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Diet composition of juvenile fish reflects adaptation to altered prey communities in a reservoir receiving thermal effluent

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Diet Composition of Juvenile Fish Reflects Adaptation to Altered Prey Communities in a Reservoir Receiving Thermal Effluent

BY

Brian A Metzke

THESIS

SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF

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CHARLESTON, ILLINOIS

2005

I HEREBY RECOMMEND THAT THIS THESIS BE ACCEPTED AS FULFILLING
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DEPARTMENT HEAD

ABSTRACT

Survival, and ultimately recruitment, of planktivorous juvenile fish is related to prey availability. Temperature regime and introduction of exotic species can change zooplankton community dynamics and alter trophic relationships between juvenile fish and their prey. Newton Lake, located in Jasper County, Illinois is used as a cooling reservoir for a coal burning power plant. Thermal effluent produced by the power plant is released into only one of two reservoir arms creating a temperature gradient. Newton Lake also contains *Daphnia lumholtzi*, an exotic zooplankter thought to create feeding difficulties for gape-limited predators like juvenile fish. It is within the context of temperature regime alteration and presence of an exotic species that I attempt to determine if zooplankton community dynamics in Newton Lake affect recruitment of juvenile largemouth bass (*Micropterus salmoides*) and bluegill sunfish (*Lepomis macrochirus*)

Limnetic zooplankton were sampled in Newton Lake from July 2003 – July 2004 to assess community structure as it relates to temperature regime. Bray-Curtis dissimilarity analysis and nonmetric multi-dimensional scaling indicate zooplankton community dynamics in Newton Lake were associated with temperature. Accordingly, zooplankton abundance and diversity was lowest during summer as a result of extremely high temperatures created by release of thermal effluent.

Littoral zooplankton communities and juvenile largemouth bass and bluegill were collected during 8 sample periods in the spring and summer of 2004 for determination of fish electivity in relation to prey availability. As with limnetic communities, littoral zooplankton structure was determined by temperature regime. Littoral communities also contained *Daphnia lumholtzi*, and based on gape length characteristics, bluegill may have difficulty ingesting this plankter resulting in an overall reduction in prey availability.

Juvenile fish exhibited specific zooplankton prey preferences related to gape-limitation and prey characteristics associated with motion and pigmentation. However, fish underwent dietary shifts as they matured with bass becoming more piscivorous while bluegill became more insectivorous. Both fish species displayed trophic adaptability in that they consumed the most profitable prey item (i.e. insects or other fish), but continued to supplement their diets with zooplankton. Therefore, this diet flexibility may allow juvenile fish in Newton Lake to avoid reduced survival and recruitment rates caused by low zooplankton prey availability and presence of *Daphnia lumholtzi*.

AKNOWLEDGEMENTS

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Thanks also to my parents, Joe and Bonnie, for their continuous encouragement throughout the past six years. Deep appreciation goes to Megan Miller for motivation and for help entering data and collecting field samples.

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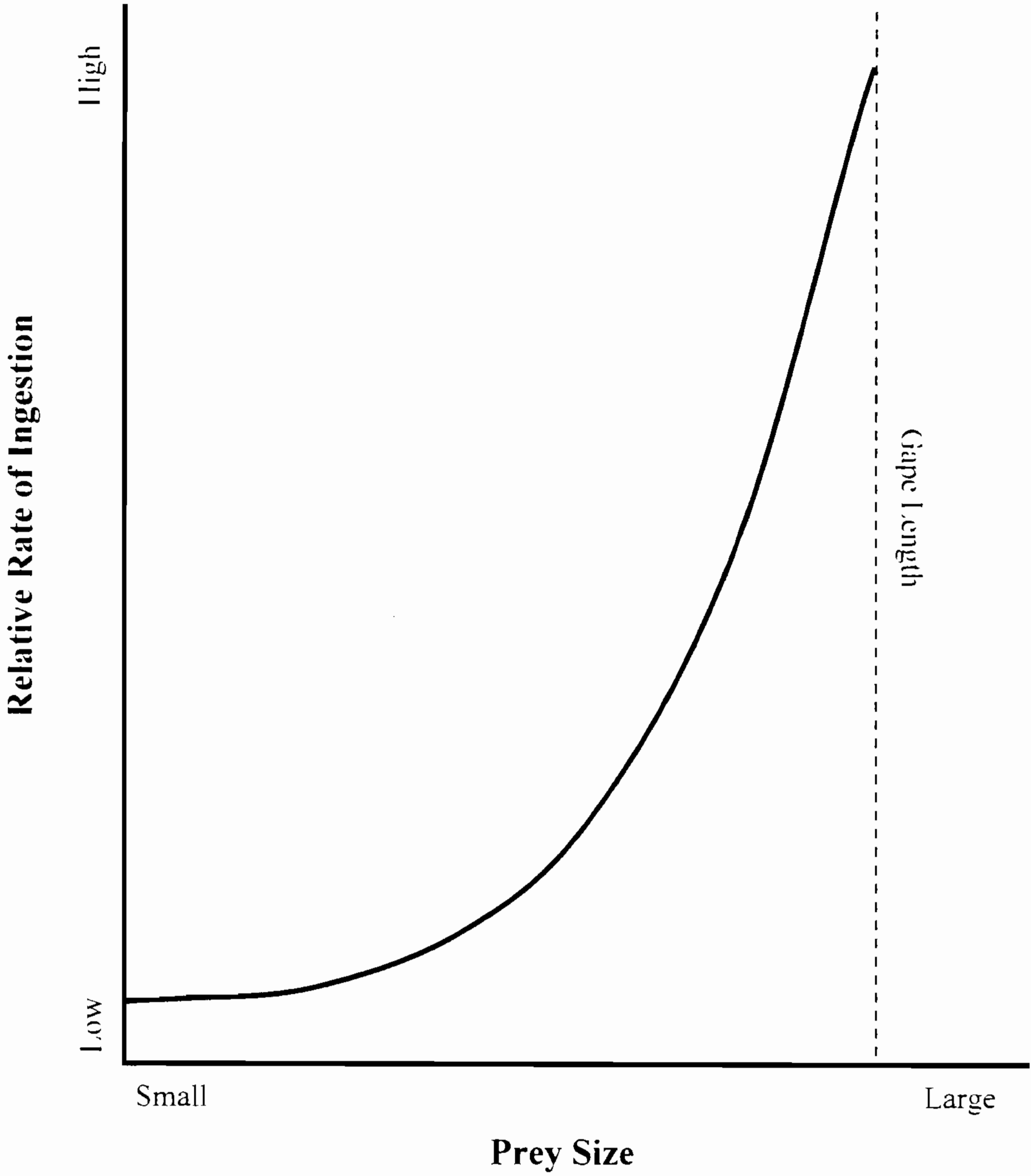
INTRODUCTION

Juvenile fish mortality rates generally are high (Noble 1975. Wetzel 2001. Graeb *et al* 2004) and largely related to predation and prey availability and community composition (Siefert 1972. DeVries *et al* 1998). Many fish species are plantivorous for a period following emergence from the egg (Forbes 1914) and follow size specific ontogenies (Osenberg *et al* 1988, Werner and Hall 1988, Olson 1996). For instance, young-of-the-year pumpkinseed sunfish (*Lepomis gibbosus*) feed initially upon microcrustaceans and later shift to insect larvae and snails as they mature (Garcia-Berthou and Moreno-Amich 2000). Similar patterns of ontogenetic diet shifts from plankton to larger items have been documented in other fish species (Olsen 1996). Therefore zooplankton are an important food source for developing juveniles and ultimately may determine growth and survival rates in juvenile fish populations (Noble 1975, Lemly and Dimmick 1982, Tytler and Calow 1985, Jobling 1994). As gape-limited predators, juvenile fish are restricted to prey no larger than their mouths (gapes). and therefore, select prey within a specific size range (Zaret 1980, Mills *et al* 1986, Barnes and Mann 1991; Figure 1). Consequently, temporal or spatial shifts in zooplankton community structure can negatively impact survival of juvenile fish, reducing recruitment of individuals into their respective populations (DeVries *et al* 1998).

Electivity is differential selection of prey items when presented with many prey choices (Zaret 1980). Electivity analysis offers a means to quantify feeding habits by comparing prey availability with relative abundance of specific prey items in gut contents of predators such as fish (Strauss 1979. Zaret 1980). For instance. electivity has been used to calculate size dependency in gape-limited predators (Mills *et al* 1986. Lemke *et al* 2003). nutritional value of preferred prey (Graeb *et al* 2004). and shifts in prey

Figure 1. Relationship of gape-limited predator response to prey size. Modified from Zaret (1980).


Relative Rate of Ingestion
High
Low
Gape Length
Small
Large
Prey Size

selection over time (Siefert 1972). In this context. electivity analysis allows for evaluation of relationships between shifts in zooplankton communities (expressed as changes in size structure. composition, or density) and planktivory in fishes. and ultimately is useful in relating feeding behavior in fish to bottom-up effects of environmental perturbations.

Environmental conditions can account for much of the seasonality in zooplankton communities present in lakes and reservoirs (Wetzel 2001). Salinity (Hall and Burns 2002), light penetration (Wissel *et al* 2003), macronutrient concentrations (Dzialowzki *et al* 2003), and food quality and abundance (Luecke *et al* 1990) all have been shown to influence the distribution and abundance of zooplankton species. Species specific unimodal ranges of optimality are observed for many of these factors. For instance, certain species of zooplankton have niche breadths within specific salinity ranges (Barnes and Mann 1991), while high water clarity increases depredation of large bodied zooplankters (Wissel *et al* 2003, Bernot *et al* 2004). However, of all abiotic factors, water temperature may be the most influential determinant of zooplankton community structure.

Temperature can directly and indirectly affect seasonality and abundance of zooplankton (Mitchell and Lampert 2000). Reproductive and mortality rates often are correlated strongly with temperature (U.S.E.P.A 1974, Wetzel 2001) as is size structure of some zooplankton populations (Achenbach and Lampert 1997). Cyclomorphological characteristics of some zooplankton species are influenced by temperature (Yurista 2000), which may result in differential rates of predation by planktivores. Phytoplankton community structure also is dependant, among other factors, on temperature (Bush *et al*

1974, Moran 1981, Laws 1993), which may, in turn, alter prey availability for herbivorous zooplankters.

Although abiotic factors, especially temperature, largely determine zooplankton community structure, biotic factors, such as exotic species introductions, may also influence distribution of native taxa. Exotics can alter trophic structure (Havel and Hebert 1993) or even completely displace native species (Dzialowski *et al* 2000). One such exotic species, present within a number of lakes and reservoirs in the United States, is *Daphnia lumholtzi* (Sars), a zooplankter native to Asia, Australia, and Africa thought to have been introduced into Lake Fairfield, Texas in the early 1980's (Havel and Hebert 1993). Cyclomophic features, including pronounced anterior and posterior spines, lateral fornices, and ventral spines produced by this cladoceran are thought to deter ingestion by gape-limited predators like juvenile fish (Swaffer and O'Brien 1996, Kolar *et al* 1997). *Daphnia lumholtzi* also may be tolerant of high temperatures (Havens *et al* 2000, Yurista 2000) when native cladoceran abundance is low. During these periods of decreased interspecific competition, increased abundance of *Daphnia lumholtzi* could thereby further reduce prey availability for gape-limited predators (Lemke *et al* 2003). Unlike other large bodied cladocerans whose summer abundance often is restricted by both temperature maxima and predation (Wetzel 2001, Hall and Burns 2002, Rettig 2003, Romare *et al* 2003, Bernot *et al* 2004, Jeppesen *et al* 2004), *Daphnia lumholtzi* may benefit from a warm temperature regime while largely avoiding predation by gape-limited predators.

Cooling water reservoirs are used by power plants as a supply of water for turbine operation and as a method for cooling heated effluent after it is has been produced during power generation (Laws 1993). Areas located near thermal discharges often experience elongated periods of warm temperatures (Brigham 1981, Gilliland 1983) and, although system dependant, temperature change above ambient levels can be drastic and may exceed 12°C (Marcy 1971). Temperature regime alteration can have such positive effects on biota as increased metabolism and growth rate of economically important fishes (Bennett and Gibbons 1973, Laws 1993), and increased biomass and diversity in winter when ambient temperatures cool (Dahlberg and Conyers 1981, Tranquilli *et al* 1981, Waite 1981). But, increased temperatures also may have detrimental effects including loss of thermally intolerant algae, zooplankton, invertebrates, and fish species (Benda and Proffitt 1973, Patrick 1973, Bush *et al* 1974, U.S.E.P.A. 1974), increased mortality of fish during extreme discharge events (Stauffer Jr. 1980, Laws 1993), increased biological oxygen demand of organisms (Laws 1993), and development of gas-bubble disease in fish (Adair and Hains 1973, Miller 1973), while creating conditions suitable for exotic species to invade and persist (King and Greenwood 1992, Havens *et al* 2000).

Appreciating feeding behaviors of juvenile fish in cooling water reservoirs requires an understanding of how abiotic and biotic factors, like temperature regime and exotic species introductions, may result in bottom-up interactions between trophic levels. Zooplankton community dynamics and the presence of *Daphnia lumholtzi* in a thermally altered system may negatively impact juvenile fish survival through alteration of prey availability. Previous studies have focused largely upon effects of thermal discharges on a single group of organisms (i.e. invertebrates, fish, etc.), but few have attempted to make connections on multiple trophic levels and explore bottom up effects of community shifts. Within this context, I will attempt to relate effects of thermal discharges in

Newton Lake, a cooling water reservoir which also contains *Daphnia lumholtzi*, to both zooplankton community dynamics and juvenile fish electivity. More specifically, I will investigate 1) response of limnetic and littoral zooplankton communities to a temperature regime influenced by heated effluent, and 2) effects of temporal and spatial variability in littoral zooplankton community structure and presence of *Daphnia lumholtzi* on recruitment of juvenile largemouth bass (*Micropterus salmoides*) and bluegill sunfish (*Lepomis macrochirus*).

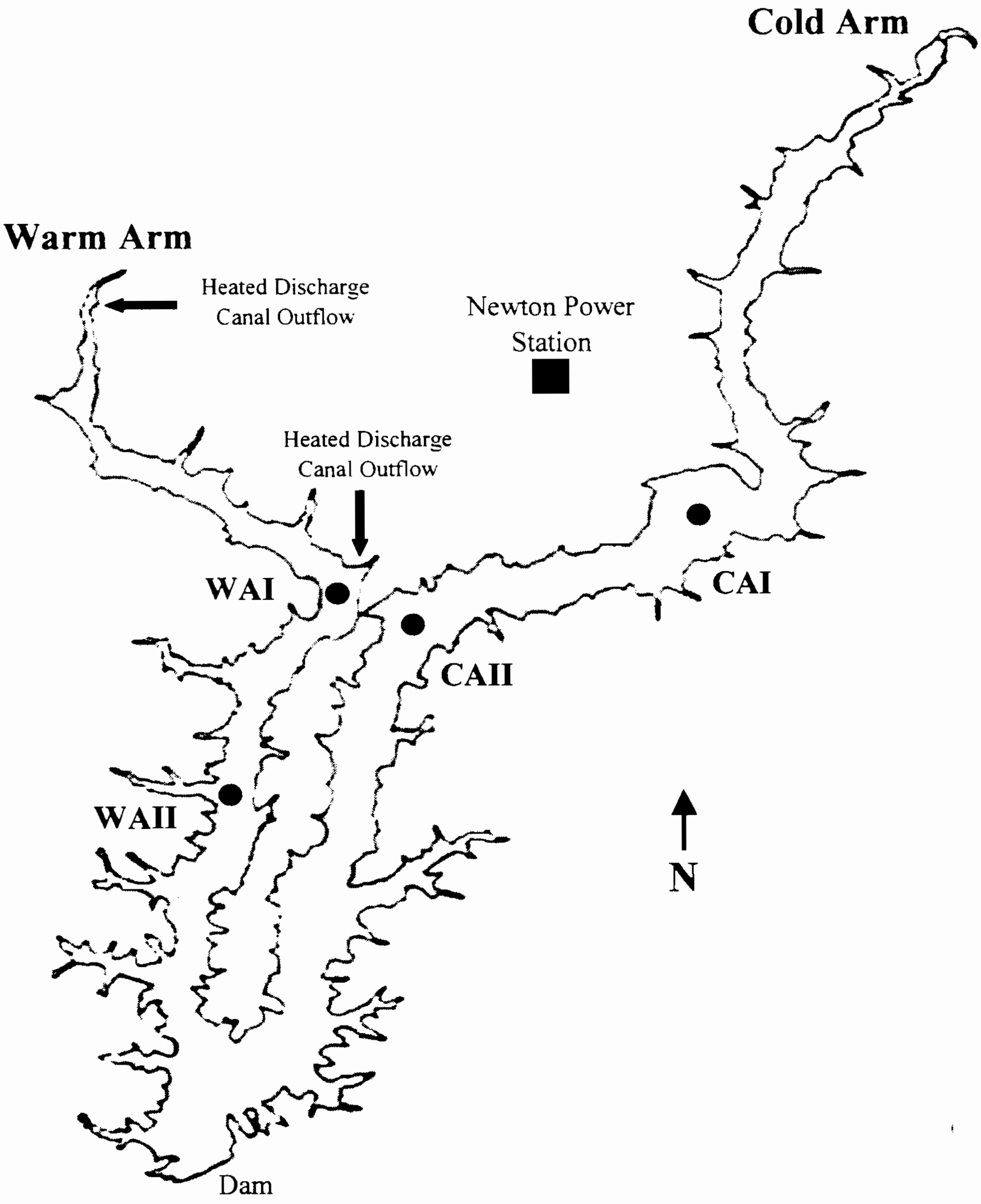
MATERIALS AND METHODS

Study Site Description

Newton Lake, located in Jasper County, Illinois, is used as a cooling water supply for the coal burning Newton Power Plant operated by Ameren (I.D.N.R. 2003, Ameren 2005). This reservoir has a surface area of 718 hectares with a maximum depth of approximately 12 meters. Newton Lake is an excellent model for exploring effects of thermal discharges on biota. Water is drawn from the eastern (cold) arm near the power plant and thermal effluent is released continuously at two locations in the northern half of the western (warm) arm (Figure 2). The cold arm, however, receives no heated effluent and provides a reference with which to compare biotic responses to the altered thermal regime in the warm arm. Water is released from the reservoir via a small overflow dam, resulting in long residence time and an elongated lacustrine zone with little mixing of water between the two arms beyond the forebay.

To achieve my study objectives, four sample sites, two on each arm, were established in the limnetic zone of Newton Lake (Figure 2). Labeled WAI and WAII on the warm arm and CAI and CAII on the cold arm, these sites are positioned at increasing distances from the heated discharge outflows. WAI is located adjacent to the southern discharge outflow while WAII is nearer to the forebay. CAI and CAII, located far from heated discharges, are intended to serve as control sites. Overall, the spatial arrangement of sample sites allows for interpretation of biotic communities as they relate to temperature regime.

Figure 2. Location of sample sites (WAI, WAII, CAI, CAII) and point source of heated effluent in Newton Lake, Jasper County, IL.


Cold Arm
Warm Arm
Heated Discharge Canal Outflow
Newton Power Station
Heated Discharge Canal Outflow
WAI
CAI
CAII
WAII
N
Dam

Physical Characteristic Measurements and Limnetic Zooplankton Collection

Sampling was conducted at biweekly intervals from July 2003 – July 2004, except from December through February when only one sample was taken each month. At each site, maximum depth was determined to the nearest 0.1 m using a Hondex Digital Depth Sounder and surface water temperature was measured (± 0.1 °C) with a YSI 85 multiple field meter. Zooplankton were collected at each of the four sample sites using a single vertical tow from substrate to surface with an 80 μm mesh conical plankton net with an 0.196 m^2 opening. All zooplankton samples were fixed using formalin-aceto-alcohol (Pennak 1953) immediately upon collection and transported to the laboratory for later analysis of zooplankton community structure.

Analysis of Limnetic Zooplankton Communities

To assess community dynamics, zooplankton were identified at 100x magnification to the lowest possible taxonomic level using Smith (2001), Thorp and Covich (2001), and Ward and Whipple (1918). Sample volumes were adjusted in the laboratory (200 - 450 mL) to facilitate counting efficiency. For each sample, a 1 mL subsample was removed and placed into a Sedgwick-Rafter counting chamber for identification and enumeration of zooplankton. Upon completion, each subsample was returned to the original sample and the above process repeated four additional times. Zooplankton densities were calculated for each subsample using the formula outlined in Wetzel (2001).

$$\text{Density} = \frac{\text{\# of Individuals} * \text{Sample Volume (mL)}}{\text{Area of Net Opening } (m^2) * \text{Site Depth (m)}}$$

For each zooplankton sample, mean densities were determined by averaging the results obtained from density estimates of 5 subsamples. Although densities for all zooplankton taxa were calculated, only those taxa categorized as prey items were used for analysis community dynamics. For the purposes of this study, prey items include copepods (including copepodids), cladocerans, ostracods, and planktonic insect larvae. These groups were chosen after it became apparent that juvenile fish did not include rotifers and copepod nauplli in their diets.

After completion of density calculations, prey item community data were used to create a Bray-Curtis dissimilarity matrix for all pair-wise site comparisons on each sample date. Considered more accurate than other dissimilarity indices (Bloom 1981), the Bray-Curtis index uses taxonomic composition and abundance to calculate a coefficient of dissimilarity between two communities, with higher coefficients indicating a greater degree of dissimilarity. Mean dissimilarity for the entire sampling period was determined for each pair-wise comparison. Subsequently, nonmetric multi-dimensional scaling (NMDS) based on Bray-Curtis dissimilarity values (McCune and Mefford 1999) was used to describe the relationship between community structure and temperature. NMDS enables low-dimensional, graphical representation of the statistical distance between samples and is well suited for use with data that are non-normal (West *et al* 2003, Pegg and McClelland 2004). NMDS results were used to assess the relative statistical difference (dissimilarity) of each community as it relates to temperature.

Juvenile Fish and Littoral Zooplankton Collection

From April 2004 – July 2004 juvenile fish were sampled from the littoral zone adjacent to each site during eight sampling events spaced 1-2 weeks apart. Fish were collected using a conical net with $^1/_8$ inch mesh and a $0.283m^2$ opening towed parallel to the boat on 6April and 5 May, 2004, while boat electrofishing was used on the remaining 6 sample dates (21 May, 2, 9, 15 and 29 June, and 7 July). For both collection methods, sampling lasted approximately 20 minutes or until 30 or more appropriately sized (those that were obviously juveniles) fish were collected. Immediately after collection, fish were placed into 200mL bottles on ice until they lost consciousness and could be preserved in 20% formalin without inducing regurgitation. Once fish were collected, littoral zooplankton were sampled from the same location using 2 4-meter oblique tows with a 118 μm mesh conical net with a $0.045\ m^2$ opening. Zooplankton samples were preserved in formalin-aceto-alcohol (Pennak 1953) upon collection and stored for later analysis.

Determination of Juvenile Fish Population Characteristics and Diet Analysis

For each site and date combination, 30 individuals for both largemouth bass and bluegill sunfish were randomly chosen for analysis, or if fewer than 30 were collected, all individuals were analyzed. Total body length and gape length of juvenile fish were measured to the nearest 0.5mm before stomachs were removed for diet analysis. Means (± 1 SE) were determined for total body length and gape length of each fish species. Stomach contents were extracted for identification and enumeration at 22x magnification. Zooplankton were identified to the lowest possible taxonomic level, while insects were recorded as either larvae, pupae, or adults. Fish found within the stomach contents were recorded as present and counted, but in most cases, could not be identified to a specific taxonomic level.

Analysis of Littoral Zooplankton Communities

Littoral zooplankton were identified and counted by removing 1mL subsamples from the overall sample and placing them into a Sedgwick-Rafter counting chamber. Enumeration concluded when 5 subsamples were completed, or when 200 prey items were identified as I was interested in calculating only proportional composition. Total length of all littoral *Daphnia lumholtzi* observed during enumeration was measured using an ocular micrometer. Mean (± 1 SE) total length was calculated for comparison with juvenile fish gape length.

Calculation of Juvenile Fish Electivity

Data from fish diets and littoral zooplankton communities were summarized by calculating relative abundances of consumed (r_i) and potential (p_i) prey items. In this study, I use Strauss's index (L) to calculate electivity as a measure of prey preference. Electivity values were calculated for each potential prey item as,

$$L_i = r_i - p_i$$

producing values ranging from -1 to +1. Values not significantly different from 0 indicate neutral electivity (no election for or against an item), whereas values above 0 indicating electivity for a prey item and values below 0 suggest avoidance. Strauss's index was used because it is less sensitive to rare taxa than other metrics, and allows for statistical comparison of a calculated value to a null hypothesis (Strauss 1979, Lemke 2003). Mean electivity values were calculated for all prey items present within the littoral zooplankton community at each site and date combination for both largemouth bass and bluegill. Independent t-tests (SPSS 2004) were used to determine if mean electivity values were significantly different from zero.

To look at general patterns electivity and eliminate problems occurring as a result of variation in electivity scores for largemouth bass and bluegill between sample dates, I developed a relative preference index (M_i). I calculated relative preference scores from the proportion of sample dates upon which positive or negative electivities were observed for specific prey items, as follows:

$$M_i = \{[n_{pos}(1)] + [n_{neg}(-1)]\}/N$$

where M_i is the overall preference for a specific prey item (i), n_{pos} is the number of occasions electivity is significantly positive, n_{neg} is the number of occasions electivity is significantly negative, and N is the total number of electivity scores, including those occasions where electivity values were neutral. Calculated as such, overall preference values range from -1 to +1, with positive values indicating preference and negative values avoidance for a specific prey item over the entire sampling period. As this index is a relative measure of preference, no statistical tests were conducted and negative or positive values were considered to indicate preference or avoidance, respectively.

Analysis of Insectivory and Piscivory Rates

During diet analysis, it became apparent juvenile fish were ingesting insects and other fish in addition to zooplankton. Accordingly, proportion of insects in diet was calculated for both largemouth bass and bluegill to measure the relative use of insects as prey in an effort to identify dietary niche shifts from zooplankton to insects. Total number of insects was divided by total number of prey items ingested to calculate a mean proportion for each predator at each site and date combination. Proportion of largemouth bass ingesting fish also was noted to evaluate rates of piscivory relative to predator length at each site. Relationship between predator size and insectivory and piscivory rate was determined using correlation analysis.

RESULTS

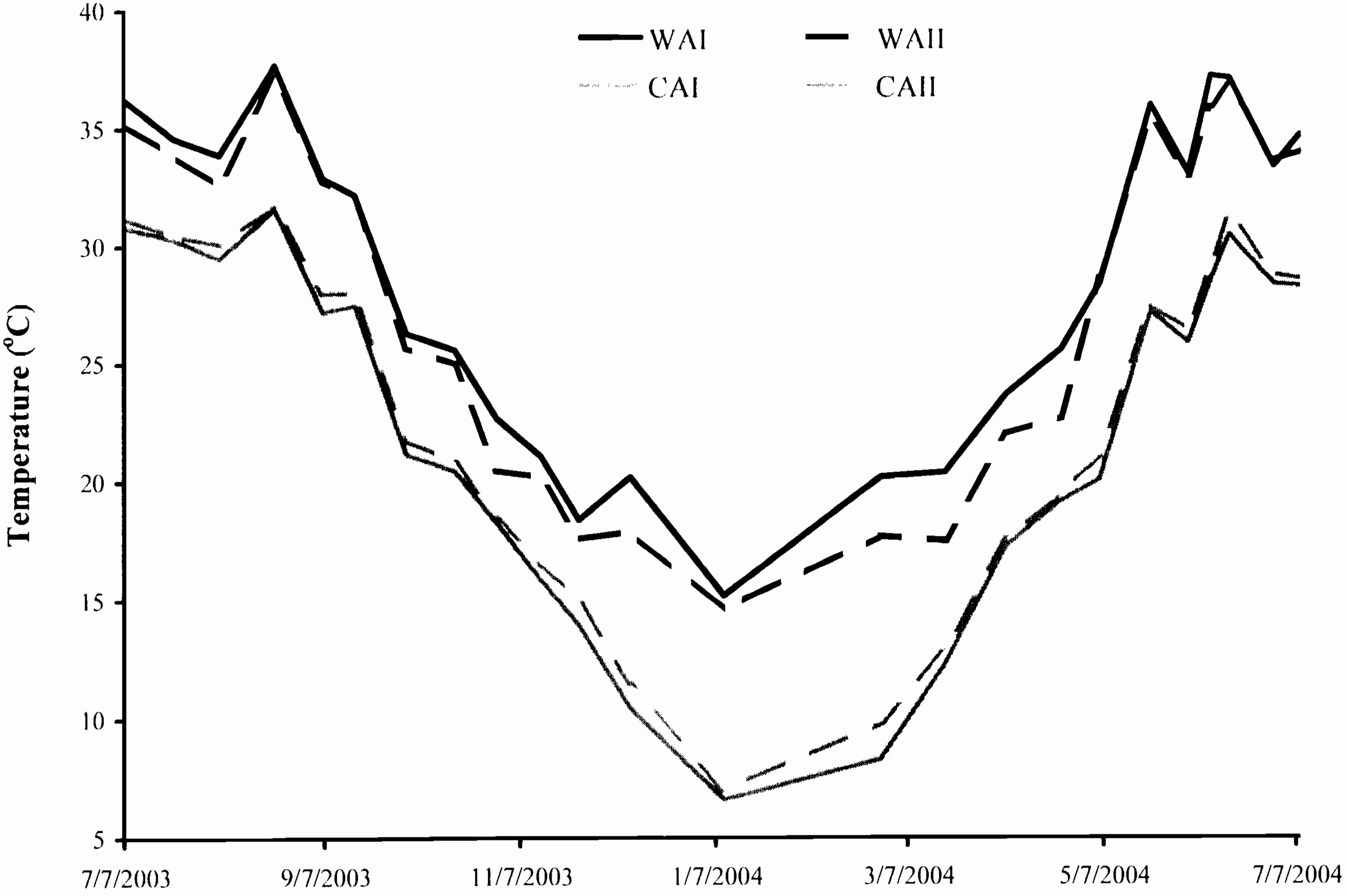
Physical Characteristics of Newton Lake

Average surface water temperatures throughout the sample period were 28.6 ± 1.4, 27.6 ± 1.5, 22.1 ± 1.6, and 22.7 ± 1.6°C for WAI, WAII, CAI, and CAII, respectively. Although there is much overlap in temperature ranges, sites in the warm arm are characterized by higher temperatures in the summer months and maintain higher temperatures in the winter months (Figure 3). Temperatures during summer in the warm arm remained above 30°C for approximately 16 weeks and reached a maximum of 37.7°C, while the cold arm maintained 30°C or above for approximately 7 weeks and reached a maximum of only 31.8°C. During seasonal transitions (spring and fall), warm arm sites cooled more slowly and warmed more rapidly than cold arm sites, while remaining above 14 °C during winter.

Limnetic Zooplankton Community Dynamics

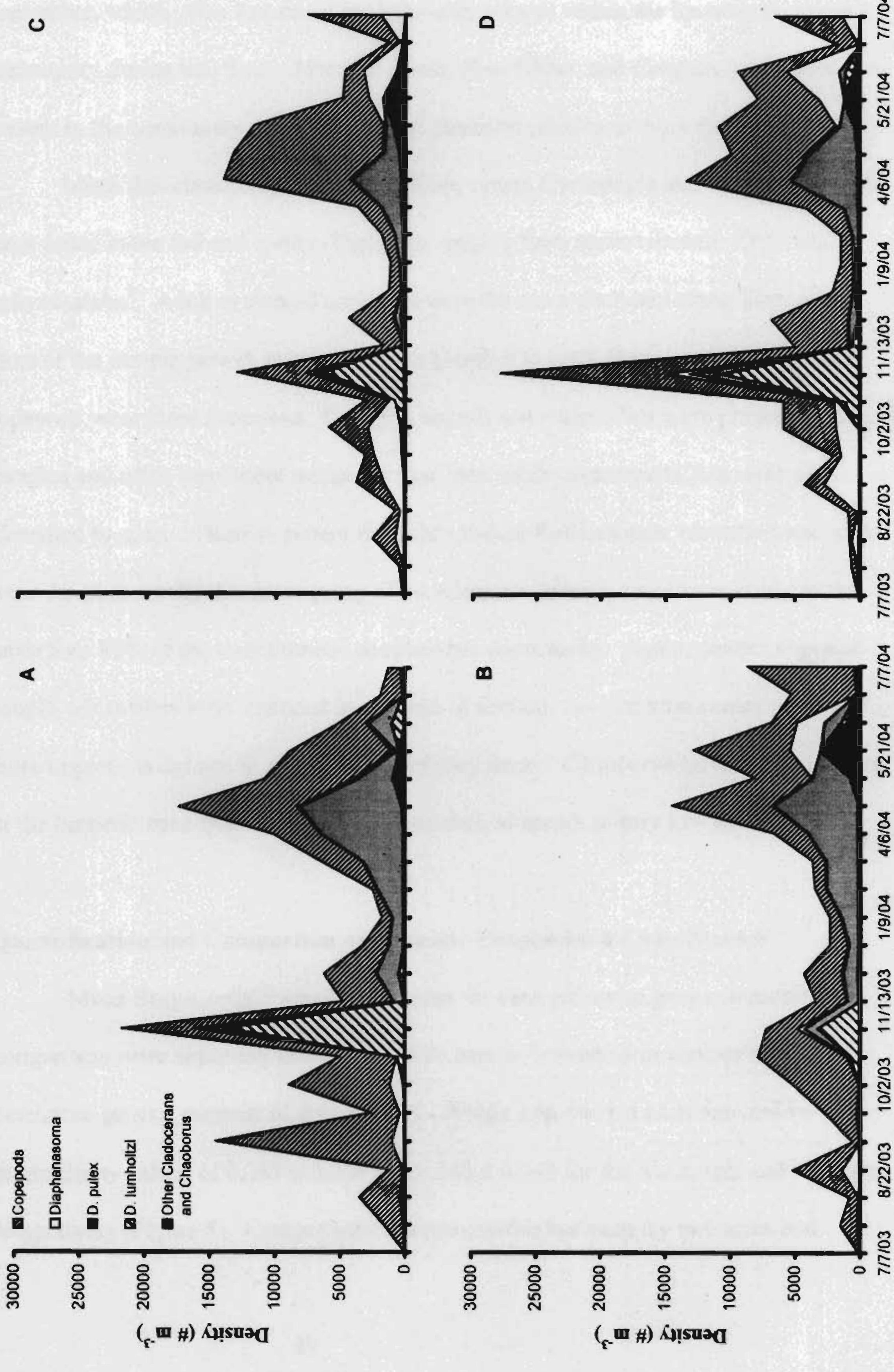
Seven cladoceran taxa, representing 5 families, were identified from the limnetic zone of Newton Lake. Cladoceran communities show similar patterns of development and decline at all four sites (Figure 4). Densities of cladoceran zooplankton were lowest during both winter and summer (<3000/m^{-3}), while peak densities occurred in late fall and late spring (>4500/m^{-3}). Taxonomic richness also was relatively higher during fall and spring (3-7 taxa), while during summer and winter richness remained at or below 3 taxa. *Daphnia lumholtzi* dominated the cladoceran community in October and November, but also was present at much lower densities in June. At other times from December through May, *Daphnia pulex* comprised the majority of cladocerans community. Species of *Daphnia* were supplanted by *Diaphanosoma* from June through

Figure 3. Temporal variation of surface water temperatures in the warm and cold arms of Newton Lake.



WAI
WAII
CAI
CAII
Temperature (°C)
40
35
30
25
20
15
10
5
7/7/2003
9/7/2003
11/7/2003
1/7/2004
3/7/2004
5/7/2004
7/7/2004

Figure 4. Density of limnetic prey taxa sampled at WAI (A), WAII (B), CAI (C), and CAII (D) from July 2003 through July 2004. 'Other Cladocerans' category includes *Alona*, *Bosmina*, *Camptocercus*, and *Ilyocryptus*.


A
B
C
D
Copepods
Diaphanasoma
D. pulex
D. lumholtzi
Other Cladocerans and Chaoborus
Density (# m-3)
30000
25000
20000
15000
10000
5000
0
7/7/03
8/22/03
10/2/03
11/13/03
1/9/04
4/6/04
5/21/04
7/7/04

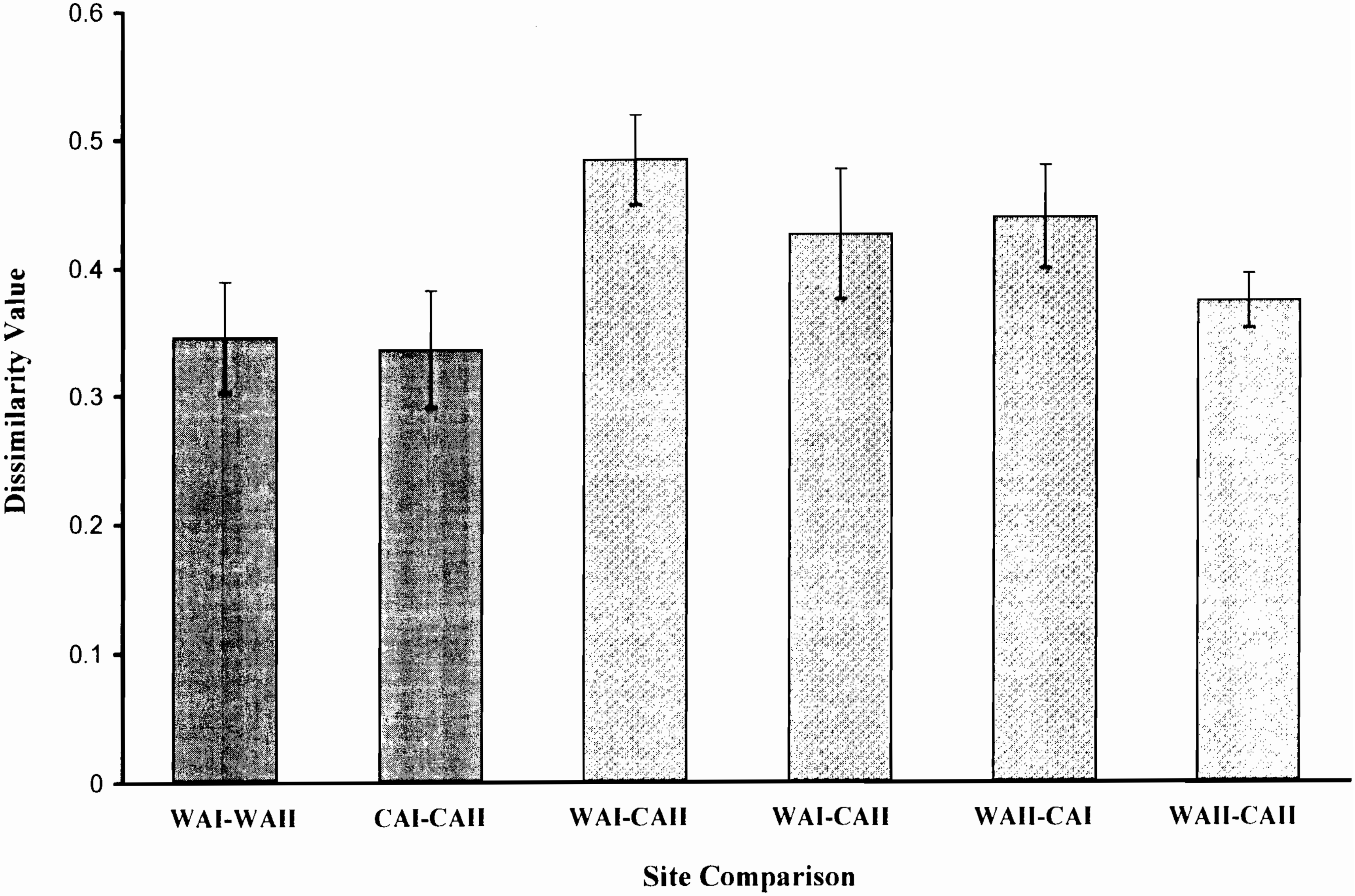
September, which often was the only cladoceran present within the limnetic zooplankton community during that time. *Bosmina*, *Alona*, *Ilyocryptus*, and *Camptocercus* were also present in the community, but never at high densities relative to more dominant taxa.

Much like cladocerans, copepods (from orders Cyclopoida and Calanoida) were most dense in the fall and spring (Figure 4), ranging from approximately 1000-14,000 individuals/m^3. Adult cyclopoid copepods were the more abundant taxon throughout most of the sample period, except from late October to early January when calanoid copepods were more numerous. Copepod nauplli and copepodids were present in all samples and often were more numerous than their adult counterparts, but were not identified to order. Thirteen genera from the phylum Rotifera were identified and often were the numerically dominate group of zooplankton present, sometimes comprising more than 85% of the total limnetic zooplankton community. Again, neither copepod nauplli nor rotifers were included in analysis of limnetic zooplankton communities, as these organisms did not fit my definition of prey items. *Chaoborus* larvae were present in the limnetic zone from late May to September, although at very low abundance.

Quantification and Comparison of Limnetic Zooplankton Communities

Mean Bray-Curtis dissimilarity values for each pair-wise prey community comparison were separated into either within arm or between arm comparisons to determine general patterns of dissimilarity. Within arm comparisons resulted in dissimilarity values of 0.337 ± 0.046 and 0.346 ± 0.043 for the warm arm and cold arm, respectively (Figure 5). Comparisons of communities between the two arms had

Figure 5. Mean (±1 SE) for each pair-wise site comparison of Bray-Curtis dissimilarity values for limnetic prey communities. The first two bars represent within arm comparisons, while the remaining bars indicate comparisons between the two arms of Newton Lake.


0.6
0.5
0.4
0.3
0.2
0.1
0
Dissimilarity Value
WAI-WAII
CAI-CAII
WAI-CAII
WAI-CAII
WAII-CAI
WAII-CAII
Site Comparison

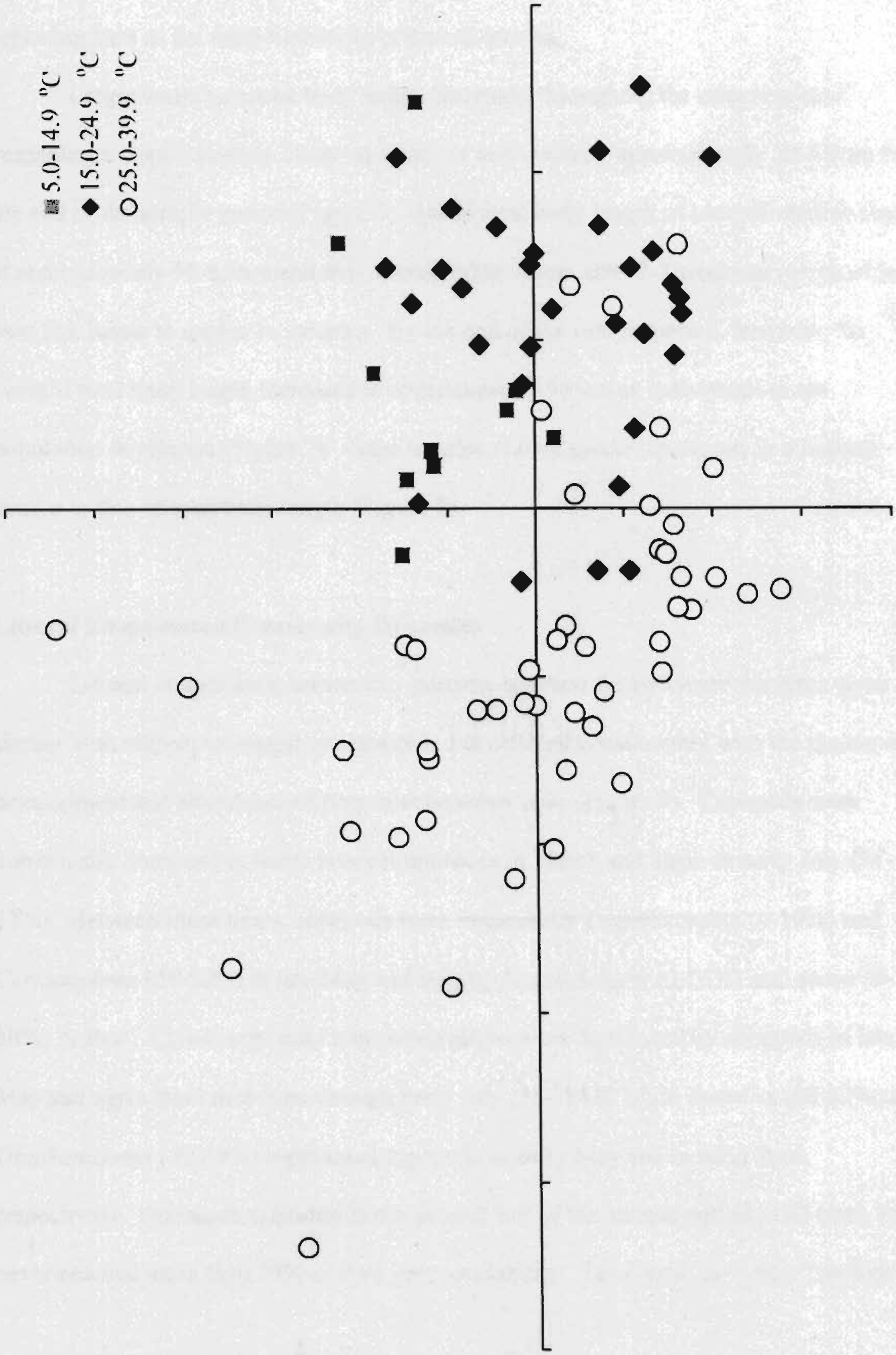
relatively higher dissimilarity values (WAI-CAI = 0.485 ± 0.035; WAI-CAII = 0.427 ± 0.051; WAII-CAI = 0.440 ± 0.040; WAII-CAII = 0.375 ± 0.021).

Statistical distance between each prey community is shown by the distribution of points within the NMDS ordination space. Each point in this space represents a community sampled at a particular site on one sample date. Points located far from one another are less similar than those that are more closely grouped. Once plotted, each point was placed into a category based on the temperature at which that sample was collected, and although arbitrary, these categories were selected based upon information collected during review of literature pertaining to temperature tolerance in zooplankton. Those temperature categories are defined as low (5.0-14.9°C), moderate (15.0-24.9°C), and high (25.0-39.9°C). Communities sampled at low temperatures are located in the upper right quadrant of the ordination space, those sampled at high temperatures are located predominately on the left half of the ordination space, while those sampled at moderate temperatures are located between the other two categories (Figure 6).

Fish Community Characteristics

Largemouth bass and bluegill were the most frequently collected littoral fish species, although gizzard shad (*Dorosoma cepedianum*) and blackstriped topminnows (*Fundulus olivaceus*) also were present. The latter two species were collected sporadically throughout the sample period, but never in sufficient number to allow for analysis of electivity. Further, of the few gizzard shad that were collected, stomach contents consisted primarily of detritus. Juvenile largemouth bass were more often collected early in the sample period (5 March – 9 June in the warm arm; 5 May – 29 June

Figure 6. Spatial distribution of limnetic prey communities within two-dimensional ordination space created by NMDS derived from Bray-Curtis values. Temperature ranges were defined as low (5.0°C-14.9°C), moderate (15.0°C-24.9°C), and high (25.0°C-39.9°C).


■ 5.0-14.9 °C
◆ 15.0-24.9 °C
○ 25.0-39.9 °C

in the cold arm) while juvenile bluegill appeared later (21 May – 7 July in both arms), replacing bass as the most frequently collected species.

Largemouth bass total body length increased throughout the sample period, beginning at approximately 20mm at each site and reaching approximately 50-55mm by the end of the sample period (Figure 7). Mean total body length of bluegill sunfish began at approximately 50-65mm and then decreased to 30mm after 2-3 weeks as young of the year fish began to appear in samples. By the end of the sample period, however, the bluegill total body length increased to approximately 40mm as individuals in the population developed (Figure 7). Gape lengths of both species increased in a fashion similar to that of total body length (Figure 8).

Littoral Zooplankton Community Dynamics

Littoral zooplankton community patterns between the two reservoir arms were similar with respect to overall composition, but differed considerably with the timing of development and abundance of prey taxa between arms (Figure 9). Copepods were numerically dominate in warm arm communities in March and again in early July (84-53%). Between these times, copepods were replaced by *Diaphanosoma* (0-19%) and *Ceriodaphnia* (21-52%) in late May and then by *Scapholeberis* (0-56%) and *Alona* (0-50%) in June. Conversely, cold arm communities were dominated by copepods in late May and again from mid-June through early July (25-79%), while *Bosmina* (80-82%) and *Diaphanosoma* (49-59%) supplanted copepods in early May and in early June respectively. Ostracods appeared in the second half of the sample period at all sites, but never reached more than 25% of total prey availability. Taxa listed as "Other" include

Figure 7. Mean total body length of largemouth bass (A) and bluegill sunfish (B) at each sample site.

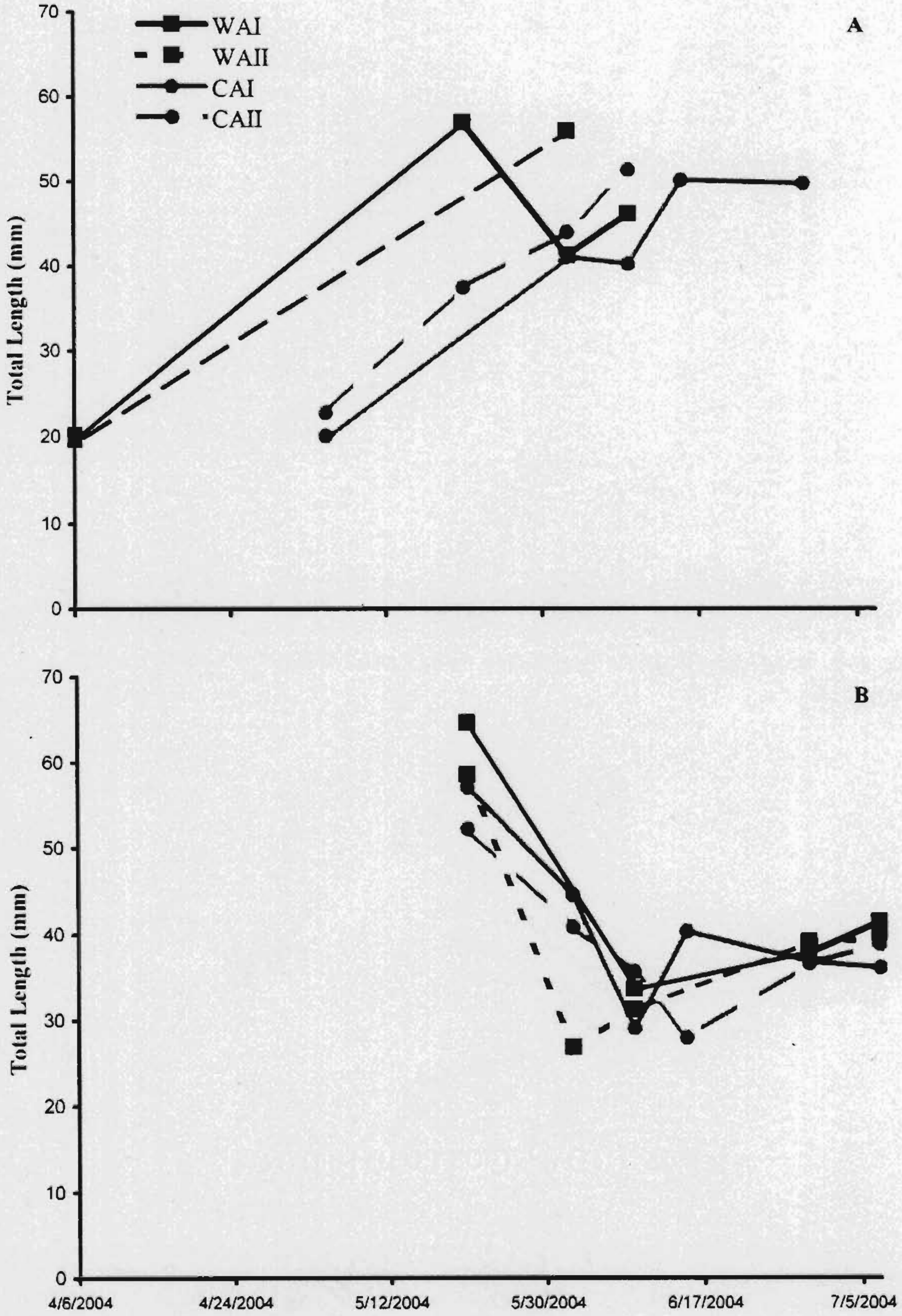

A
B
WAI
WAII
CAI
CAII
Total Length (mm)
Total Length (mm)
0
10
20
30
40
50
60
70
4/6/2004
4/24/2004
5/12/2004
5/30/2004
6/17/2004
7/5/2004

Figure 8. Mean gape length of largemouth bass (A) and bluegill sunfish (B) at each sample site.

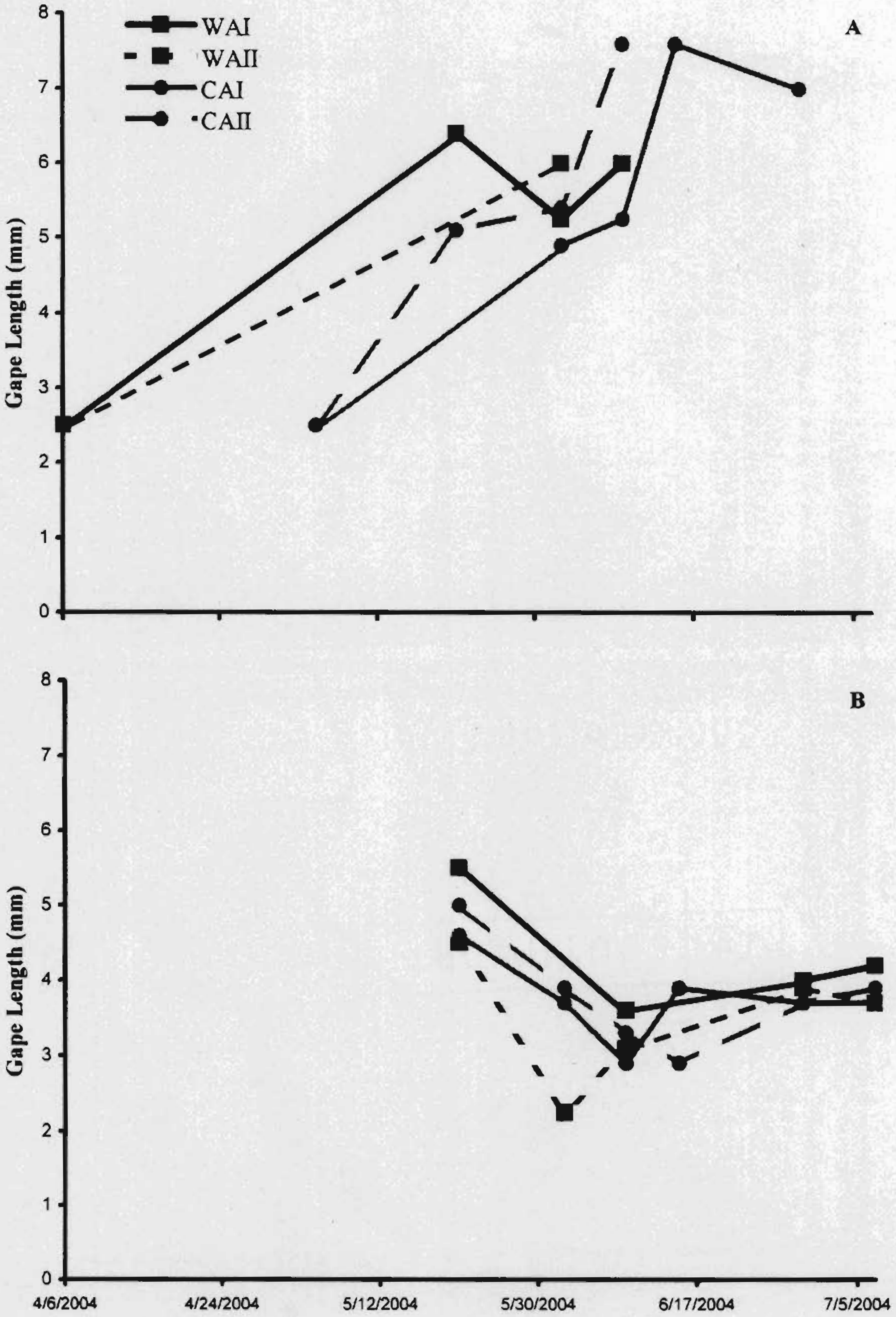
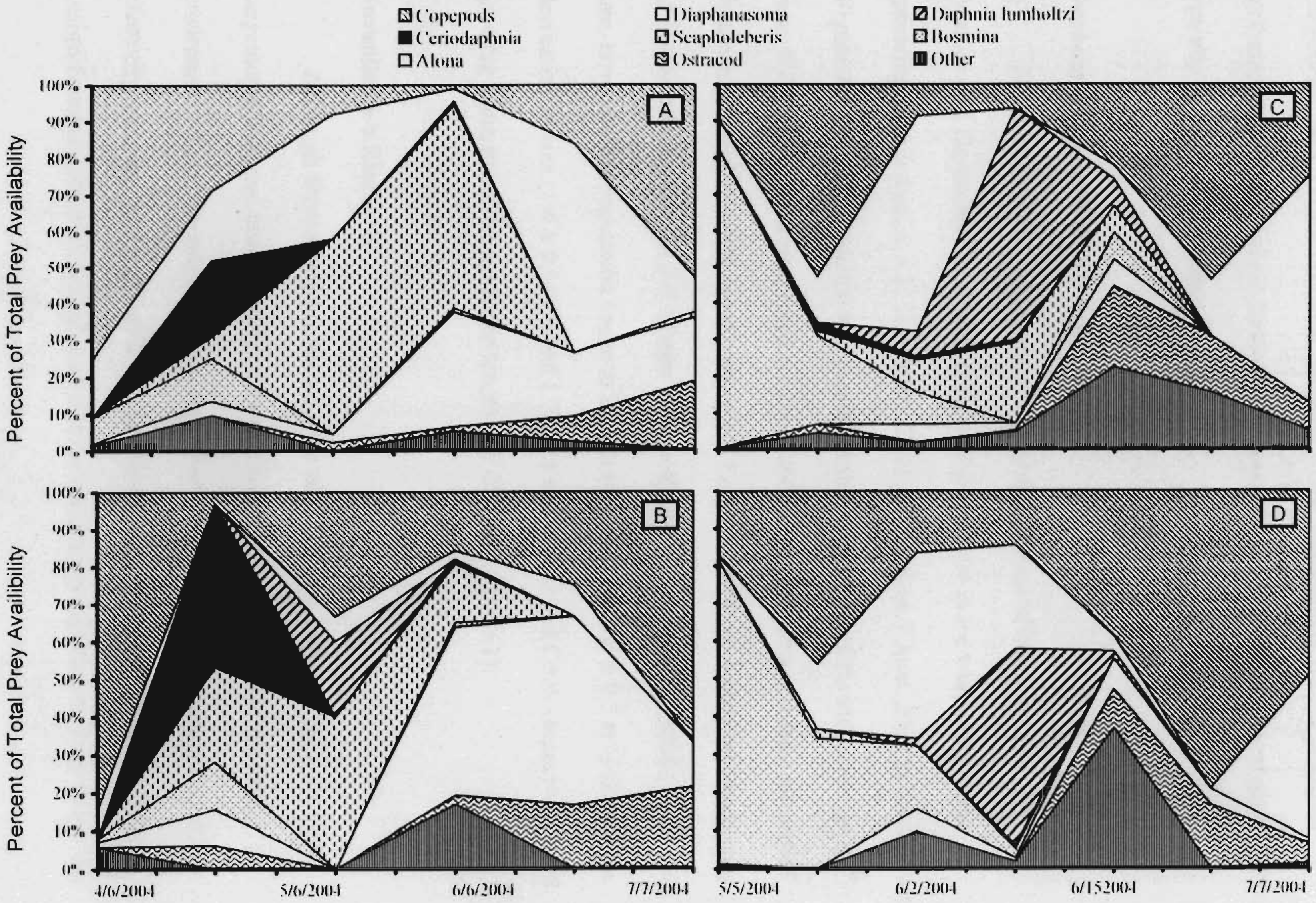

A
WAI
WAII
CAI
CAII
Gape Length (mm)
0
1
2
3
4
5
6
7
8
B
Gape Length (mm)
0
1
2
3
4
5
6
7
8
4/6/2004
4/24/2004
5/12/2004
5/30/2004
6/17/2004
7/5/2004

Figure 9. Proportional composition of littoral prey communities sampled at WAI (A), WAII (B), CAI (C), and CAII (D). Note difference in x-axis scale between warm and cold arms.


▨ Copepods
■ Ceriodaphnia
□ Alona
□ Diaphanasoma
▨ Scapholeberis
▨ Ostracod
▨ Daphnia lumholtzi
▨ Bosmina
■ Other
A
B
C
D
Percent of Total Prey Availability
Percent of Total Prey Availibility
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
4/6/2004
5/6/2004
6/6/2004
7/7/2004
5/5/2004
6/2/2004
6/152004
7/7/2004

Daphnia pulex, *Chydorus*, *Camptocercus*, *Ilyocryptus*, Amphipods, *Argulus*, and *Chaoborus*. Much of the temporal variation within this group of prey taxa can be attributed to *Chydorus*, which fluctuated between 0 and 37% of total prey availability, but typically was restricted to less than 15%.

Daphnia lumholtzi **Population Dynamics**

Daphnia lumholtzi was present in the limnetic zone of Newton Lake from 2 October – 11 December, 2003, and again on 9 June, 2004 in the warm arm, while appearing from 5 August – 11 December, 2003 and again on 9 June, 2004 in the cold arm (Figure 4). *Daphnia lumholtzi* was present in the littoral zone of Newton Lake on 2-9 June, 2004 in the warm arm, and 2–15 June, 2004 in the cold arm, reaching numerical dominance on 9 June at both cold arm sites (Figure 9, Table 1). Mean total body length of *Daphnia lumholtzi* was 3.0 ± 0mm when collected at the warm arm sites. In the cold arm, however, the population began at 2.5mm (± 1.9 at CAI and ± 0.5 at CAII) before decreasing in size (1.4 ± 0.1 mm and 1.7 ± 0.1 mm at CAI and CAII, respectively) and growing again to a more moderate length of 2.0 ± 0mm (Table 1).

Juvenile Fish Electivity

Although Strauss's index values were calculated for each prey item for both largemouth bass and bluegill, only items that comprised at least 5% of the total environmental prey abundance were considered ecologically significant and used for electivity analysis. Although arbitrary, this criterion eliminates use of ecologically insignificant results, even though they may be statistically significant. Prey items less

Table 1. Relative abundance and mean total body length of *Daphnia lumholtzi* in littoral samples collected from Newton Lake.

Population Characteristics	**Site**	**Sample Date**		
		6/2/2004	6/9/2004	6/15/2004
Proportion of Prey Community	WAI	*	0.011	*
	WAII	0.200	*	*
	CAI	0.068	0.633	0.074
	CAII	0.019	0.519	0.020
Mean Total Length (mm)	WAI	*	3.0	*
	WAII	3.0	*	*
	CAI	2.5	1.4	2.0
	CAII	2.5	1.7	2.0

* indicates no *Daphnia lumholtzi* were collected

than 5% of the total prey abundance were recorded as present, but not sufficiently abundant.

Independent t-test results were divided into four categories: 1) significant negative electivity, 2) significant positive electivity, 3) neutral electivity (no significant electivity), and 4) negative electivity, but no t-test possible (Tables 2-9). This last result occurred when there was no variation in electivity between fish in a sample (i.e. fish did not ingest a particular prey item). Circumstances occurring during some sampling events were not conducive to t-test analysis. Accordingly, other possible categories of electivity results included samples 1) where no predators (largemouth bass or bluegill) were collected, 2) where predators were collected, but the prey item in question was not present, and 3) where predators and a particular prey item were both present, but prey abundance was <5% of the total prey community (Tables 2-9). Electivity for some taxa remained constant (positive, negative, or neutral) through the sample period, while for other taxa electivity shifted from one category to one or more others resulting in temporal variability.

I used the relative electivity index to alleviate problems occurring as a result of temporal variability in electivity scores and also to look at general patterns electivity for both fish species. Relative electivity values indicate largemouth bass preferred copepods while avoiding *Diaphanasoma*, *Daphnia lumholtzi*, *Scapholeberis*, *Bosmina*, *Chydorus*, *Alona*, *Camptocercus*, and ostracods, and displayed no preference for *Ceriodaphnia* (Table 10). Bluegill preferred *Alona* and ostracods while avoiding copepods, *Diaphanasoma*, *Daphnia lumholtzi*, *Ceriodaphnia*, *Scapholeberis*, *Bosmina*, *Chydorus*, and *Argulus*, and displayed no preference for *Camptocercus* (Table 10).

Table 2. Strauss's electivity scores for littoral prey taxa as calculated for juvenile largemouth bass at WAI.

Prey Item	Electivity Value							
	4/6/04	**5/5/04**	**5/21/04**	**6/2/04**	**6/9/04**	**6/15/04**	**6/29/04**	**7/7/04**
Copepods	0.0919	■			▥	■	■	■
Diaphanosoma	-0.0661	■	-0.1900	-0.3409*	▥	■	■	■
Daphnia pulex	▥	■	▒	▒	▒	■	■	■
Daphnia lumholtzi	▒	■	▒	▒	▥	■	■	■
Ceriodaphnia	▒	■		▥	▒	■	■	■
Scapholeberis	▥	■	-0.0564			■	■	■
Bosmina	▥	■	-0.1154*	▒	▒	■	■	■
Chydorus	▥	■	-0.0577*	▒	▒	■	■	■
Alona	▥	■	▥	▥	-0.3118*	■	■	■
Camptocercus	▥	■	▥	▒	▒	■	■	■
Ilyocryptus	▒	■	▥	▒	▥	■	■	■
Amphipod	▒	■	▥	▒	▥	■	■	■
Ostracods	▥	■	▒	▥	▥	■	■	■
Argulus	▒	■	▒	▒	▥	■	■	■
Chaoborus	▒	■	▒	▒	▒	■	■	■

Table Legend

#.####	significant electivity	■	no predator present
#.####*	significant electivity, but no t-test conducted	▒	predator present, but prey item not present
	neutral electivity	▥	prey item not significantly abundant

Table 3. Strauss's electivity scores for littoral prey taxa as calculated for juvnile largemouth bass at WAII.

Prey Item	Electivity Value							
	4/6/04	5/5/04	5/21/04	6/2/04	6/9/04	6/15/04	6/29/04	7/7/04
Copepods	-0.5859	■	■		■	■	■	■
Diaphanosoma	-0.0427	■	■	-0.0667*	■	■	■	■
Daphnia pulex	▥	■	■	▒	■	■	■	■
Daphnia lumholtzi	▒	■	■	-0.2000*	■	■	■	■
Ceriodaphnia	▒	■	■	▒	■	■	■	■
Scapholeberis	▥	■	■	-0.3333	■	■	■	■
Bosmina	▥	■	■	▒	■	■	■	■
Chydorus	▥	■	■	▥	■	■	■	■
Alona	▥	■	■	▒	■	■	■	■
Camptocercus	▥	■	■	▒	■	■	■	■
Ilyocryptus	▒	■	■	▒	■	■	■	■
Amphipod	▒	■	■	▒	■	■	■	■
Ostracods	▥	■	■	▒	■	■	■	■
Argulus	▒	■	■	▒	■	■	■	■
Chaoborus	▒	■	■	▒	■	■	■	■

Table Legend

#.####	significant electivity	■	no predator present
#.####*	significant electivity, but no t-test conducted	▒	predator present, but prey item not present
	neutral electivity	▥	prey item not significantly abundant

Table 4. Strauss's electivity scores for littoral prey taxa as calculated for juvenile largemouth bass at CAI.

Prey Item	**Electivity Value**							
	4/6/04	**5/5/04**	**5/21/04**	**6/2/04**	**6/9/04**	**6/15/04**	**6/29/04**	**7/7/04**
Copepods	■	0.3627	■	0.1346		-0.1888		■
Diaphanosoma	■	-0.0800*	■	-0.3587	▥	▥	-0.1667*	■
Daphnia pulex	■	▥	■	▒	▒	▒	▒	■
Daphnia lumholtzi	■	▒	■	-0.0680*	-0.6333*	-0.0741*	▒	■
Ceriodaphnia	■	▒	■	▥	▥	▒	▒	■
Scapholeberis	■	▥	■				▒	■
Bosmina	■	-0.6529	■	-0.082	▒	-0.0741*	▒	■
Chydorus	■	▥	■	▥	▥	-0.1481*	-0.0833*	■
Alona	■	▥	■	▥	▥	-0.0741*	▒	■
Camptocercus	■	▥	■	▥	▥	-0.0741*	-0.0833*	■
Ilyocryptus	■	▒	■	▒	▥	▒	▒	■
Amphipod	■	▒	■	▒	▒	▥	▒	■
Ostracods	■	▥	■	▒	▥		-0.1667*	■
Argulus	■	▒	■	▒	▒	▒	▒	■
Chaoborus	■	▒	■	▒	▒	▒	▒	■

Table Legend

#.####	significant electivity	■	no predator present
#.####*	significant electivity, but no t-test conducted	▒	predator present, but prey item not present
	neutral electivity	▥	prey item not significantly abundant

Table 5. Strauss's electivity scores for littoral prey taxa as calculated for juvenile largemouth bass at CAII.

Prey Item	**Electivity Value**							
	4/6/04	**5/5/04**	**5/21/04**	**6/2/04**	**6/9/04**	**6/15/04**	**6/29/04**	**7/7/04**
Copepods	■	0.2579				■	■	■
Diaphanosoma	■	▥	-0.1707*		-0.2753	■	■	■
Daphnia pulex	■	▒	▒	▒	▒	■	■	■
Daphnia lumholtzi	■	▒	▒	▥	-0.5189*	■	■	■
Ceriodaphnia	■	▒	▥	▥	▒	■	■	■
Scapholeberis	■	▥	▥	▥	▥	■	■	■
Bosmina	■	-0.6858	-0.3370	-0.1650*	▥	■	■	■
Chydorus	■	▥	▥	-0.0635	▥	■	■	■
Alona	■	▥	▥	-0.0498	▥	■	■	■
Camptocercus	■	▥	▥	▥	▒	■	■	■
Ilyocryptus	■	▒	▒	▥	▒	■	■	■
Amphipod	■	▒	▒	▒	▒	■	■	■
Ostracods	■	▒	▥	▒	▒	■	■	■
Argulus	■	▒	▒	▒	▒	■	■	■
Chaoborus	■	▒	▒	▒	▒	■	■	■

Table Legend

#.####	significant electivity	■	no predator present
#.####*	significant electivity, but no t-test conducted	▒	predator present, but prey item not present
	neutral electivity	▥	prey item not significantly abundant

Table 6. Strauss's electivity scores for littoral prey taxa as calculated for juvenile bluegill sunfish at WAI.

Prey Item	**Electivity Value**							
	4/6/04	**5/5/04**	**5/21/04**	**6/2/04**	**6/9/04**	**6/15/04**	**6/29/04**	**7/7/04**
Copepods	■	■		▥	■	■	0.1225	-0.3877
Diaphanosoma	■	■		▥	■	■	-0.5747*	-0.0938*
Daphnia pulex	■	■	░	░	■	■	░	░
Daphnia lumholtzi	■	■	░	▥	■	■	░	░
Ceriodaphnia	■	■		░	■	■	░	░
Scapholeberis	■	■	-0.0539	-0.5575	■	■	░	▥
Bosmina	■	■	-0.1154*	▥	■	■	░	░
Chydorus	■	■		▥	■	■	▥	░
Alona	■	■	▥		■	■	0.4497	0.3877
Camptocercus	■	■	▥	░	■	■	░	▥
Ilyocryptus	■	■	▥	▥	■	■	▥	▥
Amphipod	■	■	░	░	■	■	░	░
Ostracods	■	■	▥	▥	■	■	-0.0453	
Argulus	■	■	░	▥	■	■	░	░
Chaoborus	■	■	░	░	■	■	░	░

Table Legend

#.####	significant electivity	■	no predator present
#.####*	significant electivity, but no t-test conducted	░	predator present, but prey item not present
	neutral electivity	▥	prey item not significantly abundant

Table 7. Strauss's electivity scores for littoral prey taxa as calculated for juvenile bluegill sunfish at WAII.

Prey Item	**Electivity Value**							
	4/6/04	**5/5/04**	**5/21/04**	**6/2/04**	**6/9/04**	**6/15/04**	**6/29/04**	**7/7/04**
Copepods	■	■	▥	0.3836		■		-0.5183
Diaphanosoma	■	■	▥	-0.0511	▥	■	-0.0833*	▥
Daphnia pulex	■	■	▒	▒	▒	■	▒	▒
Daphnia lumholtzi	■	■	▒	-0.2000*	▒	■	▒	▒
Ceriodaphnia	■	■	-0.4706	▒	▥	■	▒	▒
Scapholeberis	■	■	-0.2563*	-0.2750	-0.1539	■	▥	▒
Bosmina	■	■	-0.1481*	▒	▥	■	▥	▒
Chydorus	■	■	▥	▥	-0.0833	■	▒	▥
Alona	■	■	0.2643	▥	0.3215	■	0.1232	0.4761
Camptocercus	■	■	▥	▥	▥	■	▒	▒
Ilyocryptus	■	■	▒	▒	▥	■	▥	▒
Amphipod	■	■	▒	▒	▒	■	▒	▒
Ostracods	■	■		▒	▥	■	-0.1035	-0.0176
Argulus	■	■	▒	▒	▒	■	▒	▒
Chaoborus	■	■	▒	▒	▒	■	▒	▒

Table Legend

#.####	significant electivity	■	no predator present
#.####*	significant electivity, but no t-test conducted	▒	predator present, but prey item not present
	neutral electivity	▥	prey item not significantly abundant

Table 8. Strauss's electivity scores for littoral prey taxa as calculated for juvenile bluegill sunfish at CAI.

Prey Item	**Electivity Value**							
	4/6/04	**5/5/04**	**5/21/04**	**6/2/04**	**6/9/04**	**6/15/04**	**6/29/04**	**7/7/04**
Copepods	■	■		0.0349			-0.3271	0.1690
Diaphanosoma	■	■	-0.0749*	-0.4751	▥	▥	-0.1667*	-0.5675
Daphnia pulex	■	■	░	░	░	░	░	░
Daphnia lumholtzi	■	■	░	░	-0.6319	-0.0741*	░	░
Ceriodaphnia	■	■	▥	▥	▥	░	░	░
Scapholeberis	■	■	▥	-0.0852	-0.1607	-0.0741*	▥	░
Bosmina	■	■	-0.2294	-0.0874*	░	-0.0741*	░	░
Chydorus	■	■	▥	▥	▥		-0.0744	▥
Alona	■	■	▥	▥	▥		▥	▥
Camptocercus	■	■	▥	▥	▥			▥
Ilyocryptus	■	■	░	░	▥	░	░	░
Amphipod	■	■	▥	░	░	░	░	░
Ostracods	■	■	▥	▥	▥		0.2499	0.1765
Argulus	■	■	░	░	░	░	░	-0.0500*
Chaoborus	■	■	░	░	░	░	░	░

Table Legend

#.####	significant electivity	■	no predator present
#.####*	significant electivity, but no t-test conducted	░	predator present, but prey item not present
	neutral electivity	▥	prey item not significantly abundant

Table 9. Strauss's electivity scores for littoral prey taxa as calculated for juvenile bluegill sunfish at CAII.

Prey Item	**Electivity Value**							
	4/6/04	**5/5/04**	**5/21/04**	**6/2/04**	**6/9/04**	**6/15/04**	**6/29/04**	**7/7/04**
Copepods	█	█				-0.2884	-0.3167	-0.3327
Diaphanosoma	█	█	-0.1267		-0.2632	▥	░	-0.4279
Daphnia pulex	█	█	░	░	░	░	░	░
Daphnia lumholtzi	█	█	░	░	-0.5189*	▥	░	░
Ceriodaphnia	█	█	░	▥	▥	░	░	░
Scapholeberis	█	█	▥	-0.0874*	▥	▥	░	▥
Bosmina	█	█	-0.3415*	-0.0745*	▥	░	░	░
Chydorus	█	█	▥	▥	▥		▥	▥
Alona	█	█	▥	▥	▥	0.1748	▥	▥
Camptocercus	█	█	▥	▥	▥	▥	▥	▥
Ilyocryptus	█	█	░	░	░	▥	░	░
Amphipod	█	█	░	░	░	░	░	░
Ostracods	█	█	▥	▥	▥		0.3260	0.6801
Argulus	█	█	░	░	░	░	░	░
Chaoborus	█	█	░	░	░	░	▥	░

Table Legend

#.####	significant electivity
#.####*	significant electivity, but no t-test conducted
	neutral electivity

█	no predator present
░	predator present, but prey item not present
▥	prey item not significantly abundant

Table 10. Relative preference values for each littoral prey item as calculated for juvenile largemouth bass and bluegill sunfish.

Prey Item	Largemouth Bass	Bluegill Sunfish
Copepods	0.143	-0.105
Diaphanosoma	-0.909	-0.846
Daphnia pulex	0.000	0.000
Daphnia lumholtzi	-1.000	-1.000
Ceriodaphnia	0.000	-1.000
Scapholeberis	-0.286	-1.000
Bosmina	-1.000	-1.000
Chydorus	-1.000	-0.400
Alona	-1.000	0.778
Camptocercus	-1.000	0.000
Ilyocryptus	0.000	0.000
Amphipod	0.000	0.000
Ostracods	-0.500	0.091
Argulus	0.000	-1.000
Chaoborus	0.000	0.000

Relative Rates of Insectivory and Piscivory

Proportion of insects in juvenile largemouth bass stomachs ranged from 0.005 to 0.793 through the sample period. and. in general. increased after 2 June (Figure 10). Bluegill stomachs contained a similar range in proportion of insects (0.053-0.5997). but unlike bass. proportions decreased from initially high values. but rebounded again after 2 June (Figure 10). Proportion of insects in largemouth bass diet was not correlated with predator length (P=1.40. Sig=0.086). however. there was a significant positive correlation (P=0.181. Sig=0.003) between these variables in bluegill (Figure 11). Only largemouth bass stomachs contained fish. Proportion of bass stomachs containing fish ranged from approximately 0.1 to 0.5 and increased as predator size grew (Figure 12). Bass less than 38mm did not ingest fish. while 50% of those in the largest size classes utilized fish as prey.

Figure 10. Mean proportion of insects in diet (as related to total diet contents of all fish in each sample) of largemouth bass (A) and bluegill sunfish (B) at each sample site.

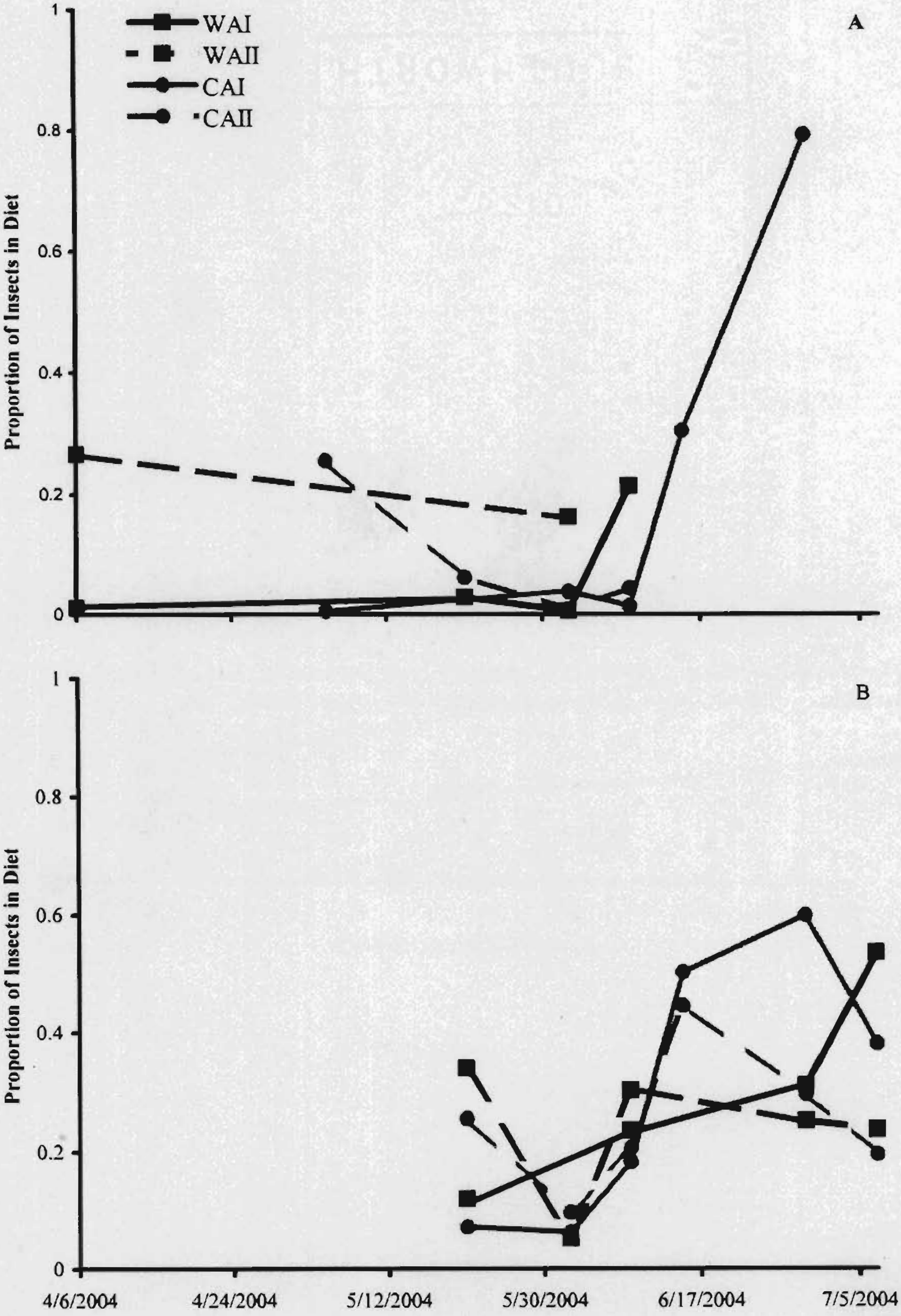
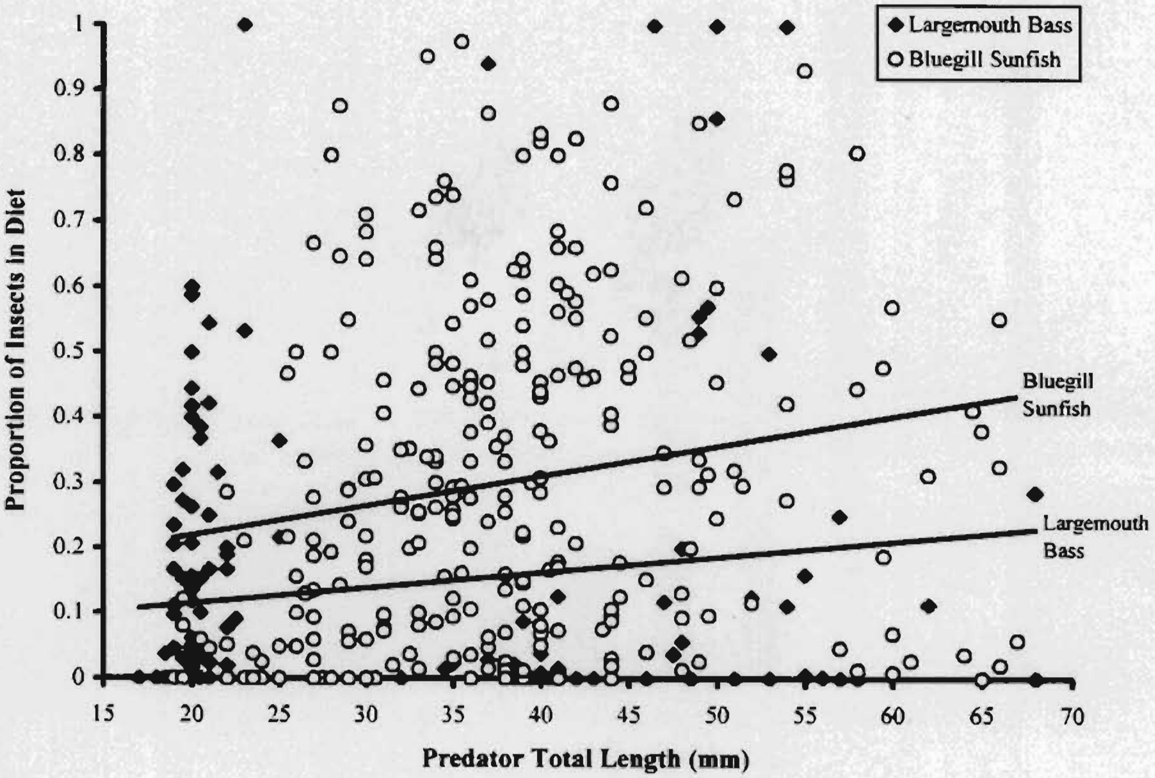
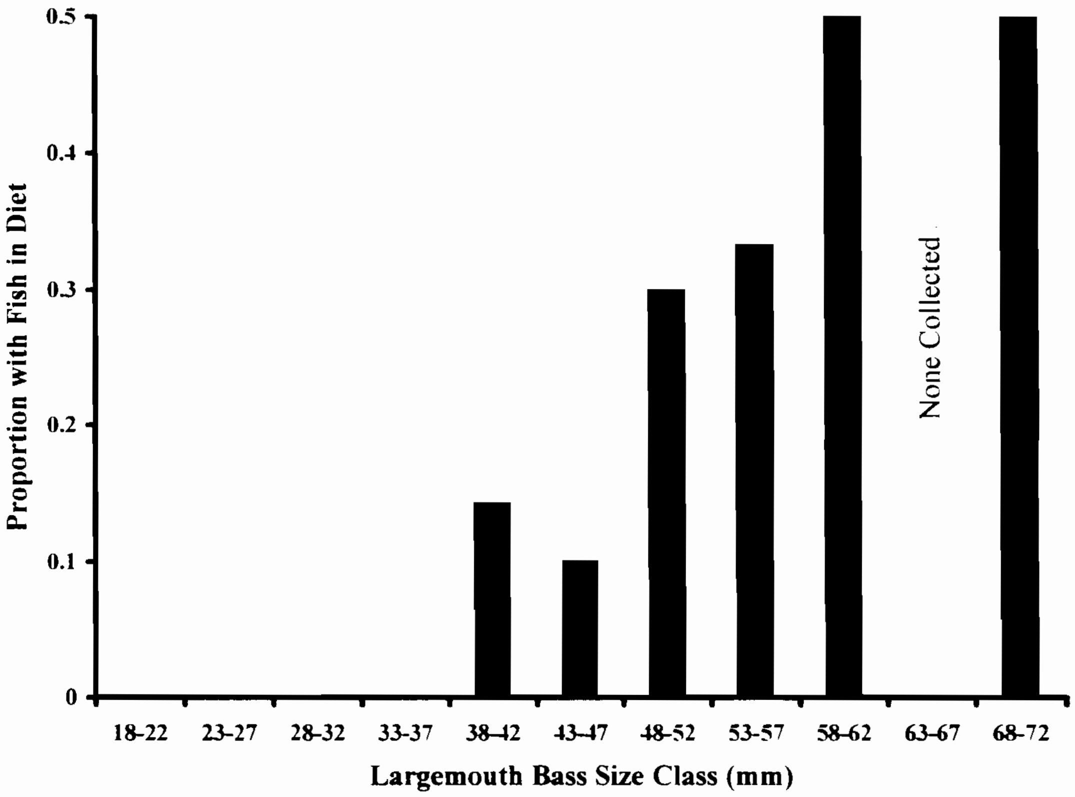

WAI
WAII
CAI
CAII
A
B
Proportion of Insects in Diet
Proportion of Insects in Diet
1
0.8
0.6
0.4
0.2
0
1
0.8
0.6
0.4
0.2
0
4/6/2004
4/24/2004
5/12/2004
5/30/2004
6/17/2004
7/5/2004

Figure 11. Comparison of predator (largemouth bass and bluegill sunfish) length and proportion of insects in diet. Each point represents a single juvenile fish.



◆ Largemouth Bass
○ Bluegill Sunfish
Proportion of Insects in Diet
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
15
20
25
30
35
40
45
50
55
60
65
70
Predator Total Length (mm)
Bluegill Sunfish
Largemouth Bass

Figure 12. Proportion of largemouth bass that ingested fish as compared to predator size. Data were pooled for all predators collected throughout the sample period.


0.5
0.4
0.3
0.2
0.1
0
Proportion with Fish in Diet
None Collected
18-22
23-27
28-32
33-37
38-42
43-47
48-52
53-57
58-62
63-67
68-72
Largemouth Bass Size Class (mm)

DISCUSSION

Thermal Effluent Creates Two Temperature Regimes

Thermal effluent released from the Newton Power Plant creates distinct thermal regimes in each of the two arms of Newton Lake. Although overall patterns of increase and decline are similar, temperatures in the warm arm are consistently higher than those in the cold arm. Lake morphometry ensures little mixing of water between the two arms of the reservoir, minimizing directional flow from the warm arm into the cold arm.

Studies of other systems used as cooling water sources describe thermal patterns similar to those in Newton Lake. Temperatures near thermal discharges can be 10°C or higher over ambient (Marcy 1971, Merriman and Thorpe 1976, Larimore and Tranquilli 1981) and a zone of increased temperature may extend several kilometers from the source (Laws 1993). The largest temperature difference observed between the two arms in Newton Lake was nearly 12°C, rivaling the most extreme temperature alterations reported in other studies (Marcy 1971, Laws 1993).

Thermal effluents in Newton Lake produce environmental pressures that do not typically occur in Illinois reservoirs. Abnormally high temperature is one obvious example, but others include decreased oxygen solubility (Wetzel 2001) and alteration of water column stratification (personal observation).

Response of Limnetic Prey Communities to Temperature Regime

Peak density and taxonomic richness of limnetic prey communities in Newton Lake occur in spring and fall, while the converse occurs in winter and summer. Patterns of zooplankton development and abundance are largely similar between the two reservoir arms, although some differences were observed. For instance, winter minimum in the warm arm is approximately 1800 individuals m^{-3} and 1150 individuals m^{-3} in the cold arm, while summer minima were 50 and 120 individuals m^{-3} in the warm and cold arms, respectively. Warm arm community dynamics suggest thermal effluent buffers zooplankton from cold temperatures in winter while exceeding maximum temperature thresholds for some species in summer, resulting in loss of taxa intolerant of warm temperatures in summer and perpetuation of those intolerant of cool temperatures in winter.

Studies of zooplankton dynamics in temperate systems conflict with respect to seasonal patterns of development and abundance. Peak zooplankton community density and taxonomic richness sometimes occur in spring and into early summer (Pennak 1953, Threlkeld 1979, Waite 1981, Gerten and Adrian 2002), although this pattern is system dependant. Others suggest a mid-summer decline resulting from intense predation by planktivores (Luecke *et al* 1990, Mehner and Thiel 1999, Mehner 2000, Jeppesen *et al* 2004). Studies in tropical regions cite a mid-summer minimum, caused by high temperatures, flanked by higher densities of zooplankton in spring and fall (Havens *et al* 2000). In this respect, prey community dynamics in Newton Lake, especially in the warm arm, are more similar to tropical systems than those in temperate regions.

Temperature has been shown to have a large impact on seasonality and abundance of cladocerans by influencing time to maturity, brood size, and longevity (Wetzel 2001). Although individual species vary, temperatures above 29-31 °C have been shown to cause increased ephippial egg production (Threlkeld 1979) and mortality in cladocerans (Carlson 1973), resulting in an overall decline in community abundance. Peak densities of cladocerans in Newton Lake occur in both spring and fall when temperatures range from approximately 15-30°C. Populations develop in spring when temperatures increase into this range, while, in fall, they recover from low summer densities as temperatures decrease below 30 °C. Consequently, low summer density of cladocerans in Newton Lake is most likely a result of extremely high temperatures.

The fact that cladoceran populations develop and presist in spring and fall suggests limited depredation by planktivores. This result contrasts other studies that have implicated depredation as the primary cause of declining cladoceran abundance in systems containing vertebrate predators (King and Greenwood 1992). One possible explanation for the persistence of cladocerans in Newton Lake is that these organisms undergo diel vertical migration (Williams and Pederson 2004) allowing them to escape visual predators (Zaret 1980, Wetzel 2001). Furthermore, lack of planktivores in the limnetic zone of Newton Lake may spatially separate cladocerans from potential fish predators.

Copepods were collected throughout the sample period, although densities varied greatly from one sample date to another. Copepods were least abundant in winter and reach maximum densities in spring and summer, when they were sometimes numerically dominant over all other prey taxa together. Large fluctuations in copepod densities observed in Newton Lake may have several explanations. Copepods are known to go through periods of diapause initiated by decreasing temperatures, reduction in dissolved oxygen concentrations, photoperiod, changes in food availability, and predation (Pennak 1953, Wetzel 2001). In Newton Lake, factors associated with diapause can change dramatically from one sample period to another, making it a likely explanation for rapid temporal variation in copepod communities. Presence of copepods in summer and winter suggests lower sensitivity to extreme temperatures than cladocerans, although the dominant copepod taxon shifts from cyclopoid to calanoid in winter. Low cyclopoid abundance in winter may be related to loss of consumable cladoceran prey. Winter cladoceran communities in Newton Lake consist primarily of *Daphnia pulex*, a prey item that may be difficult for these raptorial copepods to ingest (Chang and Hanazato 2003). Calanoid copepods, on the other hand, feed primarily upon algae (Pennak 1953) and may not be negatively impacted by reduced cladoceran richness and abundance. Alternatively, calanoids may persist and dominate copepod communities through winter if they are more tolerant of cold temperatures than cyclopoids.

Between-Site Community Differences are Attributable to Temperature Regime

Bray-Curtis dissimilarity values indicate zooplankton prey communities located in opposing arms of the reservoir are more dissimilar than those within the same arm. Dissimilarity values are greatest when comparing WAI and CAI communities and lowest between CAI and CAII communities. Furthermore, when considering only between arm comparisons, dissimilarity values are lowest between WAII and CAII communities. This pattern suggests spatial differences in community structure relate to properties of the sites themselves.

Points (representing zooplankton prey communities) within the ordination space produced by NMDS cluster according to the temperature at which they were sampled. Interpretation of NMDS results suggests zooplankton community structure changes are largely related to temperature. For instance, those communities sampled at cool temperatures were dominated by *Daphnia pulex* and, at times, calanoid copepods. On the other hand. *Chaoborus* was present in warm temperature communities. while *Diaphanosoma* and cyclopoid copepods were abundant. Communities sampled at moderate temperatures occurred mostly in spring and fall when temperatures where rising or falling resulting in variable community structure where no single taxon dominated for any length of time.

Development of Juvenile Fish Populations

Juvenile largemouth bass in Newton Lake were collected as early as April 4. Date of emergence from egg was roughly the last week in February or the first week in March for bass in the warm arm and two to three weeks later for those in the cold arm, as estimated by back calculating total body length when collected (Wheeler 1977), although this is an approximation as growth rates in the warm arm of Newton Lake are likely high as a result of temperature regime. Reproductive activity of adult bass in both arms coincides with a temperature range of 15-20°C. which matched reported ranges (Sigler and Sigler 1996).

Mean total body length of juvenile bluegill decreased for a period of about two weeks after initial samples were collected and then increased thereafter. Bluegill samples collected after May 21 were a combination of young-of-the-year and year-old fish. Accordingly. bluegill reproduction occurred around the middle of April in the warm arm and two to three weeks later in the cold arm, several weeks after largemouth bass finished spawning.

Electivity in Juvenile Fish Reflects Species-Specific Preferences

Zaret (1980) defines electivity as a quantitative measure which relates composition of a predator's diet to prey community structure. In this study, electivity values calculated for juvenile fish varied temporally, making patterns difficult to discern. Therefore, I developed a relative preference index to calculate a single preference value for each zooplankton prey taxa and fish species combination. Relative preference index values suggest largemouth bass and bluegill sunfish have specific prey preferences. Copepods are preferred by bass, while bluegill prefer *Alona* and ostracods.

Preferences for specific prey observed in juvenile fish may be related to characteristics of both the predators and prey. Gape-limited predators utilize visual senses to detect prey (Wetzel 2001), but feeding techniques vary among species. Largemouth bass can alter their feeding behaviors, but when vegetation is dense, as is the case in the littoral zone of Newton Lake, bass are primarily ambush predators (Savino and Stein, 1982) and the conspicuous movements of copepods (Pennak 1953) may trigger striking actions typical of bass feeding behavior. Bluegill sunfish can be considered more visually acute than largemouth bass (Ringler 1982), and therefore may use a different technique during prey capture. Accordingly, *Alona* and ostracods are small, but highly visible prey, which may complement the generalized sight feeding behavior in bluegill (Robison and Buchanan 1988).

Search images, or feeding patterns related to visual signals (Zaret 1980), are developed in fish through learned association of prey and their coloration or movement pattern. In this context, largemouth bass may acquire search images for copepods. Bluegill, however, feed upon those zooplankton with less apparent movement. In the absence of visual cues associated motion. darkly pigmented zooplankters typically are depredated before other. less conspicuous. species (Zaret 1980). Use of visual cues in juvenile fish in Newton Lake is also consistent with avoidance of certain taxa. like *Diaphanosoma* and *Bosmina* (Table 10). These two cladocerans are characterized by largely transparent bodies. making them difficult to detect. Use of visual cues in both fish species may develop into search images. which are then expressed as preferences as I have calculated using the relative preference index.

Preference exhibited by bass and bluegill may be further explained by size selection. The relationship between prey and predator size is strongly correlated in gape limited planktivores (Zaret 1980, Lemke *et al* 2000, Wetzel 2001). Copepods. which are preferred by bass, typically are larger than nearly all other zooplankton taxa present within the littoral prey community and rivaled in size only by *Daphnia lumholtzi*, which will be discussed below, Amphipods and *Argulus*, which are extremely rare, and transparent *Chaoborus* larvae. Bluegill prefer *Alona* and ostracods, which are similar in size, shape, and coloration, and distinct from other taxa like the relatively small *Chydorus*, and *Ceriodaphnia*, which is larger than preferred items and transparent. The amalgamation of visual cues associated with motion, coloration, and size result in specific preferences expressed in diets of juvenile largemouth bass and bluegill.

Juvenile Fish Avoid Preying Upon *Daphnia lumholtzi*

Three events must occur simultaneously for *Daphnia lumholtzi* to negatively impact gape limited predators. First, *Daphnia lumholtzi* must be present within the prey community, second, it must constitute a significant portion of the prey community so as to reduce the overall prey availability for juvenile fish, and finally, total length of *Daphnia lumholtzi* must be longer than juvenile fish gape length.

Daphnia lumholtzi was significantly abundant on few occasions in the littoral zone of Newton Lake. However, on 2 June at WAII and 9 June at both cold arm sites, prey communities contained a significant density of *Daphnia lumholtzi*. Mean largemouth bass gape lengths were larger than mean *Daphnia lumholtzi* total length during the entire period when these two organisms coexisted, however, mean bluegill gapes were less than mean *Daphnia lumholtzi* total length on 2 June at WAII (Table 11). The combination of significant *Daphnia lumholtzi* density and small bluegill gape length meets the three criteria for potential negative impact outlined above. *Daphnia lumholtzi* also occurs during a period in which zooplankton prey abundance is very low in Newton Lake. Accordingly, the presence of *Daphnia lumholtzi* may have a detrimental affect on juvenile bluegill by reducing prey availability for a short period of time in Newton Lake.

Juvenile Fish Undergo Dietary Niche Shifts

Rates of insectivory and piscivory increase as juvenile fish populations develop. Correlation results indicate bluegill become more insectivorous as they develop, while bass ingest insects consistently throughout their juvenile stage. As calculated, proportion of insects in diet is a conservative measure because it does not consider the relative mass of ingested prey items. Therefore, insects may constitute a larger proportion of juvenile fish diets than is indicated by this calculation. Proportion of largemouth bass ingesting fish increased as individuals became larger, suggesting a predator size threshold for piscivory. Although fish found in bass stomachs could not be identified, juvenile bluegill

Table 11. Mean total length of littoral *Daphnia lumholtzi* and mean gape length of juvenile largemouth bass and bluegill sunfish in Newton Lake.

Population Characteristics	**Site**	**Sample Date**		
		6/2/2004	6/9/2004	6/15/2004
D. lumholtzi Mean Total Length (mm)	WAI	*	3.0	*
	WAII	3.0	*	*
	CAI	2.5	1.4	2.0
	CAII	2.5	1.7	2.0
Largmouth Bass Gape Length (mm)	WAI	5.3	6.0	#
	WAII	6.0	#	#
	CAI	4.9	5.3	7.6
	CAII	5.4	7.6	#
Bluegill Sunfish Gape Length (mm)	WAI	#	3.6	#
	WAII	2.3	3.1	#
	CAI	3.7	2.9	3.9
	CAII	3.9	3.3	2.9

* indicates no *Daphnia lumholtzi* were collected

# indicates no juvenile individuals of the species in question were collected

were beginning to appear in the fish community when bass were becoming piscivorous. making bluegill a likely candidate for depredation by bass.

Overall. size-dependant patterns of insectivory and piscivory suggest dietary niche shifts in largemouth bass and bluegill. Prey selection is largely determined by gape size, and consequently, juvenile fish in Newton Lake exploit food sources in accordance to gape development.

Recruitment of Juvenile Fish in Relation to Diet Composition

Juvenile fish in Newton Lake are initially planktivores. but shift to insectivory, and in the case of largemouth bass, piscivory as they mature. However, even after undergoing diet shifts, juvenile fish continue to consume zooplankton. Heterogeneity in diet composition suggests generalized feeding in that they feed upon many prey types (zooplankton, insects, and other fish). In other words, juvenile fish in Newton Lake feed upon whatever prey they can detect and ingest.

Although specific zooplankton prey preferences (as determined by the relative preference index) are observed. juvenile fish in Newton Lake display trophic adaptability, or ability to change feeding patterns and adjust to changing prey quality and abundance (Wetzel 2001). Fish adapt to relatively low zooplankton prey community abundance in summer by supplementing their diets with insects and fish. Reduction in prey abundance and presence of *Daphnia lumholtzi* may, therefore, have little or no negative effect on juvenile fish feeding behavior. As a consequence of trophic adaptability, survival of juvenile fish should not decrease in response to altered zooplankton community dynamics in Newton Lake.

Recruitment is dependant upon survival of juvenile fish, which, in turn, is correlated with prey availability (Hoxmeier *et al* 2004). Trophic adaptability, expressed as dietary niche shifts, in response to poor zooplankton prey availability should allow juvenile fish in Newton Lake to avoid reduced recruitment rates associated with low prey availability.

Summary

Atypical patterns of development and abundance in zooplankton prey communities in Newton Lake likely result from alteration of temperature regime by thermal discharges released by the Newton Power Plant. Extremely high temperatures in summer create low prey richness and availability for juvenile largemouth bass and bluegill. However, juvenile fish in Newton Lake undergo ontogenetic diet shifts and begin feeding upon insects and other fish, thereby avoiding potential negative impacts of zooplankton prey community structure and abundance and presence of *Daphnia lumholtzi*. Consequently, survival associated with zooplankton prey availability may not decrease, resulting in normal rates of recruitment relative to other Illinois reservoirs. Juvenile fish in the warm arm of the reservoir likely experience faster than normal growth rates, limiting their vulnerability to predation and potentially increasing the number of juveniles (namely largemouth bass) surviving to adulthood (Davies *et al* 1982), further enhancing Newton Lake as a recreational fishery.

Prey community and juvenile fish diet analysis may be a useful tool in management of Newton Lake as a recreational fishery. Survival of stocked fish is related, in part, to prey composition and abundance (Kohler and Hubert 1993). In

Newton Lake. potentially detrimental impacts of low zooplankton prey availability can be avoided by stocking fish early in spring or releasing fish that are sufficiently large enough to ingest insects or other fish. Adopting a stocking strategy based on these recommendations would allow efficient use of limited resources allocated for development of the Newton Lake fishery.

Furthermore, results of this study may have broader ecological implications as well. Global climate change has produced gradually increasing temperatures in many aquatic systems (Scheffer *et al*), resulting in alteration biotic communities within all trophic levels (DeStasio *et al* 1996, Petchey *et al* 1999). Zooplankton dynamics have been utilized as biomonitors of long term temperature changes (George and Harris 1985, Beaugrand 2003). In particular, copepod persistence and cladoceran decline during summer in Newton Lake resemble patterns observed in experimentally manipulated and naturally warm waters (George and Harris 1985, Gerten and Adrian 2002). Zooplankton community dynamics in Newton Lake further support use of macrozooplankton as biomonitors of long-term climate change.

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