# Comparing trophic position of freshwater fish calculated using stable nitrogen isotope ratios ($\delta^{15}N$) and literature dietary data

**M. Jake Vander Zanden, Gilbert Cabana, and Joseph B. Rasmussen**

**Abstract**: Stable nitrogen isotope ratios ($\delta^{15}N$) are commonly used to represent the trophic structure of aquatic systems, yet the ability of $\delta^{15}N$ to indicate the trophic position of aquatic consumers remains untested using traditional dietary methods. Interpreting the $\delta^{15}N$ of aquatic consumers relative to large, long-lived primary consumers such as unionid mussels provides a continuous measure of an organism's trophic position that adjusts for among-system variation in baseline $\delta^{15}N$. We used this method to estimate the trophic position of eight littoral fish species from 36 lakes in Ontario and Quebec. We validated these $\delta^{15}N$ measures of trophic position by compiling literature dietary data from 342 populations of these same fish species and calculated a continuous measure of trophic position for each population. Mean dietary trophic position estimates corresponded closely to $^{15}N$ estimates, with mean trophic position ranging from 3.3 for pumpkinseed (*Lepomis gobbosus*) to 4.4 for walleye (*Stizostedion vitreum*). Both methods indicated approximately one trophic level of variation among populations of a species. This study confirms the ability of baseline-adjusted $\delta^{15}N$ to represent the trophic position of aquatic consumers.

**Résumé** : Les rapports d'un isotope stable de l'azote ($\delta^{15}N$) sont couramment utilisés pour représenter la structure trophique des systèmes aquatiques; pourtant, la capacité du $\delta^{15}N$ d'indiquer la position trophique des consommateurs aquatiques n'a pas encore été testée employant des méthodes alimentaires traditionnels. L'interprétation de $\delta^{15}N$ des consommateurs aquatiques par rapport aux consommateurs primaires de grande taille et de longue durée de vie comme les moules de la famille des unionidés fournit une mesure continue de la position trophique d'un organisme qui s'ajuste pour tenir compte de la variation intersystèmes de $\delta^{15}N$ de base. Nous avons utilisé cette méthode pour estimer la position trophique de huit espèces de poissons littoraux dans 36 lacs du Québec et de l'Ontario. Nous avons validé ces mesures de position trophique par $\delta^{15}N$ en rassemblant, dans la documentation scientifique, les données sur le régime alimentaire de 342 populations de ces mêmes espèces de poisson et avons calculé une mesure continue de la position trophique de chacune de ces populations. La valeurs estimées de la position trophique alimentaire moyenne correspondaient étroitement aux valeurs estimées de $^{15}N$, la position trophique moyenne variant de 3,3 pour le crapet-soleil (*Lepomis gobbosus*) à 4,4 pour le doré jaune (*Stizostedion vitreum*). Les deux méthodes ont indiqué une variation d'environ un niveau trophique entre les populations d'une même espèce. Cette étude confirme la capacité du $\delta^{15}N$ ajusté en fonction de la ligne de base de représenter la position trophique des consommateurs aquatiques.
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## Introduction

Accurate representation and description of trophic relationships are essential to a wide range of ecological studies. The concept of discrete trophic levels is commonly used in ecological studies and has been used successfully in studies predicting contaminant bioaccumulation in top predators (Rasmussen et al. 1990; Cabana et al. 1994). Furthermore, trophic levels provide the framework for studies of cascading trophic interactions (Carpenter et al. 1985; Wooton and Power 1993) and ecological energetics and efficiencies (Lindeman 1942; Kerr and Martin 1970). The food chain approach contrasts with food web studies, which focus on the complexity of trophic relationships in nature (Sprules and Bowerman 1988). Although food web studies recognize and quantify important attributes such as omnivory, cannibalism, and reciprocal predation (Sprules and Bowerman 1988; Polis 1991), designation of "trophic linkages" is a subjective process that fails to consider the energetic importance of the represented trophic connections (Paine 1988).

Food chains and food webs represent extreme endpoints of models used to represent trophic relationships; both approaches have the potential to misrepresent the pathways of mass transfer and energy flow through ecosystems (Murdoch 1966; Kling et al. 1992; Vander Zanden and Rasmussen 1996). Use of a continuous measure of trophic position (analogous to the concept of "realized" trophic structure of Kling et al. (1992)) provides energetically based representations of trophic relationships (Levine 1980). Trophic position calculations weigh trophic connections according to their relative energetic importance, thereby serving as a compromise between discrete food chain and food web models (Vander Zanden and Rasmussen 1996). This general approach has been successfully applied to modelling of mercury (Cabana and Rasmussen

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1994) and polychlorinated biphenyls (Vander Zanden and Rasmussen 1996) bioaccumulation in aquatic food webs.

A continuous measure of an organism's trophic position can be obtained in two ways. The dietary approach uses estimates of the trophic position of prey organisms and volumetric stomach content data, preferably for large numbers of fish. Weighted averages are then used to calculate a continuous measure of the population's trophic position (Winemiller 1990; Vander Zanden and Rasmussen 1996). A second approach relies on the consistent enrichment of the stable nitrogen isotope, $^{15}$N (3.4 ± 0.3‰) between prey and predator (Minagawa and Wada 1984; Owens 1987; Peterson and Fry 1987; Cabana and Rasmussen 1994), allowing its use as a measure of an organism's trophic position that accounts for omnivory (Cabana and Rasmussen 1994). Previous comparative stable isotope – food web studies have been complicated by among-system variation in the $^{15}$N signatures characterizing primary producers at the base of the food web. Cabana and Rasmussen (1996) overcame this problem by measuring an organism's $^{15}$N ratios ($\delta^{15}$N) relative to the lake-specific $\delta^{15}$N signature of commonly occurring primary consumers such as unionid mussels. This provides a continuous measure of an organism's trophic position amenable to comparative, multisystem studies of trophic structure.

The objective of this study was to verify $\delta^{15}$N as a measure of trophic position for a series of littoral freshwater fish species. We calculated the trophic position of eight species of freshwater fish using dietary data and $^{15}$N and compared the mean and variation in trophic position estimates attained using the two techniques. Previous studies have attempted to verify the $\delta^{15}$N measure of trophic position using within-system comparisons between dietary data and $\delta^{15}$N (Wainright et al. 1993) and attributed discrepancies to the inability of dietary data to represent temporal variation in feeding and errors in trophic position estimates of prey items. Our comparison differs in that it relies on dietary trophic position estimates for 342 fish populations and $\delta^{15}$N estimates from 113 fish populations from 36 lakes. Although the actual fish populations for our two methods do not overlap, the large sample sizes provide a robust comparison of these two measures of trophic position and serve as a test of the $\delta^{15}$N measure of trophic position recently proposed by Cabana and Rasmussen (1996).

## Materials and methods

### Dietary analysis and trophic position calculations

Dietary data for adults of eight common eastern North American game fish species were collected from literature sources: northern pike (*Esox lucius*), chain pickerel (*Esox niger*), rock bass (*Ambloplites rupestris*), pumpkinseed (*Lepomis gibbosus*), smallmouth bass (*Micropterus dolomieu*), largemouth bass (*Micropterus salmoides*), yellow perch (*Perca flavescens*), and walleye (*Stizostedion vitreum*). Data for northern pike and chain pickerel were pooled due to the small number of lakes with chain pickerel and the similar ecology, morphology, and feeding behavior of these species (Scott and Crossman 1973). These eight species were chosen because of the abundance of dietary data in the literature and because we have stable isotope estimates of trophic position for these same species from a large number of lakes.

Although the degree of taxonomic detail of prey categories in the published studies was highly variable, it was usually possible to separate prey items into the following categories: fish, zooplankton, omnivorous zoobenthos, predatory zoobenthos, mollusks, crayfish, detritus/plants/debris, and others (includes mammals, birds, and amphibians and unidentified materials). For the two highly piscivorous species, northern pike and walleye, the fish component was further subdivided to species where data permitted.

Diet data expressed as the percent contribution of a prey item to total gut volume were used for this study (also reported as percentage of dry or wet weight). Data reported in the "percentage of total number of prey organisms" format were converted to percentage of total volume using prey weight values from the dietary study, or mean values from literature reports of invertebrate prey weight (Cummins and Wuycheck 1971; Driver et al. 1974; Smock 1980; Lawrence et al. 1987). Data expressed as "percent frequency of occurrence" were not utilized in this study due to the potential error accompanying conversion of dietary data into a volumetric format.

When data for adult and juvenile fish were reported separately, only adult fish were retained for analysis; division of data in the published sources according to fish size, age, month, season, depth, and time of day was averaged for each year and treated as a single observation. When possible, data for multiple years from a lake were treated as separate observations, as a year roughly corresponds to the period of time for which an adult fish's diet is integrated using $^{15}$N (Hesslein et al. 1993). The fish dietary data set contained 342 lake–year observations for a total of 65 987 individual fish. The average diet (percent volumetric contribution of each of the previously mentioned prey categories) was calculated for each fish species.

Calculation of "trophic position" of a fish population required estimating the trophic position of prey organisms. We define primary producers as trophic level "1", primary consumers as trophic level "2", and so on. Since specific trophic interactions among invertebrate organisms remain poorly understood, the simplest possible assumptions concerning the trophic position of prey were used in this study (Table 1). Prey items known to be predominantly predatory were assigned values of 3.0; strictly herbivorous prey were assigned values of 2.0. Prey items known to be omnivorous, such as zooplankton and most orders of aquatic insect larvae, were assigned an intermediate trophic position value of 2.5, for lack of information about their realized trophic position. For piscivorous fish, northern pike and walleye, trophic position was calculated in two ways. One used all the available dietary data and assigned all fish prey items to trophic level 3.5. The second approach used only data where the fish components of their diets were further broken down to species.

Clearly, a limitation of this dietary approach is that we must assume and simplify trophic interactions at lower levels of the food web. Although the trophic positions of prey items do vary within systems and through time, our large sample sizes would cause any errors associated with these assumptions to remain constant among the fish species included in this study. Following Winemiller (1990) and Vander Zanden and Rasmussen (1996), the fish dietary data from each lake and the trophic position estimates for prey items were used to calculate trophic position for each fish population using the formula

$$T_a = \Sigma(V_i \cdot T_i) + 1 \quad (1)$$

where $T_a$ = mean trophic position of the *a*th predator population, $V_i$ = volumetric contribution of the *i*th prey item, and $T_i$ = trophic position of the *i*th food item. Although prey items may have been represented by discrete trophic level estimates, this weighted average calculation generates a continuous, fractional measure of trophic position for each fish population. The large number of populations included in this study permits a reliable estimate of the average trophic position for each species, as well as the degree of among-system variability in trophic position for each species.

### $^{15}$N calculation of trophic position

Adult individuals of these eight fish species were collected from 36 lakes (113 fish populations) in Ontario and Quebec and were analyzed for $\delta^{15}$N using a Europa Tracermass mass spectrometer (Cabana and

**Table 1.** Estimated trophic position values for prey items used in dietary calculations of trophic position.

| Prey category | Estimated trophic position | Includes |
|---|---|---|
| Fish | 2.5 | Cyprinids |
| | 3.0 | Alewife[a] |
| | 3.2 | Whitefish,[a] cisco[a] |
| | 3.3 | Centrarchids |
| | 3.5 | Suckers, trout, burbot, white bass, unidentified fish, others |
| | 3.7 | Yellow perch, trout-perch,[a] stickleback,[a] smelt,[a] sculpins[a] |
| Zooplankton | 2.5 | Cladocera, Copepoda, Ostracoda, Rotifera |
| Omnivorous zoobenthos | 2.5 | Tricoptera, Ephemeroptera, Plecoptera, Hemiptera, Coleoptera, Diptera, Oligochaeta, Amphipoda (*Gammarus* sp., *Hyalella* sp., *Diporia hoyi*, *Mysis relicta*), other unidentified insect larvae and benthic invertebrates |
| Predatory zoobenthos | 3.0 | Odonata, Hirudinea, Megaloptera |
| Molluscs | 2.0 | Gastropoda, Pelecypoda |
| Crayfish | 3.0 | Decapoda |
| Detritus | 1.0 | Detritus, plants, mud |
| Other | 2.5 | Amphibians, mammals, waterfowl, unidentified materials |

[a] Trophic position estimated using dietary data (from Vander Zanden and Rasmussen 1996).

Rasmussen 1996). These N isotopic values alone cannot be considered to represent trophic position, since the $\delta^{15}$N of primary producers (defined as organisms that convert inorganic N to organic N) are highly variable among systems (Kling et al. 1992; Kline et al. 1993; Cabana and Rasmussen 1996) and within systems through time (Toda and Wada 1990; Gu et al. 1994; Cabana and Rasmussen 1996). This necessitates that the isotopic signature of fish be measured relative to a lake-specific "baseline" $\delta^{15}$N signature. Cabana and Rasmussen (1996) interpreted fish $\delta^{15}$N relative to unionid mussels. These relatively large and long-lived primary consumer organisms integrate temporal variability in primary producer $\delta^{15}$N, thereby representing the average baseline $\delta^{15}$N signature. Unionid mussel $\delta^{15}$N ($n$ = 1–9 mussels per lake) were measured for each of the 36 study lakes. A continuous measure of trophic position (corresponding to the dietary estimates of trophic position) was calculated for each fish population using the formula

(2) $$\text{Trophic position} = [(\text{fish } \delta^{15}\text{N} - \text{mussel } \delta^{15}\text{N})/3.4] + 2$$

where 3.4 represents a 1.0 trophic level increment in $\delta^{15}$N.

## Results

### Dietary estimates of trophic position

The raw dietary data compiled for this study are presented in Appendix I. These data were summarized by calculating the average diet (percentage of total stomach volume ± 1 SD) for each species (Table 2). The summary results of the average diets of these fish are generally consistent with previous reports of the diets characterizing these species. Nearly 40% of the average diet of pumpkinseed consisted of mollusks. Fifty-three percent of yellow perch prey consisted of zoobenthos, of which more than 10% were identified as amphipods. Rock bass consumed 42% benthic invertebrates and 32% crayfish. The diet of smallmouth bass consisted of 37% fish, 28% zoobenthos, and 28% crayfish. Fifty percent of the average diet of largemouth bass consisted of fish prey. Both northern pike and walleye consumed about 85% fish. More detailed analysis of the fish components of the diets of northern pike and walleye (Appendix II) shows that walleye consume 29% yellow perch and only 8% cyprinids. Walleye diet also shows major contributions from smelt, trout-perch, and centrarchids. Northern pike consumed a broader range of prey, consuming similar amounts of yellow perch and cyprinids (13% each).

Species exhibit a mean dietary trophic position estimate ranging from 3.3 to 4.4 (Fig. 1). Pumpkinseed exhibit the lowest average dietary trophic position value of 3.3, while yellow perch and rock bass average 3.7; these three species tend to be centered between what are considered (in the classical food chain sense) secondary and tertiary consumers. Smallmouth bass and largemouth bass exhibit intermediate trophic position values averaging approximately 4.0, making them tertiary consumers. The piscivores, northern pike and walleye, both exhibit trophic position estimates of 4.35 when all the available dietary data are considered, and all fish prey are assigned to trophic level 3.5. When the data are limited to include only piscivore populations for which fish prey are identified to species, the average trophic position estimate of walleye remains the same, while that of northern pike drops by 0.07 trophic level.

### $\delta^{15}$N estimates of trophic position

Average unionid mussel $\delta^{15}$N values (reported by lake) and estimates of mean trophic position for each fish population in this study are presented in Appendix III. Seventy-eight percent of the variance in individual mussel $\delta^{15}$N signatures is explained by the lake variable. Furthermore, the species of mussel did not vary significantly with mussel $\delta^{15}$N (ANOVA; $p < 0.05$). Trophic position estimates were generally similar to those determined using dietary methods, with average values ranging from 3.38 in pumpkinseed to 4.40 in walleye.

The mean $\delta^{15}$N trophic position estimates (± 1 SD) are directly compared with the mean dietary estimates of trophic position for each species (Fig. 1; Table 3). The two measures of trophic position are in close correspondence ($\delta^{15}$N trophic position = 0.78 × dietary trophic position + 0.81; $r^2 = 0.78$). Northern pike are the only outlier, as northern pike gut content data indicate a mean trophic position value nearly 0.4 trophic level higher than the $\delta^{15}$N trophic position estimate.

### Among-population variability in trophic position

Both dietary and isotopic evidence indicates relatively high levels of among-population variability, as seen in frequency histograms of dietary and $\delta^{15}$N trophic position values (Fig. 2). The total range of trophic position among all species spans roughly two complete trophic levels. Trophic position also varies greatly among populations of a given species. The range in trophic position for a given species is about one trophic level for each of our study species; the degree of among-population variation is similar for dietary and isotopic estimates of trophic position. The observed among-population variation in trophic

**Table 2.** Mean dietary data for littoral fish species included in this study.

| Species | *n* lakes | *n* fish | Fish | Zoop | Ben | Pred ben | Mol | Cray | Det | Other |
|---|---|---|---|---|---|---|---|---|---|---|
| Pumpkinseed | 27 | 2 000 | 0.0 | 1.6 | 36.2 | 5.6 | 39.9 | 1.3 | 5.5 | 9.7 |
| Yellow perch | 91 | 8 075 | 17.2 | 13.6 | 53.9 | 4.3 | 2.3 | 4.4 | 0.8 | 3.1 |
| Rock bass | 25 | 1 962 | 10.0 | 3.0 | 42.2 | 2.8 | 1.7 | 31.2 | 2.1 | 6.4 |
| Smallmouth bass | 79 | 3 162 | 37.6 | 2.0 | 28.8 | 1.2 | 0.1 | 27.3 | 0.7 | 2.3 |
| Largemouth bass | 21 | 5 664 | 53.3 | 4.9 | 11.0 | 9.3 | 0.0 | 10.6 | 1.9 | 8.6 |
| Northern pike and chain pickerel | 67 | 34 738 | 84.1 | 0.0 | 3.5 | 2.5 | 0.0 | 7.8 | 0.2 | 1.9 |
| Walleye | 32 | 10 386 | 83.3 | 2.0 | 10.7 | 0.5 | 0.0 | 2.5 | 0.2 | 0.8 |
| Total | 342 | 65 987 | | | | | | | | |

**Note**: Zoop, zooplankton; Ben, zoobenthos; Pred ben, predatory zoobenthos; Mol, molluscs; Cray, crayfish; Det, detritus; Other, unidentified material, mammals, amphibians, birds.

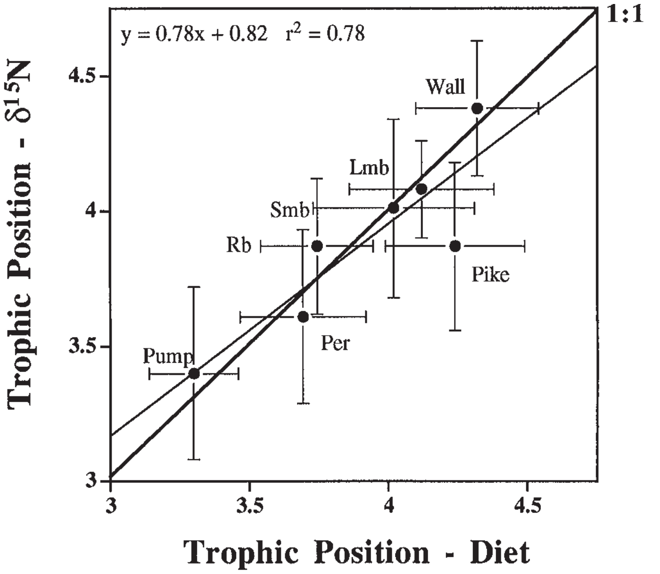


**Fig. 1.** Comparison of mean trophic position estimates of the species included in this study, calculated using dietary and $\delta^{15}N$ methods. Error bars represent 1 SD. The bold diagonal line represents the 1:1 line.

position causes a high degree of overlap in trophic position of littoral fish species.

The distribution and variation of trophic position values calculated using the two different methods correspond quite closely. Using diet data, 1 SD in trophic position averages 0.23 trophic level (range 0.11–0.28 trophic level), while for $\delta^{15}N$ estimates, 1 SD averages 0.29 trophic level (range 0.18–0.34 trophic level).

## Discussion

### Role of $^{15}N$ in food web studies

The application of $\delta^{15}N$ as a tracer of an organism's trophic position eliminates many of the problems encountered when using diet data to estimate trophic position. Use of $\delta^{15}N$ represents the major energy flow pathways at lower trophic levels, offers a time-integrated measure of the organism's trophic position, accounts for temporal and spatial variation in feeding at multiple levels of the food web, and detects trophic interactions that are otherwise "unobservable", as gut contents can differ from the material actually assimilated by an organism.

Although use of $\delta^{15}N$ is increasingly common as a tracer of trophic relationships, the N isotopic signature of primary producers is highly variable among systems (Kling et al. 1992; Kline et al. 1993; Cabana and Rasmussen 1996) and within systems through time (Toda and Wada 1990; Gu et al. 1994; Cabana and Rasmussen 1996). As a result, $\delta^{15}N$ should reflect an organism's trophic position for single-system studies (see Hobson and Welsh 1992; Wainright et al. 1993), but the applicability of $\delta^{15}N$ as an absolute measure of trophic position (or food chain length) for comparative studies is limited because the isotopic signature of baseline organisms (phytoplankton and bacteria, which transform inorganic N into organic N) is highly variable and can be mistakenly interpreted as variation in trophic structure (Kidd et al. 1995; Wainright et al. 1996). Cabana and Rasmussen (1996) used mussel $\delta^{15}N$ signatures to correct for variability in average baseline $\delta^{15}N$ signatures. These relatively large, long-lived primary consumer organisms filter-feed on phytoplankton and bacteria in the water column (Silverman et al. 1995) and thereby serve as integrators of temporal variation in the baseline N isotopic signature. Measurement of an organism's $\delta^{15}N$ relative to that of a unionid allows a continuous measure of the organism's trophic position suitable for among-system comparisons.

Using simple and uniform assumptions, we test the $\delta^{15}N$ method by comparing the average trophic position of eight common species of fish estimated from N isotope data with estimates obtained from a large fish dietary database. The close correspondence between the estimates of trophic position based on $\delta^{15}N$ and those based on dietary data supports the validity of the isotope approach to the study of food chains proposed by Cabana and Rasmussen (1996). Although diet and $\delta^{15}N$ give corresponding estimates of average trophic position, the many advantages of $\delta^{15}N$ analysis (see above) make it a preferable measure of trophic position or food chain length for aquatic consumers. Understanding of trophic relationships is enhanced through complementary use of baseline-corrected $\delta^{15}N$ and gut content evidence. $\delta^{15}N$ is used to quantify an organism's trophic position, while diet data, although subject to error when calculating trophic position for individual communities, reveal specifically which taxa are involved in feeding interactions.

### Concept of trophic position

The prevalence of omnivory and the complexity of natural food webs suggest than neither discrete food chain nor connectance food web approaches will adequately represent the pathways

**Table 3.** Mean trophic position for each species of fish, 1 SD of the mean trophic position, range of trophic position values, and number of fish populations, calculated using dietary and $\delta^{15}$N methods.

| | Dietary | | | | $\delta^{15}$N | | | |
|---|---|---|---|---|---|---|---|---|
| Species | Mean trophic position | SD | Range | *n* lakes | Mean trophic position | SD | Range | *n* lakes |
| Pumpkinseed | 3.30 | 0.16 | 3.0–3.52 | 27 | 3.38 | 0.33 | 2.81–4.15 | 19 |
| Yellow perch | 3.69 | 0.23 | 3.45–4.47 | 91 | 3.61 | 0.33 | 2.99–4.33 | 28 |
| Rock bass | 3.74 | 0.20 | 3.45–4.08 | 25 | 3.87 | 0.27 | 3.45–4.43 | 14 |
| Smallmouth bass | 4.02 | 0.29 | 3.46–4.50 | 79 | 4.02 | 0.34 | 3.55–4.73 | 15 |
| Largemouth bass | 4.12 | 0.26 | 3.55–4.49 | 21 | 4.08 | 0.18 | 3.87–4.41 | 7 |
| Northern pike | 4.31 (4.24)[a] | 0.22 | 4.15–4.51 | 67 | 3.87 | 0.32 | 3.38–4.51 | 20 |
| Walleye | 4.33 (4.35)[a] | 0.25 | 3.91–4.50 | 32 | 4.40 | 0.24 | 4.09–4.86 | 10 |

[a] Values in parentheses are mean trophic position estimates calculated only from populations where fish prey were identified to species.

of energy flow and mass transfer in aquatic ecosystems (Vander Zanden and Rasmussen 1996). The use of a continuous measure of trophic position attempts to strike a balance between food web approaches, which fail to weigh trophic connections according to their energetic importance, and linear food chain approaches, which ignore the omnivory and complexity that characterize ecosystems (Vander Zanden and Rasmussen 1996). Thus, trophic position quantifies, as a continuous variable, how many times the biomass consumed by an organism has been metabolically "processed" within the food chain since inorganic molecules have been first synthesized into organic compounds. Species with the same trophic position can be pooled into trophic guilds, which serve as functional groupings analogous to the trophic level, the difference being that they assume noninteger trophic position values (Vander Zanden and Rasmussen 1996). Note also that although a trophic guild includes organisms with similar trophic positions, members of a trophic guild may have different prey and different ecological niches within a food web (e.g., benthic versus pelagic predators). Use of stable C isotope ratios augments N isotope trophic position evidence by serving as a means of discriminating between benthic and pelagic sources of production (Hecky and Hesslein 1995).

### Patterns in trophic position

The range in trophic position values is approximately one trophic level among populations of each of the study species. This within-species variability in trophic position can be attributed to one of two factors: highly flexible and opportunistic feeding of these fish species (Dill 1983) or variation in trophic position of prey organisms. Although this variation is likely a combination of the two sources, determining the relative importance of these sources of variation would require measurement of the trophic position of organisms situated lower in the food chain. Furthermore, our estimate of the variation accompanying mean dietary trophic position values is conservative, since it fails to account for the unknown variation in the trophic position of prey items.

Previous evidence (Rasmussen et al. 1990; Cabana and Rasmussen 1994; Vander Zanden and Rasmussen 1996) has shown that the presence/absence of pelagic forage fish and *Mysis relicta* are determinants of the trophic position of lake trout. However, the complexity of littoral food webs and the lack of presence/absence data for potential prey items make it impossible to follow a similar approach in the exploration of littoral aquatic food webs. The variability and unpredictability in trophic position among populations as shown by the $\delta^{15}$N data presented here indicate that knowledge of the trophic position of a given population does not necessarily represent that of other populations of the same species. This is clearly shown by our trophic position data calculated from $\delta^{15}$N where species can switch their trophic position from lake to lake (Appendix III). For example, smallmouth bass occupies a higher trophic position (4.43) than northern pike (3.69) by about 0.75 trophic level in Lake Mazinaw, but the respective trophic positions of these two species are essentially reversed in Lake Doré (trophic positions of 3.91 and 4.41 for smallmouth bass and northern pike, respectively). The impact of the presence of a particular predator on a lake community will therefore vary from lake to lake. As a result, relying on simple assumptions stereotyping the feeding ecology of a predator species will undermine our ability to predict its impact on a particular food web.

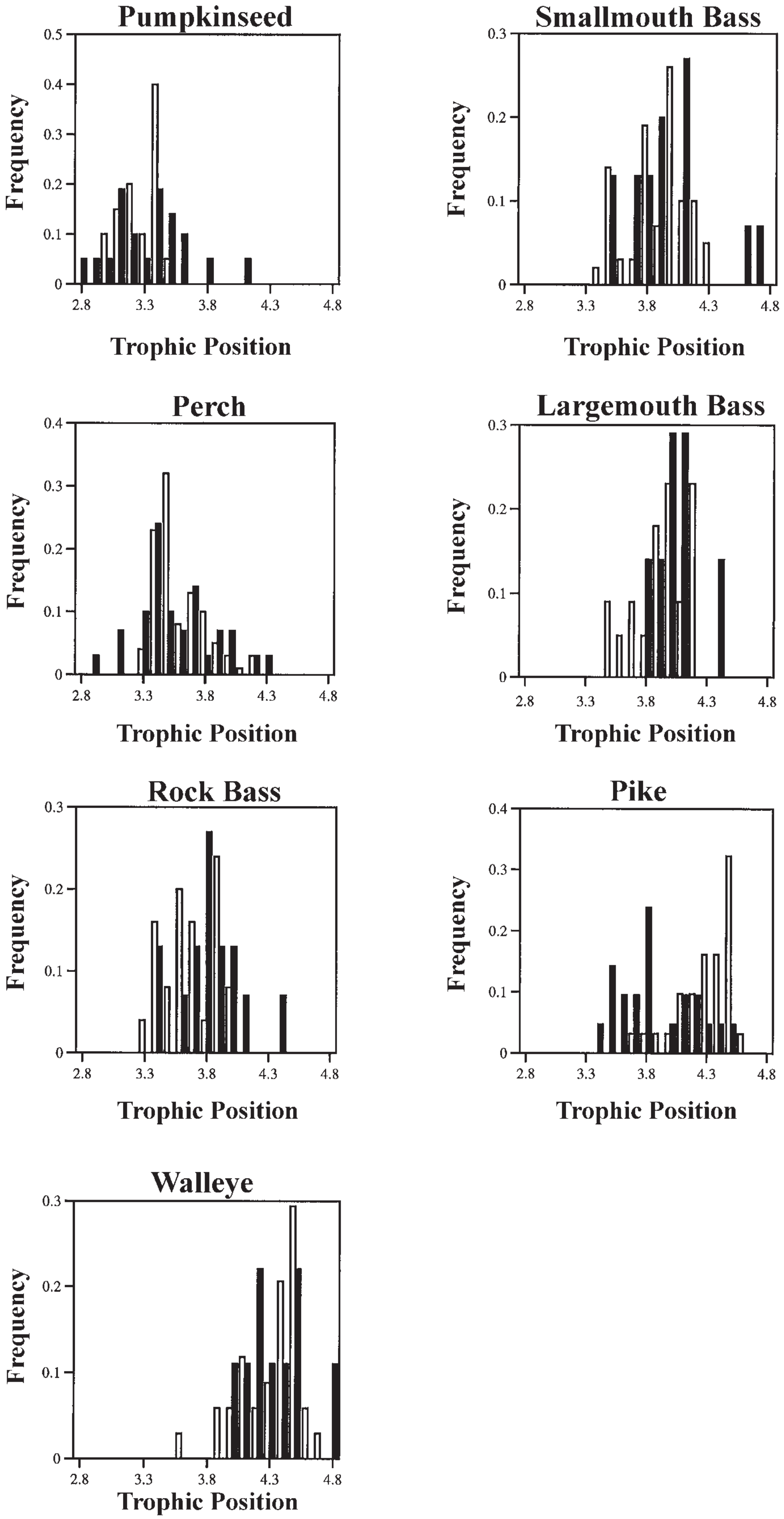
### Dietary versus isotopic approaches

Although we report a close correspondence between dietary and $\delta^{15}$N estimates of trophic position, certain limitations of the dietary approach need to be considered. One limitation is that dietary trophic position estimates require assumptions of the trophic position of prey items, thereby introducing a source of error in fish trophic position. Our estimate of 2.5 as the trophic position of zooplankton prey contrasts with Sprules and Bowerman (1988) who reported that North American zooplankton food webs have a modal food chain length varying from one to eight trophic levels (averaging between three and five trophic levels). Sprules and Bowerman (1988) tabulated food chain length without integrating omnivory into the food chain length estimate; inclusion of omnivory would result in shorter food chain length values, perhaps resembling values reported in this study.

Although our mean prey trophic position assumptions appear to be reasonable (since dietary and isotopic trophic position estimates correspond), trophic interactions among organisms at lower trophic levels remain unquantified, and may be characterized by high levels of variation. So although these assumptions appear adequate for broad-scale comparisons, as presented herein, dietary estimates of trophic position may be inadequate where detailed information for individual communities is required.

Another problem with direct comparison of dietary and $\delta^{15}$N estimates of trophic position involves the differences in the way the two methods integrate variation in trophic position.

**Fig. 2.** Proportional frequency distributions of lake-specific trophic position values for littoral fish, calculated using dietary data (open bars) and baseline-corrected $\delta^{15}N$ (solid bars).



$\delta^{15}N$ provides a relatively long-term and time-integrated measure of an organism's trophic position that also accounts for variation in feeding at lower trophic levels, in addition to the higher trophic levels. Use of dietary data provides a snapshot in time of an organism's diet, which certainly does not represent the average trophic position of a population over the year. Furthermore, when calculating trophic position using dietary data, the variability accompanying the trophic position of prey items, which would be compounded up the food chain, is not passed on to predators.

Comparison of gut content and $^{15}N$ estimates of trophic position on a lake-specific basis can only provide a robust test of $\delta^{15}N$ where a reliable dietary estimate of trophic position is available. But an accurate measure of trophic position for an individual population requires detailed gut content data for large numbers of fish, sampled throughout the year, a situation that is rare in dietary studies. We have overcome this problem by considering the mean trophic position of large numbers of populations, which serves to reduce the error that accompanies dietary trophic position estimates for any particular lake.

### Explaining the difference between $\delta^{15}N$ and dietary data for northern pike

Although $\delta^{15}N$ and dietary estimates of trophic position are in general agreement, dietary estimates for northern pike overestimate trophic position relative to $\delta^{15}N$. Determining specifically which fish taxa serve as prey of northern pike and walleye reveals the importance of yellow perch in the diet of walleye (29%) relative to northern pike (13%), while northern pike and walleye consume similar amounts of cyprinids. The high mean trophic position of yellow perch (3.7) relative to cyprinids (M.J. Vander Zanden, unpublished isotope data; DeVries and Stein 1992) may partially explain the discrepancy between $\delta^{15}N$ and dietary trophic position of northern pike.

But for studies that identify fish prey items to species, northern pike trophic position averages 4.24, compared with 4.31 when fish prey could not be further subdivided (Appendix II). The value 4.24 is in closer agreement with the $\delta^{15}N$ estimate of trophic position (3.87), although there still remains a 0.37 trophic level discrepancy between these two northern pike trophic position estimates. Breakdown of the fish prey category did not affect walleye dietary trophic position estimates (4.33 versus 4.35); gut content and $\delta^{15}N$ measures of trophic position remain in close agreement ($\delta^{15}N = 4.40$; diet = 4.35).

Although northern pike are reported to be benthic invertebrate feeders in many lakes (Chapman et al. 1989; Craig and Babaluk 1989; Chapman and Mackay 1990), these lakes were not included in this analysis because published data were presented as percent occurrence, which may not be reliably converted into a volumetric format. An effect of lake size is another possible explanation for the northern pike discrepancy. For our northern pike diet data set, lake size was positively correlated with northern pike trophic position (northern pike trophic position = 0.026(log lake area) + 4.21; $n = 36$, $p = 0.008$, $r^2 = 0.19$), and our northern pike diet study lakes tended to be larger than our $\delta^{15}N$ study lakes. Although the difference in trophic position of northern pike remains unresolved, lake-specific diet data – $\delta^{15}N$ comparisons could serve to resolve the discrepancies between the two measures of trophic position.

The presence of the additional trophic level for piscivorous fish species greatly complicates gut content trophic position estimates and introduces an additional source of error, since the trophic position of prey fish species must also be estimated. Although this was not a major problem in the simple and relatively linear pelagic systems leading to lake trout (Vander Zanden and Rasmussen 1996), estimating prey fish trophic position in the highly complex and species-rich littoral food webs becomes problematic. Although our designated trophic position estimates of littoral prey fish appear to approximate the average values for these items, our dietary calculations neglect the variation in prey trophic position, thereby underestimating the true degree of variation in average predator trophic position.

In summary, the stable isotope approach to measuring trophic structure has become widely used in ecology, offering the possibility of obtaining objective and repeatable measures of trophic position, food chain length, and omnivory (Kling et al. 1992; Hobson and Welsh 1992; Cabana and Rasmussen 1994). However, our ability to compare systems has been hampered by the problem of spatial and temporal variation in the $\delta^{15}N$ signatures at the base of the food web. Cabana and Rasmussen (1996) proposed the use of long-lived sedentary primary consumers such as unionid mussels to control for such baseline variation in $\delta^{15}N$ when calculating trophic position of consumers. The present study confirms the validity of this method by showing that $\delta^{15}N$-based estimates of trophic position in eight species of fish are strongly correlated with their trophic position estimated from dietary data.

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**Appendix I.** Study lake, location (State or Province), year, sample size, dietary data, trophic position, and data source.

| Lake | Location | Year | *n* fish | Prey category | | | | | | | | Trophic position | Reference[a] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Fish | Zoop | Ben | Pred ben | Mol | Cray | Det | Other | | |
| | | | | **Pumpkinseed (total *n* = 2000 fish)** | | | | | | | | | |
| 10 lakes | Maine | 1938 | 101 | 0.0 | 0.2 | 17.4 | 0.0 | 61.5 | 0.0 | 20.9 | 0.0 | 3.09 | 1 |
| Bassen | Michigan | 1977 | 50 | 0.0 | 0.0 | 34.5 | 16.1 | 28.8 | 0.0 | 0.0 | 21.0 | 3.44 | 3 |
| Deep | Michigan | 1977 | 50 | 0.0 | 0.0 | 29.9 | 0.0 | 17.4 | 0.0 | 0.0 | 53.0 | 3.42 | 3 |
| Dowsley Pond | Ontario | 1987 | 280 | 0.0 | 0.0 | 62.8 | 15.3 | 16.7 | 0.0 | 0.0 | 5.0 | 3.49 | 4 |
| Hamilton | Michigan | 1977 | 50 | 0.0 | 0.0 | 1.8 | 0.1 | 58.9 | 0.0 | 0.0 | 39.0 | 3.20 | 3 |
| Little Cataraqui Cr. | Ontario | 1990 | 187 | 0.0 | 12.8 | 62.2 | 6.2 | 14.1 | 0.0 | 1.9 | 2.9 | 3.45 | 5 |
| Long | Minnesota | 1962 | 8 | 0.0 | 0.0 | 17.8 | 4.4 | 77.7 | 0.0 | 0.0 | 0.0 | 3.13 | 6 |
| Maple | Minnesota | 1957 | 367 | 0.0 | 0.0 | 39.0 | 0.0 | 49.0 | 0.0 | 3.5 | 9.5 | 3.25 | 7 |
| Opinicon | Ontario | 1987 | 280 | 0.0 | 4.7 | 13.3 | 5.3 | 71.3 | 0.0 | 0.0 | 5.3 | 3.17 | 4 |
| Opinicon | Ontario | 1966 | 103 | 0.0 | 3.7 | 57.7 | 21.3 | 12.3 | 2.3 | 0.0 | 0.0 | 3.52 | 8 |
| Shaw | Michigan | 1977 | 50 | 0.0 | 0.0 | 0.2 | 0.0 | 99.7 | 0.0 | 0.0 | 0.0 | 3.00 | 3 |
| Sieverson | Minnesota | 1962 | 66 | 0.0 | 0.0 | 16.9 | 3.9 | 79.2 | 0.0 | 0.0 | 0.0 | 3.12 | 6 |
| Sister | Michigan | 1972 | 65 | 0.0 | 3.9 | 40.9 | 4.6 | 28.8 | 0.0 | 5.0 | 16.7 | 3.35 | 9 |
| Squaw | Minnesota | 1962 | 25 | 0.0 | 0.0 | 42.6 | 3.0 | 33.5 | 20.3 | 0.0 | 0.6 | 3.45 | 6 |
| Tuckahoe Creek | Virginia | 1958 | 35 | 0.0 | 0.2 | 79.1 | 0.0 | 0.0 | 0.0 | 20.7 | 0.0 | 3.40 | 10 |
| U. Poole Pond | Ontario | 1987 | 280 | 0.0 | 2.0 | 46.3 | 14.3 | 29.3 | 0.0 | 0.0 | 8.0 | 3.43 | 4 |
| Winona | Wisconsin | 1940 | 3 | 0.0 | 0.0 | 52.3 | 0.0 | 0.0 | 0.0 | 41.6 | 4.0 | 3.26 | 11 |
| Mean | | | | 0.0 | 1.6 | 36.2 | 5.6 | 39.9 | 1.3 | 5.5 | 9.7 | 3.30 | |
| | | | | **Yellow perch (total *n* = 8075 fish)** | | | | | | | | | |
| 10 lakes | Maine | 1938 | 30 | 71.6 | 1.2 | 15.7 | 0.8 | 0.0 | 0.0 | 10.7 | 0.0 | 4.17 | 1 |
| 7 lakes | Maine | 1941 | 78 | 78.3 | 0.3 | 6.2 | 14.8 | 0.3 | 0.0 | 0.1 | 0.0 | 4.36 | 1 |
| Alle | Wisconsin | 1931 | 3 | 0.0 | 0.0 | 100.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 3.50 | 12 |
| Arbor | Wisconsin | 1931 | 8 | 0.0 | 0.0 | 89.5 | 0.0 | 0.0 | 0.0 | 0.0 | 9.0 | 3.48 | 12 |
| Brome | Quebec | 1984 | 17 | 0.0 | 0.0 | 97.0 | 0.0 | 3.0 | 0.0 | 0.0 | 0.0 | 3.48 | 13 |
| Bromont | Quebec | 1984 | 34 | 14.3 | 2.6 | 53.0 | 25.8 | 0.0 | 0.0 | 0.0 | 4.2 | 3.77 | 13 |
| Brompton | Quebec | 1984 | 34 | 26.5 | 0.0 | 69.7 | 0.3 | 3.5 | 0.0 | 0.0 | 0.0 | 3.75 | 13 |
| Cedar | Michigan | 1941 | 112 | 80.7 | 12.0 | 7.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 4.31 | 14 |
| Clear | Wisconsin | 1931 | 13 | 11.0 | 0.0 | 86.5 | 0.0 | 0.0 | 0.0 | 1.5 | 0.0 | 3.59 | 12 |
| Clear | Wisconsin | 1932 | 7 | 6.0 | 6.0 | 80.0 | 0.0 | 3.0 | 5.0 | 0.0 | 0.0 | 3.57 | 12 |
| Crane | Wisconsin | 1932 | 11 | 10.5 | 0.0 | 85.5 | 0.0 | 0.0 | 0.0 | 0.0 | 4.0 | 3.61 | 12 |
| Crystal | Wisconsin | 1931 | 9 | 56.5 | 2.0 | 33.0 | 0.0 | 0.0 | 0.0 | 0.0 | 8.0 | 4.06 | 12 |

**Appendix I** (*continued*).

| | | | *n* | Prey category | | | | | | | | Trophic | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Lake | Location | Year | fish | Fish | Zoop | Ben | Pred ben | Mol | Cray | Det | Other | position | Reference[a] |
| Cub | Michigan | 1974 | 201 | 24.5 | 1.8 | 37.8 | 27.0 | 2.5 | 0.0 | 0.0 | 6.0 | 3.86 | 15 |
| D'Argent | Quebec | 1984 | 34 | 0.0 | 11.2 | 86.2 | 0.0 | 1.6 | 0.0 | 0.9 | 0.0 | 3.49 | 13 |
| Drolet | Quebec | 1984 | 17 | 0.0 | 19.1 | 76.9 | 3.3 | 0.7 | 0.0 | 0.0 | 0.0 | 3.51 | 13 |
| Erie | Ohio | 1971 | 436 | 21.4 | 14.2 | 48.9 | 0.0 | 0.0 | 0.0 | 0.0 | 15.5 | 3.71 | 16 |
| Erie | Ohio | 1983 | — | 4.0 | 37.0 | 59.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 3.54 | 17 |
| Erie | Ohio | 1984 | — | 14.5 | 53.6 | 31.9 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 3.65 | 17 |
| Erie | Ohio | 1985 | — | 7.8 | 34.9 | 57.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 3.58 | 17 |
| Erie | Ohio | 1983 | 8 | 3.0 | 28.0 | 59.0 | 0.0 | 10.0 | 0.0 | 0.0 | 0.0 | 3.48 | 18 |
| Erie | Ohio | 1984 | 20 | 16.0 | 58.0 | 23.0 | 0.0 | 3.0 | 0.0 | 0.0 | 0.0 | 3.65 | 18 |
| Erie | Ohio | 1985 | 13 | 5.0 | 43.0 | 48.0 | 0.0 | 4.0 | 0.0 | 0.0 | 0.0 | 3.53 | 18 |
| Western Basin (Erie) | Ohio | 1981 | 82 | 19.6 | 53.9 | 23.4 | 0.0 | 3.2 | 0.0 | 0.0 | 0.0 | 3.68 | 19 |
| Geneva | Wisconsin | 1921 | 19 | 5.3 | 40.0 | 40.0 | 0.0 | 0.0 | 0.0 | 0.0 | 15.0 | 3.56 | 20 |
| Hertel | Quebec | 1984 | 17 | 0.0 | 13.5 | 80.8 | 0.0 | 5.7 | 0.0 | 0.0 | 0.0 | 3.47 | 13 |
| Houghton | Michigan | 1939 | 78 | 24.6 | 6.0 | 69.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 3.75 | 21 |
| Houghton | Michigan | 1940 | 267 | 69.1 | 1.8 | 27.8 | 1.3 | 0.0 | 0.0 | 0.0 | 0.7 | 4.21 | 21 |
| Saginaw Bay (Huron) | Ontario | 1956 | 241 | 12.0 | 23.0 | 48.0 | 0.0 | 6.0 | 0.0 | 0.0 | 11.0 | 3.59 | 22 |
| Little Minnow | Ontario | 1970–75 | 312 | 10.0 | 5.0 | 22.0 | 40.0 | 0.0 | 8.0 | 0.0 | 15.0 | 3.84 | 23 |
| Long | Wisconsin | 1931 | 98 | 5.0 | 43.5 | 37.5 | 0.0 | 0.0 | 0.0 | 0.0 | 15.0 | 3.57 | 12 |
| Magog | Quebec | 1984 | 17 | 0.0 | 0.6 | 83.8 | 0.0 | 8.2 | 7.4 | 0.0 | 0.0 | 3.50 | 13 |
| Maple | Minnesota | 1957 | 97 | 49.0 | 0.0 | 40.0 | 0.0 | 1.5 | 0.0 | 0.0 | 10.0 | 3.99 | 7 |
| Massawippi | Quebec | 1984 | 17 | 0.0 | 11.4 | 60.0 | 26.0 | 2.6 | 0.0 | 0.0 | 0.0 | 3.62 | 13 |
| Memphramagog | Quebec | 1984 | 34 | 8.0 | 1.7 | 86.1 | 3.4 | 0.8 | 0.0 | 0.0 | 0.0 | 3.59 | 13 |
| Muskellunge | Wisconsin | 1931 | 207 | 48.0 | 14.0 | 20.0 | 0.0 | 2.0 | 1.0 | 6.0 | 9.5 | 3.95 | 12 |
| Muskellunge | Wisconsin | 1932 | 375 | 17.5 | 15.5 | 39.1 | 0.0 | 5.0 | 0.0 | 1.0 | 21.0 | 3.63 | 12 |
| Nebish | Wisconsin | 1931 | 109 | 2.5 | 1.5 | 89.2 | 0.0 | 5.5 | 0.0 | 0.1 | 2.5 | 3.52 | 12 |
| Nebish | Wisconsin | 1932 | 178 | 2.5 | 21.5 | 63.6 | 0.0 | 5.0 | 0.0 | 0.0 | 6.0 | 3.48 | 12 |
| Nebish | Wisconsin | 1977 | 102 | 23.5 | 5.1 | 58.9 | 10.9 | 1.6 | 0.0 | 0.0 | 0.0 | 3.78 | 24 |
| Nebish | Wisconsin | 1978 | 122 | 7.6 | 4.1 | 77.0 | 6.0 | 0.8 | 0.0 | 4.5 | 0.0 | 3.58 | 24 |
| Nebish | Wisconsin | 1979 | 92 | 24.0 | 2.3 | 58.4 | 6.7 | 5.0 | 0.0 | 3.6 | 0.0 | 3.73 | 24 |
| Nebish | Wisconsin | 1980 | 123 | 3.0 | 2.1 | 16.0 | 4.2 | 1.8 | 72.0 | 0.9 | 0.0 | 3.90 | 24 |
| Nebish | Wisconsin | 1981 | 111 | 34.2 | 9.4 | 38.1 | 5.7 | 10.8 | 0.0 | 1.7 | 0.0 | 3.81 | 24 |
| Nipigon | Ontario | 1921 | 14 | 7.1 | 36.8 | 56.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 3.57 | 25 |
| Nipigon | Ontario | 1921 | 43 | 25.5 | 8.5 | 55.0 | 0.0 | 0.0 | 4.0 | 0.0 | 7.0 | 3.78 | 26 |
| Nipigon | Ontario | 1927 | — | 0.0 | 0.0 | 100.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 3.50 | 27 |
| Oneida | New York | 1975 | 254 | 0.0 | 91.8 | 8.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 3.50 | 28 |
| Oneida | New York | 1976 | 212 | 0.0 | 88.5 | 11.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 3.50 | 28 |
| Oneida | New York | 1977 | 232 | 0.0 | 73.7 | 26.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 3.50 | 28 |
| Oneida | New York | 1927 | — | 0.0 | 0.0 | 100.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 3.50 | 27 |
| Opinicon | Ontario | 1966 | 79 | 0.0 | 11.5 | 62.5 | 24.0 | 0.0 | 1.5 | 0.0 | 0.0 | 3.62 | 8 |
| Opinicon | Ontario | 1971 | 1033 | 18.4 | 11.5 | 13.6 | 30.9 | 2.8 | 19.6 | 0.0 | 3.2 | 3.87 | 29 |
| Opinicon | Ontario | 1972 | 49 | 7.5 | 17.0 | 5.0 | 48.0 | 2.0 | 15.0 | 0.0 | 0.0 | 3.80 | 29 |
| Opinicon | Ontario | 1973 | 49 | 9.5 | 19.5 | 8.0 | 33.0 | 1.0 | 14.0 | 0.0 | 0.0 | 3.60 | 29 |
| Pallette | Wisconsin | 31 | 8 | 55.0 | 0.0 | 33.0 | 0.0 | 13.5 | 0.0 | 0.0 | 0.0 | 4.01 | 12 |
| Pepin | Wisconsin | 1921 | 15 | 11.3 | 18.8 | 59.6 | 0.0 | 5.8 | 0.0 | 0.0 | 4.0 | 3.58 | 20 |
| Plum | Wisconsin | 1931 | 15 | 31.5 | 0.0 | 13.5 | 0.0 | 0.5 | 50.5 | 0.0 | 3.0 | 4.05 | 12 |
| Rock | Wisconsin | 1931 | 23 | 33.5 | 0.1 | 51.5 | 0.0 | 0.5 | 0.0 | 12.0 | 3.5 | 3.79 | 12 |
| Roxton | Quebec | 1984 | 34 | 0.0 | 0.0 | 96.9 | 0.0 | 3.1 | 0.0 | 0.0 | 0.0 | 3.48 | 13 |
| Silver | Quebec | 1984 | 17 | 0.0 | 0.1 | 89.3 | 8.4 | 2.0 | 0.0 | 0.0 | 0.0 | 3.53 | 13 |
| Silver | Wisconsin | 1931 | 176 | 6.5 | 9.5 | 57.1 | 0.0 | 3.5 | 11.0 | 2.0 | 8.0 | 3.56 | 12 |
| Silver | Wisconsin | 1932 | 273 | 96.0 | 0.0 | 2.0 | 0.0 | 0.0 | 2.0 | 0.0 | 0.0 | 4.47 | 12 |
| Simcoe | Ontario | 1927 | 13 | 11.0 | 0.0 | 77.0 | 0.0 | 4.0 | 8.0 | 0.0 | 0.0 | 3.63 | 27 |
| Spider | Wisconsin | 1931 | 32 | 25.0 | 0.0 | 15.5 | 0.0 | 3.0 | 48.5 | 4.0 | 5.0 | 3.97 | 12 |
| Starr | Wisconsin | 1931 | 4 | 0.0 | 0.0 | 68.5 | 0.0 | 0.0 | 31.5 | 0.0 | 0.0 | 3.66 | 12 |
| Susquehanna R. | Maryland | 1982 | 698 | 2.0 | 0.0 | 79.0 | 0.0 | 15.0 | 0.0 | 0.0 | 4.0 | 3.45 | 30 |
| Trout | Wisconsin | 1931 | 160 | 36.0 | 4.0 | 35.7 | 0.0 | 1.0 | 16.0 | 2.0 | 4.5 | 3.91 | 12 |
| Trout | Wisconsin | 1932 | 106 | 39.0 | 0.0 | 43.1 | 0.0 | 6.0 | 1.0 | 1.5 | 9.0 | 3.85 | 12 |

**Appendix I** (*continued*).

| | | | | Prey category | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Lake | Location | Year | *n* fish | Fish | Zoop | Ben | Pred ben | Mol | Cray | Det | Other | Trophic position | Reference$^a$ |
| Vieux | Wisconsin | 1931 | 35 | 13.5 | 0.0 | 79.5 | 0.0 | 0.0 | 0.0 | 4.0 | 2.5 | 3.61 | 12 |
| Vieux | Wisconsin | 1932 | 76 | 6.0 | 0.1 | 84.0 | 0.0 | 4.5 | 0.0 | 0.5 | 5.0 | 3.54 | 12 |
| Waskesiu | Saskatchewan | 1927 | — | 0.0 | 0.0 | 100.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 3.50 | 27 |
| Waterloo | Quebec | 1984 | 34 | 0.0 | 1.8 | 91.1 | 5.2 | 1.8 | 0.0 | 0.0 | 0.0 | 3.52 | 13 |
| Weber | Wisconsin | 1931 | 178 | 6.5 | 2.5 | 85.6 | 0.0 | 0.1 | 0.0 | 0.5 | 5.0 | 3.57 | 12 |
| Weber | Wisconsin | 1932 | 184 | 1.0 | 14.0 | 80.7 | 0.0 | 0.5 | 0.0 | 0.0 | 2.0 | 3.48 | 12 |
| West BIue | Manitoba | 1971 | 240 | 5.5 | 21.8 | 45.5 | 0.0 | 0.0 | 3.8 | 0.0 | 23.0 | 3.57 | 31 |
| Winona | Wisconsin | 1940 | 6 | 40.0 | 0.0 | 33.6 | 0.0 | 10.4 | 16.0 | 0.0 | 0.0 | 3.93 | 11 |
| Mean | | | | 17.2 | 13.6 | 53.9 | 4.3 | 2.3 | 4.4 | 0.8 | 3.1 | 3.69 | |
| **Rock bass (total *n* = 1962 fish)** | | | | | | | | | | | | | |
| Alle | Wisconsin | 1931 | 10 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 93.0 | 1.0 | 3.0 | 3.94 | 12 |
| Bear | Wisconsin | 1931 | 12 | 0.0 | 0.0 | 40.5 | 0.0 | 3.5 | 47.0 | 0.0 | 9.0 | 3.72 | 12 |
| Clear | Wisconsin | 1931 | 4 | 0.0 | 0.0 | 37.5 | 0.0 | 0.0 | 58.5 | 0.0 | 4.0 | 3.79 | 12 |
| Clear | Wisconsin | 1932 | 3 | 0.0 | 0.0 | 97.0 | 0.0 | 3.0 | 0.0 | 0.0 | 0.0 | 3.49 | 12 |
| Georgian Bay (Huron) | Ontario | 1928 | 40 | 28.5 | 0.0 | 10.2 | 0.0 | 0.0 | 60.4 | 0.9 | 0.0 | 4.08 | 32 |
| Goose Creek | Virginia | 1986 | 40 | 0.0 | 14.0 | 86.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 3.50 | 33 |
| Muskellunge | Wisconsin | 1931 | 338 | 12.5 | 0.0 | 41.0 | 0.0 | 3.0 | 13.5 | 11.0 | 6.0 | 3.68 | 12 |
| Muskellunge | Wisconsin | 1932 | 371 | 12.0 | 0.1 | 58.8 | 0.0 | 0.5 | 5.5 | 2.0 | 20.5 | 3.63 | 12 |
| Nebish | Wisconsin | 1931 | 184 | 3.5 | 7.5 | 81.1 | 0.0 | 5.0 | 0.0 | 0.1 | 2.0 | 3.50 | 12 |
| Nebish | Wisconsin | 1932 | 209 | 7.5 | 3.5 | 79.7 | 0.0 | 0.5 | 0.0 | 0.1 | 6.0 | 3.53 | 12 |
| Nebish | Wisconsin | 1932 | 27 | 3.5 | 50.5 | 31.5 | 0.0 | 12.0 | 0.0 | 0.0 | 2.0 | 3.47 | 12 |
| Nipissing | Ontario | 1929-30 | 12 | 19.1 | 0.0 | 16.1 | 0.0 | 0.0 | 64.6 | 0.2 | 0.0 | 4.01 | 32 |
| Opinicon | Ontario | 1966 | 96 | 10.0 | 0.0 | 6.7 | 52.7 | 0.0 | 30.0 | 0.0 | 0.0 | 4.00 | 8 |
| Ozark streams | Arkansas | 1980 | 210 | 9.0 | 0.0 | 18.0 | 0.0 | 0.0 | 73.0 | 0.0 | 0.0 | 3.96 | 34 |
| Pallette | Wisconsin | 1931 | 11 | 0.0 | 0.0 | 92.0 | 0.0 | 5.0 | 0.0 | 0.0 | 1.0 | 3.45 | 12 |
| Plum | Wisconsin | 1931 | 1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 | 0.0 | 0.0 | 4.00 | 12 |
| Rock | Wisconsin | 1931 | 4 | 24.5 | 0.0 | 61.5 | 0.0 | 0.0 | 0.0 | 4.0 | 10.0 | 3.73 | 12 |
| Silver | Wisconsin | 1931 | 124 | 5.0 | 0.0 | 52.0 | 0.0 | 0.1 | 35.5 | 1.0 | 4.5 | 3.69 | 12 |
| Silver | Wisconsin | 1932 | 3 | 37.5 | 0.0 | 62.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 3.88 | 12 |
| Simcoe | Ontario | 1927 | 9 | 4.0 | 0.0 | 22.0 | 0.0 | 0.0 | 74.0 | 0.0 | 0.0 | 3.91 | 27 |
| Star | Wisconsin | 1931 | 1 | 20.0 | 0.0 | 20.0 | 0.0 | 0.0 | 30.0 | 30.0 | 0.0 | 3.70 | 12 |
| Trout | Wisconsin | 1931 | 38 | 13.5 | 0.1 | 63.0 | 0.0 | 0.0 | 20.5 | 1.0 | 3.0 | 3.75 | 12 |
| Trout | Wisconsin | 1932 | 103 | 4.0 | 0.5 | 45.1 | 0.0 | 0.0 | 36.5 | 0.0 | 14.0 | 3.72 | 12 |
| Vieux | Wisconsin | 1932 | 2 | 0.0 | 0.0 | 24.0 | 0.0 | 0.0 | 0.0 | 0.0 | 76.0 | 3.50 | 12 |
| Winona | Wisconsin | 1940 | 10 | 26.6 | 0.0 | 9.5 | 18.0 | 7.1 | 37.3 | 0.0 | 0.0 | 3.98 | 11 |
| Mean | | | | 10.0 | 3.0 | 42.2 | 2.8 | 1.7 | 31.2 | 2.1 | 6.4 | 3.74 | |
| **Smallmouth bass (total *n* = 3162 fish)** | | | | | | | | | | | | | |
| 11 lakes | Maine | 1936–38 | 31 | 14.9 | 0.3 | 6.0 | 12.5 | 0.0 | 66.3 | 0.0 | 0.0 | 4.04 | 1 |
| 7 lakes | Maine | 1940 | 66 | 80.3 | 0.0 | 3.6 | 0.0 | 0.0 | 14.4 | 1.7 | 0.0 | 4.37 | 44 |
| 8 lakes | Maine | 1941 | 259 | 83.9 | 5.8 | 8.0 | 1.6 | 0.0 | 0.0 | 0.7 | 0.0 | 4.34 | 1 |
| — | Michigan | 1964 | 177 | 43.0 | 0.0 | 0.5 | 0.0 | 0.0 | 56.5 | 0.0 | 0.0 | 4.21 | 45 |
| Bay de Noc (Michigan) | Michigan | 1966–68 | 57 | 75.0 | 0.0 | 0.1 | 0.0 | 0.0 | 25.0 | 0.0 | 0.0 | 4.38 | 46 |
| Bay de Noc (Michigan) | Michigan | 1966–68 | 112 | 97.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.0 | 0.0 | 0.0 | 4.45 | 46 |
| Bear | Wisconsin | 1931 | 1 | 100.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 4.50 | 12 |
| Cacapon R. | Virginia | 1939 | 104 | 2.7 | 0.0 | 87.6 | 8.2 | 0.4 | 1.1 | 0.0 | 0.2 | 3.57 | 47 |
| Cache | Ontario | 1935-36 | 52 | 28.7 | 16.0 | 19.7 | 0.0 | 0.0 | 35.7 | 0.0 | 0.0 | 3.97 | 48 |
| Clear | Wisconsin | 1931 | 2 | 100.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 4.50 | 12 |
| Crystal | Wisconsin | 1931 | 4 | 0.0 | 0.0 | 97.5 | 0.0 | 0.0 | 0.0 | 3.5 | 0.0 | 3.50 | 12 |
| Douglas | Michigan | 1915 | 8 | 10.0 | 0.0 | 0.0 | 0.0 | 0.0 | 70.0 | 0.0 | 20.0 | 3.95 | 20 |
| Erie | Ontario | 1938 | 157 | 82.5 | 0.0 | 0.2 | 0.0 | 0.0 | 17.5 | 0.0 | 0.0 | 4.41 | 48 |
| Genesee R. | New York | 1927 | 13 | 18.4 | 0.0 | 24.2 | 0.0 | 0.0 | 56.0 | 0.0 | 0.0 | 3.94 | 20 |
| Geneva | Wisconsin | 1921 | 21 | 33.0 | 4.0 | 43.0 | 0.0 | 0.0 | 20.6 | 0.0 | 0.0 | 3.94 | 20 |
| Georgian Bay | Ontario | 1936 | 45 | 62.5 | 0.0 | 1.5 | 0.0 | 0.0 | 33.5 | 0.0 | 0.0 | 4.26 | 48 |
| Georgian Bay | Ontario | 1928 | 98 | 27.7 | 0.0 | 0.4 | 0.2 | 0.0 | 71.7 | 0.2 | 0.0 | 4.14 | 32 |
| Illinois R. | Illinois | 1880 | 10 | 5.0 | 0.0 | 35.0 | 0.0 | 0.0 | 60.0 | 0.0 | 0.0 | 3.85 | 20 |

**Appendix I** (*continued*).

| Lake | Location | Year | *n* fish | Prey category: Fish | Zoop | Ben | Pred ben | Mol | Cray | Det | Other | Trophic position | Reference[a] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Juniala R. | Pennsylvania | 1990 | 102 | 0.0 | 0.0 | 93.9 | 0.0 | 0.0 | 6.2 | 0.0 | 0.0 | 3.53 | 49 |
| Jute | Wisconsin | 1931 | 28 | 83.5 | 0.0 | 13.0 | 0.0 | 0.0 | 0.0 | 0.0 | 2.0 | 4.31 | 12 |
| Kathenne | Michigan | 1974 | 167 | 28.0 | 8.7 | 32.0 | 5.3 | 0.0 | 13.0 | 0.0 | 13.0 | 3.87 | 15 |
| Larry | Wisconsin | 1931 | 14 | 0.0 | 2.0 | 94.5 | 0.0 | 0.0 | 0.0 | 1.5 | 0.0 | 3.46 | 12 |
| Memphremagog | Quebec | 1973 | 24 | 50.1 | 0.0 | 3.2 | 0.0 | 0.0 | 50.0 | 0.0 | 0.0 | 4.30 | 50 |
| Michigan | Wisconsin | 1921 | 2 | 98.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.5 | 0.0 | 4.48 | 20 |
| Monona | Wisconsin | 1918 | 4 | 80.0 | 0.0 | 20.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 4.30 | 20 |
| Muskellunge | Wisconsin | 1931 | 57 | 75.0 | 0.0 | 12.0 | 0.0 | 1.0 | 0.0 | 11.0 | 1.0 | 4.19 | 12 |
| Muskellunge | Wisconsin | 1932 | 61 | 42.0 | 1.5 | 48.5 | 0.0 | 0.0 | 0.0 | 6.5 | 2.0 | 3.90 | 12 |
| Nebish | Wisconsin | 1931 | 66 | 20.5 | 12.0 | 62.0 | 0.0 | 1.5 | 0.0 | 0.0 | 3.0 | 3.68 | 12 |
| Nebish | Wisconsin | 1932 | 42 | 41.0 | 0.0 | 56.5 | 0.0 | 0.0 | 0.1 | 0.0 | 2.0 | 3.90 | 12 |
| Nebish | Wisconsin | 1977 | 101 | 7.2 | 0.0 | 3.2 | 5.4 | 0.0 | 84.2 | 0.0 | 0.0 | 4.02 | 24 |
| Nebish | Wisconsin | 1978 | 126 | 22.0 | 0.3 | 11.0 | 2.9 | 0.0 | 64.0 | 0.0 | 0.0 | 4.06 | 24 |
| Nebish | Wisconsin | 1979 | 104 | 15.5 | 0.1 | 8.8 | 5.8 | 0.0 | 69.9 | 0.0 | 0.0 | 4.04 | 24 |
| Nebish | Wisconsin | 1980 | 125 | 10.0 | 0.0 | 3.4 | 4.1 | 0.0 | 82.6 | 0.0 | 0.0 | 4.04 | 24 |
| Nebish | Wisconsin | 1981 | 111 | 8.9 | 0.1 | 7.2 | 4.4 | 0.0 | 80.1 | 0.0 | 0.0 | 4.02 | 24 |
| Nipigon | Ontario | 1921 | 9 | 48.0 | 35.3 | 16.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 3.98 | 25 |
| Nipissing | Ontario | 1929 | 106 | 20.6 | 0.0 | 0.4 | 0.0 | 0.0 | 79.0 | 0.0 | 0.0 | 4.10 | 32 |
| Opeongo | Ontario | 1936 | 91 | 9.7 | 0.0 | 2.3 | 0.0 | 0.0 | 87.0 | 0.0 | 0.0 | 4.02 | 48 |
| Oxtongue R. | Ontario | 1930 | 6 | 20.0 | 0.0 | 80.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 3.70 | 32 |
| Ozark streams | Arkansas | 1980 | 74 | 34.0 | 0.0 | 6.0 | 0.0 | 0.0 | 60.0 | 0.0 | 0.0 | 4.14 | 34 |
| Pallette | Wisconsin | 1931 | 16 | 58.5 | 1.5 | 40.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 4.09 | 12 |
| Pallette | Wisconsin | 1932 | 30 | 58.5 | 2.5 | 35.5 | 0.0 | 0.0 | 0.0 | 1.5 | 9.5 | 4.09 | 12 |
| Pepin | Wisconsin | 1921 | 12 | 56.5 | 5.7 | 29.8 | 0.0 | 0.0 | 9.1 | 0.0 | 0.0 | 4.13 | 20 |
| Perch | Ontario | 1930–31 | 123 | 49.7 | 1.7 | 5.3 | 0.1 | 0.0 | 39.2 | 0.2 | 3.9 | 4.19 | 32 |
| Phantom | Ontario | 1930 | 18 | 4.0 | 0.0 | 22.6 | 0.0 | 0.0 | 71.7 | 1.7 | 0.0 | 3.89 | 32 |
| Potomac | Virginia | 1939 | 96 | 4.1 | 0.0 | 94.6 | 0.5 | 0.1 | 0.6 | 0.0 | 0.1 | 3.55 | 47 |
| Razor | Wisconsin | 1931 | 18 | 39.5 | 2.0 | 53.0 | 0.0 | 0.0 | 0.0 | 0.0 | 6.0 | 3.90 | 12 |
| Rock | Wisconsin | 1931 | 6 | 5.0 | 0.0 | 88.5 | 0.0 | 0.0 | 0.0 | 5.5 | 1.0 | 3.52 | 12 |
| Shenandoah R. | Virginia | 1939 | 108 | 37.3 | 0.0 | 49.8 | 8.1 | 0.0 | 4.3 | 0.0 | 0.5 | 3.93 | 47 |
| Silver | Wisconsin | 1931 | 31 | 35.0 | 0.0 | 55.0 | 0.0 | 0.0 | 9.5 | 1.0 | 0.0 | 3.90 | 12 |
| Silver | Wisconsin | 1932 | 5 | 100.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 4.50 | 12 |
| Simcoe | Ontario | 1927 | 16 | 29.0 | 0.0 | 7.0 | 8.0 | 3.0 | 53.0 | 0.0 | 0.0 | 4.08 | 27 |
| Spider | Wisconsin | 1931 | 3 | 0.0 | 0.0 | 27.0 | 0.0 | 0.0 | 15.5 | 0.0 | 58.0 | 3.59 | 12 |
| Star | Wisconsin | 1931 | 1 | 0.0 | 0.0 | 50.0 | 0.0 | 0.0 | 50.0 | 0.0 | 0.0 | 3.75 | 12 |
| Trout | Wisconsin | 1931 | 10 | 0.0 | 7.0 | 89.5 | 0.0 | 0.0 | 0.0 | 0.0 | 4.5 | 3.52 | 12 |
| Trout | Wisconsin | 1932 | 1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 | 0.0 | 0.0 | 4.00 | 12 |
| Weber | Wisconsin | 1931 | 29 | 6.0 | 5.0 | 76.0 | 0.0 | 0.0 | 0.0 | 1.0 | 14.0 | 3.59 | 12 |
| Weber | Wisconsin | 1932 | 2 | 83.0 | 0.0 | 17.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 4.33 | 12 |
| Mean | | | | 37.6 | 2.0 | 28.8 | 1.2 | 0.1 | 27.3 | 0.7 | 2.3 | 4.02 | |
| **Largemouth bass (total *n* = 5664 fish)** | | | | | | | | | | | | | |
| Bear | Wisconsin | 1931 | 5 | 80.0 | 0.0 | 20.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 4.30 | 12 |
| Cub | Michigan | 1974 | 340 | 54.3 | 0.0 | 0.0 | 11.0 | 0.0 | 0.0 | 0.0 | 35.0 | 4.10 | 15 |
| Deer lsland | — | 1973 | 169 | 53.4 | 0.4 | 19.6 | 0.0 | 0.0 | 14.9 | 0.1 | 11.9 | 4.11 | 35 |
| DeGray | Arkansas | 1976 | 748 | 59.0 | 0.0 | 0.3 | 0.0 | 0.0 | 37.6 | 0.5 | 3.0 | 4.28 | 36 |
| Fork | — | 1941 | | 48.0 | 0.0 | 18.2 | 11.0 | 0.0 | 113 | 0.0 | 11.0 | 4.08 | 37 |
| Geneva | Wisconsin | 1918 | 78 | 8.7 | 18.1 | 48.1 | 0.0 | 0.0 | 0.0 | 0.0 | 25.0 | 3.59 | 20 |
| L. Dixie | Missouri | 1964 | 900 | 50.1 | 0.0 | 1.5 | 0.7 | 0.0 | 39. | 0.6 | 6.3 | 4.18 | 38 |
| Long | Wisconsin | 1931 | 3 | 50.0 | 0.0 | 4.0 | 0.0 | 0.0 | 0.0 | 0.0 | 46.0 | 4.00 | 12 |
| Maple | Minnesota | 1957 | 83 | 96.0 | 3.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.0 | 0.0 | 4.46 | 7 |
| Murphy Flowage | Wisconsin | 1961–64 | 1146 | 33.5 | 0.0 | 1.2 | 0.0 | 0.0 | 56.1 | 6.1 | 0.0 | 4.04 | 39 |
| Muskellunge | Wisconsin | 1931 | 19 | 50.5 | 32.0 | 9.5 | 0.0 | 0.0 | 0.0 | 1.5 | 7.5 | 4.01 | 12 |
| Muskellunge | Wisconsin | 1932 | 8 | 94.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 6.0 | 0.0 | 4.41 | |
| Opinicon | Ontario | 1991 | 10 | 85.7 | 1.8 | 0.0 | 0.0 | 0.0 | 11.4 | 0.0 | 0.0 | 4.40 | 2 |
| Paul | Michigan | 1987 | 235 | 42.0 | 11.0 | 8.0 | 39.0 | 0.0 | 0.0 | 0.0 | 0.0 | 4.12 | 40 |
| Paul | Michigan | 1988 | | 55.0 | 10.0 | 14.0 | 21.0 | 0.0 | 0.0 | 0.0 | 0.0 | 4.16 | 40 |

**Appendix I** (*continued*).

| Lake | Location | Year | $n$ | Prey category |  |  |  |  |  |  |  | Trophic | Reference[a] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  |  | fish | Fish | Zoop | Ben | Pred ben | Mol | Cray | Det | Other | position |  |
| Peter | Michigan | 1987 | 235 | 0.0 | 6.5 | 45.6 | 46.5 | 0.8 | 0.0 | 0.0 | 0.0 | 3.72 | 41 |
| Peter | Michigan | 1988 | 235 | 54.0 | 6.0 | 8.0 | 32.0 | 0.0 | 0.0 | 0.0 | 0.0 | 4.20 | 40 |
| Peter | Michigan | 1987 |  | 0.0 | 15.0 | 15.0 | 35.0 | 0.0 | 0.0 | 0.0 | 35.0 | 3.68 | 40 |
| Shelbyville | Illinois | 1980 | 97 | 99.2 | 0.0 | 0.8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 4.49 | 42 |
| Shelbyville | Illinois | 1978–81 | 1347 | 88.8 | 0.0 | 0.6 | 0.0 | 0.0 | 11.4 | 0.0 | 0.0 | 4.46 | 43 |
| Winona | Wisconsin | 1940 | 6 | 17.6 | 0.0 | 16.9 | 0.0 | 0.0 | 40.5 | 25.0 | 0.0 | 3.75 | 11 |
| Mean |  |  |  | 53.3 | 4.9 | 11.0 | 9.3 | 0.0 | 10.6 | 1.9 | 8.6 | 4.12 |  |
| **Northern pike and chain pickerel (total $n$ = 34 738 fish)** |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 19 lakes | Maine | 1940 | 110 | 94.8 | 0.0 | 0.2 | 0.0 | 0.0 | 0.5 | 0.0 | 4.4 | 4.37 | 44 |
| 20 lakes | Maine | 1937–41 | 95 | 95.1 | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | 4.8 | 4.24 | 1 |
| Babcock Pond | Connecticut | 1941 | 71 | 91.4 | 0.0 | 0.0 | 3.7 | 0.0 | 0.0 | 0.0 | 4.8 | 4.04 |  |
| Bay de Noc (Michigan) | Michigan | 1966–68 | 405 | 100.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 4.36 |  |
| Bay of Ouinte (Ontario) | Ontario | 1958–64 | 131 | 100.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 4.55 | 74 |
| Brochet | Quebec | 1953 | 131 | 40.2 | 0.0 | 9.3 | 32.1 | 0.0 | 18.4 | 0.0 | 0.0 | 4.15 | 52 |
| Cree | Saskatchewan | 1955 | — | 95.0 | 0.0 | 0.0 | 5.0 | 0.0 | 0.0 | 0.0 | 0.0 | 4.48 | 53 |
| Georgian Bay (Huron) | Ontario | 1928 | 11 | 53.8 | 0.0 | 0.0 | 0.0 | 0.0 | 46.2 | 0.0 | 0.0 | 4.27 | 32 |
| Grande Rivière | Quebec | 1977 |  | 97.9 | 0.0 | 0.3 | 0.0 | 0.0 | 0.0 | 0.0 | 1.8 | 4.48 | 52 |
| Great Slave | N.W.T. | 1944–47 | 73 | 95.0 | 0.0 | 5.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 4.45 | 54 |
| Grove | Minnesota | 1957 | 133 | 90.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 10.0 | 4.40 | 7 |
| Heming | Manitoba | 1950–62 | 29477 | 99.9 | 0.0 | 0.1 | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 | 4.42 | 55 |
| Keller | N.W.T. | 1962 | 125 | 97.2 | 0.0 | 0.0 | 2.8 | 0.0 | 0.0 | 0.0 | 0.0 | 4.59 | 56 |
| Lincoln Pond | New York | 39 | 145 | 32.8 | 1.4 | 47.4 | 17.6 | 0.0 | 0.0 | 0.0 | 0.8 | 3.72 |  |
| Maple | Minnesota | 1957 | 70 | 100.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 4.50 | 7 |
| Mecan R. | Wisconsin | 1959 | 91 | 95.9 | 0.0 | 0.0 | 0.0 | 0.0 | 1.5 | 0.0 | 2.6 | 4.31 | 58 |
| Memphremagog | Quebec | 1973 | 27 | 60.0 | 0.0 | 2.1 | 0.0 | 0.0 | 40.0 | 0.0 | 0.0 | 4.09 | 50 |
| Mississippi | Mississippi | 1968 | 58 | 96.5 | 0.0 | 0.0 | 0.0 | 0.0 | 3.5 | 0.0 | 0.0 | 4.36 | 59 |
| Monroe | Quebec | 1953 | 221 | 99.5 | 0.0 | 0.1 | 0.1 | 0.0 | 0.3 | 0.0 | 0.0 | 4.50 | 52 |
| Murphy Flowage | Wisconsin | 1965 | 1412 | 99.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.2 | 0.0 | 0.0 | 4.29 | 39 |
| Nipigon | Ontario | 1921 | 23 | 95.2 | 0.7 | 0.7 | 0.0 | 0.0 | 0.0 | 0.0 | 3.8 | 4.46 | 26 |
| Nipissing | Ontario | 1929–30 | 10 | 36.3 | 0.0 | 0.0 | 0.0 | 0.0 | 59.4 | 0.0 | 4.0 | 4.15 | 32 |
| Ontario | New York | 1972 | 87 | 100.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 4.02 | 61 |
| Pocotopaug | Connecticut | — | 30 | 63.0 | 0.0 | 11.0 | 11.0 | 0.0 | 8.0 | 4.0 | 4.0 | 4.19 | 76 |
| Various | — | — | — | 64.0 | 0.0 | 22.0 | 0.0 | 0.0 | 12.0 | 1.0 | 1.0 | 3.82 | 76 |
| Seney Refuge | Michigan | 1941–42 | 378 | 69.5 | 0.0 | 1.8 | 0.9 | 0.1 | 23.1 | 0.0 | 4.6 | 4.31 | 2 |
| Seney Refuge | Michigan | 1952 | 84 | 65.4 | 0.0 | 0.1 | 2.5 | 0.1 | 21.4 | 0.0 | 10.6 | 4.28 | 2 |
| Simcoe | Ontario | 1982 | 50 | 100.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 4.49 | 62 |
| Ste. Anne | Alberta | 1976–78 | 1290 | 99.5 | 0.0 | 0.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 4.50 | 63 |
| Wollaston | Saskatchewan | 1956 | — | 95.0 | 0.0 | 5.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 4.45 | 53 |
| Mean |  |  |  | 84.1 | 0.1 | 3.5 | 2.5 | 0.0 | 7.8 | 0.2 | 1.9 | 4.31 |  |
| **Walleye (total $n$ = 10 386 fish)** |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Bay de Noc (Michigan) | Michigan | 1966–68 | 103 | 100.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 4.39 | 46 |
| Bay of Ouinte (Ontario) | Ontario | 1958–62 | 692 | 99.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.0 | 4.04 | 74 |
| Clear | Wisconsin | 1931 | 15 | 60.0 | 12.0 | 19.5 | 0.0 | 0.0 | 0.0 | 4.5 | 5.0 | 4.06 | 12 |
| Clear | Wisconsin | 1932 | 23 | 40.5 | 0.0 | 59.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.5 | 3.92 | 12 |
| Erie | Ontario | 1979–81 | 906 | 100.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 4.50 | 64 |
| Falcon | Manitoba | 1959 | 288 | 92.2 | 0.0 | 5.5 | 0.0 | 0.0 | 3.0 | 0.0 | 0.0 | 4.48 | 45 |
| Great Slave | N.W.T. | 1944–47 | 116 | 75.0 | 0.0 | 25.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 4.25 | 54 |
| James Bay | Quebec | 1979 | 584 | 72.3 | 1.3 | 24.0 | 2.4 | 0.0 | 0.0 | 0.0 | 0.0 | 4.24 | 65 |
| Lac la Ronge | Saskatchewan | 1948–55 | 276 | 97.0 | 0.0 | 2.8 | 0.0 | 0.0 | 0.3 | 0.0 | 0.0 | 4.35 | 66 |
| Lake of the Woods | Ontario | 1968–70 | 1417 | 98.8 | 0.3 | 1.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 4.61 | 67 |
| Lake of the Woods | Ontario | 1968–70 | 1605 | 88.0 | 1.5 | 11.3 | 0.0 | 0.0 | 1.8 | 0.0 | 0.0 | 4.49 | 67 |
| Lost | Wisconsin | 1932 | 18 | 99.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.0 | 0.0 | 0.0 | 4.50 | 12 |
| Memphremagog | Quebec | 1973 | 8 | 100.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 4.70 | 50 |
| Nipigon | Ontario | 1920–21 | 74 | 91.1 | 0.0 | 6.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 4.35 | 25 |
| Nipigon | Ontario | 1921 | 4 | 50.0 | 47.4 | 2.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 4.00 | 26 |

**Appendix I** (*concluded*).

| | | | | Prey category | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Lake | Location | Year | *n* fish | Fish | Zoop | Ben | Pred ben | Mol | Cray | Det | Other | Trophic position | Reference[a] |
| Nipissing | Ontario | 1929–30 | 16 | 48.3 | 0.0 | 28.1 | 0.0 | 0.0 | 22.9 | 0.0 | 0.0 | 4.08 | 32 |
| Oahe | South Dakota | 1993 | 478 | 99.6 | 0.0 | 0.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 4 50 | 68 |
| Ontario | Michigan | 1966–68 | 103 | 100.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 4.50 | 46 |
| Pike | Minnesota | 1962 | 470 | 43.2 | 0.0 | 26.5 | 9.3 | 0.0 | 18.0 | 3.0 | 0.0 | 4.11 | 72 |
| Simcoe | Ontario | 1982 | 50 | 100.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 4.57 | 62 |
| Sparkling | Wisconsin | 1982–83 | 113 | 97.8 | 0.0 | 2.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 4.42 | 69 |
| Trout | Wisconsin | 1931 | 30 | 96.0 | 0.0 | 1.0 | 0.0 | 0.0 | 0.0 | 0.0 | 2.5 | 4.45 | 12 |
| Trout | Wisconsin | 1932 | 22 | 100.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 4.50 | 12 |
| West Blue | Manitoba | 1970 | 79 | 79.8 | 0.0 | 9.3 | 0.0 | 0.0 | 11.0 | 0.0 | 0.0 | 4.51 | 70 |
| West Blue | Manitoba | 1966 | — | 78.0 | 0.0 | 4.2 | 0.6 | 0.0 | 15.6 | 0.0 | 1.5 | 4.53 | 75 |
| West Blue | Manitoba | 1969–70 | — | 71.5 | 0.0 | 16.9 | 5.0 | 0.0 | 4.8 | 0.0 | 1.9 | 4.43 | 75 |
| Wilson | Minnesota | 1964–65 | 390 | 70.7 | 0.0 | 27.6 | 0.0 | 0.0 | 0.0 | 0.0 | 1.7 | 4.19 | 73 |
| Wilson | Minnesota | 67–70 | 230 | 41.4 | 0.0 | 44.4 | 0.0 | 0.0 | 2.1 | 0.0 | 12.1 | 3.88 | 73 |
| Winnebago | Wisconsin | 1960 | 1148 | 99.0 | 0.0 | 1.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 4.43 | 71 |
| Winnebago | Wisconsin | 1960 | 629 | 99.7 | 0.0 | 0.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 4.26 | 71 |
| Winnebago | Wisconsin | 1961 | 56 | 95.4 | 0.4 | 4.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 4.26 | 71 |
| Winnebago | Wisconsin | 1961 | 231 | 81.6 | 0.0 | 18.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 4.10 | 71 |
| Mean | | | | 83.3 | 2.0 | 10.7 | 0.5 | 0.0 | 2.5 | 0.2 | 0.8 | 4.33 | |

**Note**: Dietary data are broken down into the prey categories described in Table 1. The summary presented at the end of each species represents the mean diet and trophic position for the species.

[a] (1) Cooper 1942; (2) Lagler 1956; (3) Laughlin and Werner 1980; (4) Fox and Keast 1990; (5) Snetsinger 1992; (6) Etnier 1971; (7) Seaburg and Moyle 1964; (8) Keast and Welsh 1968; (9) Sadzikowski and Wallace 1976; (10) Flemer and Woolcott 1966; (11) Parks 1949; (12) Couey 1935; (13) Boisclair 1988; (14) Moffett and Hunt 1943; (15) Clady 1974; (16) Griswold and Tubb 1977; (17) Parrish and Margraf 1990; (18) Parrish and Margraf 1994; (19) Schaeffer and Margraf 1986; (20) Adams and Hankinson 1928; (21) Hunt and Carbin 1950; (22) Tharratt 1959; (23) Fraser 1978; (24) Serns and Hoff 1984; (25) Clemens et al. 1923; (26) Clemens et al. 1924; (27) Rawson 1930; (28) Mills and Forney 1981; (29) Keast 1977; (30) Weisberg and Janicki 1990; (31) Ward and Robinson 1974; (32) Tester 1932; (33) Vadas 1990; (34) Probst et al. 1984; (35) Saiki and Tash 1978; (36) Bryant and Moen 1980; (37) Bennett 1948; (38) Herman et al. 1969; (39) Snow 1971; (40) Hodgson et al. 1991; (41) Hodgson et al. 1989; (42) Miller and Storck 1984; (43) Storck 1986; (44) Cooper 1941; (45) Fedoruk 1966; (46) Wagner 1972; (47) Surber 1941; (48) Doan 1940; (49) Johnson and Dropkin 1995; (50) Nakashima and Leggett 1975; (51) Foote and Blake 1945; (52) Vallieres and Fortin 1988; (53) Rawson 1959; (54) Rawson 1951; (55) Lawler 1965; (56) Johnson 1972; (57) Raney 1942; (58) Hunt 1965; (59) McIlwain 1970; (61) Wolfert and Miller 1978; (62) Mathers and Johansen 1985; (63) Diana 1979; (64) Knight et al. 1984; (65) Hazel and Fortin 1986; (66) Rawson 1965; (67) Swenson and Smith 1976; (68) Bryan et al. 1995; (69) Lyons and Magnuson 1987; (70) Kelso 1973; (71) Priegel 1963; (72) Johnson and Hale 1977; (73) Johnson 1977; (74) Hurley and Christie 1977; (75) Kelso and Ward 1977; (76) Hunter and Rankin 1939.

**Appendix II.** Diets of northern pike, chain pickeral, and walleye in lakes where fish prey items could be further separated into species.

| | | | | % | % volume | | | | | | | | | | | | | | Trophic | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Lake | Location | Year | *n* fish | fish | Perc. | Cypr. | Cent. | Trpe. | Cato. | Scul. | Alew. | Smel. | Core. | Salm. | Burb. | Stic. | Wb. | Other | position | Reference[a] |
| **Northern pike and chain pickerel (total *n* = 32 284 fish)** | | | | | | | | | | | | | | | | | | | | |
| 19 lakes | Maine | 1940 | 110 | 94.8 | 7.9 | 14.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 3.2 | 0.0 | 0.0 | 0.0 | 0.0 | 58.0 | 11.2 | 4.37 | 44 |
| 20 lakes | Maine | 1937–41 | 95 | 95.1 | 19.4 | 22.5 | 1.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.0 | 0.0 | 24.5 | 0.0 | 0.0 | 25.6 | 1.0 | 4.24 | 1 |
| Babcock Pond | Connecticut | 1941 | 71 | 91.4 | 0.0 | 42.4 | 5.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 43.7 | 4.04 | 51 |
| Bay de Noc | Michigan | 1966–68 | 405 | 100.0 | 2.8 | 7.0 | 4.6 | 10.7 | 0.0 | 0.0 | 34.2 | 39.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.6 | 4.36 | 46 |
| Bay of Quinte | Ontario | 1958–64 | 131 | 100.0 | 53.2 | 0.0 | 2.0 | 21.8 | 0.0 | 0.0 | 19.9 | 3.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 4.55 | 75 |
| Heming | Manitoba | 1950–62 | 29477 | 99.9 | 22.5 | 19.8 | 0.0 | 34.4 | 12.9 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 10.3 | 4.42 | 55 |
| Keller | N.W.T. | 1962 | 125 | 97.2 | 0.0 | 0.0 | 0.0 | 0.0 | 5.7 | 28.6 | 0.0 | 0.0 | 0.0 | 0.0 | 37.2 | 22.9 | 0.0 | 2.9 | 4.59 | 56 |
| Lincoln Pond | New York | 1939 | 145 | 32.8 | 0.0 | 17.4 | 15.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 3.72 | 57 |
| Mecan River | Wisconsin | 1959 | 91 | 95.9 | 0.0 | 4.6 | 0.0 | 0.0 | 9.0 | 22.8 | 0.0 | 0.0 | 0.0 | 59.6 | 0.0 | 0.0 | 0.0 | 0.0 | 4.31 | 58 |
| Memphremagog | Quebec | 1973 | 27 | 60.0 | 30.0 | 30.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 4.09 | 50 |
| Mississippi | Mississippi | 1968 | 58 | 96.5 | 0.0 | 0.0 | 59.9 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 36.6 | 4.36 | 59 |
| Murphy Flowage | Wisconsin | 1965 | 1412 | 99.1 | 13.8 | 6.0 | 77.7 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | 1.4 | 4.29 | 39 |
| Ontario | New York | 1972 | 87 | 100.0 | 2.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 97.7 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 4.02 | 61 |
| Various | — | — | — | 64.0 | 12.6 | 41.0 | 2.3 | 0.0 | 0.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 7.5 | 3.82 | 77 |
| Simcoe | Ontario | 1982 | 50 | 100.0 | 28.4 | 1.5 | 4.9 | 1.6 | 35.3 | 0.0 | 0.0 | 8.0 | 20.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 4.49 | 62 |
| Mean | | | | 88.4 | 12.9 | 13.8 | 11.5 | 4.6 | 4.2 | 3.4 | 10.1 | 3.6 | 1.3 | 5.6 | 2.5 | 1.5 | 5.6 | 7.7 | 4.24 | |
| **Walleye (total *n* = 8369 fish)** | | | | | | | | | | | | | | | | | | | | |
| Bay de Noc | Michigan | 1966–68 | 103 | 100.0 | 0.0 | 0.0 | 0.0 | 0.0 | 8.8 | 0.0 | 37.3 | 40.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 13.8 | 4.39 | 46 |
| Bay of Quinte | Ontario | 1958–62 | 692 | 99.0 | 0.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 94.6 | 4.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 4.04 | 75 |
| Falcon | Manitoba | 1959 | 288 | 92.2 | 49.5 | 6.2 | 8.4 | 2.2 | 12.4 | 1.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 12.4 | 4.48 | 45 |
| James Bay | Quebec | 1979 | 584 | 72.3 | 0.0 | 0.0 | 0.0 | 41.1 | 0.0 | 0.0 | 0.0 | 0.0 | 26.6 | 0.0 | 4.5 | 0.0 | 0.0 | 0.0 | 4.24 | 65 |
| Lac la Ronge | Saskatchewan | 1948–55 | 276 | 97.0 | 1.0 | 2.0 | 0.0 | 31.0 | 7.0 | 0.0 | 0.0 | 0.0 | 56.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 4.35 | 66 |
| Lake of the Woods | Ontario | 1968–70 | 1417 | 98.8 | 30.0 | 3.3 | 0.0 | 53.7 | 0.0 | 0.0 | 0.0 | 0.0 | 6.1 | 0.0 | 0.0 | 0.0 | 0.0 | 5.6 | 4.61 | 67 |
| Lake of the Woods | Ontario | 1968–70 | 1605 | 88.0 | 72.8 | 9.5 | 0.0 | 5.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 4.49 | 67 |
| Memphremagog | Quebec | 1973 | 8 | 100.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 4.70 | 50 |
| Pike | Minnesota | 1962 | 470 | 43.2 | 27.4 | 0.1 | 0.0 | 0.5 | 13.3 | 1.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.6 | 0.0 | 0.0 | 0.0 | 4.11 | 73 |
| Simcoe | Ontario | 1982 | 50 | 100.1 | 19.4 | 11.0 | 0.0 | 1.0 | 0.0 | 0.0 | 0.0 | 68.7 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 4.57 | 62 |
| Sparkling | Wisconsin | 1982–83 | 113 | 97.8 | 69.2 | 19.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 9.5 | 0.0 | 0.0 | 0.0 | 4.42 | 69 |
| West Blue | Manitoba | 1970 | 79 | 79.8 | 71.0 | 0.0 | 0.0 | 8.8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 4.51 | 70 |
| West Blue | Manitoba | 1966 | — | 78.0 | 77.2 | 0.0 | 0.0 | 0.8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 4.53 | 76 |
| West Blue | Manitoba | 1969–70 | — | 71.5 | 63.9 | 0.0 | 0.0 | 7.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 4.43 | 76 |
| Wilson | Minnesota | 1964–65 | 390 | 70.7 | 55.8 | 14.9 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 4.19 | 74 |
| Wilson | Minnesota | 1967–70 | 230 | 41.4 | 20.6 | 20.8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 3.88 | 74 |
| Winnebago | Wisconsin | 1960 | 1148 | 99.0 | 19.9 | 10.9 | 2.6 | 8.9 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 4.1 | 0.0 | 0.0 | 52.6 | 4.43 | 71 |
| Winnebago | Wisconsin | 1960 | 629 | 99.7 | 0.0 | 34.3 | 7.1 | 58.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 4.26 | 71 |
| Winnebago | Wisconsin | 1961 | 56 | 95.4 | 0.0 | 1.6 | 93.8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 4.26 | 71 |
| Winnebago | Wisconsin | 1961 | 231 | 81.6 | 0.0 | 16.1 | 47.0 | 18.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 4.10 | 71 |
| Mean | | | | 85.3 | 28.9 | 7.5 | 7.9 | 11.9 | 2.1 | 0.1 | 6.6 | 10.6 | 4.5 | 0.0 | 0.9 | 0.0 | 0.0 | 4.2 | 4.35 | |

**Note**: Perc., yellow perch; Cypr., cyprinids; Cent., centrarchids; Trpe., trout-perch; Cato., catostomids; Scul., sculpins; Alew., alewife; Smel., smelt; Core., coregonids; Salm., salmoninae; Burb., burbot; Stic., sticklebacks; Wb., white bass; Other, nonspecified species.

[a] See footnote *a* to Appendix I.

**Appendix III.** Estimated trophic position of adult littoral fish species based on $\delta^{15}$N from 36 lakes in Ontario and Quebec.

| Lake | $\delta^{15}$N Unionid mussel | Trophic position | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Pump. | Perc. | Rb. | Smb. | Lmb. | Pike | Wall. |
| Ahmic | 5.3 | — | 3.92 | 3.84 | — | — | 3.53 | 4.24 |
| Balsam | 4.1 | 3.45 | 3.73 | 3.65 | — | — | — | — |
| Bernard | 3.1 | — | — | — | 3.55 | — | — | — |
| Big Rideau | 4.7 | 3.23 | 2.99 | — | — | — | 3.82 | — |
| Brandy | 3.9 | 3.83 | 3.42 | 3.77 | 3.91 | — | 3.78 | — |
| Buck | 3.8 | 3.53 | 3.56 | — | 4.16 | 4.03 | 3.63 | — |
| Carson | 1.6 | — | — | — | 3.94 | 4.41 | — | — |
| Christie | 4.4 | — | 3..77 | — | — | — | 4.18 | 4.10 |
| Clear | 5.7 | — | 3.39 | — | — | — | 4.02 | — |
| Cameron | 4.5 | 2.81 | 3.50 | 3.45 | — | — | — | — |
| Constan | 3.3 | — | — | — | — | — | 3.38 | — |
| Crotch | 4.1 | — | 3.46 | — | 3.73 | 3.87 | 3.77 | — |
| Dalrymple | 6.0 | 3.14 | — | — | 3.89 | — | 4.02 | — |
| Doe | 4.7 | 3.36 | 3.73 | 3.96 | 3.87 | — | 3.59 | — |
| Doré | 5.1 | 3.45 | 3.34 | 3.92 | 3.91 | — | 4.41 | — |
| Fox | 4.2 | 3.68 | — | — | — | 4.13 | 3.73 | — |
| Gloucester Pool | 3.7 | — | 3.90 | — | — | — | 4.08 | 4.55 |
| Golden | 3.1 | — | 4.00 | — | 4.20 | — | 4.08 | 4.55 |
| Hurds | 3.2 | 3.45 | 4.25 | 4.04 | — | 4.18 | 4.31 | — |
| Kashagawigamog | 4.8 | — | 3.87 | 3.45 | — | — | — | — |
| Kennisis | 2.3 | — | 4.33 | — | — | — | — | — |
| Mazinaw | 1.3 | 4.15 | 3.76 | 4.43 | 4.73 | — | 3.69 | 4.86 |
| Memphremagog | 7.6 | — | 3.16 | — | — | — | — | — |
| Memesagamesing | 4.3 | — | — | — | — | — | 3.80 | — |
| Mississippi | 3.9 | 3.68 | 3.69 | 3.86 | — | 3.92 | — | 4.30 |
| Oak | 4.9 | 2.93 | 3.11 | — | 3.57 | — | — | — |
| Obabika | 3.9 | — | 3.52 | — | — | — | 3.49 | — |
| Pickerel | 4.2 | 3.05 | 3.42 | — | — | 4.02 | 3.57 | 4.53 |
| Peninsula | 3.3 | — | — | — | 4.63 | — | — | — |
| Rice | 7.3 | — | 3.34 | 3.76 | — | — | — | 4.09 |
| Robertson | 4.0 | 3.54 | 3.46 | 4.17 | 3.79 | — | 4.51 | — |
| Round | 5.4 | 3.18 | 3.40 | — | 4.17 | — | — | 4.48 |
| Sand | 3.9 | — | 4.07 | — | — | — | — | — |
| Stenburg | 3.9 | 3.21 | 3.43 | 3.81 | 4.18 | — | — | — |
| Sturgeon | 4.8 | 3.11 | 3.65 | 4.09 | — | — | — | 4.29 |
| Wollaston | 4.3 | 3.52 | — | — | — | — | — | — |

**Note**: Pump., pumpkinseed; Perc., yellow perch; Rb., rock bass; Smb., smallmouth bass; Lmb., largemouth bass; Pike, northern pike and chain pickerel; Wall., walleye.