PROC. N.S. INST. SCI (1986)
Volume 37, pp. 37-51

ANALYSIS OF ZOOPLANKTON COMMUNITIES OF NOVA SCOTIAN LAKES WITH REFERENCE TO WATER CHEMISTRY

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Zooplankton collections from Nova Scotian lakes were analysed to determine if relationships existed between plankton distributions and chemical variables associated with acid rain. A total of 27 taxa was identified. The most common species included *Diaptomus minutus, Bosmina longirostris* and *Mesocyclops edax.* Most lakes contained 3-7 species (excluding rotifers and copepod nauplii) and were dominated by 1-3 species. Simple statistics such as the number of species, diversity index, and evenness index were poorly correlated with abiotic variables. The best correlations indicated that diversity and evenness were negatively correlated with water temperature, water transparency and lake area, and positively correlated with conductivity. Principal component analysis demonstrated that two species, *D. minutus* and *B. longirostris,* account for the greatest proportion of the abiotic variance in zooplankton communities. *D. minutus* was associated with warm, turbid waters of decreased acidity whereas *B. longirostris* dominated in the opposite conditions (PC1). *Mesocyclops edax* was usually dominant in clear, deep lakes (PC2), and *Daphnia catawba* was often dominant in lakes with highly coloured water (PC3). The first three principal components accounted for about 73% of the total variance in zooplankton composition.

Les collections de zooplanktons des lacs en Nouvelle Ecosse ont été examiné pour élucider les rélations, si présent, entre la distribution des planktons et les paramètres chimiques associés avec la pluie acide. Un total de 27 taxa a été identifié. Parmi les espèces les plus courantes se trouvaient *Diaptomus minutus, Bosmina longirostris,* et *Mesocyclops edax.* Entre 3 et 7 espèces étaient trouvées dans la plupart des lacs (excluant les rotifères et les copépodes nauplii) avec une prédominance d'entre 1-3 espèces. Les statistiques simples telles que le nombre d'espèces, l'indice de diversité, et l'indice de distribution correspondaient mal avec les paramètres abiotiques. Les meilleures corrélations ont indiquées que la diversité et l'égalité de la distribution des zooplanktons correspondaient de façon inverse à la température de l'eau, la limpidité de l'eau et la surface du lac et correspondaient de façon directe à la conductivité. L'analyse par composant principal a montré que deux espèces, *D. minutus* et *B. longirostris* expliquent la plupart de la variation abiotique des communautés de zooplankton. *D. minutus* se trouve dans les eaux chaudes et troublées d'acidité diminuée tandis que *B. longirostris* prédomine dans les conditions opposées. *Mesocyclops edax* est normalement prédominant dans les lacs limpids et profonds (PC2) et *Daphnia catawba* est souvent prédominant dans les lacs ou l'eau est très colorié (PC3). Les trois premiers composants expliquent environ 73 % de la variance totale dans la compositions des communautés de zooplanktons.

Introduction

The species composition and distribution of zooplankton in lakes are controlled by numerous abiotic environmental factors. Numbers of zooplankton species and species diversity have been shown to be directly correlated with pH in numerous studies in Canada (Confer et al. 1983; Sprules 1975a, 1977; Carter et al 1986; Roff and Kwiatkowski 1977) and elsewhere (Wright et al. 1976; Hendry and Wright 1975). In some of these studies, the effect of pH on the plankton communities was not pronounced until lake pH fell to 5.5-5 (eg. Roff and Kwiatkowski 1977; Fryer 1980); in another study, however, the relationship was approximately linear over the entire pH range sampled of 4.5 - 7.2 (Confer et al. 1983). In addition, Sprules (1977), Janicki and DeCosta (1979), and Carter et al. (1986) have shown using principal component analysis that distinct zooplankton species groups are associated with some factor related either to pH or buffering capacity of the water.

Low pH values are a recent condition of many lakes in Nova Scotia (Gorham 1957; Watt et al. 1979) attributed to acid rain. To help establish the extent of this problem in

Nova Scotia, the Department of Fisheries and Oceans collected zooplankton samples from a total of 42 lakes in 1983-84 as part of a province wide lake survey. A series of concurrent abiotic measurements were also made (depth, area, selected chemistry). The data from zooplankton collections of 36 of these lakes were statistically analysed here to determine if low lake pH has affected Nova Scotian lake plankton communities in any measureable way, either through reductions in the number of species or species diversity, or through more subtle mechanisms involving replacement of acid sensitive species with those more acid tolerant, resulting in plankton communities indicative of particular limnological conditions.

Materials and Methods

Plankton collections were obtained at each of 36 lakes in Nova Scotia (Fig 1) during summers and early autumns of 1983 or 1984. Single unmetered tows were made using a 50 cm diameter - 73 μm mesh ring net as nets were raised from near bottom to surface. Samples were collected about midday and were preserved in the field using a buffered 5% formalin solution. Each lake was sampled on one date only.

Each sample was made up to a standard volume (1 L) and subsampled using a wide mouthed pipette. At least 200 organisms, including rotifers, were counted and identified to species where possible from each sample. Larger organisms (*Leptodora, Chaoborus*) were counted from the entire sample. Concentrations were calculated (using the diameter of the net, depth of tow and fraction size of the subsample) as numbers of organisms of each species per litre of lake water filtered.

Physical and chemical analyses were conducted either in the field or on water samples returned to the laboratory from each of the 36 lakes. Field and laboratory measurements obtained in this study include maximum depth, surface temperature, Secchi disk transparency (mean of raising and lowering), surface pH, bottom pH (if lake was isothermal then bottom pH was assumed to be the same as surface pH), acidity, alkalinity, hardness, colour, and conductivity. Methods for these analyses are described elsewhere (Watt et al. 1983). Lake basin area and watershed bedrock geology were determined from geological and topographical maps. Lakes whose watersheds were located on two or more different geological formations were assigned the formation with the greatest buffering capacity. Each lake was assigned a numerical value (1, 2 or 3) for one of three watershed geological types (1-Goldenville granite formations; 2-Halifax formations; 3-all other formations).

For all statistical analyses discussed the zooplankton species list was edited to remove all rotifers as their small size did not permit them to be collected quantitatively with the mesh size used or be identified to species in all samples. Copepod nauplii were also excluded from statistical analyses as they also were not identified to species; including them would have created an additional taxon that was a subset of other species. Number of species (N), species diversity (H'; Shannon-Wiener Index) and species evenness (J', J'=H'/log N; Pielou 1975) were computed for each sample for the crustacean and insect zooplankton.

Using N, H' and J' as the dependent variables, stepwise correlation coefficients were calculated using the abiotic limnological variables as independent variables. This stepwise multiple regression treats each variable as if it had been added to the regression equation after all the other variables had been included. Because watershed geology was a discontinuous variable, the relationship of N, H' and J' to this variable was examined using a one-way analysis of variance (ANOVA) with the three geological types being considered as treatment groups.

The second type of statistical analysis involved the use of principal component analysis (PCA). This procedure was used to identify species associations and characterise them in terms of relationships to abiotic variables. The analysis groups lakes that

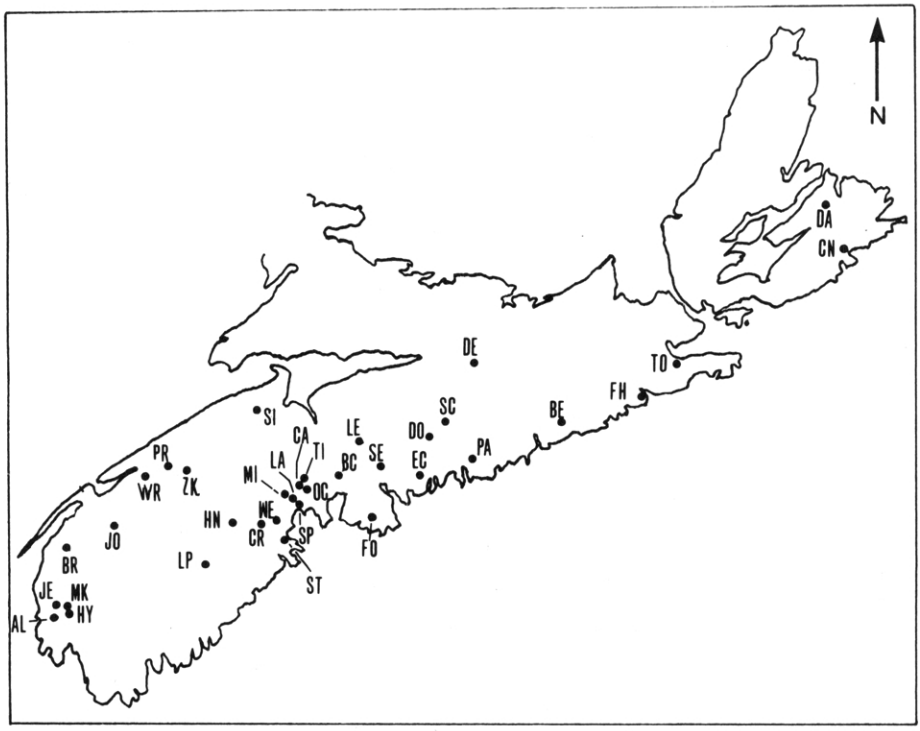

Fig 1. Map of Nova Scotia showing the locations of each of the 36 lakes surveyed for zooplankton during this study, and numbers used in Figures and Tables in text.

AL	Allens	- 1	BC	Big Connor	- 7
BE	Bear	-14	BR	Brights	- 3
CA	Connaught	-11	CN	Canoe	- 9
CR	Caribou	-15	DA	Dalem	- 4
DE	Deyarmont	-16	DO	Dollar	-17
EC	Echo	-18	FH	Fishermans Hbr	-19
FO	Fourth	-20	HN	Haynes	-22
HR	Hardy	-10	HY	Halfway	-21
JE	Jesse	- 8	JO	Joli	-23
LA	Larder	-25	LE	Lewis	-26
LP	Little Ponhook	- 6	MI	Millet	-27
MK	Mink	-28	OC	Officer's Camp	- 5
PA	Paces	-29	PR	Paradise	-30
SC	Scots	- 2	SE	Second	-24
SI	Simpson's	-13	SP	Spectacle	-31
ST	Steverman	-32	TI	Timber	-12
TO	Tom	-33	WE	Western	-35
WR	Upper Wright	-34	ZK	Zwickers	-36

have similar zooplankton communities, identifies the species of the communities, and determines the abiotic attributes common to the lakes of each group. The principles behind the procedure and the methodology used are detailed in Sprules (1977).

Species abundance data were first converted into % composition data; these data were then normalised before analysis using the arcsine square root transformation of Sokal and Rohlf (1969). The covariance matrix between species was then calculated, thus standardising the normalised abundances by subtraction of the species means. This preserves the variability of individual species (Angel and Fasham 1973), which was considered by Sprules (1977) to be an important indicator of environmental differences. Other methods of delineating zooplankton community structure, such as recurrent group analysis (eg. Huntley et al. 1983), utilise only presence/absence information and were not considered for use here because available data on variability in species abundance would not be utilised. N, H' and J' were not used in the PCA. Since the principal components are characterised in terms of species, the zooplankton composition common to a cluster of lakes was evident from scatterplots of PCA scores for various principal components. A limnological interpretation of this pattern was derived by examination of Spearman rank correlations of the PCA scores and the abiotic limnological variables (pH, depth, area, etc.) for each lake.

Results

Lakes

The list of lakes sampled during this study together with their identification numbers assigned for use in the statistical analyses are shown in Fig 1. Lakes not sampled with the plankton net have been excluded from the figure. The lakes exhibited a wide variety of sizes, depths and transparencies (Table I). Lakes varied in size from 1-919 ha, in maximum depth from 1-42 m, and in Secchi disc transparency from 0.63-9.38 m. Surface pH showed a variation of 4.60-7.00, with most lakes having a surface pH $>$ 5.5. Water surface temperature varied throughout the study (June -October) from 12-25°C.

Species Occurrences

Twenty seven different taxa were identified during this study. The taxa identified here are in general accordance with the organisms identified from other limnological studies of Nova Scotia lakes (Carter et al. 1986; Blouin et al. 1984a, b; Lane and Blouin 1985). Species concentrations are presented in Table II.

Table III summarises frequency of occurrence of each zooplankton species. The copepod *Diaptomus minutus* was the most numerous, followed closely by another copepod, *Mesocyclops edax*, the cladoceran *Bosmina longirostris* and the rotifer *Keratella taurocephala*. Each of these species occured in at least 75% of all lakes sampled. These species also occurred very commonly in the study by Carter et al. (1986) in their study of Nova Scotia and New Brunswick lakes. Other species that were collected in a high proportion of the lakes sampled included the cladocerans *Daphnia catawba, Holopedium gibberum* and *Diaphanosoma leuchtenbergianum,* the copepod *Tropocyclops prasinus,* and the rotifers *Kellicotia longispina, Keratella cochlearis,* and *Polyarthra* sp.

Table IV shows the ranges of pH for each species. Most species were found over the whole range of pH 4.6-7.0. A few species including *D. ambigua* pH $>$ 5.61), *D. retrocurva* (pH $>$ 5.99), *D. brachyurum* (pH $<$ 5.99), *H. gibberum* (pH $<$ 6.65), *E. nordenskioldi* (pH $<$ 6.20), *Trichocera* sp. (pH $<$ 6.30) and *Chaoborus* sp. (pH $>$ 5.61) were collected only at the pH's indicated.

Diversity, Evenness and Number of Species

Number of species per lake ranged from 0 - 10 (the lake with zero species contained only rotifers and copepod nauplii), but the majority of lakes contained 3 - 7 species, and almost all lakes were dominated (cf. Sprules 1975a) by only 1 - 3 species

(Table V). Low and generally statistically non-significant correlation coefficients were observed between the abiotic limnological variables and H', J' and N (Table VI); this was especially true for N. There was consistent negative correlation of H' and J' with water temperature, water transparency and lake area, and positive correlation with conductivity, indicating that the greatest diversity and community evenness indices were found in samples from small, cool, low clarity lakes with some buffering capacity. The statistic N was largely uncorrelated with any of the measured variables within the range of measurement.

Table I Physical and chemical limnological variables.

#	Date	Z_{max}	Geo	A	°C	Secchi	pH (S)	pH (B)	Acid	Alk	Hard	Con	Col
1	840627	13.0	1	94	16.1	2.75	6.5	6.5	3.36	4.57	13.44	80	35
2	840821	17.0	1	6	22.8	5.15	5.3	4.8	3.36	.00	3.90	24	15
3	840727	10.0	1	18	18.6	8.00	6.0	6.0	2.46	.78	4.97	32	25
4	840802	8.0	3	31	23.3	2.20	6.3	6.2	1.90	.53	5.75	50	15
5	840613	14.0	1	36	22.7	1.85	4.6	4.5	14.67	.00	3.81	28	110
6	840710	13.0	2	76	22.0	4.50	6.2	5.6	2.02	.68	4.97	34	15
7	840704	13.0	1	10	22.5	3.75	4.7	4.6	6.50	.00	2.82	24	25
8	840624	8.0	3	26	19.8	2.75	5.9	5.6	3.70	.92	7.79	41	35
9	840731	12.0	3	25	23.5	4.50	6.6	5.9	3.14	4.33	8.38	33	25
10	840730	17.0	3	25	22.5	4.10	6.1	5.8	4.14	1.94	7.60	33	35
11	840622	15.0	1	213	19.5	2.50	4.6	4.5	8.96	.00	2.73	23	55
12	840618	30.0	1	335	18.2	3.50	5.1	4.9	4.48	.00	3.71	21	25
13	840829	9.0	3	1	22.5	2.40	6.6	5.9	4.93	8.36	13.44	46	35
14	831013	9.5	1	18	15.2	3.63	6.2	6.1	9.09	1.99	7.28	29	25
15	830823	30.0	1	274	20.3	9.38	6.6	6.0	1.97	1.62	5.15	26	5
16	831004	6.0	3	31	17.9	1.38	6.0	5.9	7.00	1.99	6.17	20	75
17	830802	34.0	2	241	21.5	2.88	5.0	4.9	4.93	.00	4.49	23	35
18	830712	7.0	2	217	21.0	2.25	4.8	4.7	6.53	.00	8.05	38	30
19	831012	3.0	2	92	13.8	.63	4.7	4.7	12.41	.00	2.34	34	150
20	830718	3.7	1	21	23.0	1.30	5.0	4.9	7.35	.00	6.18	46	60
21	831018	4.0	1	88	12.0	3.00	6.4	6.4	3.69	1.70	5.52	41	5
22	830808	4.5	2	3	24.9	2.38	7.0	7.0	2.02	4.29	6.55	24	20
23	830912	5.0	1	222	20.5	1.63	4.8	4.9	6.76	.00	2.81	25	65
24	830727	10.0	2	106	21.5	3.88	6.5	5.6	3.03	2.32	9.73	58	15
25	830812	3.7	1	15	23.2	2.50	6.6	6.6	2.46	2.83	5.99	50	10
26	830728	6.0	1	72	21.5	3.25	6.0	6.0	3.15	1.31	8.14	43	15
27	830830	23.0	2	67	21.0	2.25	5.6	5.1	5.53	7.50	4.21	28	55
28	831017	16.0	1	139	15.0	5.00	6.2	5.7	4.30	1.21	7.02	58	15
29	830907	42.0	1	368	21.5	4.13	5.2	5.1	4.67	.00	3.74	23	20
30	830816	10.0	1	919	22.2	2.25	5.4	5.3	3.69	.00	2.81	21	35
31	830808	18.0	1	28	24.0	4.63	5.9	5.3	2.40	1.87	4.96	47	15
32	830823	5.0	2	29	21.5	2.75	6.8	6.6	4.06	7.68	10.76	48	15
33	831011	11.0	2	64	15.2	.88	4.9	5.1	12.90	.00	2.80	30	110
34	830816	5.5	3	18	21.2	1.88	5.7	5.6	4.92	.00	4.31	29	35
35	830830	2.7	3	24	24.0	2.60	6.0	6.0	2.69	.87	3.51	20	15
36	830817	5.5	3	50	22.0	5.38	6.4	6.3	2.46	1.97	5.43	38	5

Notes: # - lake number, see Fig. I; date - YYMMDD; Z_{max} - depth (m); Geo: - bedrock geology, 1 = Granite/Goldenville Formation, 2 = Halifax Formation, 3 = "other" formations; A - surface area (ha); °C - surface temperature; Secchi - mean of lowering and raising (m); pH - (S) - pH at surface; pH - (B) - pH at bottom (assumed = pH - (S) if lake was isothermal); Acid-Alk-Hard - Acidity, Alkalinity and Hardness (mg/L as $CaCO_3$); Con - conductivity in umhos/cm; Col - colour in relative units.

Table II Concentration (number of organisms per Litre) of zooplankton taxa from plankton net collections.

Lake #	Number of Organisms^{-1}													
	BOSM	CER	AMB	CAT	RET	BRA	BIR	HOLO	LEP	MIN	SIC	LAC	NOR	MESO
1	0.25			0.05	0.02		0.01	0.64		0.14				0.02
2	0.44							0.09		0.47				0.78
3	0.24			0.02			1.14	0.58		11.44			0.36	1.32
4														
5				0.25						1.81				
6	0.20			0.27				0.30	0.03	1.04				0.20
7	0.03			0.03			0.36			2.97			0.06	0.24
8								0.42		0.50			0.04	0.04
9	0.14			0.11						0.92				0.21
10	0.04		0.02	0.04			0.04			2.29			0.20	
11	1.80			0.06			1.09	0.13		3.54			0.06	0.13
12	0.05			0.14						0.80				0.60
13	1.19													20.30
14	8.17			0.44				2.65		6.40				5.74
15								0.17		4.42				0.11
16				15.98						6.64				0.25
17	0.57			0.19		2.58				4.49				1.24
18	15.66							6.05		3.55			2.71	1.25
19	21.24							1.18		6.49				1.77
20	0.11			1.68			0.11			6.00			2.74	0.11
21	59.00									11.21				2.36
22	5.62	14.05								29.50				2.81
23	4.59			0.44						14.42				2.40
24	5.09			0.49			2.67			4.85		1.70		1.94
25	4.31						3.23			30.72				4.85
26	0.19						1.94			17.87		0.97		1.94

Table II (continued)

Lake #	Number of Organisms^{-1}												
	TROP	CHAO	OST	NAUP	BRAC	EUCH	KELL	COCH	QUAD	TAUR	ARTH	PLOE	TRI
1	0.10			1.13	0.01		0.02	0.04	0.02	0.04	0.09		
2	0.03			2.00				0.19		0.03	0.03		
3				1.17			0.06			0.12			
4								5.10					0.02
5				0.20						2.84			
6	0.07			0.44			0.34	0.07		0.40			
7	0.09			0.09						0.58			
8				2.62			0.33			0.83	0.04		4.54
9	0.14	0.01		4.60			0.42	0.57			0.64		
10				2.69				0.04					
11				1.80						5.15			0.13
12				1.03			0.41		0.04	0.55	0.02	0.02	0.04
13		0.08		11.94			1.59	23.49					
14	0.88			7.28				20.97					
15				3.36			1.62	0.34		1.40			
16	1.47			2.95			0.49				0.25		
17				0.76			0.76	0.10		15.97	0.10		
18				0.84						6.26			
19				2.95						18.29			
20	0.11			6.42				0.11		1.26			
21	27.41			10.03				11.80		4.72			
22	12.64		2.81	54.78		1.40	8.43	2.81		1.40			
23	0.87			6.77						8.96	0.44		
24	6.55			45.12			2.91	4.12			2.91		
25	8.62			26.41						0.69			
26	0.19			21.73			2.33			1.17	0.19		

Table II (continued)

Lake #	Number of Organisms^{-1}													
	BOSM	CER	AMB	CAT	RET	BRA	BIR	HOLO	LEP	MIN	SIC	LAC	NOR	MESO
27				0.90						2.34				2.34
28	0.97			0.29				0.23		3.44				3.44
29	0.65						0.15	0.07		1.82			0.07	1.46
30	0.18			0.18				0.55		15.28			0.36	0.18
31	0.34			0.17	0.17		1.02			9,85				2.89
32	1.64									1.64				
33	1.21	1.78		1.15				0.57		1.78				1.59
34	1.56			1.04			1.56			15.57	2.08			2.60
35	2.53													
36							9.13			22.71				1.49

Table II (continued)

Lake #	Number of Organisms^{-1}												
	TROP	CHAO	OST	NAUP	BRAC	EUCH	KELL	COCH	QUAD	TAUR	ARTH	PLOE	TRI
27		0.26		10.80				19.80			0.72		
28	0.57			1.55				0.75		0.34			
29				6.11				1.24		1.75			
30				15.65			0.73	0.36		0.55	1.82		
31	0.34			15.28			0.51	0.85	0.17	1.70			
32	3.28			39.33				175.35		4.92	11.47		
33				0.83			0.13	0.06		1.40			
34	1.04	0.52		14.01			3.63	21.80		1.56	3.63		1.56
35	0.51	0.51		9.10							10.62		
36				12.31						0.64			

BOSM = Bosmina longirostris, CER = Ceriodaphnia reticulata, AMB = Daphnia ambigua, CAT = D. catawba, RET = D. retrocurva, BRA = Diaphanosoma brachyurum, BIR = D. birgei, HOLO = Holopedium gibberum, LEPT = Leptodora kindtii, MIN = Diaptomus minutus, SIC = D. siciloides, LAC = Epischura lacustris, NORD = E. nordenskioldi, MESO = Mesocyclops edax, TROP = Tropocyclops prasinus, CHAO = Chaoborus sp., OST = unidentified ostracod, NAUP = unidentified copepod nauplii, BRAC = Brachionus sp., EUCH = Euchlanis sp., KELL = Kellicotia longispinus, COCH = Keratella cochlearis, QUAD = K. quadrata, TAUR = K. taurocephala, ARTH = Polyarthra sp., PLOE = Ploesoma sp., TRIC = Trichocera sp.

PCA Results

A total of 8 principal components was required to account for all the variance in the proportionate numerical abundance of the 17 species and 35 lakes selected for analysis, (lake 4 had only rotifers and nauplii and was consequently dropped from the PCA) with the first 3 components accounting for 73% (Table VII). *Diaptomus minutus* had a significant positive correlation to PC1 whereas *Bosmina longirostris* had a significant negative correlation to PC1 (Table VIII). PC2 was significantly positively correlated with *Mesocyclops edax* and negatively correlated with *B. longirostris* and *D. minutus*. PC3 was positively correlated with *Daphnia catawba* and negatively correlated to *D. minutus*. Thus, lakes with relatively high abundances of *D. minutus* and relatively low abundances of *B. longirostris* will have high scores on PC1; low scores on PC1 will be obtained by the reverse situation. Because PC1 accounts for the greatest proportion of the total variance in the data, it can be concluded that the greatest difference among lakes is due to dominance of these two species, with secondary effects due to variations in *M. edax* (via PC2) and *D. catawba* (via PC3). *D. minutus* and *B. longirostris* relative abundances behave differently to PC1 but similarly to PC2 and PC3.

Table III Provisional species list of taxa identified from plankton net collections, number and percentage of lakes in which each taxa was found, and rank order.

Taxon	# Lakes	% Lakes	Rank Order
Cladocera			
Bosmina longirostris	29	81	3
Ceriodaphnia lacustris	2	6	16
Daphnia ambigua	1	3	19
D. catawba	21	58	6
D. retrocurva	2	6	16
Diaphanosoma brachyurum	1	3	19
D. birgei	13	36	11
Holopedium gibberum	14	39	10
Leptodora kindtii	1	3	19
Copepoda			
Diaptomus minutus	34	94	1
D. siciloides	1	3	19
Epischura lacustris	2	6	16
E. nordenskioldi	9	25	12
Mesocyclops edax	31	86	2
Tropocyclops prasinus	19	53	7
Rotifera			
Brachionus sp.	1	3	19
Euchlanis sp.	1	3	19
Kellicotia longispina	17	47	8
Keratella cochlearis	22	61	5
K. quadrata	3	8	15
K. taurocephala	27	75	4
Ploesoma sp.	1	3	19
Polyarthra sp.	15	42	9
Trichocera sp.	5	14	13
Other			
Chaoborus sp.	5	14	13
unid. Ostracoda	1	3	19

Fig 2 presents a scatterplot of the scores for each of the 35 lakes for PC1 *vs* PC2. Four separate groups of lakes have been identified. The first group, also the largest, contains a total of 26 lakes that did not score highly on either PC1 of PC2; these lakes are not characterised by any particular type of zooplankton community. Lake 13 scored high on PC2 but low on PC1; this lake was dominated (94%) by *M. edax*. A third group (lakes 18, 19, 21 and 35) was characterised by negative scores on both PC1 and PC2, and contained zooplankton communities dominated by *B. longirostris*. The fourth group (lakes 5, 10, 15 and 30) scored high on PC1 but low on PC2 and were characterised by dominance of the zooplankton community by *D. minutus* but with strong representation by *B. longirostris*.

A scatterplot of PC1 *vs* PC3 is shown in Fig 3. Five groups were identified, with the largest group of 10 lakes not demonstrating any strong correlation to either component. Group 2 (lakes 5, 6, 9 and 12) was characterised by the co-dominants *D. minutus* and *D. catawba* and graded into group 3 (lakes 16, 20, 27 and 33) which were increasingly dominated by *D. catawba* (in particular lake 16 which contained 66% *D. catawba*). At the other end of the continuum, group 2 graded into group 4 (lakes 3, 7, 8, 10, 11, 15, 22, 25, 26, 30 and 31) which was dominated by *D. minutus* (especially lake

Table IV Distribution of zooplankton species in relation to pH.

Taxon	Range of pH	
	Lower	Upper
Cladocera		
Bosmina longirostris	4.60	7.00
Ceriodaphnia lacustris	4.98	7.00
Daphnia ambigua	6.14	6.14
D. catawba	4.60	6.59
D. retrocurva	5.99	6.59
Diaphanosoma brachyurum	5.05	5.05
D. birgei	4.60	6.59
Holopedium gibberum	4.60	6.59
Leptodora kindtii	6.20	6.20
Copepoda		
Diaptomus minutus	4.60	7.00
D. siciloides	5.73	5.73
Epischura lacustris	6.03	6.58
E. nordenskioldi	4.60	6.20
Mesocyclops edax	4.60	7.00
Tropocyclops prasinus	4.79	7.00
Rotifera		
Brachionus sp.	6.59	6.59
Euchlanis sp.	7.00	7.00
Kellicotia longispina	4.98	6.65
Keratella cochlearis	4.88	7.00
K. quadrata	5.10	6.59
K. taurocephala	4.60	7.00
Ploesoma sp.	5.10	5.10
Polyarthra sp.	4.88	6.59
Trichocera sp.	4.60	6.30
Other		
Chaoborus sp.	5.61	6.65
unid. Ostracoda	7.00	7.00

Table V Distribution of total number of species and number of dominant species in plankton collections.

Number Species	% of lakes	
	Total	Dominant
0	3	—
1	0	17
2	3	31
3	14	43
4	17	3
5	11	3
6	28	3
7	19	0
8	6	0
9	0	0
10	0	0

Table VI Correlation matrix of H', J' and N with physical and chemical limnological variables, and results of ANOVA for geology. All correlation coefficients and F-statistics are non-signficiant ($p > 0.05$)

Variables	Correlation Coefficient With H'	J'	N
Date	0.1034	0.2275	-0.1263
Depth	0.0208	-0.0733	0.0330
Geology		see below	
Area	-0.1536	-0.2148	0.0753
Temperature	-0.2426	-0.2602	-0.0737
Secchi	-0.1184	-0.1733	0.0706
pH-T	-0.0266	0.0231	-0.1045
pH-B	-0.0430	0.0345	-0.1310
Acidity	0.0669	0.0903	-0.0431
Alkalinity	-0.0397	0.1198	-0.1785
Hardness	0.0290	0.0272	0.0078
Conductivity	0.1195	0.0409	0.1032
Colour	-0.0133	0.0128	-0.0579

	F	df	P
Geology with N	4.050	1,34	0.052
H'	3.174	1,33	0.084
J'	1.079	1,33	0.306

(Halifax and Granite/Goldenville vs. other formations)

Table VII Cumulative proportion of variance in factor space explained by PCA components.

Principal Component	Cumulative Proportion of Total Variance
1	40.7
2	61.0
3	73.0
4	83.9
5	89.5
6	94.1
7	97.2
8	100.0

15 which contained 94% *D. minutus*). A fifth group of lakes (lakes 13, 18, 19, 21, 24 and 35) were dominated by the cladoceran *B. longirostris* (lake 35 contained 71% *B. longirostris*).

The limnological characteristics underlying these patterns can be determined by examination of Table IX which shows the correlation coefficients of the first three components with the abiotic limnological variables. PC1 is most strongly correlated negatively with acidity and positively with Secchi disc transparency and temperature. PC2 is strongly correlated positively to depth and Secchi disc transparency, and PC3 is significantly correlated positively only to colour. The interpretation of the PCA scatterplots, therefore, suggests that highly coloured lakes are characterised by a

Table VIII Component score correlation coefficients of first 3 components.

Taxon	PC1	PC2	PC3
D. minutus	0.774*	-0.433*	-0.323*
H. gibberum	0.201	0.012	-0.070
T. prasinus	0.186	0.078	-0.078
M. edax	0.142	0.784*	-0.166
ostracod	0.004	0.002	-0.008
C. lacustris	0.004	-0.033	-0.001
D. retrocurva	0.002	0.001	0.002
L. kindtii	0.001	-0.001	0.002
D. ambigua	-0.001	-0.001	-0.001
D. siciloides	-0.002	-0.003	0.007
E. lacustris	-0.002	0.005	0.004
D. brachyurum	-0.005	-0.006	-0.013
Chaoborus	-0.042	0.002	0.017
E. nordenskioldi	-0.099	0.050	-0.058
D. birgei	-0.135	0.007	0.033
D. catawba	-0.142	-0.177	0.880*
B. longirostris	-0.474*	-0.583*	-0.272

* - $P < 0.05$

predominance of *D. catawba* and lack of *D. minutus;* clear, deep lakes are characterised by domination of *M. edax* and a lack of *B. longirostris* and *D. minutus;* less clear, cool lakes with increased levels of acidity are characterised by *B. longirostris;* and clear, warm lakes with decreased acidity are dominated by *D. minutus.*

Discussion

Numerous studies have now established that lake communities have been affected by the deposition of acid rain. Other studies have clearly connected acid rain to industrial emissions (see Haines 1981 for a review). Studies in Nova Scotia (Gorham 1957; Watt et al. 1979; Watt et al. 1983) have demonstrated that rivers and lakes are becoming more acidic due to industrial pollution, and that this decreasing pH has a measureable effect on the ecosystems. The objective of the present study was to compare the mid-summer zooplankton communities of a number of lakes throughout Nova Scotia to see if increased acidity or any of its correlates could be shown to be a factor in explaining the observed distributions.

In this study, measured abiotic variables were generally not significantly correlated to simple population summary statistics such as numbers of species, species diversity and species evenness. No statistically significant ($p < 0.05$) correlation between the abiotic variables and the population summary statistics were observed, although the correlations (all negative) between temperature and J' or H' were among the best recorded overall, indicating that the greatest diversity and evenness were partly related to cool temperatures. This was not related to date of sampling as those correlations with H' and J' were very low and not consistent in sign. The relationships of H' and J' to lake area were also among the highest recorded, and also were consistently negative, indicating that smaller lakes were more likely to have more diverse and even zooplankton communities. Other studies have demonstrated that number of species is positively correlated to lake area (Confer et al. 1983).

Other studies have demonstrated a relationship between lake pH and the number of zooplankton species (eg. Fryer 1980; Roff and Kwiatkowski 1977; Confer et al. 1983), but no such relationship was discovered in this study. This anomaly may be due to one of two reasons. Firstly, both Confer et al. (1983) and Roff and Kwiatkowski (1977) counted greater numbers of organisms per sample than I did; consequently, rare and infrequently occurring organisms would be more likely counted in their samples, resulting in greater numbers of species actually enumerated. Secondly, all three studies, but in particular those of Fryer (1980) and Roff and Kwiatkowski (1977), counted species numbers from lakes with pH's substantially lower than those studied here, and it would be in these lakes where the effect of pH could be expected to be the greatest.

The results of the principal component analysis were rewarding. PCA characterises each lake in terms of its score along a series of axes or principal components in an n-dimensional hyperspace that are derived from contributions of each species to the total sample. The PCA scores for each lake can then be compared both to abiotic variables and the actual distribution of the species to determine potential affinities between the zooplankton and the environment. Table X summarises the results of PCA.

The first three principal components accounted for 73% of the variance in the observed species abundance matrix. This compares favourably with the study of Sprules (1977) where the first three components accounted for about 61-74% of the variance. PC1 was most strongly correlated with temperature, transparency and acidity and also showed the best correlations with *B. longirostris* and *D. minutus*. This suggests that these two species dominate lakes of very different conditions, with the former being associated with cool temperatures, increased transparency and increased acidity and the latter in conditions the opposite of these. In most samples, however, these two species were either co-dominant or shared dominance with other species. PC2 was related both to water depth and transparency, with the

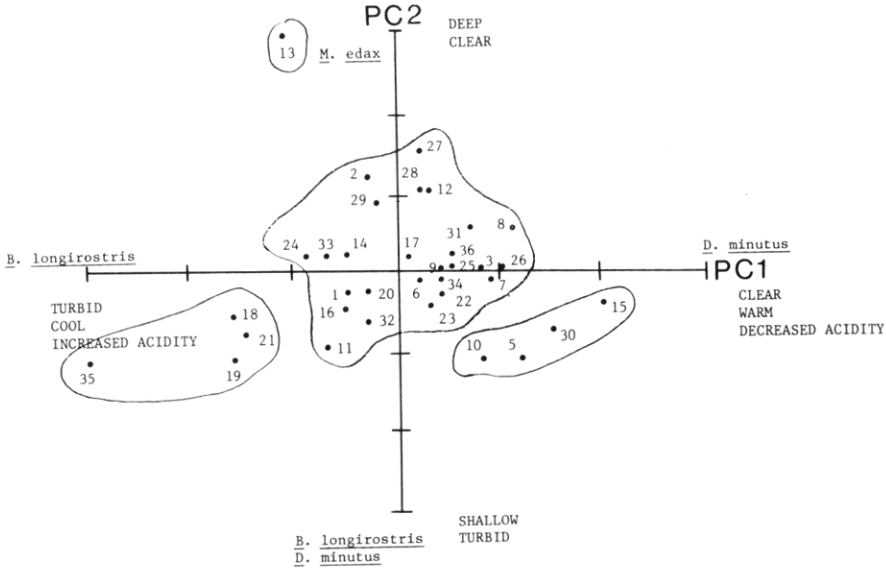

Fig 2. Principal component ordination of PC1 and PC2. Solid lines represent lake groups determined from PCA. Species and limnological labels correspond to those identified in Tables VIII and IX.

copepod *M. edax* correlated very highly to this factor. Because both *D. minutus* and *B. longirostris* were negatively correlated to PC2, indicating an affinity for decreased clarity (the reverse of PC1 for the former species), I conclude that water depth is the most important correlate of PC2 as a factor controlling the observed species distributions. PC3 was correlated with water colour; *D. catawba* was also positively correlated with this factor.

One of the earliest effects of acid precipitation on aquatic ecosystems is the reduction and ultimately the disappearance of fish populations, which may in itself effect substantial change in the plankton community as large vertebrate predators are replaced with invertebrate predators (Zaret 1980). Thus, some of the observed patterns may be due to the absence or reduction of fish predation. Studies were not conducted on zooplankton species to determine if, in the absence of fish predation, zooplankton were adversely affected by low pH. Most acidic lakes are characterised by a reduction in the numbers of daphniids and an increase in the proportion of bosminids. Few species of daphniids were collected during this study, the most comon was *D. catawba*. This species was associated with principal components related to softness, low pH and coloured water conditions. *B. longirostris*, both in this study and others, was strongly associated with factors related to decreased transparency and increased acidity.

The species found most frequently in this study have also been found to be common in other lakes in eastern Canada with low pH where they have been identified as acid tolerant species (Carter et al. 1986; Blouin et al. 1984a). These species include *D. minutus, B. longirostris, E. nordenskioldi* and *K. taurocephala. D. minutus* was found in almost all lakes in the present study, and Carter et al. (1986) have suggested that the distribution of this species may be controlled as much by predation as by factors related to pH. Further studies aimed at determining the role of lake chemistry in the structuring of pelagic communities would be rewarding.

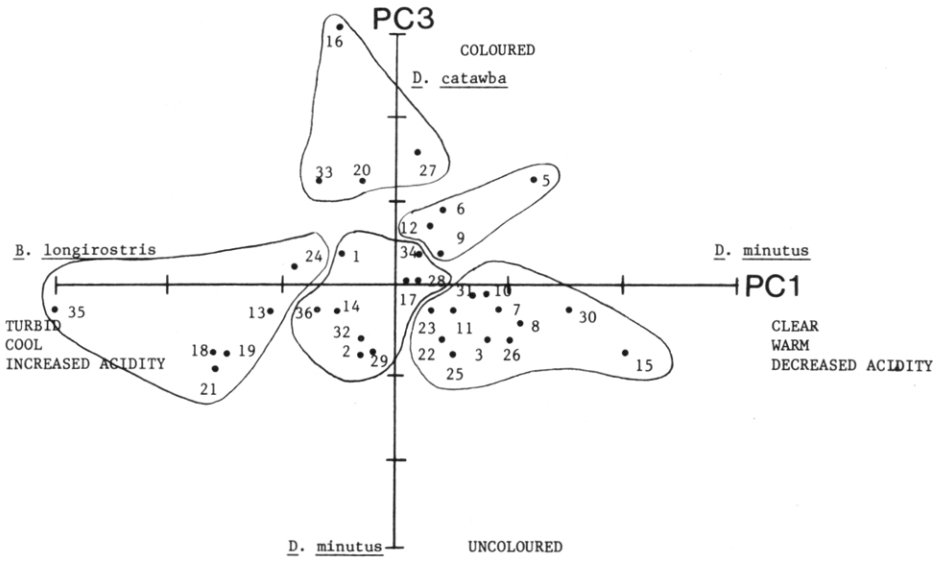

Fig 3. Principal component ordination of PC1 and PC3. Solid lines represent lake groups determined from PCA. Species and limnological labels correspond to those identified in Tables VIII and IX.

Table IX Spearman rank order correlation coefficients of first 3 principal components with the abiotic limnological components for large net samples.

Variable	Correlation Coefficient		
	PC1	PC2	PC3
Date	0.0405	0.0856	0.0728
Depth	0.2966	0.3953*	0.2512
Geology	0.1757	0.0418	0.1590
Area	-0.0356	-0.1559	0.0168
Temperature	0.3066*	-0.0136	-0.0007
Secchi	0.3582*	0.3550*	-0.1854
pH-T	0.0878	0.1484	-0.1266
pH-B	0.0654	0.0448	-0.1869
Acidity	-0.3761*	-0.1131	0.2580
Alkalinity	-0.0360	0.1937	0.0508
Hardness	-0.0349	0.1646	-0.0101
Conductivity	-0.0541	0.1526	-0.0394
Colour	-0.1584	-0.2049	0.4101*

* - $P < 0.05$

Table X Summary of PCA results for zooplankton collections.

PRINCIPAL COMPONENTS		MAJOR CORRELATES (r)	
PC1	WARM	0.307	COOL
	> TRANSPARENCY	0.358	< TRANSPARENCY
	< ACIDITY	-0.376	> ACIDITY
	D. MINUTUS (0.774)		B. LONGIROSTRIS (-0.474)
	H. GIBBERUM (0.201)		
PC2	DEEP	0.395	SHALLOW
	> TRANSPARENCY	0.355	< TRANSPARENCY
	M. EDAX (0.784)		D. MINUTUS (-0.443)
			B. LONGIROSTRIS (-0.583)
PC3	COLOURED	0.410	UNCOLOURED
	D. CATAWBA (0.880)		B. LONGIROSTRIS (-0.272)
			D. MINUTUS (0.323)

Acknowledgements

This project was funded through Supply and Services Canada. I wish to thank W. Watt, W. White and A. Hamilton for their support. W. White reviewed an earlier version of this report.

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