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Diet of Larval Ruffe (*Gymnocephalus cernuus*) in the St. Louis River Harbor, Lake Superior

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ABSTRACT. *The diet of larval (3-17 mm total length) ruffe (*Gymnocephalus cernuus*) is described from samples collected in 1994 at two locations in the St. Louis River Harbor, a tributary to Lake Superior. Copepoda,* Daphnia *spp., and* Bosmina longirostris *dominated the diet of larval ruffe in the St. Louis River Harbor. Larger Copepoda and* Daphnia *spp. occurred more often and in larger numbers as ruffe total length increased, whereas smaller* Bosmina longirostris *occurred less often and in smaller numbers as ruffe total length increased. Ruffe from Whaleback Bay consumed* Daphnia *spp. rarely and in very small numbers whereas ruffe from Allouez Bay consumed* Daphnia *spp. often and in large numbers. A general decrease in Copepoda and increase in* Daphnia *spp. occurred in the second and third weeks of June for ruffe from Allouez Bay, but not Whaleback Bay.*

INDEX WORDS: *Ruffe,* Gymnocephalus cernuus*, larval fish, diet.*

INTRODUCTION

Ruffe (*Gymnocephalus cernuus*) were accidentally introduced to the St. Louis River Harbor, a tributary to Lake Superior, in the early 1980s (Pratt *et al.* 1992). There was immediate concern by resource managers that the ruffe, a percid native to Europe and Asia, would seriously negatively impact native species (Gunderson *et al.* 1998). Concern regarding the negative impact of ruffe has apparently subsided among some (Gunderson *et al.* 1998). However, observations of large population expansions in areas invaded by ruffe (Bronte *et al.* 1998), range expansion in the Lake Superior drainage (Ogle 1998), and the demonstration that ruffe can outcompete the economically important (Leigh 1998) native yellow perch (*Perca flavescens*) when food resources are limited (Henson 1999) indicate that concern regarding ruffe should still exist. Thus, studies of important life history characteristics of ruffe, especially in newly invaded environments, are still vital to our understanding of ruffe for purposes of population control and management.

Diet is an important life history characteristic as it is related to energy transfer between trophic levels and potential competition among fishes. Because of this importance, the diets of young-of-the-year (≥ 20 mm) and adult ruffe have been thoroughly described for ruffe in European and Asian systems (reviewed by Holker and Thiel 1998, Kovac 1998, Ogle 1998, and Popova *et al.* 1998) and in the St. Louis River Harbor (Ogle *et al.* 1995). The diet of larval ruffe (≤ 15 mm) in European and Asian systems has been only briefly described (Johnsen 1965) or summarized (Kovac 1998, Popova *et al.* 1998). The diet of larval ruffe in the St. Louis River Harbor or in any other system invaded by ruffe has not been described.

Inasmuch as the larval stage is a critical life stage for many fish species (Miller *et al.* 1988), it is important to thoroughly describe the diet of larval ruffe. In this note, we describe the diet of larval ruffe from two locations in the St. Louis River Harbor by examining the effects of total length, sampling date, and sampling location on the average

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TABLE 1. Collection dates (in 1994) and sample sizes of larval ruffe examined for diet.

	Allouez Bay		Whaleback Bay		
Date Code	Date	Sample size	Date	Sample size	Description
1	18 May	1	21 May	8	Third week of May
2	1 Jun	24	30 May	30	Last week of May
3	6 Jun	31	4 Jun	15	First week of June
4	15 Jun	38	13 Jun	31	Second week of June
5	20 Jun	58	18 Jun	34	Third week of June
6	29 Jun	12	27 Jun	5	Last week of June

number and occurrence of major food items in larval ruffe stomachs.

METHODS

Larval ruffe were collected with a pushnet approximately weekly in 1994 at two locations, Allouez Bay and Whaleback Bay, in the St. Louis River Harbor (Table 1) as described in detail by Brown *et al.* (1998). All larval ruffe were preserved in the field in 95% ethanol but only ruffe with completely absorbed yolk sacs were used for diet analysis. For each date and location, the stomach contents were carefully removed under a dissecting microscope from as many as five ruffe that contained food from each 1-mm size class (e.g., 4.0–4.9 mm labeled as 4 mm; Table 2). All organisms were identified (using Balcer *et al.* 1984), if possible, to genus or species with the exception of Ostracoda. Some organisms were identified only to order or suborder due to an advanced stage of digestion. For each ruffe, the total number and occurrence of each prey item was recorded. Items that could not be identified to order or lower, and invertebrate eggs, were excluded from any further analysis.

For purposes of initial analysis, the identified prey items were categorized into broader groups (e.g., Copepoda, *Daphnia*). An initial analysis showed that only three broad groups averaged more than one item per ruffe for at least one combination of sampling location, sampling date, and ruffe length. Thus, all further analyses were restricted to these three groups and a combined "other" group (Table 3). In addition, preliminary analyses indicated that depth of capture did not significantly affect diet composition and, thus, was not considered further.

We used the general linear model

$$\text{Ln(number in prey group + 1)} = \text{TL + LOC + TL*LOC} \qquad (1)$$

TABLE 2. Sample sizes of larval ruffe examined for diet by total length.

	Ruffe Total Length (mm)														
Location	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Allouez	0	20	24	25	22	20	15	9	5	8	5	3	6	1	1
Whaleback	6	29	23	18	16	14	8	2	1	1	0	4	0	1	0

TABLE 3. Major prey item group labels and the specific identified organisms in each group.

Major Prey Item	Identified Organisms in the Group
Copepoda	*Acanthocyclops vernalis*, *Diacyclops thomasi*, Cycolopoida, Calanoida, Unidentified Copepoda
Bosmina longirostris	
Daphnia spp.	*Daphnia galeata mendotae*, *Daphnia retrocurva*, Unidentified *Daphnia*
Other	*Eubosmina coregoni*, *Alona* spp., *Alonopsis elongata*, Unidentified Chydoridae, Ostracoda, *Diaphanasoma* spp., *Graptoleberis testudinaria*, Rotifera, Protozoa, Unidentified Cladocera, Chironomidae, *Leptodora* spp.

where TL is the total length (mm) of the ruffe and LOC is coded 0 for Allouez Bay and 1 for Whaleback Bay, to determine if the relationship between the number of each major prey group and ruffe total length was the same between locations. The general linear model

$$\text{Ln(number in prey group + 1)} = \text{TL} + \text{DATE} \qquad (2)$$

where DATE is coded for sampling date as shown in Table 1, was then fit for each prey group and sampling location to determine the effect of sampling date on the average number of each prey group. The TL in (1) and (2) serves as a covariate in the analysis (specifically in (1) when the interaction term is non-significant) and effectively adjusts the data to a common mean TL for comparing the other factor (i.e., LOC in (1) and DATE in (2)). Thus, all interpretations for LOC and DATE are said to be for the length-adjusted means which allows for comparisons among locations or sampling dates without the confounding effect of different sizes of fish among locations or sampling dates (Trippel and Hubert 1990). If a significant DATE term was found, differences in the average number in a food group were determined with Tukey's HSD multiple comparison technique. No interaction term was used in (2) because of the high collinearity between TL and DATE. Model (2) was fit to each sampling location separately because model (1) indicated that the relationship between the average number in a food group and ruffe total length was different between locations for two of the four major food groups. The number of prey was transformed to the natural log scale in both (1) and (2) to stabilize the variances (adding one to each count was used to account for the zeroes in the data).

Finally, a logistic regression model with TL, LOC, and TL*LOC terms was used to examine the effect of total length and sampling location on the occurrence of each major prey item. A sampling date term was not used in the logistic regression model because doing so resulted in small sample sizes in many cells of the data table and thus a lack of model fit robustness. The results of the logistic regression model were back-transformed to provide (i) an estimate of the ratio of the odds of consuming a prey item at TL x to the odds of consuming a prey item at TL x+1 and (ii) an estimate of the probability of consuming a prey item at a given TL. All statistical tests used a significance level of 0.05.

RESULTS AND DISCUSSION

All larval ruffe in the 3 mm length class possessed yolk sacs except for six fish sampled from Whaleback Bay on 21 May and nine fish (all with empty stomachs) from Whaleback Bay on 30 May. All larval ruffe in the 4 mm length class had completely absorbed yolk sacs except for six fish sampled from Whaleback Bay on 21 May. A high percentage of fish with empty stomachs was found on the third and last weeks of May at Whaleback Bay (60% of 3 mm, 82% of 4 mm, and 47% of 5 mm ruffe were empty), on the third week of May at Allouez Bay (80% of 4 mm ruffe were empty), and on the last week of June in Whaleback Bay (43% of 4 mm ruffe were empty). All other sampling date, location, and length combinations had 20% or fewer fish with empty stomachs. Overall, only two ruffe larger than 5 mm had empty stomachs.

Copepoda, *Daphnia* spp., and *Bosmina longirostris* dominated the overall diet of larval ruffe in the St. Louis River Harbor (Table 3). Similar to these results, Kovac (1998) reported that zooplankton were the primary food of larval ruffe, whereas Popova *et al.* (1998) reported that cladocerans (primarily *Bosmina*) and copepods were primary foods for larger larval ruffe (6–10 mm). Johnsen (1965) and Popova *et al.* (1998) reported that larval ruffe of approximately 4–5 mm fed on rotifers and copepod nauplii. We documented very few rotifers and no copepod nauplii in any of our fish. Fisher and Willis (1997) found that the consumption of rotifers and copepod nauplii by small larval yellow perch was related to the environmental availability of these two prey items and, because of low abundance in some years, rotifers and copepod nauplii would not be present in the diet of larval yellow perch.

The number and occurrence of items within the three major food groups differed with increasing total length of larval ruffe. More Copepoda and *Daphnia* spp. and fewer *Bosmina longirostris* were consumed as ruffe total length increased (Table 4, Fig. 1). Similarly, Copepoda and *Daphnia* spp. occurred more often and *Bosmina longirostris* occurred less often as ruffe total length increased (Table 5, Fig. 2). This pattern of increased consumption of larger prey items with increasing body size is consistent with observations for other larval fish (e.g., Siefert 1972, Schael *et al.* 1991) and is likely explained by an increase in gape width with increasing body size (Schael *et al.* 1991).

Differences in the number and occurrence of

TABLE 4. The coefficient and p-value (in parentheses) for the terms in model (1) and the overall coefficient of determination (R^2) for each major prey item group.

Major Prey Item	Constant	TL	LOC	TL*Loc	R^2
Copepoda	0.6556 (< 0.0005)	0.0844 (< 0.0005)	–1.5367 (< 0.0005)	0.2398 (< 0.0005)	32.5%
Bosmina longirostris	2.1999 (< 0.0005)	–0.1214 (< 0.0005)	–0.8689 (0.001)	0.0503 (0.168)	15.8%
Daphnia spp.	–1.7105 (< 0.0005)	0.3264 (< 0.0005)	1.4967 (< 0.0005)	–0.2830 (< 0.0005)	76.4%
Other	–0.1300 (0.200)	0.0586 (< 0.0005)	0.0643 (0.675)	–0.0033 (0.876)	10.8%

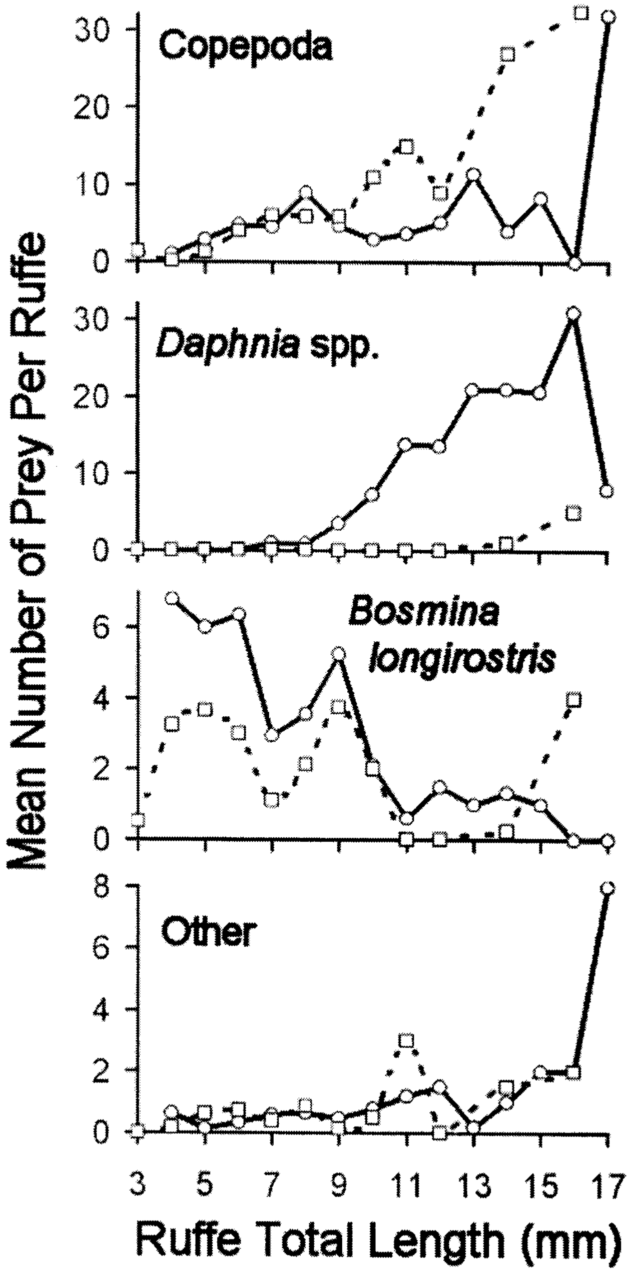

FIG. 1. The mean number of prey items per larval ruffe for the major prey item groups by ruffe total length and sampling location (open circles, solid line = Allouez Bay; open squares, dashed line = Whaleback Bay).

TABLE 5. Estimated odds ratio (with 95% confidence interval) for the occurrence of each major prey item by location for a 1-mm increase in ruffe total length. All odds ratios are significantly different from 1 except where noted by an asterisk. The odds ratio was significantly different between sampling locations if an odds ratio is listed for each location.

Major Prey Item	Allouez Bay	Whaleback Bay
Copepoda	1.12 (0.99, 1.27)*	6.65 (3.21, 13.76)
Bosmina longirostris	0.83 (0.73, 0.93)	
Daphnia spp.	3.71 (2.40, 5.73)	1.50 (1.17, 1.92)
Other	1.24 (1.11, 1.39)	

items in the three major food groups also occurred between sampling locations and among sampling dates. Ruffe from Whaleback Bay consumed *Daphnia* spp. rarely and in very small numbers whereas ruffe from Allouez Bay consumed *Daphnia* spp. often and in large numbers (Figs. 1 and 3). In addition, a general decrease in Copepoda and increase in *Daphnia* spp. consumed by ruffe in Allouez Bay occurred in the second and third weeks of June (Fig. 3). A similar pattern was not observed in ruffe from Whaleback Bay (Fig. 3). The observed differences between locations and among sampling dates is difficult to explain because we do not have zooplankton samples to identify the availability of prey to ruffe. We (Brown 1997) did observe, without quantification or further identification, that "far more zooplankton were collected with the larval ruffe at Allouez Bay than at the Whaleback." Inasmuch as this observation may suggest larger numbers of *Daphnia* spp. at the relatively lacustrine Allouez Bay site, compared to the riverine Whaleback Bay site, we hypothesize that larval ruffe may replace Copepoda with *Daphnia* spp. when *Daphnia* spp. are more available.

Our description of the diet of larval ruffe in the St. Louis River Harbor indicates that the diet of

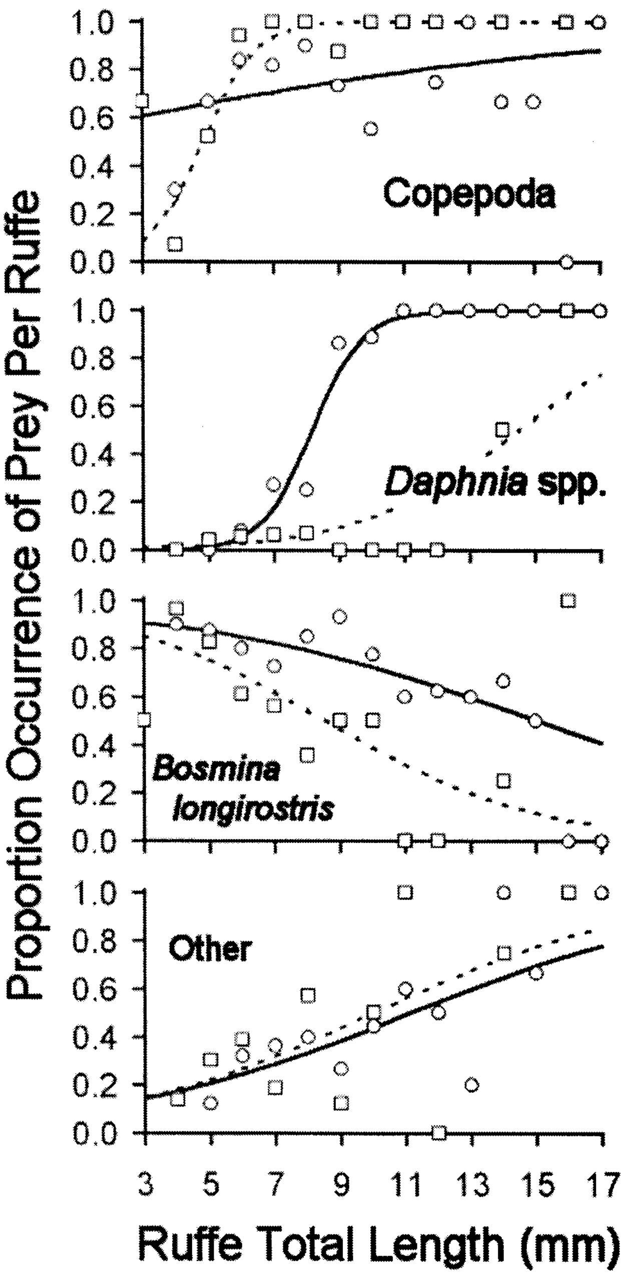

FIG. 2. Proportion occurrence of the major prey item groups and logistic regression model fit by location (open circles, solid line = Allouez Bay; open squares, dashed lines = Whaleback Bay).

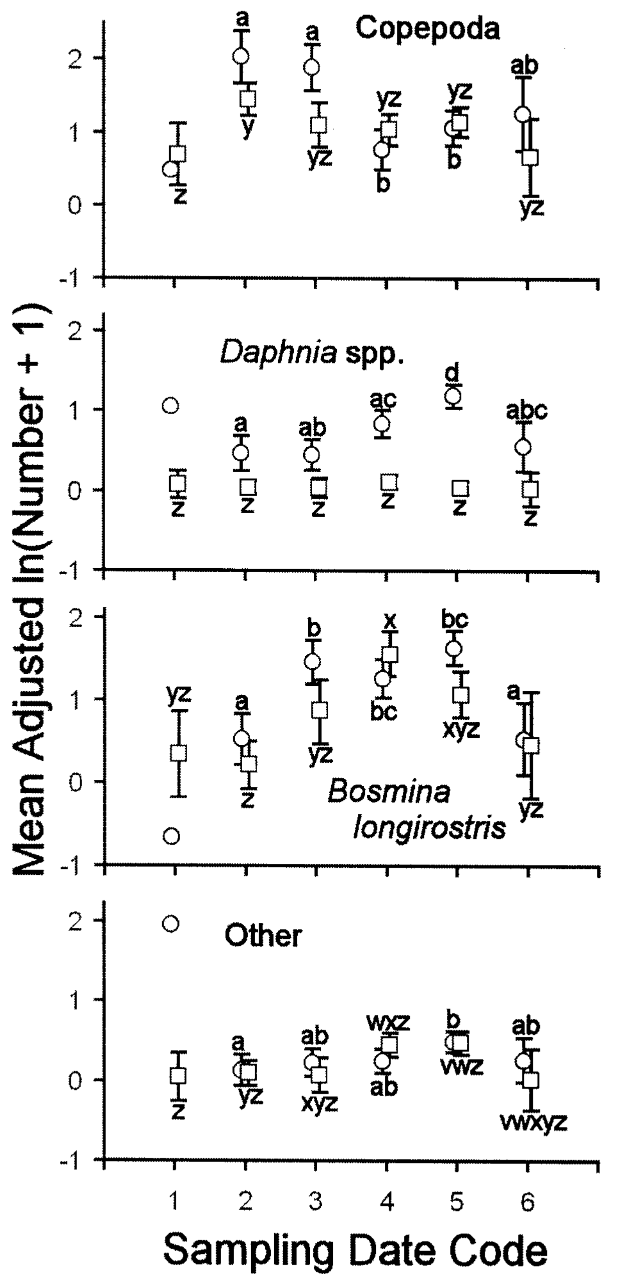

FIG. 3. The length-adjusted mean log number of prey items (+1) per larval ruffe for the major prey item groups by location (open circles = Allouez Bay; open squares = Whaleback Bay) and sampling date (date codes in Table 1). Error bars represent +2SE. Sampling dates with the different letters are significantly different within a sampling location. Significance letters from the beginning of the alphabet (e.g., a,b,c,d) refer to Allouez Bay, whereas letters from the end of the alphabet (e.g., z,y,x,w,v) refer to Whaleback Bay. No error bar or significance letter is shown for the first sampling date in Allouez Bay because only one larval ruffe was collected.

ruffe changes ontogenetically and by date and location. The ontogenetic changes are likely explained by morphometric (i.e., gape width) and behavioral (i.e., becoming more benthic in nature with increasing size; Brown 1997) changes, but the date and location differences (adjusted for length, as we did) indicate that the diet of larval ruffe may reflect the environmental availability of prey. This observed flexibility in diet, coupled with the extended spawning period of ruffe (Brown *et al.* 1998), suggest that ruffe may overlap in time and diet with other fish. Field studies should be conducted to specifically address spatial and temporal overlap in occurrence, diet, and prey selectivity of larval ruffe and other larval fishes to specifically define the effect of larval ruffe on other fish of importance in the Great Lakes watershed.

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