NATURAL CHANGES IN THE PLANKTONIC ROTIFERA OF A SMALL ACID LAKE NEAR SUDBURY, ONTARIO FOLLOWING WATER QUALITY IMPROVEMENTS

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ABSTRACT. Swan Lake is a small, acidic, metal-contaminated lake located near Sudbury, Ontario. During the past 8 yr, the lake has experienced a substantial increase in pH, together with significant reductions in the concentrations of heavy metals and base cations. These changes were observed only after acid and metal emissions from Sudbury area smelters were reduced. The composition of the planktonic Rotifera in the lake has changed concurrent with improvements in water chemistry. Dominance of the rotifer community by the acidophile Keratella taurocephala has been sharply reduced in recent years, while significant increases in the densities of Polyarthra spp., Chromogaster ovalis, Conochiloides natans and Trichocerca similis have been observed.

1. INTRODUCTION

A large number of studies have documented the deleterious impact of acidification on aquatic ecosystems. In Ontario, synoptic (Sprules, 1975; Keller and Pitblado, 1984) and experimental (Schindler et al., 1985) investigations have revealed extensive modifications of zooplankton communities concurrent with lake acidification. However, most studies to date have been confined to examining acidification effects on macrozooplankton communities. Since rotifers often contribute significantly to zooplankton production (Makarewicz and Likens, 1979) and abundance (Roff and Kwiatkowski, 1977) and since species abundances are often affected by pH (see review in Pennak, 1978), rotifers are of particular interest to studies attempting to assess acidification-induced changes in zooplankton communities.

In the Sudbury, Ontario region many lakes have been acidic for decades owing to emissions from large-scale smelting operations. However, Sudbury SO_2 and metal emission levels have decreased dramatically since 1972 (Keller and Pitblado, 1986), due primarily to the implementation of emission abatement equipment and a general reduction in smelting activities. Some lakes in the region have already responded

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chemically to the decreased inputs of acid and metals (Hutchinson and Havas, 1986; Keller and Pitblado, 1986).

While the biological responses of acidic Sudbury area lakes to experimental liming are known (Yan and Dillon, 1984; Hamilton *et al.*, 1985), natural responses of lakes following improvements in water quality have not yet been described. In this study we attempt to characterize the chemical and biological responses which have occurred since 1977 in Swan Lake, located near Sudbury. Emphasis is placed on changes which have occurred in the planktonic rotifer community. Rotifers have previously been demonstrated to comprise an important component of the Swan Lake zooplankton (Yan and Geiling, 1985).

2. MATERIALS AND METHODS

Swan Lake is located 15 km southwest of Sudbury. The lake has an area of 5.78 ha, a volume of 1.62 $m^3 * 10^5$ and a maximum depth of 8.8 m (MOE, 1982). Whole lake water samples for chemical analyses were collected from a central station on a twice monthly basis during the ice-free season, and were volume-weighted according to lake morphometry. Chemical analyses were conducted following the methods described by Ontario Ministry of the Environment (MOE, 1981).

Planktonic rotifer samples were collected bi-weekly in 1977, 1982, 1983 and 1984 with a 34 L Schindler-Patalas trap. The trap was outfitted with 76 um mesh Nitex netting in 1977, and 35 um netting during other years. Samples were collected from June through September at depths of 1, 4 and 7 m. All samples were enumerated using a 1 ml Sedgewick-Rafter cell, except 1983 samples which were counted using sedimentation tubes. Median rotifer densities were derived from monthly mean values, which were calculated from mean depth densities. Rotifer biomass was calculated assuming dry weight to represent 7% of wet weight. Dry weight data are summarized in MacIsaac (1986).

Parametric and non-parametric (Kruskal-Wallis) one-way analysis of variance (ANOVA) tests were performed on chemical parameters and rotifer species densities respectively, to determine the significance of differences between years.

3. RESULTS

The water chemistry of Swan Lake has changed considerably since 1977, concurrent with the observed reductions in emissions from Sudbury area smelters. For example, mean lake pH has risen from 4.0 in 1977 to 5.1 in 1984 (Table I; also see: Dillon *et al.*, 1986). The greatest changes in pH were observed between 1977 and 1982, although mean values have continued to rise slowly.

The concentration of sulphate in the lake decreased significantly ($P < 0.001$) from 583 ueq L^{-1} in 1977 to 182 ueq L^{-1} in 1984 (Table I). A dramatic reduction was also observed in the conductivity of the lake ($P < 0.001$); Table I). Similarly, significant decreases in concentration occurred between 1977 and 1984 for Cu, Ni, Al, Mn, Zn ($P < 0.001$; Table I), Ca, Mg, K and Na. The decrease in concentrations of heavy metals were of greater magnitude than those observed for the base cations.

Decreases in concentrations of Cu, Ni and Al were especially great.

In addition to dramatic chemical changes, both lake transparency and color have changed significantly ($P < 0.05$; Table I). Secchi disc transparency values decreased from 6.7 m in 1977 to 4.1 m in 1984. Lake color increased from 8.1 to 16.5 Hazen units between 1982 and 1984.

Table I.
Selected chemical characteristics of Swan Lake between 1977 and 1984.

Parameter	Year							
	1977		1982		1983		1984	
	$\overline{X} + SD$	n	$\overline{X} + SD$	n	$\overline{X} + SD$	n	$\overline{X} + SD$	n
pH	4.0 (3.8-4.1) *	19	4.8 (4.7-5.0)	12	5.0 (4.7-5.6)	13	5.1 (4.6-5.7)	12
Conductivity (µS./cm)	98 + 4	18	51 + 2	12	46 + 2	13	46 + 2	12
Sulphate (µeq/L)	583 + 17	10	223 + 17	11	202 + 16	13	182 + 16	11
Total Phosphorus (µg/L)	11 + 3	16	10 + 5	11	12 + 8	13	11 + 4	11
Colour (Hazen)	–	–	8.1 + 4.5	11	6.0 + 4.9	13	16.5 + 8.5	11
Secchi Disc (m)	6.7 + 1.3	18	4.5 + 0.4	12	5.3 + 0.9	13	4.1 + 0.8	12
Cu (µg/L)	64 + 12	17	17 + 6	11	12 + 5	13	9 + 3	11
Ni (µg/L)	301 + 30	18	82 + 11	11	80 + 12	13	58 + 22	11
Zn (µg/L)	36 + 5	17	17 + 12	11	11 + 3	13	12 + 11	11
Al (µg/L)	289 + 51	11	76 + 17	11	67 + 38	13	47 + 17	11
Mn (µg/L)	213 + 10	11	116 + 6	11	100 + 3	13	99 + 3	11

* range given for pH

The composition of the planktonic rotifer community in Swan Lake has changed significantly since 1977, when it was dominated by two species. During 1977, K. taurocephala had a median density of 250.0 individuals L^{-1} and comprised 94.3% of the total rotifer abundance (Table II), and 59.5% of the biomass (Table III). A large species of Synchaeta had a 1977 median density of 12.6 individuals L^{-1} (Table II) and contributed an additional 4.8% and 39.0% to community abundance and biomass (Table III), respectively. Thus, K. taurocephala and Synchaeta together accounted for greater than 98% of both rotifer abundance and biomass during 1977. In contrast, K. taurocephala had median densities of 140.0, 62.0 and 68.7 individuals L^{-1} in 1982, 1983 and 1984, respectively (Table II). These densities correspond to 52.0%, 11.0% and 31.2% of the total rotifer abundances for those years (Table II), and only 33.4%, 5.8% and 16.8% of the biomass (Table III). However, since the within-year variability in species density was great, the overall density differences between years were not significantly ($P > 0.05$) different for K. taurocephala. Similarly, the density of Synchaeta did not differ significantly ($P > 0.05$) between study years, although a general decline appears to have occurred since 1977 (Table II).

Densities of Polyarthra (P. remata and P. vulgaris), C. natans, T. similis and C. ovalis differed significantly ($P < 0.05$ or less) between 1977 and 1984. Each species was very rare in 1977, although by 1984 they accounted for 55.8% of the total rotifer density (Table II) and 55.6% of community biomass (Table III). The increase in importance of Polyarthra

Table II.

Median density and % of total abundance for planktonic rotifers in Swan Lake between 1977 and 1984.

	1977 Median Density (ind./L)	1977 % Total Abundance	1982 Median Density (ind./L)	1982 % Total Abundance	1983 Median Density (ind./L)	1983 % Total Abundance	1984 Median Density (ind./L)	1984 % Total Abundance
Keratella taurocephala	250.0	94.3	140.0	52.0	62.0	11.0	68.7	31.2
Polyarthra spp.	<0.1	<0.1	87.0	32.3	345.5	61.5	81.9	37.1
Synchaeta spp.	12.6	4.8	7.8	2.9	22.2	4.0	5.5	2.5
Trichocerca similis	<0.1	<0.1	5.1	1.9	107.3	19.1	10.2	4.6
Conochiloides natans	<0.1	<0.1	<0.1	<0.1	13.6	2.4	30.3	13.7
Chromogaster ovalis	<0.1	<0.1	1.3	0.5	7.7	1.4	1.0	0.4
other rotifers	2.4	0.8	27.9	10.4	3.6	0.6	23.0	10.5

between 1977 and 1982 was especially great, and corresponded to the greatest changes in lake chemistry. T. similis also increased substantially between 1977 and 1982, although another large increase was observed in 1983 (Table II). In contrast, C. natans and C. ovalis did not show demonstrable increases in density until 1983.

Other species which have increased in abundance since the lake's chemistry has 'improved' include Gastropus stylifer, Keratella crassa and Pleosoma truncatum.

Table III.

Median biomass and % of total biomass for planktonic rotifers in Swan Lake between 1977 and 1984.

	1977 Median Biomass (µg/L)	1977 % Total Biomass	1982 Median Biomass (µg/L)	1982 % Total Biomass	1983 Median Biomass (µg/L)	1983 % Total Biomass	1984 Median Biomass (µg/L)	1984 % Total Biomass
Keratella taurocephala	5.00	59.5	2.8	33.4	1.2	5.8	1.4	16.8
Polyarthra spp.	<0.1	<0.1	3.0	35.3	11.8	55.0	2.8	34.5
Synchaeta spp.	3.3	39.0	2.0	24.3	5.8	27.1	1.4	17.7
Trichocerca similis	<0.1	<0.1	<0.1	1.0	1.6	7.5	0.2	1.8
Conochiloides natans	<0.1	<0.1	<0.1	<0.1	0.7	3.3	1.6	19.4
Chromogaster ovalis	<0.1	<0.1	<0.1	0.2	0.1	0.7	<0.1	0.2
other rotifers	.0.1	1.4	0.6	5.7	0.2	0.6	0.7	9.1

4. DISCUSSION

Acidic deposition and heavy metal contamination have impacted both terrestrial (Freedman and Hutchinson, 1980) and aquatic (Keller and Pitblado, 1984, and the references cited therein) ecosystems in the Sudbury region. Swan Lake has been strongly affected, likely because it is underlain with Precambrian Shield bedrock, lies along a prevailing wind direction from Sudbury, and is in close proximity to the Sudbury smelters.

However, recent reductions in the input of acid and metals into the lake have been manifested as significant improvements in water quality. Such changes have also been demonstrated for other lakes in the Sudbury area (Hutchinson and Havas, 1986; Keller and Pitblado, 1986). Thus, the observed natural response of Swan Lake is part of a more general chemical recovery of Sudbury area lakes.

The community composition of the planktonic Rotifera in Swan Lake has also changed significantly since 1977. In particular, the relative contributions of *K. taurocephala* and *Polyarthra* have changed dramatically. Three hypotheses may be constructed to account for the decline of *K. taurocephala*. First, the observed differences do not reflect actual density differences between years, but rather reflect differences in the sampling protocols between the study years. Second, seasonal and annual variation in rotifer species abundance is often striking (Nauwerck, 1978; Makarewicz and Likens, 1979), and may be sufficient to account for the observed pattern. Third, *K. taurocephala* is a species highly adapted for living in acidic waters, but it is virtually excluded from high pH waters either due to physiological intolerance or species interactions.

The first hypothesis may be tested by considering the density of *K. taurocephala* for the years 1977 and 1982 (Table II). The median density of the species in 1977 was 250.0 individuals L^{-1} when collected with a 76 um mesh Schindler-Patalas trap, and 140.0 individuals L^{-1} in 1982 when collected with a 35 um mesh Schindler-Patalas trap. Yan and Geiling (1985) estimated that a 76 um mesh trap would under-estimate *K. taurocephala* densities by a factor of two. Thus, even if its densities were under-estimated in 1977, *K. taurocephala* densities were still much greater than in years when finer grades of net were used. Thus, the data in Table II do not support the first hypothesis. However, the marked increases in abundance of *C. ovalis*, *Polyarthra*, *C. natans* and *T.similis* indicates that enumeration procedures may have affected some 1983 densities. This problem does not detract from the overall results of the study, however, as it is not sufficient to explain the shift in community importance from *K. taurocephala* to *Polyarthra*.

The second hypothesis appears untenable on the grounds that the density of *K. taurocephala* in a nearby acidic lake (Clearwater), has remained very stable during the periods of 1976-1978 (Yan and Miller, 1984) and 1981-1985 (Yan, 1986). In each year, the species has accounted for more than 90% of the total abundance.

Evidence has accrued in the literature which provides limited support for the third hypothesis. A number of studies (Siegfried *et al.*, 1984; Carter *et al.*, 1986; MacIsaac, 1986) have demonstrated a preference by *K.*

taurocephala for acidic waters. Indeed, McCormick et al. (1985) reported that the species displayed extensive acid tolerance in field bioassays, while Chengalath and Koste (1983) described the species as an acidobiont. Thus, although the species appears highly adapted to acidic waters, it should be emphasized that the reason(s) for the decline in abundance of K. taurocephala with increasing pH in this study is not clear.

Hamilton et al. (1985) found that after an acidified Ontario lake was neutralized with calcite, K. taurocephala was replaced by Polyarthra and a number of other species, an observation which coincides with the natural changes which have occurred in Swan Lake. Moreover, a survey of 47 Ontario lakes of varying acidity revealed that members of the genus Polyarthra were present only in lakes of pH greater than 4.65 (MacIsaac, 1986), hence the virtual absence of Polyarthra in Swan Lake during 1977 was not unexpected. Similarly, the occurrence of Synchaeta in Swan Lake during 1977 was not surprising, as members of the genus have been recorded in other highly acidic Sudbury area lakes (MOE, 1982).

Conochiloides natans was very rare in Swan Lake while the lake was highly acidic, but has increased since 1983 (Table II). This observation accords with its geographic distribution in other Sudbury area lakes (MacIsaac, 1986). Furthermore, the species demonstrated a distinct preference for cool hypolimnetic waters (Keller, 1986), agreeing with its classification as a cold stenotherm (Stemberger 1979).

In summary, the changes which have occurred in the planktonic Rotifera in Swan Lake are likely the result of many interacting factors. Certainly pH is a contributing factor; however, caution should be exercised in over-emphasizing pH alone, since it is difficult, if not impossible, to separate its effects from changes in food resources, crustacean competitors, invertebrate predators and direct metal effects. It appears likely, however, that the decrease in SO_2 and metal emissions from Sudbury smelters initiated both the chemical and biological changes.

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