stomachs of more medium chinook salmon than small and large chinook salmon contained fish in all years. Empty stomachs were also observed in a large proportion (32-58%) of sampled chinook salmon. Non-fish food items generally were of minor numerical importance (<25% of stomachs), but were most frequently observed in stomachs of small chinook salmon (Figure 2).

Predator size

When summer was used as an index period (sampling was conducted in all years during June-August), average dry weight of stomach contents comprised of three primary forage fish (alewife, bloater, and smelt combined) increased with increasing chinook salmon size, from 0.8 g for small chinook salmon to 6.5 g for large chinook salmon (Table 2). Average dry weight of alewife also increased with increasing chinook salmon size, but weight of bloater and smelt was highest for medium chinook salmon. Alewife was the primary forage for small and large chinook salmon (67% and 75% of diet by weight; Table 2). Medium chinook salmon consumed primarily bloater (58% by weight); alewife made up 33% of the diet for this size class of chinook salmon. Small chinook salmon consumed a significant percentage of smelt (21% by weight), but smelt made up only a small portion (<10%) of the diet of chinook salmon >37 cm long (Table 2).

The length distribution of the prey-fish species in chinook salmon diets, when compared to the length distribution of fish collected in mid-water trawls, showed distinct size selectivity by chinook salmon for alewife, bloater, and smelt. Small chinook salmon consumed a higher proportion of smaller alewife, whereas large chinook salmon consumed alewife over a wide length range, with larger alewife occurring in greater diet proportion than their abundance in the trawl catch (Figure 3). Length distributions of bloater and smelt in the diet of chinook salmon followed patterns similar to those observed for alewife diet items, although for bloater in the diet of small chinook salmon and smelt in the diet of large chinook salmon too few prey were collected to construct length frequencies.

Interannual variation in diet

Consumption of two of the three major forage fish species (alewife and smelt) varied significantly across years for small and medium chinook salmon, but not for large chinook salmon (Kruskal-Wallis, $P<0.05$). Bloater were not a major food item in the diet of small chinook salmon in any year (20% or less by weight; Figure 4), and the mean dry weight of bloater in the diet of medium and large chinook salmon did not vary significantly among years ($P>0.05$).

For samples collected during the summer index period, mean reconstructed dry weight of alewife in the diet of small chinook salmon decreased from 0.86 g in 1991 to 0.48 g in 1992, and 0.31 g in 1993 ($P<0.05$). Percent (by weight, g) of alewife in the diet of small chinook salmon followed a similar pattern, declining to 46% in summer 1993 (Figure 4). Mean dry weight of alewife in the diet of medium chinook salmon also declined from 1991 (1.31 g) to 1993 (1.02 g; $P<0.05$), as did percent of alewife by weight (Figure 5). No statistically significant difference in mean weight of alewife in the diet of large chinook salmon occurred among years (Figure 6). Consumption of smelt by the three length classes of chinook salmon was generally low. However, percent of smelt in the diet during the summer index period increased in 1993 in all length classes and significantly so for small

(Figure 4) and medium (Figure 5) chinook salmon.

Seasonal variation in diet

Alewife predominated in the diet of small chinook salmon in all seasons (Figure 4). Seasonal species composition in the diet of medium and large chinook salmon generally switched from alewife in the spring to larger proportions of bloater in the summer and fall (Figures 5 and 6). Smelt were consumed in greatest quantities by small and medium chinook salmon, primarily during spring and summer.

The diet/mid-water trawl electivity index showed no statistical preference by small chinook salmon for any of the three major forage-fish species in the spring ($P > 0.05$; Figure 7). During summer, the electivity index indicated a strong preference for alewife, random feeding on bloater, and an avoidance of smelt. For medium chinook salmon, the mid-water trawl index indicated a preference for bloater in all three seasons (Figure 7). Smelt and alewife were in all seasons either avoided or eaten only in proportion to their abundance in mid-water trawls. Large chinook salmon showed a preference for alewife in mid-water during spring and summer, and a shift to bloater in the fall (Figure 7). Smelt appeared to be avoided by or inaccessible to large chinook salmon; the electivity index was always significantly less than zero ($P \leq 0.05$).

Water depth

Species composition of forage fish in the diet of chinook salmon was significantly different between fish collected in water less than 45 m deep and greater than 45 m deep for both small and medium chinook salmon (Kruskal-Wallis, $P < 0.05$; Table 3). The mean dry weight of smelt in the diet of small chinook salmon collected in shallow water was significantly greater than that for fish collected in deep water (0.27 g versus 0.02 g). For medium chinook salmon, the mean dry weight of alewife in the diet of fish collected in water greater than 45 m deep was significantly greater than for fish collected in water less than 45 m deep (1.09 g versus 0.90 g), while chinook salmon in shallow water consumed more bloater than did fish in deep water (2.80 g versus 1.71 g; Table 3). Water depth had no significant influence on diet of large chinook salmon.

Disease status

The percentage of BKD-infected chinook salmon declined from May (24.1%, all years combined) to September (5.7%; Table 4); this trend was most apparent in 1992. In addition, the percentage of empty stomachs decreased from May (78%) to August-September (26%; Table 5). Over all months, 83% of stomachs from BKD-infected chinook salmon were empty, as compared to 42% for BKD-free chinook salmon. More BKD-positive chinook salmon had empty stomachs in all months except July (Table 5), whereas BKD-negative chinook salmon had more non-empty stomachs in four of five months for which sampling was conducted.

Discussion

Chinook salmon in this study consumed primarily a mix of alewife, bloater, and smelt, consistent with earlier findings (Kogge 1985, Jude et al. 1987, Elliott 1993). Kogge (1985) and Elliott (1993) reported that chinook salmon diets also contained yellow perch and small quantities of trout perch, shiners, sculpins *Cottus spp*., and sticklebacks *Gasterosteus aculeatus*, depending on region and season. These other forage species were absent from salmon diets in this study, even though they all occur in the study area. Perhaps the abundance of alewife, bloater, and smelt in the study area buffered other forage species from predation by salmon (Jude et al. 1987). Alternatively, the difference may be due to differences in sampling location among the various studies. Although a limited number of prey species were used by chinook salmon sampled in the current study, significant temporal and spatial influences were observed on diet of three size classes of chinook salmon.

We observed significant changes in diet of chinook salmon with increasing size. Small chinook salmon consumed insects and other invertebrate food items to a greater extent than large fish, but the majority of their diet was still fish. Small chinook salmon ate primarily alewife but also made significant use of smelt, while the most important diet item for medium chinook salmon was bloater. However, by the time chinook salmon reached a size of 58 cm, they were consuming mainly alewife (>75% by weight). We observed distinct size selectivity by these three sizes of chinook salmon for alewife, bloater, and smelt, but some disagreement exists concerning the extent to which chinook salmon are size-selective predators. Based on an analysis of prey total length frequencies similar to the analysis we conducted, Jude et al. (1987) concluded that salmonines in Lake Michigan selected larger sizes of alewife and smelt. However, the degree of selectivity varied seasonally; selectivity for large prey items was strongest in spring for smelt and in summer for alewife. Two other studies of salmonine diets (Diana 1990, Elliott 1993) reported little evidence for selection of prey by length. However, these studies made comparisons based on regression analysis or comparison of average prey lengths; size distribution of prey consumed is probably a more relevant measure to use in determining selectivity (Diana 1990).

Seasonal and year-to-year variation in diet was most pronounced for small and medium chinook salmon; diet diversity for these groups generally was highest in summer and increased from 1991 to 1993, possible due to changes in forage availability during this time period. This finding is similar to results reported in earlier studies. Jude et al. (1987) observed that the diet of large chinook salmon is generally less diverse than that of smaller fish. Diana (1990) observed a decline from spring through summer in the percentage of alewife in salmonine diet from Lake Huron. Increased diversity in the diet of smaller fish can probably be explained based on morphological and energetic constraints. Smaller salmon are forced to feed on smaller, more diverse food items due to gape limitations and smaller items come closer to meeting their energetic requirements. The increase in diet diversity in summer, as compared to spring and fall, may be the result of young-of-year prey fish becoming available to predators at this time (Elliott 1993).

Partitioning of spatial, temporal, and food resources can lead to segregation of salmonine species in the Great Lakes (Olson et al. 1988). In this study, chinook salmon less than 58 cm in length exhibited significant differences in use of forage when collected from two different depths. Salmon collected in water less than 45 m deep tended to make use of a greater variety of forage fish, whereas fish collected in deeper water ate primarily alewife. Large salmon in both areas fed primarily on alewife. The difference in diet of smaller salmon collected in shallow water may have reflected availability of forage rather than differences in prey preference; electivity of salmon for smelt in near-shore waters was consistently negative, even though the diet of this group consisted of up to 40% smelt by weight. Although few spatial differences existed in diet of larger salmon (those normally taken by the sport fishery in near-shore waters), results of diet studies conducted using only these larger, angler-caught fish should not be extrapolated to small chinook salmon from either near-shore or offshore populations.

Strauss' (1979) electivity index was used in describing diet and selection of prey by chinook salmon. This index assumes that the species composition of forage fish in prey samples (in this case trawl catch) is proportional to that in the forage population, and representative of what is available to predators. Although mid-water trawl samples most accurately represented the forage population for these purposes, some problems were also involved with using this gear. The sometimes patchy distribution of forage fish in the water column made them difficult to find and sample; catches were highly variable (0-25 kg) and catches of a kilogram or less were not uncommon. No instruments were attached to the trawl to record the depth at which the trawl was being towed, so data are not available concerning the precise spatial relationship between forage fish and salmonine predators in the water column. This lack of consistency in sampling location could bias results in a number of ways. For example, if a trawl sample was taken at a depth below the target depth and distribution of bloater was biased toward deeper samples, chinook salmon electivity for bloater might be underestimated. Methods for determining prey fish abundance and species composition are continuously being refined (hydroacoustic sampling, remote control of trawl depth) and this improved technology will allow for increasingly accurate estimates of electivity, both spatially and by size classes of salmonines.

Chinook salmon in east-central Lake Michigan demonstrated the ability to make use of forage other than alewife. However, the effects of diet changes on growth and survival of chinook salmon have not been fully investigated. Growth of age 0.1 chinook salmon has decreased in recent years, while growth of age 0.3 and 0.4 chinook salmon has increased (Wesley 1996), but it is difficult to separate the effects of forage, disease, and chinook salmon density on growth rates. Beyond influences on chinook salmon, a reduction in alewife may have negative implications for other Lake Michigan sport fish species, especially given the continued foraging pressure exerted by chinook salmon. Alternatively, reductions in alewife abundance may have positive implications for reproduction by lake trout (Jones et al. 1995, Krueger et al. 1995) and other Lake Michigan species. Future research should focus not only on the impacts of a shift in diet on growth and angler harvest of chinook salmon, but also on the potential effects of changes in forage fish abundance, coupled with varying chinook salmon foraging strategies, on other Lake Michigan species. Additionally, future diet studies of Great Lakes salmonines need to consider temporal (including time of day) and spatial variables. A diet study which relies on a sport fishery as the sole source of data has inherent biases (Diana 1990). If the fishery is highly seasonal, tends to fish primarily either near-shore or offshore, and is size selective for its target species, then the diet data collected will not accurately reflect consumption rates or prey composition for the entire population.

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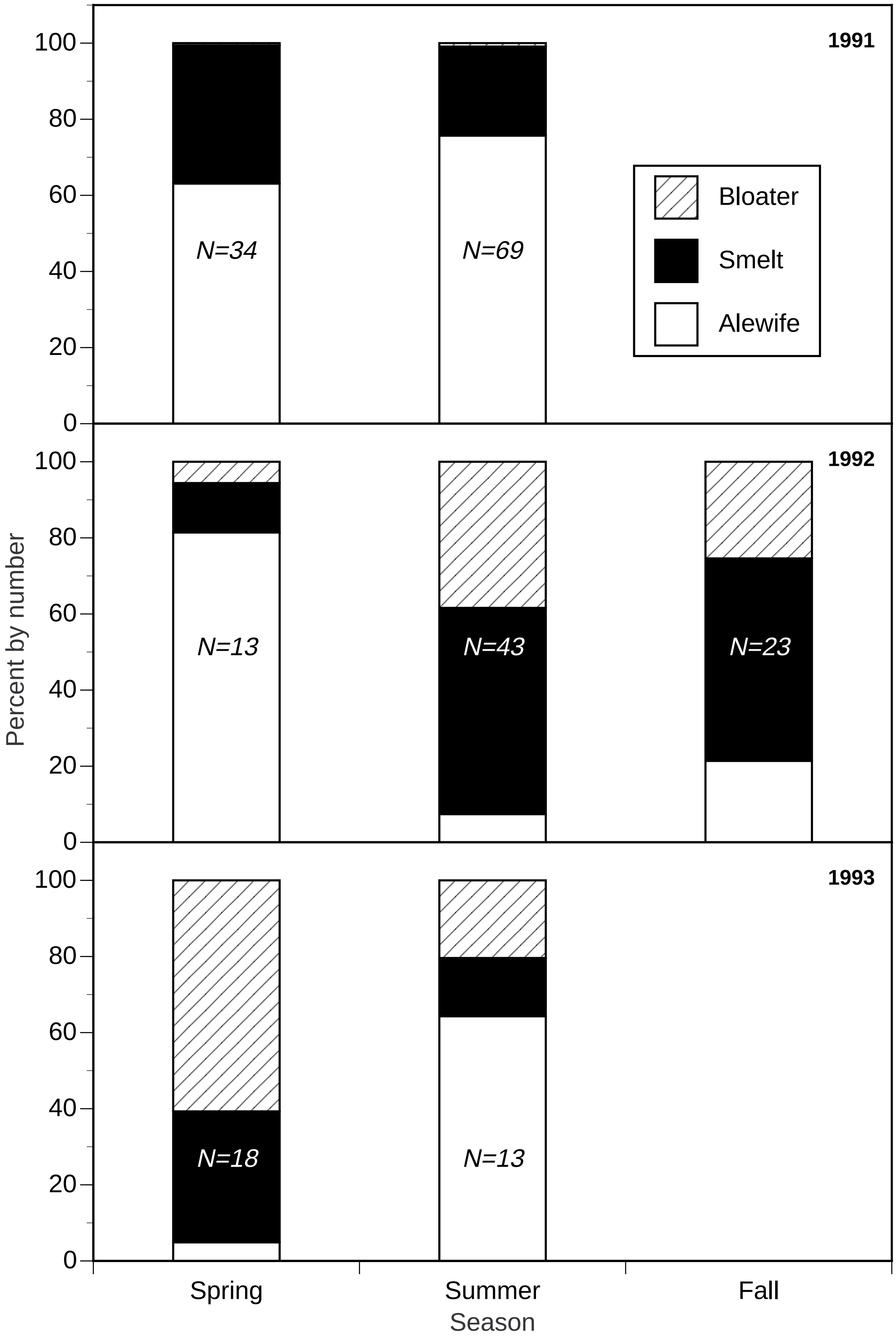

Figure 1.—Percent composition by number of three prey-fish species in mid-water trawl samples. *N* is the number of trawl samples collected in each season and year combination.

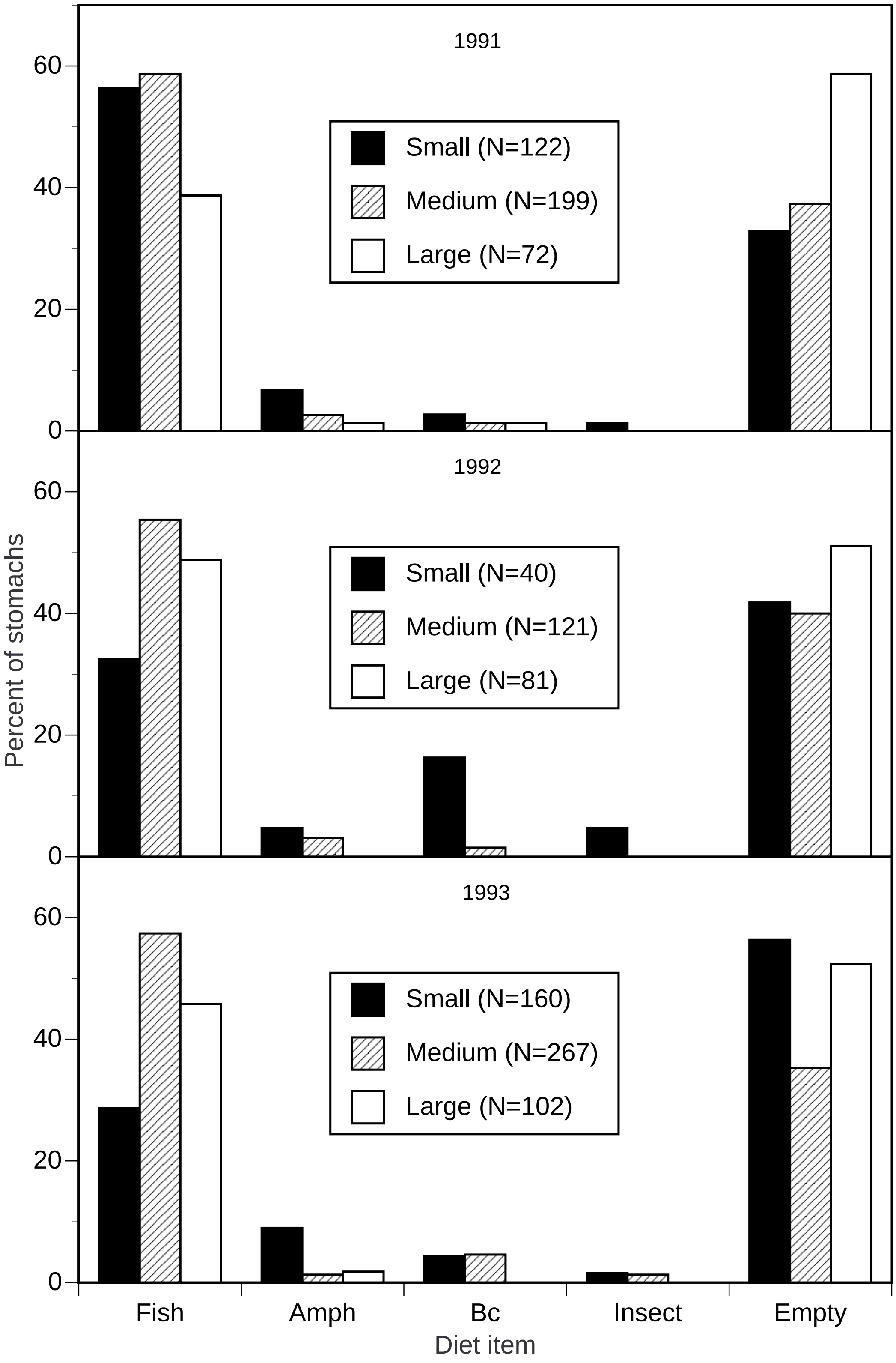

Figure 2.—Percent frequency of stomachs containing four diet items (fish, amphipods, *Bythotrephes cederstroemi*, and terrestrial insects) for three size classes (small, medium, large) of chinook salmon by year collected. Percent of empty stomachs is also shown. *N* is the number of fish of each size class sampled in each year.

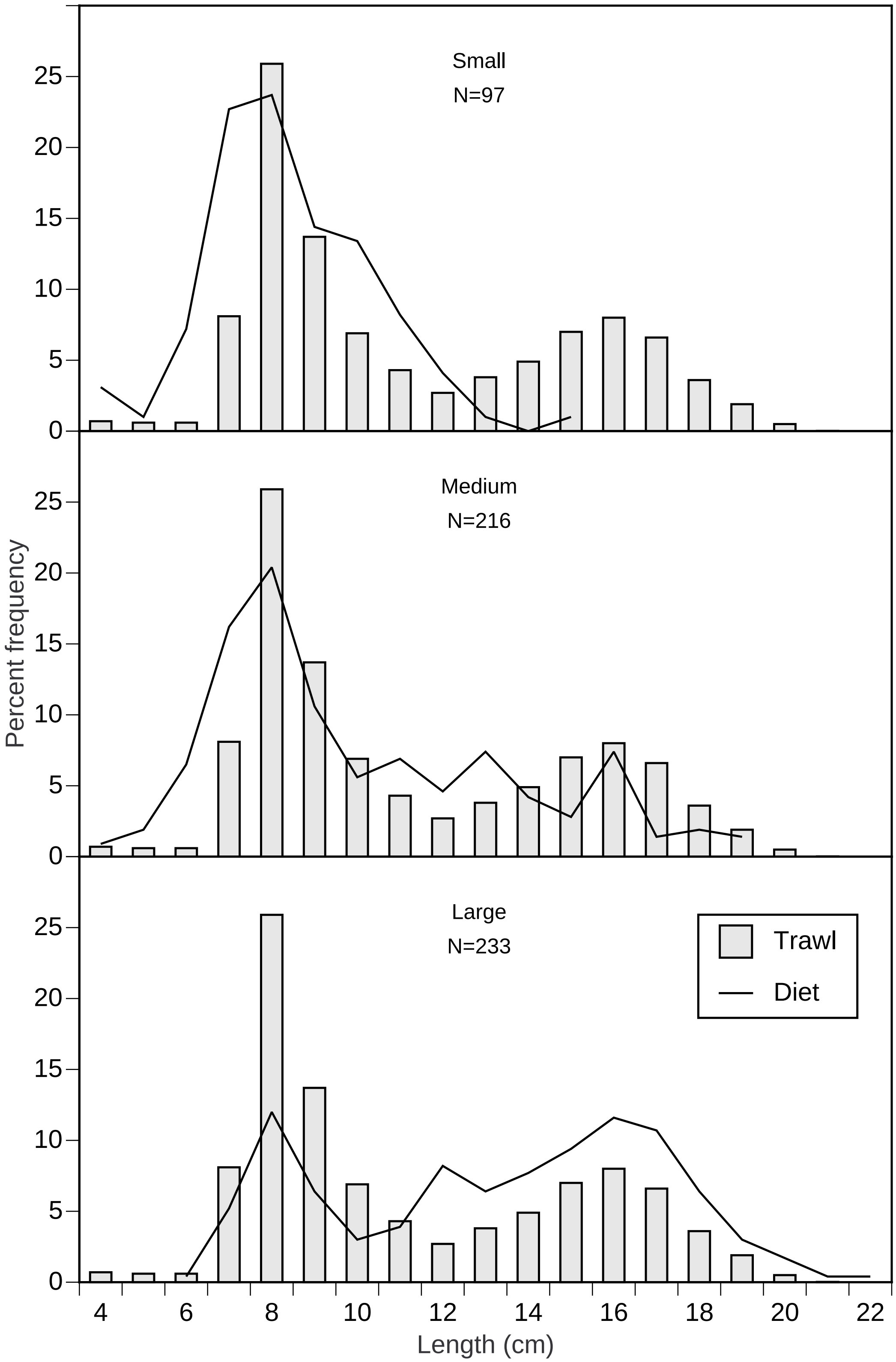

Figure 3.—Length (total length, cm) frequency of alewife in mid-water trawl samples and in the diet of three size classes (small, medium, and large) of chinook salmon. *N* is the number of alewife measured from the diet of each size of salmon. The trawl length frequency is based on a sample of 5,826 alewife.

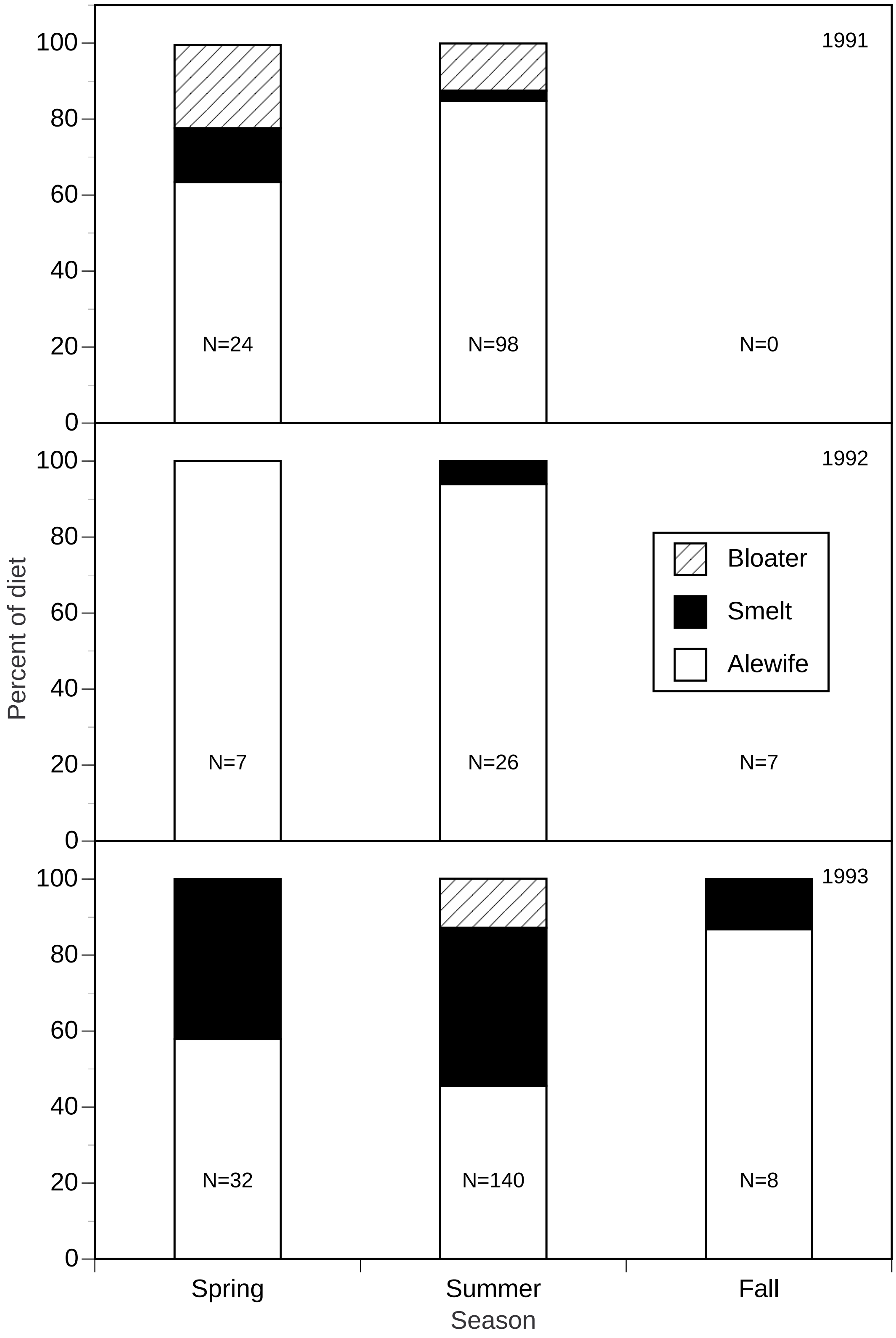

Figure 4.—Diet (percent by weight, g) of small (<38 cm) chinook salmon during three seasons in Lake Michigan. Spring is the month of May, summer is June through August, and fall is the month of September. *N* is the number of chinook salmon sampled in each season and year combination. Chinook salmon collected in fall 1992 had not eaten bloater, smelt, or alewife.

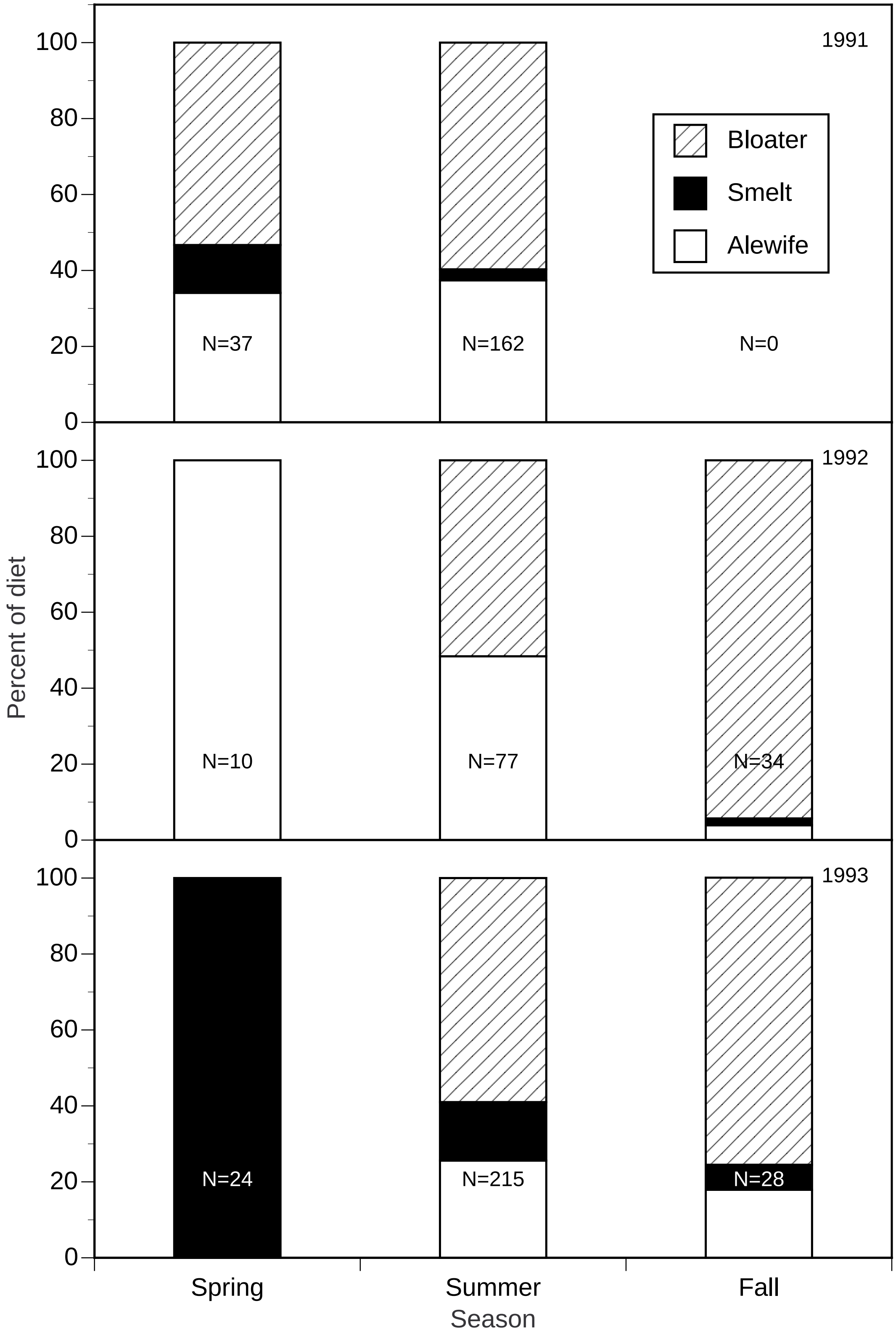

Figure 5.—Diet (percent by weight, g) of medium (<38-57 cm) chinook salmon during three seasons in Lake Michigan. Spring is the month of May, summer is June through August, and fall is the month of September. *N* is the number of chinook salmon sampled in each season and year combination.

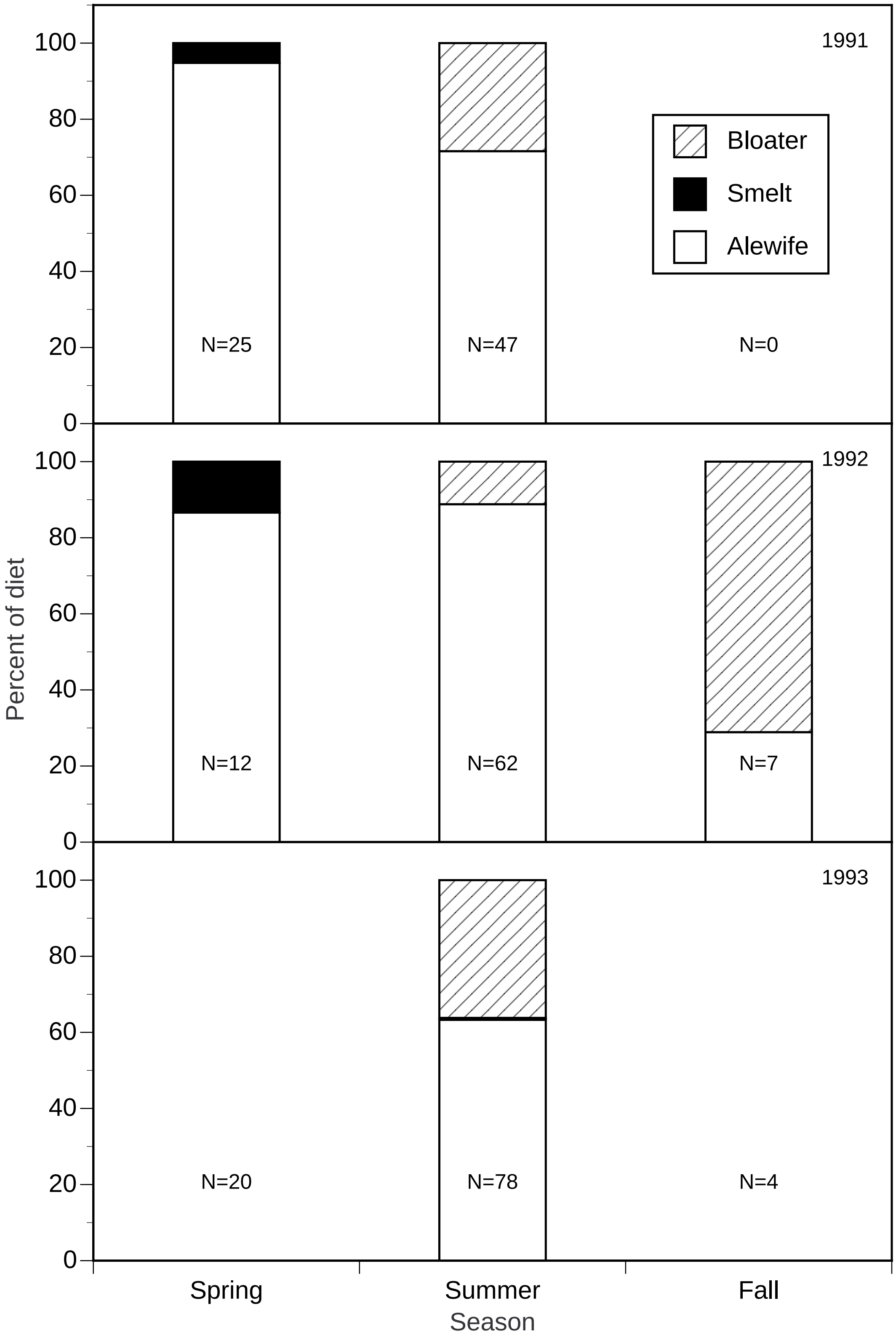

Figure 6.—Diet (percent by weight, g) of large (>57 cm) chinook salmon during three seasons in Lake Michigan. Spring is the month of May, summer is June through August, and fall is the month of September. *N* is the number of chinook salmon sampled in each season and year combination. Chinook salmon collected in spring and fall 1993 had not eaten bloater, smelt, or alewife.

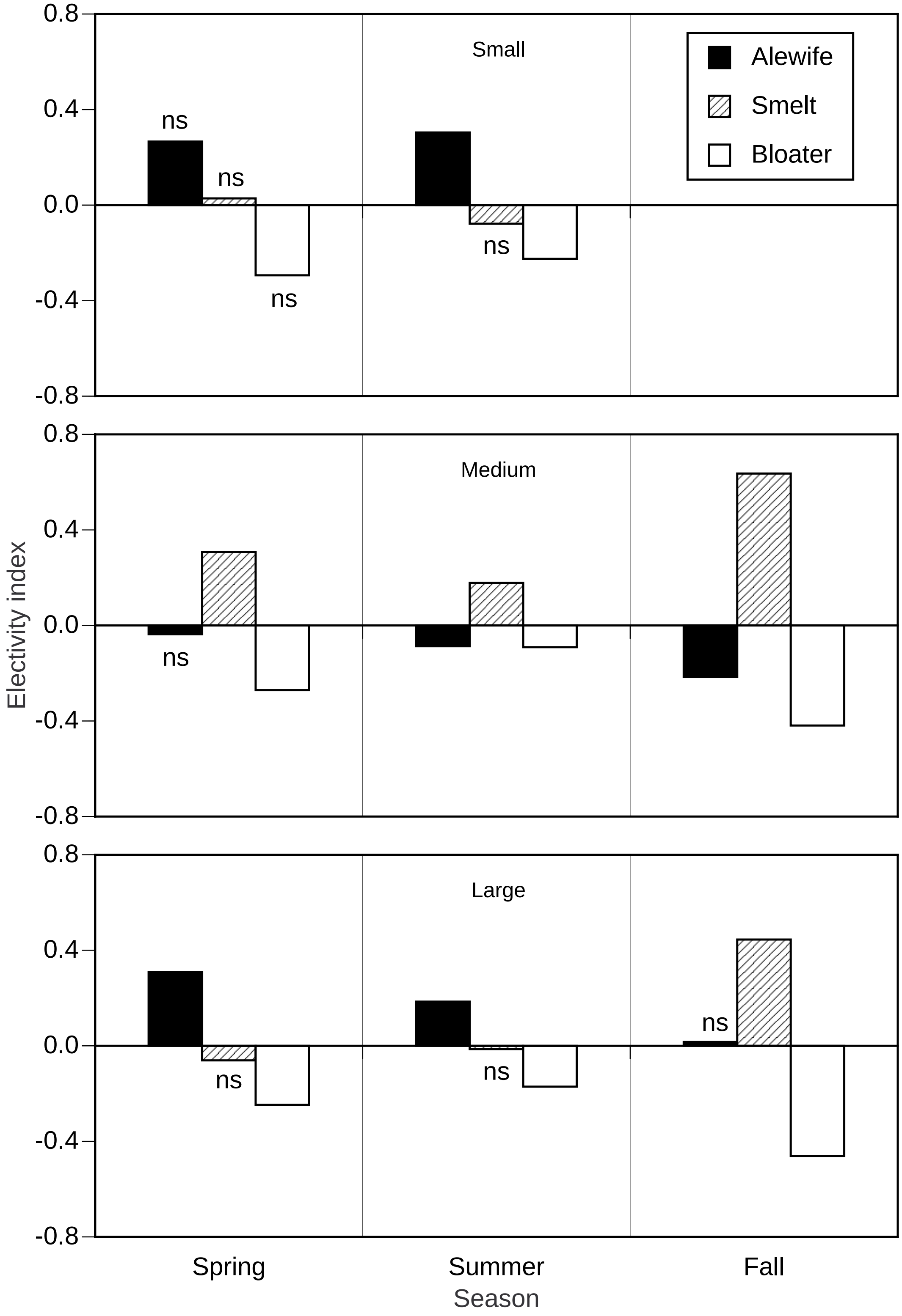

Figure 7.—Electivity by three size classes (small, medium, and large) of chinook salmon for three species of prey fish. Indices are based on mid-water trawl samples. Values marked “ns” are not significantly different from zero. Spring is the month of May, summer is June through August, and fall is the month of September.

Table 1.–Linear regression models for converting caudal vertebrae length (X) to predicted total length (Y), and predicted total length to dry weight (W) of alewife, bloater, and smelt from Lake Michigan.

Forage species	Regression model	
	Total length (Y_{mm})	Dry weight (W_g)
Alewife	$Y_{mm} = 3.31 + 23.86\ X_{mm}$ (r^2=0.94, P<0.05, N=38)	$\ln(W_g) = -9.77 + 2.28 \ln(Y_{mm})$ (r^2=0.80, P<0.05)
Bloater	$\ln(Y_{mm}) = 3.78 + 0.21\ X_{mm}$ (r^2=0.96, P<0.05, N=44)	$\ln(W_g) = -16.61 + 3.67 \ln(Y_{mm})$ (r^2=0.89, P<0.05)
Smelt	$Y_{mm} = 0.78 + 26.43\ X_{mm}$ (r^2=0.97, P<0.05, N=60)	$\ln(W_g) = -16.82 + 3.63 \ln(Y_{mm})$ (r^2=0.97, P<0.05)

Table 2.–Percent by weight and average dry weight per stomach (g) of three forage species consumed by three sizes of chinook salmon. Chinook salmon were sampled in the Ludington-Pentwater area of Lake Michigan during summer (June-August) 1991-93. N is the number of chinook salmon sampled in each size class.

Chinook salmon size	N	Forage species Alewife %	 Alewife Dry weight	 Bloater %	 Bloater Dry weight	 Smelt %	 Smelt Dry weight	 Combined %	 Combined Dry weight
Small	265	67.2	0.5	11.9	0.1	20.9	0.2	100	0.8
Medium	458	32.6	1.2	58.3	2.1	9.1	0.3	100	3.6
Large	187	75.2	4.9	24.6	1.6	0.2	<0.1	100	6.5

Table 3.–Average dry weight (g) of chinook salmon stomach contents by salmon size class (small, medium, large) and forage species. Chinook salmon were collected in two water depth strata (≤45 m and >45 m). N is the number of chinook salmon sampled in each size class and water depth combination.

		Forage species		
Water depth	N	Alewife	Bloater	Smelt
			Small	
≤45 m	170	0.37	0.08	0.27
>45 m	172	0.56	0.07	0.02
			Medium	
≤45 m	316	0.90	2.80	0.29
>45 m	271	1.09	1.71	0.27
			Large	
≤45 m	125	4.87	0.73	0.06
>45 m	130	3.74	2.13	0.06

Table 4.–Percent frequency of bacterial kidney disease in chinook salmon sampled from Lake Michigan in the Ludington-Pentwater area, by month and year. Total number of chinook salmon sampled is shown in parentheses.

Month sampled	Year			
	1991	1992	1993	All years
May	20.9 (86)	27.6 (29)	26.3 (76)	24.1 (191)
June	12.7 (191)	16.1 (93)	17.5 (189)	15.3 (473)
July	17.2 (29)	2.5 (40)	11.9 (67)	10.3 (136)
August	1.0 (98)	3.1 (32)	17.3 (179)	10.6 (309)
September	– (0)	0.0 (48)	12.5 (40)	5.7 (88)
All months	11.9 (404)	10.3 (242)	17.6 (551)	14.2 (1,197)

Table 5.–Percent frequency of empty stomachs for chinook salmon testing positive and negative for bacterial kidney disease (BKD), by month, 1990-93. Number of chinook salmon sampled is shown in parentheses.

Month sampled	BKD status	
	Positive	Negative
May	97.8 (46)	71.7 (145)
June	88.7 (71)	47.8 (391)
July	42.9 (14)	44.3 (122)
August	66.7 (33)	22.1 (276)
September	80.0 (5)	22.9 (83)
All months	82.8 (169)	41.8 (1,017)

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