Zooplankton Abundance, Biomass, and Size-Distribution in Selected Midwestern Waterbodies and Relation with Trophic State[a]

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ABSTRACT

Zooplankton abundance and biomass were measured in natural lakes and impoundments in Iowa, Kansas, Missouri, and Oklahoma during summer. Zooplankton exhibited wide ranges of abundance (70,000-1,000,000 individuals/m^3) and biomass (45-1,000 mg/m^3). Communities were dominated by rotifers; they comprised 70% or more of the zooplankton abundance in 41 lakes and, on average, comprised 53% of zooplankton biomass. Zooplankton in Missouri were significantly smaller than those collected in the other states, suggesting predation and regulation of size structure by zooplanktivorous fish may have differed among states at the time of this study. Within the data set, neither the microzooplankton nor the component groups of the macrozooplankton showed consistent changes with lake trophy. Among the Missouri reservoirs, *Daphnia sp.* decreased and *Diaphanosoma sp.* increased in relation to algal chlorophyll. Both zooplankton abundance and biomass were positively correlated with algal chlorophyll (r=0.30-0.58). This finding is consistent with general zooplankton-lake productivity relations, and correlations improved when our data were combined with literature values (r= 0.73 and 0.78) to encompass a broad trophic state and geographic range.

INTRODUCTION

This paper describes zooplankton data from natural lakes and impoundments in a four state region of the Midwest. It is a component of a larger regional assessment of reservoir limnology and trophic state (Jones and Knowlton 1993, Knowlton and Jones 1993). The objectives were to: (1) assess abundance, biomass, and size-distribution of zooplankton in selected Midwestern waterbodies; and (2) determine the relation between zooplankton abundance/biomass and size-distribution with lake trophic state, as measured by algal chlorophyll. These objectives address the current paradigms that zooplankton size distribution is a function of predation forces (McQueen et al. 1986, McQueen 1990) and that the size-distribution generally decreases with lake trophic state (Brooks 1969, Bays and Crisman 1983), whereas zooplankton abundance and biomass are largely regulated by the resource base and increase with lake trophic state (McCauley and Kalff 1981).

SITE DESCRIPTION

Forty-five Midwestern waterbodies, consisting of natural lakes and impoundments, in Iowa, Kansas, Missouri, and Oklahoma, were sampled on two to five occasions during May through September 1983 (Figure 1). Limnological and morphological data for these lakes are presented in Knowlton and Jones (1989a, 1993). Several sampling stations were located in the large multi-armed reservoirs to account for longitudinal and spatial gradients common to such waterbodies (Jones and Novak 1981, Knowlton and Jones 1989b). For the purposes of this paper we grouped sampling sites into lake unit designations. Natural lakes and small reservoirs having one basin were each given a single lake unit designation. In large reservoirs, each arm was considered a lake unit and data collected at sites within the arm were averaged to best represent conditions in that region of the waterbody. Sites near the dams were assigned separate lake unit designations. In all, 57 lake units on 45 different waterbodies were sampled. Lake units varied in area from 6 to 10,031 ha and included one to four sampling stations (Canfield 1988). All future reference to lake in this study will equate with lake unit, unless otherwise stated.

MATERIALS AND METHODS

Chlorophyll measurements (μg/L) of surface water were determined by using a cold Dimethyl sulfoxide:Acetone (DMSO:Acetone) technique (Burnison 1980) with a Turner Designs model 10 fluorometer (Knowlton 1984).

A plankton net with a mesh size of 80 μm and a mouth diameter of 20 cm was used to collect zooplankton at each station. Zooplankton were sampled by taking vertical tows from 0.3 m above the bottom to the surface in unstratified lakes. In stratified lakes, tows were taken from 1 m below the anoxic zone to the surface. A zooplankton sample from each station consisted of two separate vertical tows combined into one container. All zooplankton samples were preserved with a sucrose/formalin solution to prevent carapace distortion and loss of eggs (Haney and Hall 1973).

The preserved samples were used to determine zooplankton abundance (individuals/m^3), length, and calculate mean dry weight biomass (mg/m^3). Zooplankton enumeration was done with a large bore pipette, Sedwick-Rafter cell, and compound microscope under 40X power. Zooplankton were enumerated in the following taxonomic groups: calanoid and cyclopoid copepods and their nauplii; cladocerans, including *Daphnia sp.*, *Bosmina sp.*, *Ceriodaphnia sp.* and *Diaphanosoma sp.*; and rotifers according to the methods of Elliott (1977). Zooplankton biomass (mg/m^3) was determined for each sample by projecting a zooplankton image onto a Bausch and Lomb Hipad digitizer with a Bausch and Lomb Trisimplex projecting microscope. Zooplankton (excluding rotifers) were measured with the digitizer which was connected to a desktop computer programmed to record length measurements. Cladocerans were measured from the tip of the helmet to the base of the tail spine, and copepods were measured from the tip of the metasome to the base of the urosome. Biomass values (dry weight) were calculated from the length measurements with the length:weight equations of Dumont et al. (1975). Rotifer biomass was approximated by multiplying the total number of rotifers present by 0.52 μg.

This value was obtained by averaging the dry weight values (Dumont et al. 1975) for several rotifer genera observed in this study. Total biomass and total abundance of each zooplankton taxa were calculated assuming 100% net filtering efficiency.

Statistical analyses were performed with the SAS computer package (Statistical Analysis System 1982). All correlations and regressions between the zooplankton parameters and measures of trophic state were obtained on log-transformed summer (May-September) means for the data from a given lake unit. Means were compared by using the LSMEANS program. If not reported, statements of statistical significance imply $P \leq 0.05$.
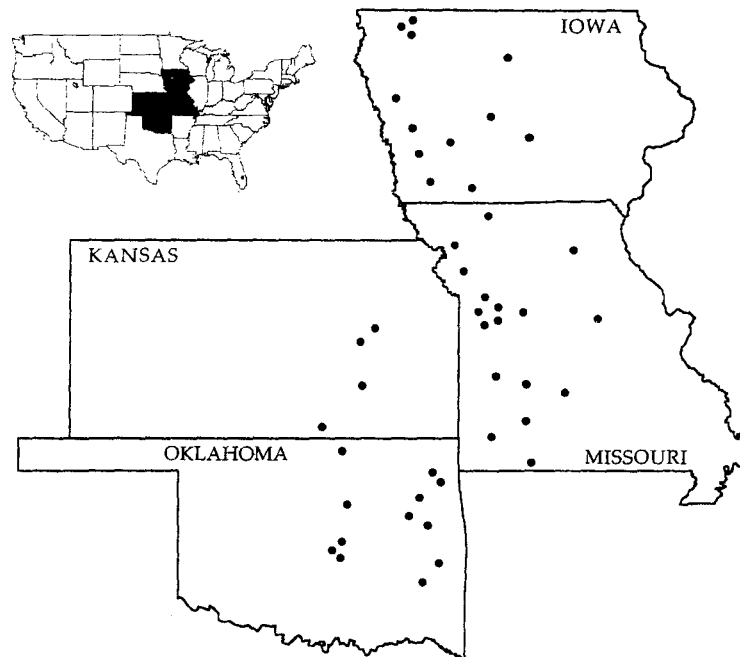

Figure 1. Map of the four state study area showing the general location of lakes and reservoirs sampled. For additional information see Canfield (1988).

RESULTS

Zooplankton Abundance and Biomass

Mean abundance values for the zooplankton communities of these lakes ranged from 70,000/m^3 in Lake Eufaula, Oklahoma to 1,000,000/m^3 in Blackhawk Lake, Iowa (Figure 2); however, in 80% of the lakes values were less than 475,000/m^3. Rotifers were numerically dominant in all but four lakes, copepods were more abundant than cladocerans in all but two lakes, and cladocerans were never the dominant taxa.

Biomass of the zooplankton community ranged from an average of 45 mg/m^3 in Lake Eufaula, Oklahoma to 1,000 mg/m^3 in Blackhawk Lake, Iowa (Figure 2). All lakes but three had mean values <500 mg/m^3, and in 60% of

TOTAL ZOOPLANKTON   **COPEPODS**   **CLADOCERANS**
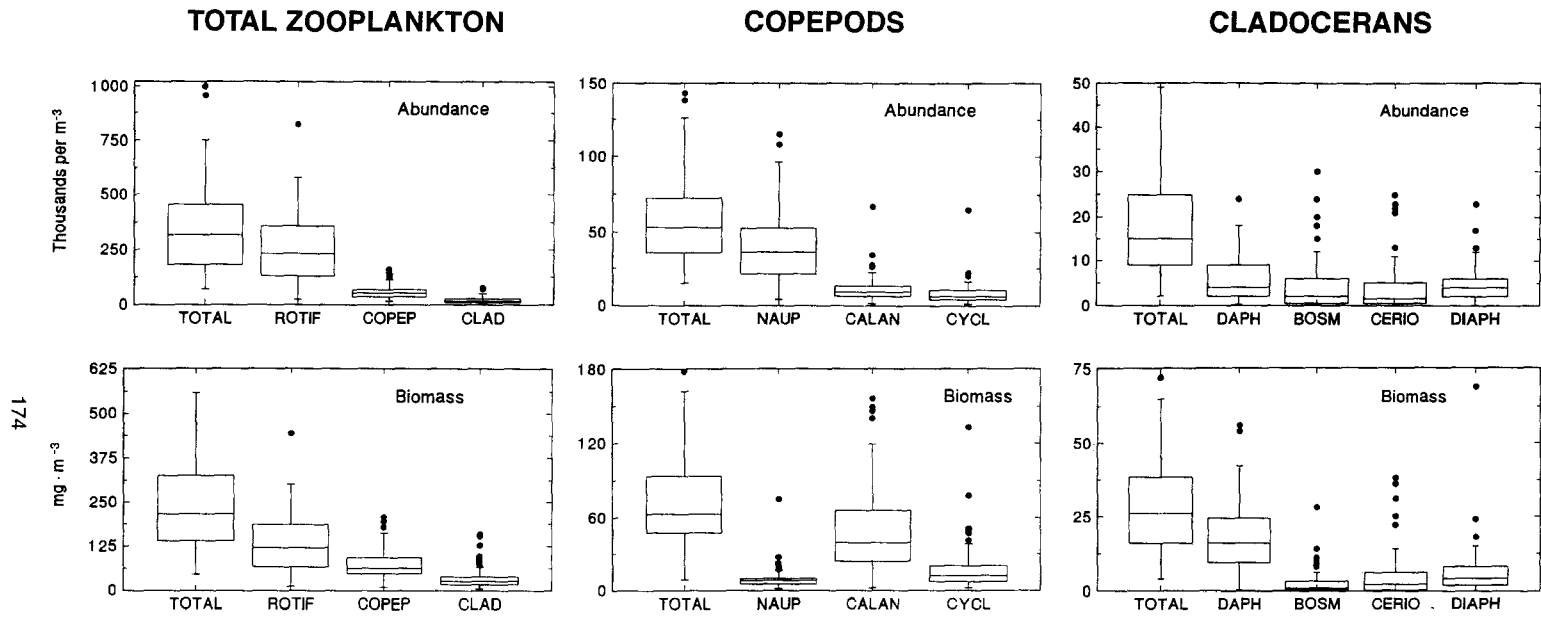
Figure 2. Comparative abundance and biomass of the total zooplankton community (total zooplankton, rotifers, copepods, and cladocerans), of the copepods (total copepods, nauplii, calanoids, and cyclopoids), and of the cladocerans (total cladocerans, Daphnia, Bosmina, Ceriodaphnia, and Diaphanosoma).

the lakes values were <250 mg/m³. Rotifers were the major component of zooplankton biomass in 45 of the 57 lakes sampled, while copepods dominated in 11 lakes and cladocerans dominated in one lake (Canfield 1988).

Among the copepods, nauplii were most numerous (Figure 2) but, on average, only accounted for about 11% of copepod biomass. Calanoid and cyclopoid copepods were sampled in about equal numbers but the larger calanoids accounted for about three times the biomass of cyclopoids. Among the cladocerans there were large differences in the abundance of individual taxa within individual lakes (Canfield 1988), but averaged across lakes none of the taxa was numerically dominant (Figure 2). Expressed as biomass, however, *Daphnia sp.* were dominant in most lakes.

Zooplankton Length Frequency and Mean Length

Mean total body length for the various taxa are reported (Table 1). Calanoid copepods were the largest organisms in about 40% of the lakes, and *Daphnia sp.* were largest in the others. Mean length of *Daphnia* showed a wider range than other taxa; values ranged from 0.43 mm in Montrose Lake, Missouri to 1.63 mm in Lake West Okoboji, Iowa. In 75% of the lakes, mean length of *Daphnia* was between 0.6 and 0.9 mm.

Zooplankton length-frequency, expressed as the percent zooplankton distributed within nine incremental length classes (Figure 3), was similar among most lakes sampled. In 49 lakes, 70% or more of the zooplankton were less than 0.6 mm. Small-bodied zooplankton dominated communities in Missouri lakes such that within each taxonomic category organisms from Missouri were significantly smaller than those in Iowa, Oklahoma and Kansas. In seven Iowa lakes and one Oklahoma lake, the distribution was shifted toward larger size classes such that between 13 and 27% of the zooplankton population was greater than 1 mm (Figure 3). Collectively, the lengths of calanoid and cyclopoid copepods, *Daphnia sp.*, and *Diaphanosoma sp.* were significantly longer in Iowa lakes than those in Oklahoma and Kansas.

TABLE 1. Body length (mm) for component groups of the zooplankton taxa.

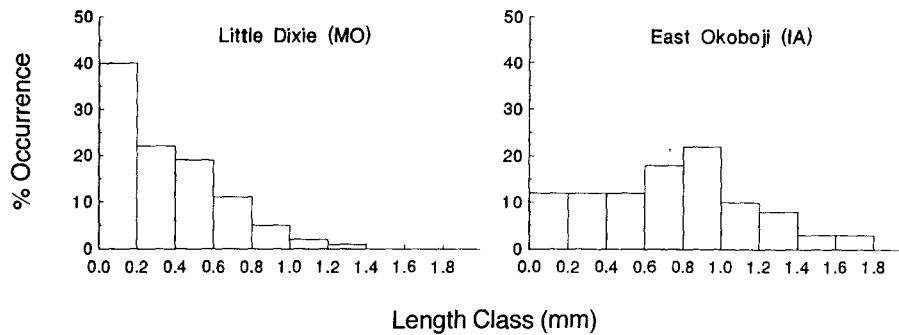| METRIC	MEAN	MINIMUM	MAXIMUM
Copepoda			
Nauplii	0.18	0.16	0.23
Calanoid	0.75	0.52	0.96
Cyclopoid	0.60	0.50	0.81
Cladocera			
Daphnia	0.83	0.43	1.63
Bosmina	0.29	0.19	0.43
Ceriodaphnia	0.42	0.28	0.62
Diaphanosoma	0.53	0.38	0.99

Figure 3. Examples of zooplankton size-distribution plots. Little Dixie (MO) represents the size-distribution pattern of the majority of lakes in this study. East Okoboji (IA) represents the pattern in lakes Anita, Big Creek, Clear, East Okoboji, Hawthorne, Spirit, and West Okoboji (Iowa) and Hefner (Oklahoma).

Zooplankton Abundance, Biomass and Size-Distribution vs Lake Trophic State

There were positive and significant correlations between mean abundance/biomass for the entire zooplankton community and for each separate taxonomic group with mean algal chlorophyll concentrations. Correlations ranged from 0.30 to 0.47 for abundance and from 0.30 to 0.58 for biomass. The strongest relations were between estimates of mean abundance and biomass for the entire community and mean algal chlorophyll ($r=0.47$ $p \leq 0.001$, $r=0.58$ $p \leq 0.0002$, respectively). The weakest correlations were between Cladocera abundance and biomass and algal chlorophyll ($r=0.30$, $p \leq 0.04$; $r=0.30$, $p \leq 0.03$, respectively).

Incorporating values from the literature to encompass the trophic spectrum shows that relations between chlorophyll and zooplankton abundance ($r=0.73$, $p \leq 0.0001$, Figure 4), and zooplankton biomass ($r=0.78$, $p \leq 0.0001$, Figure 5) are much stronger when examined over a wide range of lake types. Values from our study are consistent with the general trend of increasing zooplankton abundance and biomass with increasing chlorophyll observed in the context of the broader relation. Values from Midwest lakes fit in the mid-range of this trophic continuum. At any given chlorophyll value, however, there can be order of magnitude differences in zooplankton abundance and biomass.

Size-distribution of the zooplankton community is thought to decrease such that the biomass of microzooplankton increases relative to macrozooplankton as lake trophic state increases (Bays and Crisman 1983). In our regional data set the microzooplankton, rotifers and copepod nauplii, accounted for the majority of total zooplankton biomass (mean = 56%, range 4-97%) but the correlation with algal chlorophyll was not significant, suggesting no consistent change with trophic state. Within the macrozooplankton, none of the component groups exhibited a relation with algal chlorophyll (as percent of total or macrozooplankton biomass, and as abundance). When this analysis was limited to the Missouri reservoirs, *Daphnia sp.* decreased and *Diaphanasoma sp.* increased in relation to algal chlorophyll ($r=-0.51$ and 0.48, respectively, $n=27$,

p$\leq$0.05) when expressed as a percent of macrozooplankton biomass, and results were similar when expressed as percent of total biomass. Among Missouri reservoirs, *Daphnia* abundance varied independently of lake trophic state while mean body length showed a weak negative correlation with chlorophyll (r=-0.34, p<0.1). Abundance and mean body length of *Diaphanasoma* were positively correlated with chlorophyll (r=0.65 and 0.45, respectively, p$\leq$0.05).
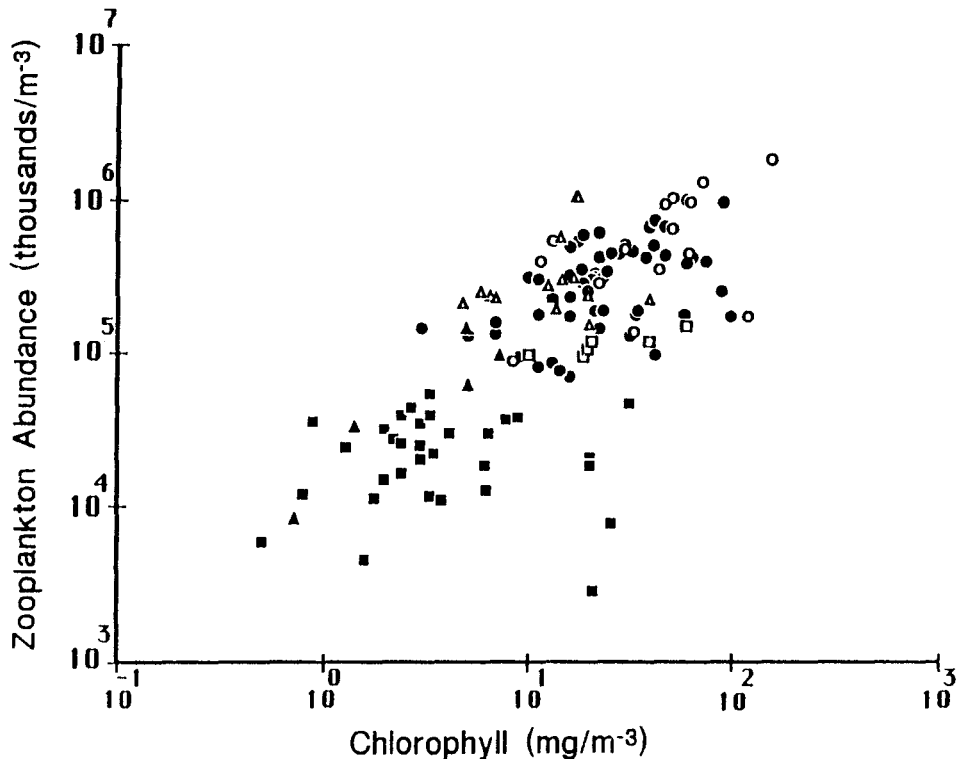

Figure 4. Log zooplankton abundance (thousands per m^{-3}) versus log algal chlorophyll (mg/m^{-3}). This analysis includes data from our regional study and the literature (closed circles=present study, closed squares=Patalas 1971, closed triangle=Patalas 1972, open circles=Noonan 1979, open square=Haertal 1976, open triangle=Hoyer 1981). Log ZP = 4.19 + 0.85 log chl, n=130, r=0.73. Data from our regional study lies in the mid-range of this trophic continuum. Log ZP = 4.86 + 0.43 log chl, n=57, r=0.47.

DISCUSSION

Most lakes sampled were dominated by small-bodied forms such as rotifers and nauplii. This finding is consistent with previous studies of productive lakes, particularly during summer (Gannon and Stemberger 1978, Pace and Orcutt 1981, Bays and Crisman 1983). In Missouri all taxa were represented by small-bodied forms. This analysis of size-distribution suggests

that predation from planktivorous fish was intense in most waterbodies at the time we sampled (Brooks and Dodson 1965, Carpenter et al. 1985, Mazumder et al. 1992). Fisheries management in Missouri has long included the stocking of gizzard shad (*Dorosoma cepedianum*). Extensive predation by shad would result in small zooplankton. Several lakes in Iowa supported large zooplankon; none of these lakes had been stocked with shad (D. Bonneau, Iowa Department of Conservation, personal communication). Presumably, all lakes sampled contained planktivorous fish but available data on fish structure does not allow an elaborate evaluation of cascading trophic interactions in our study lakes. Within the regional data set size-distribution of the zooplankton community varied independently of lake trophic state; this finding agrees with Canfield and Watkins (1984) and Pace (1986). The increase in *Diaphanasoma sp.* and decrease in *Daphnia sp.* with trophic state in Missouri is consistent with theoretical changes in macrozooplankton with eutrophication (Brooks 1969).
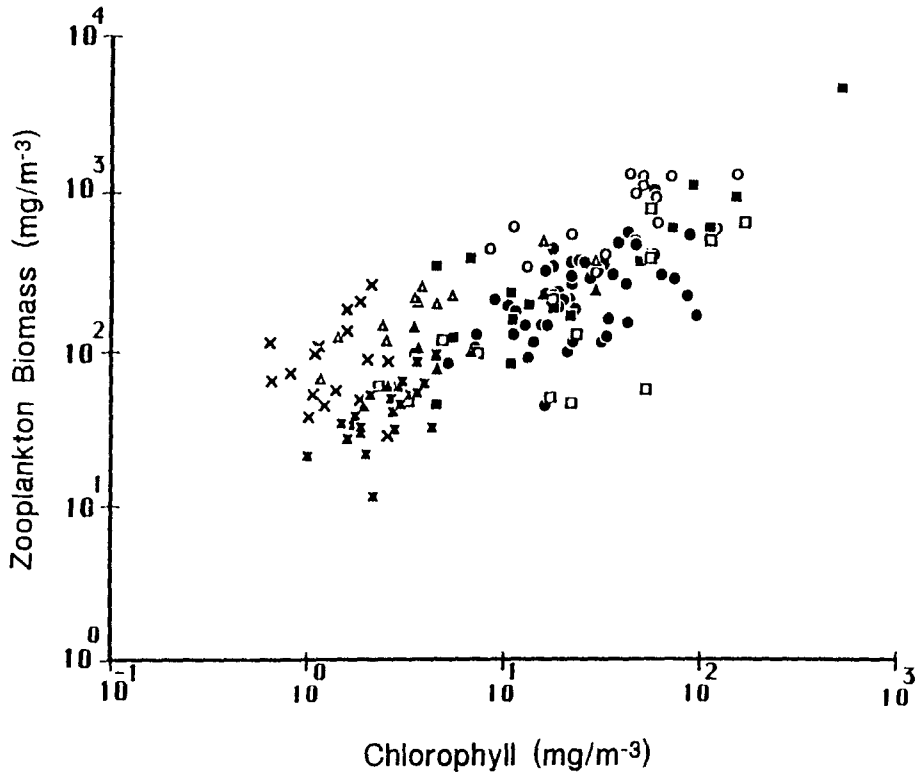

Chlorophyll (mg/m⁻³)

Figure 5. Log zooplankton biomass (mg·m⁻³) versus log algal chlorophyll (mg/m⁻³). This analysis includes data from our regional study and the literature (closed circles = present study, closed squares = McCauley and Kalff 1981, closed triangle = Hanson and Peters 1984, open circles = Noonan 1979, open square = Mills and Schiavone 1982, open triangle = Pace 1984, x = Shortreed and Stockner 1986, crossed x = Rognerud and Kjellberg 1984). Log ZP = 1.59 + 0.59 log chl, n = 166, r = 0.78. Data from our regional study lies in the mid-range of this trophic continuum. Log ZP = 1.68 + 0.49 log chl, n = 57, r = 0.58.

Previous investigators have shown zooplankton abundance and biomass increases as lakes become more productive (Patalas 1972, O'Brien and de Noyelles 1974, McCauley and Kalff 1981, Beaver and Crisman 1982, Mills and Schiavone 1982, Hanson and Peters 1984, Yan 1986). This generalization is based on examinations of single systems (O'Brien and de Noyelles 1974, Edmondson and Litt 1982) or comparisons among systems in north temperate lakes (Patalas 1972, Noonan 1979, Pace 1986) or sub-tropical lakes in Florida (Beaver and Crisman 1982, Bays and Crisman 1983, Blancher 1984, Canfield and Watkins 1984). The variable used most often to assess lake productivity in these assessments has been algal chlorophyll.

Lakes in this study largely encompass the middle trophic range, with no oligotrophic and few hypereutrophic lakes (Jones and Knowlton 1993, Knowlton and Jones 1993). Abundance and biomass values from this study are consistent with the general trend of increasing zooplankton abundance and biomass with increasing algal chlorophyll observed in these global relations. The regression coefficients for our generalized relation for zooplankton biomass-algal chlorophyll are similar to previous studies (Mills and Schiavone 1982, Hanson and Peters 1984, Pace 1984). The relations are curvilinear (slope < 1), such that as with increasing algal biomass, zooplankton biomass increases at a slower rate across the range of lakes examined. This finding is consistent with food web theory and previous studies of zooplankton and lake trophic state (McCauley and Kalff 1981). These relations suggest that algal chlorophyll can be used as a general predictor of zooplankton. Although, at any given chlorophyll value, there can be an order of magnitude difference in zooplankton abundance and biomass.

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