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THE EFFECT OF LIME ON THE ZOOPLANKTON POPULATION OF SANDY LAKE, HALIFAX COUNTY, NOVA SCOTIA

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Liming of Sandy Lake, Nova Scotia, during July and August of 1981 produced an abrupt and transient increase in the pH of the lake and concurrent changes in the zooplankton community. Immediately following liming, the cladoceran *Bosmina longirostris* could not be recovered from the lake but returned the following year after pH levels had fallen to pre-liming levels. The acidophilic rotifer *Keratella taurocephala* was also less numerous subsequent to liming. Other species, particularly rotifer species, were either more numerous or were collected for the first time in the two years immediately following the liming.

Le chaulage du lac Sandy en Nouvelle Ecosse pendant juillet et août de 1981 a provoqué une augmentation brusque et transitoire dans le pH du lac et en même temps des changements dans les communautés de zooplanktons. Immédiatement après le chaulage, le cladocéran *Bosmina longirostris* a disparu du lac pour réappaître l'année suivante après que le niveau de pH soit retombé au niveau observé avant le chaulage. La population des rotifères acidophiles *Keratella taurocephala* a été réduite après le chaulage. D'autres espèces, et en particulier les espèces de rotifères, ont été soit plus nombreuses, soit collectionées pour la première fois dans les deux ans immédiatement suivant le chaulage du lac.

Introduction

Many rivers in eastern Canada no longer support Atlantic salmon due to habitat deterioration caused by declining pH (Watt et al. 1983). Fisheries and Oceans Canada initiated an experimental whole-lake liming study extending from 1980 to 1983 on Sandy Lake, near Halifax, Nova Scotia, Canada, to determine if lake liming was a viable means of neutralizing low pH Atlantic salmon river habitat. Whole-lake liming was successfully employed in Scandinavia (Dickson 1978; Bengtsson 1980; Hultberg and Andersson 1982; Sverdrup and Bjerle 1983) and elsewhere in Canada (Scheider et al. 1975; Scheider and Dillon 1976; Dillon et al. 1979) to neutralise acidified lake habitat. Based upon these studies, White et al. (1984) reasoned that lake liming would provide a large volume of higher pH water to be discharged into a river system continuously over a period of time, reducing the need for repeated and frequent application of base (lime). Accordingly, Sandy Lake was limed during July and August of 1981.

Vertical zooplankton collections were also obtained from the lake prior to liming and for several years thereafter. Recent studies show that zooplankton populations may be correlated to pH or related variables (Sprules 1975, 1977; Confer et al. 1983; Carter et al. 1986), and various authors have suggested that lake liming should, with time, have restorative effects on acid-stressed pelagic communities (eg. Scheider and Dillon 1976; Bengtsson 1980; Hultberg and Andersson 1982). I therefore decided to compare pre- and post-liming plankton collections and water chemistry data for Sandy Lake to see if such relationships existed. The liming procedure and the results of the chemical studies are described in White et al. (1984).

Methods

Plankton collections were obtained at the deepest location in Sandy Lake, Nova Scotia, from June, 1981, to November, 1983, approximately every two weeks during spring and summer and monthly during the remainder of the year. Triplicate unmetered tows were made at the same location on each sampling date using a 50 cm diameter - 73 μm mesh ring net raised from 1 m above the bottom (-20 m) to the surface. Samples were collected about midday and were preserved in the field using a buffered 5% formalin solution.

In the laboratory, each zooplankton sample was made up to 1 L and subsampled using a wide mouthed pipette. At least 200 organisms, including rotifers, were counted and identified from each sample. Large organisms (*Leptodora, Chaoborus*) were counted from the entire sample. Each organism was identified to species if possible. Concentrations were calculated as mean numbers of organisms of each species per litre for each sampling date based upon the mouth opening of the net and the depth of the tow. I assumed a 100% net efficiency and calculated concentrations per unit volume are lower limits as presented. Rotifers in particular were poorly sampled using mesh sizes of 73 μm (Likens and Gilbert 1970). Physical and chemical analyses were conducted either in the field or on water samples returned to the laboratory. Methods for these analyses, together with a list of chemical variables measured and the detailed methodology for liming of Sandy Lake, are presented in White et al. (1984).

Table I Morphometric and hydrological data for Sandy Lake.

Surface Area	74 ha
Volume	5.1×10^6 m^3
Maximum Depth	20 m
Mean Depth	6.9 m
Area of Watershed	1714 ha
Water Retention Time	0.34 years

Results

Water Chemistry

Hydrological and morphometric data for Sandy Lake are included in Table I. Prior to liming, water chemistry of Sandy Lake was typical of lakes on metamorphic rocks in

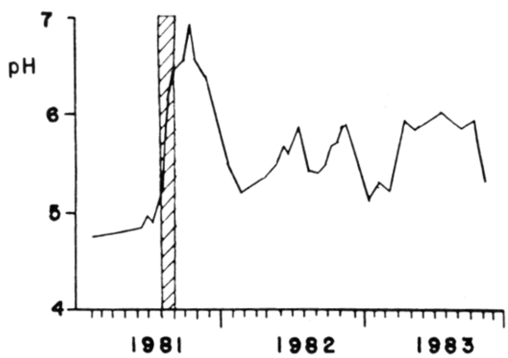

Fig 1. Whole-lake pH measurements for Sandy Lake. Hatched bar represents time of liming.

Halifax County (Watt et al. 1979; White et al. 1984). The watershed lies entirely on metamorphic rock of the Goldenville Formation. The lake is fed by two small brooks, and there was no evidence of organic pollution. Surface pH before the addition of lime varied from 4.1-5.1, varying little with depth. Gorham (1957) reported a pH of 5.02-5.18 for Sandy Lake in December, 1955, and Watt et al. (1979) remeasured the pH in January, 1977, and reported values of 4.56-4.58.

Lake pH measurements (average of pH's of all depths sampled—depths usually included 0, 1, 3, 6, 12, 16 and 18 m) are presented in Fig 1. The pH increased after the lime application from about 4.9 in August to 6.9 in October, 1981, followed by a decline to a post liming minimum of 5.2 in February of 1982. The pH varied thereafter from 5.4 to 5.8, declining to 5.1 by January, 1983. A similar pattern was repeated during the remainder of 1983. The pH did not return to the low values recorded during the pre-liming period. White et al. (1984) determined that pH increases in 1982 following the February 1982 minimum were largely due to increased pH levels in one of the two inlet streams (their Fig 5); I assume that the same factor contributed to increases during 1983.

Table II shows dissolved metal concentrations before and after liming. No changes in concentration were observed for dissolved potassium, sodium or lead. Concentrations of dissolved aluminium, manganese, copper and zinc were substantially reduced following application of the lime. Dissolved iron concentrations, on the other hand, increased following liming, at least partly due to the high iron content of the limestone (0.436%, White et al. 1984).

Table II Comparison of pre-liming and post-liming metal concentrations in Sandy Lake. Measurements taken 11 June - 23 July, 1981 (pre-liming) and 31 August - 23 November, 1981 (post-liming).

Metal	Mean Concentration ($mg\ L^{-1}$) pre-liming	post-liming
K	0.56	0.56
Na	10.91	8.57
Al	0.48	0.31
Mn	0.25	0.20
Fe	0.23	0.45
Cu	0.0050	0.0006
Zn	0.03	0.01
Pb	0.002	0.002

Zooplankton Distributions

Eighteen taxa were identified from Sandy Lake. Of these, 12 taxa were collected regularly in at least one of the three years. The concentrations of each taxa on each sampling date are included in Table III.

Rotifera

Eight different taxa of rotifers were collected. *Brachionus* sp., *Polyarthra* sp. and *Trichocera* sp. were not numerous on any collecting date. *Brachionus* sp. was collected primarily in 1981, with *Polyarthra* sp. and *Trichocera* sp. being collected mostly in the 1983 samples. The other 5 taxa of rotifers occurred much more commonly. The most numerous rotifer was *Keratella taurocephala,* followed by *Asplanchna* sp. and *Kellicotia longispina. Keratella quadrata* and *K. cochlearis* were also frequently collected.

Table III Mean concentration of zooplankton species from Sandy Lake. Results are means of 3 replicates.

Date YY MM DD	Coch	Taur	Quad	Kelli	Brach	Poly	Aspl
810612		1.09			3.79		
810624		3.64			5.40		
810713		14.64					
810804		17.80					
810820		29.34					
810902		19.15					
810918		5.59					
810929		.75					
811015		.76					
811029		.42		.02			
811124	.09	.69			.01		
820420	.33	.77	.49	.17			.85
820524	.22	.66	3.85	.68	.12		.05
820610		8.92	2.99	8.98			1.41
820624		6.29	2.16	8.03			28.70
820707		31.96	.28	5.64	.09		9.81
820720		27.88	.32	2.21			.62
820804		51.03	.24	1.33			.76
820818		39.61	.40	3.25			3.21
820909		20.38	.83	8.87			30.73
820923		5.02		1.01	.05		
821014	.20	1.37		5.18			13.57
821027	.21	.74		11.90		.19	6.01
821108	.24	.65		6.03			9.77
821118	2.55	1.95	.21	19.03		.52	7.02
821206	1.56	.53	.09	5.30		.16	9.54
830412	.12	.03	.04	.06			
830429							
830511							
830525							
830608	.04	.04	.04				
830621	.03	.03	.06	.03		.03	
830706	2.77	.03	.06				
830720				.06		.07	
830825				.03			
830929	.08	.12					
831027		.11					
831125		1.94		.02			

Coch - K. cochlearis; Taur - K. taurocephala; Quad - K. quadrata; Kelli - K. longispina; Brach -Brachionus sp.; Poly - Polyarthra sp.; Aspl - Asplanchna sp.; Min - D. minutus; Edax - M. edax; Tropo - T. prasinus; Naup - unidentified copepod nauplii; Nord - E. nordenskioldi; Bosm - B. longirostris; Ambig - D. ambigua; Diaph - D. brachyurum; Chao - Chaoborus sp. L. kindtii was found on 7.7.82 and 18.11.82; and Trichocera sp. on 25.8.83 at 1 and 3 L^{-10} respectively.

Rotifers collected during 1982 and 1983 were notably absent during 1981. Of exception was *K. taurocephala* which was most numerous during July-September, 1981. *Brachionus* sp. was also collected during 1981, but in much lower concentrations than the former species. *K. taurocephala* was numerous in 1982, but three other rotifers, *K. longispina, Asplanchna* sp., and *Keratella quadrata* were also found

Min	Edax	Tropo	Naup	Nord	Bosm	Ambig	Diaph	Chao
	Numbers per litre							
6.94			12.48		.32			
11.48			11.90		.48	.08		
13.24	.18		6.20		2.79			
8.08			19.62		23.51	.06		.06
9.75			22.38		12.51	.49		
5.60			4.04		6.08	.35	.11	.06
7.56	.09		2.16		.98	.64	.45	
10.46			.99			.13	.10	
4.32	.01		.45			.23	.08	.01
5.46			.56			.43	.02	
4.40			.05			1.37		.05
5.44			9.89					
4.40			20.41		.12			
15.46	.22		28.05			.53	.11	
4.49			17.52	.08		.50	.09	
5.53	.53		10.95	.09		.35		
19.98	.19		13.82		.10	.59	.10	.01
13.61	.31		24.63		9.51	.24	.94	.01
15.78	.18		11.17	.09	.90	1.10	1.65	.01
12.86	.81		7.50		.61	.43	.56	.02
15.39			.63	.05	1.73	.47	.57	.01
26.09			3.59		.27		.08	.01
16.93			.68		.60	1.16	.33	.01
7.31			1.90		.81	.46		.01
7.00			2.18		2.60	.74		
11.45	.16		7.55		5.14	1.97		.01
5.47	.04		19.12		.65	.03		
4.60	6.68		12.15		.16	.12		
1.97	2.82	.02	8.18		.15	.16		
1.39	1.96		9.53		.25	.20		
.83	.59		10.43		.28	.12		
2.40	1.70		19.77	.03	.39	.27		
6.14	.45		5.12	.24	1.03	.66		
3.88	.39	.06	13.21	.21	2.02	3.43		
4.39	1.26		11.53		.36	1.77		
13.46	3.42		4.45		7.20	1.08	.06	
6.43	4.25	.03	.74		6.09	.11		
3.25	2.28		.42	.02	2.16	.02		

abundantly during this year. These three taxa were not collected in significant numbers in 1983. Unlike *K. taurocephala,* each of *K. longispina, Asplanchna* sp. and *K. quadrata* were collected over much of the year from June-December in high and variable concentrations. Rotifer concentrations were again low in 1983, especially concentrations of *K. taurocephala* whose mid-summer abundance was between 2 and 3 orders of magnitude less than for the same time period in 1981 and 1982. *Keratella cochlearis* was the only species of rotifer collected in greater concentrations in 1983 than any other year, due primarily to increased concentrations on one sampling date in July. Overall, however, more species of rotifers were collected in 1983 than in 1981.

Cladocera

Four species of Cladocera were collected. The most numerous was *Bosmina longirostris,* followed by *Daphnia ambigua* and *Diaphanosoma brachyurum.* The larger and predacious *Leptodora kindtii* was collected on two sampling dates in 1982.

B. longirostris was most abundant during the summer of 1981. This species decreased dramatically in abundance from mid-September, 1981, to late June, 1982, but subsequently *B. longirostris* was collected on every successive sampling date. *D. ambigua* was collected in all three years, with the greatest concentrations observed during summers and autumns. *D. brachyurum* was not collected in 1981 until after August following liming. It was commonly collected during the spring and summer of 1982, and was absent again from November 1982 until July 1983. During 1983 it was rarely collected.

Copepoda

Four species of copepods were collected. *Tropocyclops prasinus* and *Epischura nordenskioldi* occurred infrequently overall and not at all in 1981. *Diaptomus minutus* and *Mesocyclops edax* were collected throughout the three years. *D. minutus* was the most commonly occurring crustacean collected overall and was most abundant in 1982. Copepod nauplii, which were not identified to species, were also abundant in the lake in all three years and were usually numerous in all samples.

M. edax, by contrast to *D. minutus* was much more numerous during 1983 than other years, and was virtually absent from the lake during 1981. Copepod nauplii were numerous in all years, with summer concentration maxima and late autumn concentration minima.

Discussion

Liming of Sandy Lake in July and August of 1981 resulted in a significant immediate increase in pH of almost 2 pH units. The increase was temporary, however, as the short retention time of the lake basin (0.34 yr) quickly flushed away the supply of available base and the lake returned near to its pre-liming pH by January — February of 1982. The pH of the lake subsequently remained higher than the 1981 pre-liming conditions during the spring and summer of each of 1982 and 1983, although lower than the pH immediately following the application of lime. Concurrent changes, occurring either coincidentally due to random population fluctuations or directly due to liming, were also observed in the zooplankton community of Sandy Lake. These changes included the appearance in samples collected subsequent to liming of species that had not been found in the lake previously; and substantial increases or decreases in concentration in succeeding years of other species that had been collected prior to liming.

Prior to liming in 1981, the zooplankton of Sandy Lake was dominated by *K. taurocephala, B. longirostris* and *D. minutus.* These species, in particular the first one, have been considered by other authors to be characteristic in eastern Canada of acidified conditions, due in part to a preference for acidic waters (Siegfried et al. 1984) and in part to decreased competition from other species and predation pressure from fish (Carter et al. 1986). At least one of them was usually the dominant taxa observed in other Nova Scotian lake surveys (Strong 1987; Blouin et al. 1984, Carter et al. 1986).

Immediately following liming, *B. longirostris* disappeared from the lake and was not collected again until the spring of 1982 when lake pH had fallen. *K. taurocephala* was collected in samples in 1982 in concentrations similar to those of 1981, but was almost completely absent from the lake during 1983. *D. minutus* continued to be collected in all three years, but not as abundantly in 1983. Reduction in concentrations of these latter two species in the second year following liming suggest that perhaps these species were being limited by competition from other species occupying similar niches that were reestablishing in the lake following the onset of more favourable conditions. The immediate loss of *B. longirostris,* however, seems more likely due to intolerable conditions in the lake caused by liming.

Other species were found only in samples collected subsequent to liming. The most notable of these included the rotifers *Asplanchna* sp. and *K. longispina* which were found only during 1982. Hultberg and Andersson (1982) indicated that, in Sweden, limed lakes still contained many of the same species that had previously existed in the lake, but the addition of new species such as *Asplanchna priodonta* also occurred. Carter et al. (1986) showed that the distribution of *A. priodonta,* as well as *K. cochlearis* and *K. longispina,* was significantly related to a factor that was associated with (increased) pH. It may not be coincidental, therefore, that *Asplanchan* sp., *K. longispina* and *K. cochlearis* occurred and were most abundant in the year immediately following liming.

Two factors contributed to the increase of the pH of Sandy Lake. The first, the actual liming, had a major and immediate effect on water chemistry but was transient in nature. A smaller but longer lasting effect occurred due to an unexpected increase in the pH of one of the two inflowing streams; this effect presumably extended until the end of this study. Changes in the planktonic community of Sandy Lake may be due to either or both of these factors, either through direct consequence of increased or decreased suitability of the water chemistry, or as an indirect effect due to increased or decreased competition for resources mediated by direct effects. Also possible, and likely contributing at least some of the observed annual variation in species occurrence, is random interannual variation typical of small bodies of water. In this study it was not possible to resolve the contribution to the variation in species abundances caused by each of these components. However, evidence suggests that the increased pH of Sandy Lake from late 1981 to the end of 1983 is reflected by predictable variations in the zooplankton community.

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