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The rotifer communities of acid-stressed lakes of Maine

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Abstract

The structure of the rotifer community in relation to lake pH, trophic status, the type of planktivore assemblage and the crustacean community was assessed in a survey of 23 lakes ranging in pH from 4.4 to 7.3, and in a study of two lakes – one acidic, the other circumneutral – during two summers. In both investigations the number of rotifer species encountered per sample was strongly reduced with pH. Although the reason for this is not clear acid-stress, the ultraoligotrophic nature of the acidic lakes, and competitive interactions with crustacean zooplankters may all have played a role. More importantly the ecological significance of this relationship is not known. The rotifer *Keratella taurocephala* was a principle species in the most acidic lakes, while several common rotifers were notably absent from these lakes. Although rotifer abundance was correlated with lake pH, the results of this study indicate that rotifer abundance is not a result of lake pH *per se*, but of lake trophic status and interactions with the crustacean community.

Introduction

A considerable amount of research has been carried out on acidification influences on zooplankton communities, however, the vast majority of this work has focused on the crustacean component of the zooplankton (Brett, 1989b). Of those studies dealing with rotifers the general findings include reductions in the number of species encountered per sample with pH (Almer *et al.*, 1974; Roff & Kwiatkowski, 1977; Hobæk & Raddum, 1980; Brezonik *et al.*, 1984; Chengalath *et al.*, 1984; Siegfried *et al.*, 1984, 1988; Yan & Geiling, 1985; Carter *et al.*, 1986; MacIssac *et al.*, 1987), and dominance of the communities of acidic temperate eastern Northern American lakes by *Keratella taurocephala* (Chengalath *et al.*, 1984; Siegfried *et al.*, 1984, 1988; Yan & Geiling, 1985, Carter *et al.*, 1986; MacIssac *et al.*, 1987; Pinel-Alloul *et al.*, 1987; Schaffner, 1989).

Considerable confusion exists as to the relationship between rotifer abundance or biomass and lake pH. Yan & Geiling (1985) reported extensive rotifer communities, 15 to 51% of total zooplankton biomass, in two acidic metal contaminated lakes relative to six circumneutral lakes, where rotifers comprised no more than 2% of the total biomass. During the experimental acidification of lake 223 the importance of rotifers, as portion of total zooplankton biomass, increased slightly as pH was reduced from 6.8 to 5.0 (Schindler *et al.*, 1985). In apparent contradiction to these results Roff & Kwiatkowski (1977), Carter *et al.* (1986), and MacIssac *et al.* (1987) have all reported reduced rotifer abundance with pH. However, Pinel-Alloul *et al.* (1987) and Siegfried *et al.* (1987) observed that even across broad lake acidity gradients rotifer community abundance was more closely related to factors associated with lake trophic status, i.e. chlorophyll *a* and total phosphorus, than to lake pH.

This study examined the relationship between lake pH, trophic status, the planktivore community and the planktic crustacean and rotifer communities in a survey of 23 lakes across a pH gradient, and in a seasonal comparison of two lakes (one acidic and the other circumneutral) during two summers.

Methods

The 23 lakes investigated were all forest lakes located in isolated regions of Maine, northeastern United States; i.e. these lakes had little or no human development in their watersheds. Lake selection was biased to include a broad range of pH values, from 4.45 to 7.20, with relatively little variation in lake morphology. These lakes were small, oligo- to mesohumic, with soft water, and were generally oligotrophic, see Table 1. Five of the lakes, the most acidic, were fishless and contained dense populations of limnetic hemipterans – especially *Buenoa macrotibialis*, while four contained allopatric populations of brook char (*Salvelinus fontinalis*), and the remaining 14 contained cyprinid fish, mainly golden shiners (*Notomigonus crysoleucas*) (Brett, 1989a).

Each of the lakes was sampled once at its deepest point for zooplankton and water chemistry in July or August of 1984. Zooplankton sampling was carried out using a 63 μm Wisconsin net drawn at a rate of 0.5 m sec^{-1} from 1 to 2 m above the sediment to the surface, except for Mud Pond which was sampled from 5 m above the

Table 1. Limnological characteristics of the 23 lakes surveyed, all values reported as averages for paired duplicate surface (0.5 m) and bottom (1 m above sediment surface) samples taken on the same dates as the zooplankton samples.

Lake	Elevation (m)	Surface area (ha)	Maximum depth (m)	pH	Alkalinity (μeq/l)	Conductivity (μs/cm)	Color (Pt units)	Total P (μg/l)	Planktivore type classification
Unnamed P. (WC)	73	2.8	5.2	4.45	– 29.1	18	35	7	Insect
Dead P.	48	4.9	10.8	4.50	– 30.4	14	30	6	Insect
Kerosene P.	67	2.8	5.2	4.50	– 19.1	17	45	7	Insect
Mud P.	97	2.2	14.0	4.60	– 26.5	25	20	2	Insect
Salmon P. (WC)	42	4.5	6.7	4.85	– 12.3	14	35	6	Insect
Lily L.	72	13.0	7.3	5.15	– 1.8	17	40	6	Cyprinid
Ledge P.	948	2.4	7.3	5.45	8.9	17	50	5	Salmonid
Anderson P.	65	5.0	6.0	5.45	2.8	16	5	5	Cyprinid
Eddy P.	793	3.6	6.7	5.65	10.8	16	10	6	Salmonid
Garrock P.	145	0.8	6.0	5.75	29.2	17	60	31	Cyprinid
Grenell P.	388	2.4	5.5	5.80	86.2	18	70	9	Salmonid
Hosea Pug L.	88	23.5	10.7	5.85	13.4	16	35	8	Cyprinid
Round P.	279	2.4	9.5	5.85	88.4	25	45	13	Cyprinid
Salmon P. (HC)	85	4.1	10.7	5.90	55.8	25	15	11	Cyprinid
Unnamed P. (PC)	380	6.8	2.0	5.90	43.0	16	85	27	Cyprinid
Secret P.	385	5.7	10.4	6.00	88.2	22	35	12	Cyprinid
Possum P.	80	12.1	5.5	6.10	7.9	14	35	8	Cyprinid
Harvey P.	291	4.1	2.4	6.15	54.8	26	10	11	Cyprinid
Daicey P.	329	15.4	7.9	6.15	6.28	18	10	8	Cyprinid
Trout L.	274	2.0	3.0	6.20	50.7	22	25	11	Cyprinid
Upper Basin P.	745	14.2	9.0	6.30	14.8	14	5	1	Salmonid
Grindstone P.	394	2.4	9.1	6.40	195.9	31	20	9	Cyprinid
Carry P.	900	6.9	3.7	7.20	534.4	63	20	13	Cyprinid

sediment. These samples were preserved in formalin.

Two of the lakes included in the survey, Mud Pond and Salmon Pond (HC), were chosen for more extensive investigations because they represented extremes in the lake types included in the lake survey – Mud Pond was acidic and fishless, while Salmon Pond (HC) was circumneutral with fish – and because they were morphologically similar and located approximately 100 m apart, see Table 2. These lakes were sampled on four dates in 1983 and six dates in 1984 at biweekly intervals during the mid-summer period. The sampling was carried out at eight stations in the littoral zone using a vertical tube sampler (1 m). Samples were filtered through a 64 μm filter apparatus and preserved in Lugol's solution. The results for the two-lake comparison are presented as pooled data for all stations on each date.

For both the lake survey and the two-lake comparison, rotifers and nauplii were counted by decanting known volumes of the samples, subsampling with a Henson-Stemple pipette, and enumerating with 1 ml Sedgwick-Rafter counting cells until at least 400 individuals were counted. The entire sample was scanned for rarer species. The whole of each sample was counted for crustacean zooplankters. In order to generate biomass values for the lake survey the first 20 individuals of each crustacean group, generally genus, were measured and their lengths recorded. Then length weight regressions (McCaully, 1984) were used to calculated the average weight for the group or species. When possible, equations for the same species, or most common species of a genus, from the same region were used. Alternatively the same species from another region or a similar species regression was used. Rotifer weights were adapted from Makarewicz & Likens (1979). Species identifications were based on the taxonomic works of Edmondson (1959), Ruttner-Kolisko (1974), Chengalath & Mulamoothil (1975), Kiefer & Fryer (1978), Pennak (1978) and Stemberger (1979).

In order to rank the lakes surveyed according to their presumed predation pressure, the lakes were first divided into three categories based on the type of planktivore present, and then ranked within these groupings according to the capture rate of the dominant planktivore in that lake (Brett, 1989a). Thus the lake dominated by limnetic insects with the lowest capture rate, during sweep net sampling, received the lowest rank while the cyprinid-fish dominated lake with the highest capture rate received the highest ranking.

Table 2. Selected physical, biological, and chemical characteristics of Mud Pond and Salmon Pond (HC). All chemical data expressed as μeq L^{-1}, except as otherwise noted.

	Mund Pond	Salmon Pond (HC)
Surface area (ha)	1.6	2.4
Maximum depth (m)	14	11
Elevation (m.a.s.l.)	97	85
Fish	absent	present
Notonectidis	abundant	rare
Chaoborus	rare	present
pH	4.6	6.2
Alkalinity	−26.5	55.8
Ca	28.3	72.4
Al	37.5	3.6
SO_4	104	52
Total phosphorus (ppb)	2	11
Color (Pt units), Na, K, Mg, Fe, Zn, Mn, NO_3, Cl	similar between the lakes	

Results

In the lake survey 29 rotifer species were collected and identified, of which only 12 were found in 40% or more of the lakes. Of these *Keratella cochlearis*, *Kellicottia bostoniensis*, *Kellicottia longispina*, *Polyarthra remata*, *Trichocerca multicrinis*, *Asplanchna priodonta* and *Collotheca mutabilis* were greatly reduced or absent from those lakes below pH 5.0. In fact these seven species had a 73% rate of occurrence in the lakes above pH 5.0., but only a 17% rate in lakes below this pH. In contrast the rotifer *Keratella taurocephala* was found in every lake investigated (Table 3).

Table 3. The rotifer community structure of the lakes surveyed, expressed as individuals per liter. Those species listed individually occurred in ≥40% of the lakes surveyed, while those occurring in fewer lakes are listed all together under other rotifers.

	NRS	RA	*Kt*	*Kc*	*Kb*	*Kl*	*Pv*	*Pr*	*Cn*	*Cu*	*Tm*	*Tc*	*Ap*	*Cm*	oth
Unnamed P. (WC)	5	2	2												<1
Dead P.	7	6	1						4		<1	<1			1
Kerosene P.	7	19	5			1	11		1						1
Mud P.	5	8	7	<1	+		1					<1			
Salmon P. (WC)	5	132	1	<1						131					+
Lily L.	7	138	5	17	6	1	27		67	15					+
Ledge P.	9	132	33	<1	5		+	1	+	93	<1				<1
Anderson P.	7	86	25	30	+	8	22	1							+
Eddy P.	9	17	9	+			2	+	1	5		+		+	
Garcock P.	14	1920	2	318	1220		276	+	1	50	11	19	20	+	3
Grenell P.	10	124	6	28	<1	19	+	5	39	4					
Hosea Pug L.	14	80	4	27	1	12	28	2	3		2	1	1	+	+
Round P	14	100	4	44	8	13	31	9	24	2			1	1	+
Salmon P. (HC)	14	89	10	<1	6	2	31	2	1	20	1	13	1	3	2
Unnamed P. (PC)	8	471	348	43	1		71	+			1	+	6		
Secret P.	14	171	1	12	8	87	34	1	+	3	4		+	+	24
Possum P.	12	210	18	18	<1	11	106	7	4	35	6	5		+	
Harvey P.	14	92	46	10	1	1	5	5	+	23	<1	+		1	+
Daicey P.	9	128	+	3	3	8	11			103			+	+	+
Trout L.	9	176	3	1	+	167	5			+	+	1			+
Upper Basin P.	5	9	<1	<1	1			<1		8					
Grindstone P.	12	250	1	158	20	52	9	4		+		1	1		5
Carry P.	8	191	1	30	2	8	136	12					4		+

NRS = number of rotifer species per sample; RA = rotifer abundance per liter; Kt = *Keratella taurocephala; Kc = Keratella cochlearis* including *K.c. cochlearis, K.c. tecta* and *K.c.* ssp.; Kb = *Kellicottia bostoniensis*; Kl = *Kellicottia longispina*; Pv = *Polyarthra vulgaris*, including *P. dolichoptera* from one lake; Pr = *Polyarthra remata*; Cn = *Conochiloides natans*: Cu = *Conochilus unicornus*, including *C. hippocrepis* from one lake; Tm = *Trichocerca multicrinis*; Tc = *Trichocerca cylindrica*; Ap = *Asplanchna priodonta*; Cm = *Collotheca mutablis*; oth = other rotifer species, including *Lecane lunaris, L. luna, Synchaeta* spp., *Ascomorpha ecaudis, Keratella hiemalis, Trichocerca elongata, T. platessa, T. myersi, T. simillis, Polyarthra euryptera, Ploesoma truncatum, P. hudsoni, Filinia longiseta*, and *Gastropus stylifer.*

Table 4. A correlation matrix for various chemical and biological characteristics of the lakes surveyed. All statistically significant relationships are shown in bold type.

	pH										
Total phosphorus	**0.474**	Total phosphorus									
Predation rank	**0.589**	**0.788**	Predation rank								
Specific conductivity	0.396	**0.508**	0.304	Specific conductivity							
Color	−0.353	0.336	0.174	−0.114	Color						
Rotifer species	**0.482**	**0.704**	**0.634**	0.412	0.148	Rotifer species					
Rotifer abundance	**0.580**	**0.669**	**0.799**	0.261	0.357	**0.526**	Rotifer abundance				
Rotifer biomass	**0.594**	**0.550**	**0.678**	0.090	−0.055	**0.548**	0.403	Rotifer biomass			
Crustacean species	0.169	**0.499**	0.303	0.326	0.122	**0.465**	0.054	0.273	Crustacean species		
Crustacean abundance	0.145	0.023	0.006	−0.019	−0.093	−0.117	0.257	−0.204	−0.386	Crustacean abundance	
Crustacean biomass	0.129	0.229	0.078	**0.413**	−0.198	−0.035	−0.088	0.031	0.158	−0.044	Crustacean biomass
Total biomass	0.272	0.389	0.250	0.287	−0.117	0.293	−0.041	**0.536**	0.402	−0.317	**0.718**

If $r > 0.412$ then $p < 0.05$.
If $r > 0.531$ then $p < 0.01$
If $r > 0.633$ then $p < 0.001$.

Table 5. Mean zooplankton community parameters when the lakes surveyed are divided into dominant planktivore catagories. Least-square means were calculated, then the data was ranked and compared for significant differences ($P < 0.05$).

Class *n* =	Limnetic insect 5	Salmonid 4	Cyprinid 14	Significant differences
pH	4.6	5.8	6.0	LI*SL; LI*CY
Total phosphorus 1	5	5	12	LI*CY; SL*CY
Rotifer species	5.9	8.3	11.2	LI*CY
Rotifer abundance 2	13.6	48.9	263.2	LI*CY; SL*CY
Rotifer biomass 1	0.9	4.5	21.9	LI*CY; SL*CY
Total biomass 1	66.2	72.6	115.4	
RA/CA 3	0.6	3.3	5.9	LI*CY
	Zooplankton community biomass proportional composition			
Rotifers	1	6	19	LI*CY; SL*CY
Nauplii	5	4	18	LI*CY; SL*CY
Bosmina	9	2	3	
Diaphanosoma	8	<1	2	LI*CY; LI*SL
Holopedium	29	32	6	LI*CY; SL*CY
Daphnia	<1	17	17	LI*CY
Diaptomus	45	32	24	
Cyclopida	3	2	11	LI*CY; SL*CY

1. in μg per liter.
2. in individuals per liter.
3. RA/CA = rotifer abundance/crustacean abundance.

Table 4 is a correlation matrix for various chemical and biological characteristics of the lakes surveyed. Notably this matrix shows a very high amount of interrelatedness between the predictor variables pH, total phosphorus, and predation rank. These variables, in turn, predicted nearly identical variation in the rotifer community parameters – rotifer species, rotifer abundance, and rotifer biomass.

By dividing the lakes into planktivore categories and analyzing for differences in zooplankton community composition between them, strong differences emerge. Namely, in both absolute terms (rotifer abundance and rotifer biomass) and relative terms (the ratio between rotifer abundance and crustacean abundance and the rotifer portion of the zooplankton biomass) rotifers were strongly favored by cyprinid predation relative to limnetic insect predation. Likewise, cyprinid predation was associated with enhanced nauplii and cyclopoid components of the zooplankton, whereas the relatively large and less evasive cladocerans *Holopedium gibberum* and *Diaphanosoma birgei* were more important in the limnetic insect dominated lakes.

In the two-lake study 16 rotifer species were identified from the acidic lake, and 21 species were observed in samples from the circumneutral lake. The acidic lake averaged 4.5 $\pm$ 2.2 ($\pm$ sd) species per sample while the circumneutral lake averaged 10.4 $\pm$ 2.2. The rotifer community of the acidic lake was strongly dominated by *Keratella taurocephala* (98% of individuals observed) while the rotifer community of the circumneutral lake was composed of 3 to 5 species, with *Keratella taurocephala* again the dominant (77% of individuals observed), but with *Keratella cochlearis*, *Kellicottia longispina*, *Trichocerca cylindrica*, *Conochilus unicornis*, and *Collotheca mutabilis* periodically common.

Notably, the crustacean community of the acidic fishless lake was principally composed of the calanoid *Diaptomus minutus* and the cladocerans *Diaphanosoma birgei* and *Polyphemus* *pediculus*, while the crustacean community of the circumneutral fish-containing lake was again dominated by *D. minutus*, but also contained large cyclopoid and *Bosmina longirostris* components, Tables 6 and 7. Rotifer abundance was generally reduced in the acidic lake, relative to the crustacean community of that lake and to the rotifer community of the circumneutral lake, except for the month of August 1984 when rather high abundances were observed (Tables 6, 7). This rise in rotifer abundance coincided with a marked decline in the cladoceran abundance

Table 6. Zooplankton community structure in Mud Pond, expressed as individuals per liter.

	Date 1983				1984					
	21/6	7/7	21/7	8/8	12/6	28/6	12/7	26/7	9/8	27/8
Copepods 1	6	8	4	1	26	3	3	6	14	0
Nauplii	37	10	5	4	28	<1	<1	<1	<1	<1
Cladocerans 2	7	4	5	1	7	4	9	2	2	0
Keratella taurocephala	<1	9	7	8	6	1	8	37	229	287
Other rotifers	<1		<1	<1	<1	<1	<1	<1	<1	<1
Total rotifer abundance	<1	9	7	8	6	1	8	37	229	287
Number of rotifer species per sample	3	1	5	7	3	3	6	6	8	3

1. copepods = 96% *Diaptomus minutus*, 4% *Mesocyclops edax.*
2. cladocerans = 58% *Diaphanosoma bigrei*, 26% *Polyphemus pediculus*, 16% *Bosmina longirostris.*

Table 7. Zooplankton community structure in Salmon Pond (HC), expressed as individuals per liter.

	Date 1983				1984					
	21/6	7/7	21/7	8/8	12/6	28/6	12/7	26/7	9/8	27/8
Copepods 1	21	10	7	10	24	17	19	8	46	6
Nauplii	13	32	12	13	1	12	60	12	5	1
Cladocerans 2	32	9	5	8	11	5	6	9	20	2
Keratella taurocephala	27	36	36	63	49	93	120	50	77	11
Keratella cochlearis	20	2	1	26	6	8	4	3	12	4
Kellicottia longispina		<1	<1	<1	3	5	8	2	1	
Trichocerca cylindrica	<1		<1	3	<1	1		4	13	1
Conchilus unicornis		<1			10	1		1		
Collotheca mutabilis	<1					<1	2	6		
Asplanchna priodonta	1	<1	<1	2	3			<1	1	2
Polyarthra vulgaris	1	<1	4	<1	1	1	<1			
Other rotifers	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Total rotifer abundance	48	38	38	97	72	109	135	67	103	19
Number of rotifer species per sample	8	7	13	12	12	13	8	11	9	11

1. copepods = 72% *Diaptomus minutus*, 18% *Tropocyclops prasinus mexicanus*, 10% *Mesocylops edax.*
2. cladocerans = 92% *Bosmina longirostris*, 7% *Diaphanosoma birgei.*

during this period. In samples collected at the same time, but from the pelagic as apposed to the littoral region of Mud Pond, crustacean zooplankters were much more abundant and the rotifers were greatly reduced (Table 3, 6).

Discussion

The most obvious result of this study, for both the lake survey and the two-lake comparison, was a reduction in the number of rotifer species per sample with pH. This observation has been made in several other studies (Almer *et al.*, 1974, Roff & Kwiatkowski, 1977; Hobæk & Raddum, 1980; Brezonik *et al.*, 1984; Chengalath *et al.*, 1984; Siegfried *et al.*, 1984, 1988; Yan & Geiling, 1985; Carter *et al.*, 1986; MacIssac *et al.*, 1987), however to what extent this is a direct result of lake acidity or the otherwise simplified nature of acidic lakes is poorly understood. In the present material the number of species per sample was also strongly, in fact more strongly, correlated to total phosphorus, lake predation rank, and rotifer density. It has been suggested (Pejler, 1983) that ultra-oligotrophic lakes, such as the most acidic lakes of the present study, are generally species depauperate relative to mesotrophic lakes, such as several of the circumneutral lakes of the present study. The strong relationship between rotifer species number and abundance may in fact be important, for instance reduced rotifer abundance might be indicative of conditions unfavorable for rotifers as a whole. One could also speculate that reduced predation pressure on the crustaceans – invertebrate versus fish, could act to increase competitive interactions and hence dominance of large cladocerans over rotifers as a group, thereby reducing 'niche space' for rotifers in the most acidic lakes. The fact that *Keratella taurocephala* was so strongly dominant in the most acidic of the two lakes compared, and that it was important in several of the other acidic lakes examined, as well as other acidic lakes in eastern North America (Chengalath *et al.*, 1984; Siegfried *et al.*, 1984, 1988; Yan & Geiling, 1985; Carter *et al.*, 1986; MacIssac *et al.*, 1987; Pinel-Alloul *et al.*, 1987; Schaffner, 1989) indicates that acid-stress, at least in influencing competitive interactions between species, might have an important influence on rotifer species number. Furthermore that several common species had greatly reduced rates of occurrence in lakes below pH 5.0 relative to lakes above this pH is also indicative of stress influences. Notably MacIssac *et al.* (1986) reported that when a severely acidic metal-contaminated lake partially recovered, pH change from 4.0 to 5.0, the rotifer community shifted from one dominated almost exclusively by *Keratella taurocephala* and *Synchaeta* spp., to one dominated by these species plus *Polyarthra* spp., *Trichocerca similis*, and *Conociloides natans*. A more fundamental problem is the ecological significance of the reduced species number in the acidic lakes. Is this observation ecologically irrelevant – but technically easy to generate, or is it of real importance to the functioning of acid-stressed ecosystems?

The abundance of rotifers in the present study was also correlated with pH as has been observed in several other studies (Roff & Kwiatkowski, 1977; Brezonik *et al.*, 1984; Carter *et al.*, 1986, MacIssac *et al.*, 1987). However, rotifer abundance was more strongly correlated with total phosphorus. This in agreement with the results of several other studies which found zooplankton abundance in acid-stressed lakes to be more closely related to lake trophic status, and hence presumably the availability of edible algae and bacteria, than to pH *per se* (Brezonik *et al.*, 1984; Pinel-Alloul *et al.*, 1987; Kerekes *et al.*, 1988; Siegfried *et al.*, 1987). This finding is also consistent with several nutrient enrichment studies of acidic lakes (Yan *et al.*, 1982; DeCosta *et al.*, 1983; Yan & Lafrance, 1984) showing dramatic increases in zooplankton community abundance or biomass after enrichment, and is consistent with the relationship between nutrient levels and community standing crop typical for non-acidic lakes.

Analysis of zooplankton community structure across planktivore type categories suggests that planktivore type influenced the relative composition of the zooplankton. Cyprinid fish predation was associated with increased representation of the rotifer community, nauplii, and cyclopoids – small or highly evasive groups – at the expense of the much larger *Holopedium gibberum* and *Diaphanosoma birgei*, both in absolute, and more importantly relative terms, e.g. as regards portion of the zooplankton community biomass. This would indicate that fish predation, which is presumably most concentrated on larger cladocerans – for reasons of size and evasiveness, liberated resources or reduced competitive interactions with crustacean zooplankters thereby benefitting the rotifers. The extreme case of this can be exemplified by Garcock Pond which had an allopatric population of golden shiners, a very large population relative to lakes of this region, which reduced the crustacean community to less than one individual per liter, despite the fact that this lake had the highest total phosphorus concentration of the lakes examined. In this lake the rotifer abundance was estimated at 2 000 individuals per liter, an abundance 5 times higher than that recorded in any of the other lakes studied.

Interactions between the crustacean and rotifer communities was also indicated by the results from the acidic lake of the two-lake comparison, where the rotifer *K. taurocephala* increased dramatically after first the cladocerans and then the copepods were greatly reduced in the littoral zone. This pattern was not observed in the pelagic zone of this lake during the same period, presumably because the chief planktivore in this lake was not particularly abundant in the pelagic relative to the littoral zone. Other studies of acid-stressed zooplankton communities have also indicated the importance of interactions between the rotifer and crustacean components of the zooplankton, namely Yan & Geiling (1985) used the reduced crustacean biomass, relative to six circumneutral lakes, and hence reduced competition with rotifers, to explain the extremely high rotifer biomasses attained in their two acidic lakes. While Yan *et al.*, (1982) showed dramatic increases in *K. taurocephala* abundance of an acidic lake after predation by *Chaoborus* had virtually eliminated the crustacean community. Furthermore, several studies of non-acidic systems have clearly shown the ability of crustaceans to depress rotifer populations (Gilbert, 1985), and have also shown that intense predation on the crustacean component of the zooplankton can greatly increase rotifer abundance (Neill, 1984).

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