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The effects of low pH on planktonic communities. Case history of a small forest pond in eastern Finland

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The pH of a small (0.13 ha), natural forest pond in eastern Finland decreased from > 6.0 to 4.0 during a dry summer. The cause of the acidification is unknown, but may have been localized groundwater acidification due to oxidation of sulfide compounds in the soil. The species composition and biomass of the phyto- and zooplankton during this period are reported and compared to those of a larger, connected pond, located ca. 20 m away, which retained its normal pH (> 6.0). The acidic pond had lower values for the species richness of phytoplankton, the mean chlorophyll *a* content (7.0 vs 10.4 μg/l) and the mean phytoplankton biomass (372 vs 928 mg/m^3). The lower biomass was probably partly due to the lower nutrient content of the acidic pond. In the larger pond, green algae predominated in the phytoplankton (e.g., *Koliella spiculiformis*), whereas the acidic pond supported a virtual monoculture of *Peridinium inconspicuum* (Dinophyceae) in July-August, and *Dinobryon sertularia* (Chrysophyceae) in September. The mean biomass of the zooplankton was also lower in the acidic pond (23.4 vs 53.0 mg/m^3), which was mainly due to the small numbers of Crustacea in late summer, when the pH values were lowest. The low zooplankton biomass was probably caused directly by the low pH or indirectly by a shortage of food.

1. Introduction

The world-wide anthropogenic acidification of freshwater ecosystems is well documented and many of the mechanisms behind the effects on the biota are known (Dillon et al. 1984, Schindler et al. 1985, Schindler 1988). A great deal of information on acidification in Finland has recently been collected into one volume (Kauppi et al. 1990).

Here, I wish to present the case of the dramatic, but apparently natural, acidification (to pH 4.0) of a small forest pond in eastern Finland. The acidified pond was connected by a short ditch to a larger pond, which retained its normal pH (> 6.0) during the study period. I shall report the effects of the acidification on the phyto- and zooplankton abundances and community structure and compare patterns between the acidic pond and the unaffected main pond. Data on the sedi-

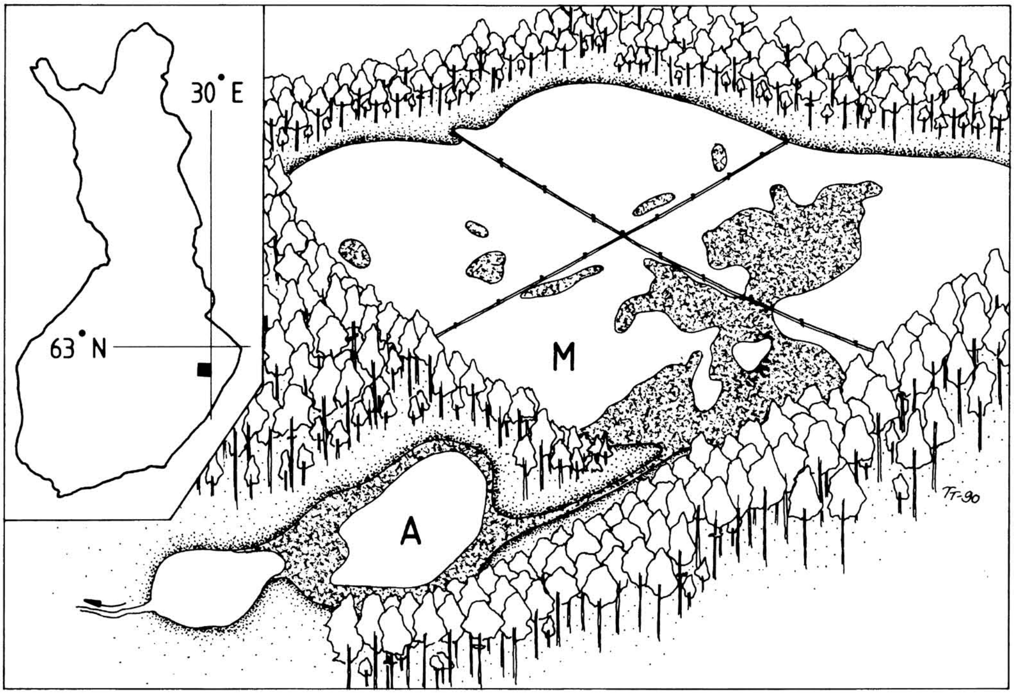

Fig. 1. The location and outline of the pond. M denote the closest section of the divided main pond and A the acidic side pond. Floating-leaved macrophyte vegetation is shown by shading.

ment chemistry and fish ecophysiology in these ponds are given in Holopainen & Oikari (1991).

2. Study area

Hermanninlampi, an oligotrophic, natural forest pond, is situated in the Karelian schist area in eastern Finland (62°41′N, 29°41′E) ca. 10 km north-west of the city of Joensuu. The pond was formed 130 years ago in a flat-bottomed sandy depression in a glaciofluvial plain, when human activity caused a decrease of 9.5 m in the water level of the large Lake Höytiäinen. In the pond bottom, below the transgressive littoral sand, is a layer of strongly humified peat representing an ancient mire (Hyvärinen & Alhonen 1970, Vesajoki 1980). The pond is surrounded by pine forest, the margins consisting of a narrow paludified zone with grass, sedges and *Sphagnum* (Fig. 1). The main pond has a surface area of 1.5 ha and a maximum depth of 1.6 m (for description see Holopainen & Pitkänen 1985, Holopainen et al. 1989). It is normally ice-covered from late October to early May. Because of winter anoxia, the only fish species present in this pond is the crucian carp (Piironen & Holopainen 1988). For experimental purposes, the main pond was divided into four sections (Fig. 1) by plastic fences in the summer of 1985.

The main pond has no clear inlets, but drains from section C to a side pond (here called the acidic pond) via a 20 m ditch through a mire (Table 2). The acidic pond has a maximum depth of 1.0 m and is partly overgrown by sedge and *Sphagnum* inshore and by *Sparganium sp.* offshore. The data presented for the main pond refer to the section connected to the acidic pond, unless otherwise mentioned.

In the main pond, the populations of the crucian carp, the only fish present, were manipulated in May–June 1986 (Holopainen et al. 1991a, Tonn et al. 1991). After treatment with rotenone in May 1985, the section connected to the side pond was stocked with 785 crucian carp (mean total length 7.3 cm), resulting in a fish density of 0.24 ind./m^2. In autumn, its fish density was estimated to be 0.7 ind./m^2, due to the large number of young-of-the-year fish produced in this section.

In early June 1986, all fish (1007 individuals) were removed from the acidic pond by trapping and replaced with 422 fish (mean total length = 8.2 ± 0.4 cm), which gave a density of 0.32 adult fish per m^2. The density of young-of-the-year fish was not known, but was assumed to be low.

3. Material and methods

Background data for the fish studies, on chlorophyll *a*, phytoplankton and zooplankton, were obtained by collecting samples from the acidic pond and all four experimental sections in the main pond at 2–3-week intervals (six samples altogether) over the summer of 1986. Water quality was analysed on samples from the surface layer by standard methods in the Water Laboratory of the Karelian Institute, University of Joensuu; the chlorophyll *a* and phytoplankton samples were collected with a 0.5-m tube sampler as mixed samples of three lifts from the 0–0.5 m water column. Phytoplankton was preserved with Lugol's solution in the field and later with formaldehyde, and identified and counted by inverted microscopy (Utermöhl technique). The biovolumes were mainly calculated after Naulapää (1972). The zooplankton was sampled similarly with a 0.5-m tube sampler (total volume of three lifts 10.6 l), sieved through a 55-µm net and preserved with formaldehyde. The biomass values are based on carbon weights collected from the literature (e.g., Latja & Salonen 1978, Salonen & Latja 1988) and calculated with the computer program of Viljanen & Alm (1985).

To test for differences between the two ponds in the plankton species numbers and biomasses during the summer, I used Wilcoxon's matched pairs signed ranks test in the SPSS program package at the University of Joensuu.

4. Results

Summer 1986 was dry and warm, and the ditch connecting the acidic pond with the main pond was dry from mid-summer to late autumn. The water levels and volumes in both ponds were lower than normal. The pH of the main pond stayed between 6.6 and 6.1 during the study period (27 May 1986 – 3 March 1987).

When first measured on 7 July, the pH in the smaller acidic pond was already much lower than in the main pond; two months later it had decreased down to pH 4.0 (Table 1) and it remained low (pH 4.5) through late October. During the winter the pH increased to 6.6.

The decrease in pH was followed by a pronounced clearing of the water in August. At this

Table 1. Water quality in the acidic pond (A) and the adjacent section (M) of the main pond in 1986 and January 1987.

	7 July		9 Sept.		29 Sept.		26 Jan.	
	A	M	A	M	A	M	A	M
Temperature, °C	19	19	–	9.5	4.0	4.6	1.5	0.7
Oxygen, mg/l	4.8	8.1	8.2	9.3	10.7	11.7	0.0	10.1
Conductance, mS/m	3.1	3.1	1.0	3.5	6.6	4.9	14.5	4.3
Gran alk., µmol/l	–	–	–	–	–46.5	58.4	–	–
pH	5.2	6.6	4.0	6.1	4.4	6.4	6.6	6.1
Colour, Pt mg/l	80	80	5	40	15	25	500	80
COD_{Mn}, O_2 mg/l	11.0	11.0	1.7	8.2	3.3	7.0	34.0	9.5
Total N, µg/l	621	522	155	394	510	405	1180	445
Total P, µg/l	28	29	14	43	9	12	51	8
Cl, mg/l	1.6	1.4	1.4	1.5	1.5	1.3	–	–
Total Fe, µg/l	1890	1828	320	276	217	722	39	892
Mn, µg/l	36	7	–	–	4	24	150	27
Na+K+Ca+Mg, mg/l	3.5	4.7	7.8	5.6	5.9	4.4	6.8	7.2
Total Al, µg/l	–	–	–	–	198	3	685	43

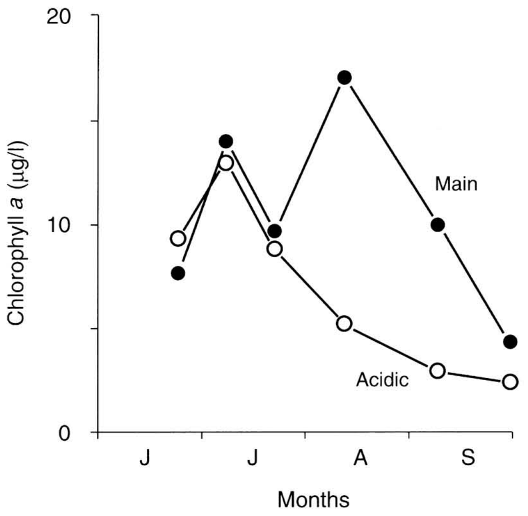

Fig. 2. The dynamics of the chlorophyll *a* concentration in 1986 in the main and in the acidic pond.

time the acidic pond was also characterised by lower conductivity, COD_{Mn} and nutrient levels (Table 1).

4.1. Phytoplankton

The mean phytoplankton biomass (July–October) was much lower (372 mg/m^3) in the acidic pond than in the main pond (928 mg/m^3, Table 2.), the difference was greatest from August onwards. In the main pond the chlorophyll *a* content showed two peaks (early July and mid-August); the first peak also appeared in the acidic pond, but the second, larger peak was absent (Fig. 2).

Species richness was higher in the main than in the acidic pond (Table 2). The number of taxa in the main pond increased from 21 in late June to a maximum of 50 in mid-August; 33 species were still present in mid-September. In the acidic pond, the number of taxa decreased steadily from 25 in early July to 6 in mid-September.

The phytoplankton community in the main pond was clearly dominated by green algae, Chlorophyceae made up 67 % of the mean open water biomass (consisting mainly of *Koliella spiculiformis* and *Cosmarium* spp.), followed by Dinophyceae (12 %, *Gymnodinium* spp., Peridinae), Chrysophyceae (12 %, Chrysomonadinae), Diatomophyceae (7 %, *Synedra* sp., *Tabellaria fenestrata*) and Cryptophyceae (2 %, *Cryptomonas* spp.).

In the acidic pond, the mean open water biomass consisted mainly of Dinophyceae (57 %) and Chrysophyceae (28 %); the rest being Cryptophyceae (7 %), Chlorophyceae (5 %) and Diatomophyceae (2 %). Except for a minor peak of *Cryptomonas* sp. in late July, the phytoplankton community in the acidic pond consisted primarily of two species: *Peridinium inconspicuum* formed a major peak in July-August, and *Dinobryon sertularia* in September (Fig. 3). Other taxa

Table 2. Mean values of phytoplankton, chlorophyll *a* and zooplankton in the main and acidic pond, for late summer and autumn (8 July – 6 October 1986, n = 5–6). Results of Wilcoxon's paired tests (z and p) are given. *P < 0.05.

		Main	Acidic	z	p
Pond area, m^2		3273	1300	–	–
volume, m^3		2473	700	–	–
Phytoplankton					
biomass (mg/m^3)		928	372	–2.02	0.043*
number of taxa		35	15	–1.83	0.068
chlorophyll *a* (µg/l)		10.4	7.0	–2.02	0.043*
Zooplankton					
biomass (mg/m^3)	total	53.0	23.4	–2.20	0.028*
	Crustacea	46.2	18.8	–2.02	0.043*
	Rotifera	6.9	4.6	–0.94	0.345
number of taxa	total	13.0	10.4	–0.944	0.345
	Crustacea	5.0	3.6	–1.079	0.281
	Rotifera	8.0	6.9	–1.048	0.295

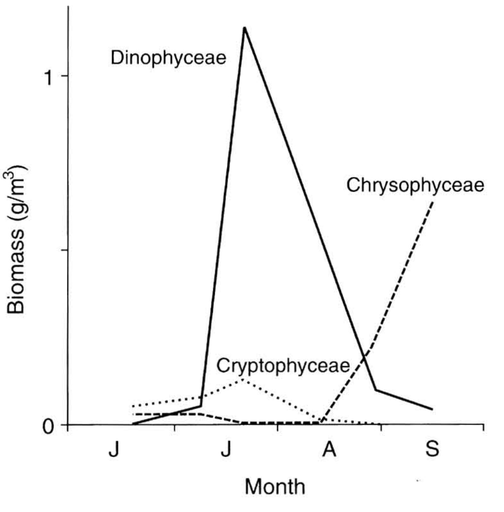

Fig. 3. The dynamics of the biomass of various phytoplankton taxa in the acidic pond. The Cryptophyceae consisted of small and medium *Cryptomonas* spp. only; the Dinophyceae peak was *Peridinium inconspicuum*, and the Chrysophyceae consisted solely of *Dinobryon sertularia*.

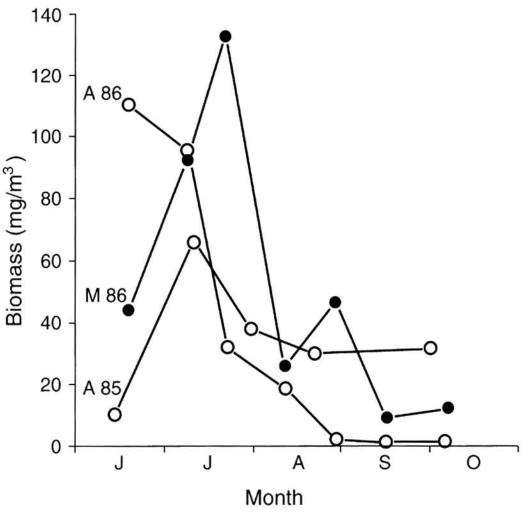

Fig. 4. The dynamics of the zooplankton biomass in the acidic pond (A) in 1985 and 1986 and in the nearest section of the main pond (M) in 1986.

having a mean biomass > 1 mg/m^3 during the period of lowest pH in late August-September, were (in order of decreasing importance): *Gymnodinium* spp. (very small size), *Peridinae* (small), *Asterionella ralfsii*, *Cryptomonas* sp. (medium), *Tabellaria fenestrata*, *Closterium limneticum*, *C. acutum*, and *Staurastrum brachiatum*.

4.2. Zooplankton

The late-summer mean biomass in the acidic pond (23.4 mg/m^3) was much lower than in both the adjacent (53.0 mg/m^3, Table 2.) and the other main pond sections (mean 57.8, range 31–92 mg/m^3). This was mainly due to a biomass minimum during the most acidic period, in late August and September (Fig. 4). In the previous year (1985), before acidification, the smaller side pond had a higher biomass (41.1 mg/m^3); the main pond was not sampled in 1985 because of the rotenone treatment in May.

The zooplankton species richness was equal in the main pond and the acidic pond until July. In early August, copepods began to disappear from the acidic pond and by October no Crustacea were present. Slightly fewer rotifer taxa were present in the acidic pond than in the adjacent section of the main pond (Table 2), but the number was well within the range (6.3–9.2) of the other sections of the main pond.

In the main pond, the dominant Crustacea from June to October were *Eudiaptomus spp.* (two species, *E. gracilis* and *E. graciloides* were present but not routinely separated) and *Bosmina longirostris*. Other abundant species, from June to early August, were *Heterocope appendiculata* and *Diaphanosoma brachyurum*.

In the acidic pond, *D. brachyurum* and *Eudiaptomus* spp. (*E.gracilis/ graciloides*) were most abundant and predominated over *Bosmina longirostris* and *Heterocope appendiculata* in June and July. On 11 August only small numbers of *Bosmina* and *Eudiaptomus* were found. On 28 August and 15 September, the only Crustacea present were, respectively, *Chydorus sphaericus* and *Bosmina longirostris*. On 6 October, the zooplankton consisted solely of Rotifera.

The proportion of Rotifera in the late-summer biomass was 20 % in the acidic pond and 13 % in section C; in the other sections of the main pond it varied between 8 % and 34 %.

In mid-May the dominant Rotifera in both the main and acidic pond were *Keratella hiemalis* (57 % of numbers), *Synchaeta* spp. (26 %) and *Keratella serrulata* (10 %).

From June to October, the dominant Rotifera in the main pond were *Collotheca* spp. (60 % of numbers). From June to August, the next most abundant was *Conochilus unicornis* (35 %) but in September–October it was replaced by *Keratella hiemalis* (10 %) and *Synchaeta* spp. (4 %).

In the acidic pond, *Polyarthra vulgaris* (80 %) predominated from June to late August. The species present in numbers > 1/l during the most acidic period in September–October were *Keratella hiemalis* (27 %), *Collotheca* spp. (19 %), *Polyarthra vulgaris* (18 %), *Trichocerca porcellus* (18 %), *Synchaeta* spp.(7 %) and *Rotaria* spp (5 %).

In the previous year, 1985, the dominant rotifer in the acidic pond (which was not rotenoned but divided from the main pond by a turf dam) was also *P. vulgaris*.

On 30 September 1985, the dominant Rotifera in all sections of the main pond (which was rotenoned on 20 May), were *Collotheca* spp. and *Asplanchna priodonta*. The crustaceans present at that time were *Chydorus sphaericus* and copepodid stages of Cyclopoida and Calanoida.

5. Discussion

The reason for the acidification of Hermanninlampi's smaller side pond during the summer of 1986 is not known. One potential cause is localized ground water acidification.

Groundwater acidification at a time of low water-level could be caused by oxidation of soil sulphide compounds producing sulphate ions (Hartikainen & Ylihalla 1986). Sufficient quantities of sulphides could have accumulated by anoxic mineralization of organic S in the soil. These early post-glacial organic deposits are buried under littoral sand deposits formed by the transgressive increase in the water level of Lake Höytiäinen before its artificial lowering (Vesajoki 1980). A similar potential source of acidity is sulphide minerals possibly occurring in the glacially deposited till and gravel in this area of Karelidic schist bedrock.

Cases of abrupt decreases in pH that can be connected with sulphite mobilization at times of low groundwater levels have been observed on a larger scale in some river systems on the Finnish west coast (Alasaarela 1980, Palko et al. 1985).

Atmospheric fallout or anthropogenic acidification could not have been involved, due to the limited area affected. Visual examination of the pond did not show any foreign objects that could have caused the acidification.

Data from other years also show lower pH values in the acidic pond than in the main pond. In the cold and rainy summer of 1987, the pH varied between 5.5 and 5.8 (4 May – 3 August, $n = 5$) in the acidic pond, but between 6.2 and 6.8 (18 May – 9 Sept., $n = 10$) in the main pond (Holopainen, unpubl.). Interestingly, in 1987 the pH values in early May were equally low in the two ponds (5.7–5.8). Compared with that in 1986, the pattern in 1987 is more typical of aerial deposition, with low pH values occurring at the time of the snowmelt in spring.

Whatever the causes of the acidity, the isolation and smaller (by an order of magnitude) water volume of the acidic pond in the dry summer of 1986 probably contributed greatly to the drop in pH to 4.0. Naturally acidic lakes in Northern Karelia normally have pH values > 4.5 (Ilmavirta & Huttunen 1990).

In any case, a reduction in species diversity at different trophic levels is a commonly reported phenomenon in both naturally acidic and anthropogenically acidified fresh waters (e.g. Almer et al. 1974, Sprules 1975, Ilmavirta & Huttunen 1989, Blouin 1989).

5.1. Phytoplankton

The low number of phytoplankton taxa in the acidic pond is similar to the number (ca. 10) given by Almer et al. (1974) for the most acidic Swedish lakes. Although the impoverishment of a phytoplankton community is often followed by a reduction in biomass, the replacement of small species by larger ones may cause an increase in biomass (Findlay & Kasian 1986, Blouin 1989). Consequently, biomass changes are not considered good indicators of acidification. Changes in phytoplankton biomass are often explained by changes in nutrient content and transparency rather than pH (Yan 1979, Kerekes et al. 1990). The phosphorus content of the acidic pond was much lower in early September (Table 1) and probably already in August, which could explain the missing second peak in phytoplankton biomass (Fig. 2).

Dinobryon sertularia appears to be a species very tolerant of lowered pH (Bradt et al. 1986; Findlay & Kasian 1986; Almer et al. 1974). It has not, however, been previously reported as important in acidic lakes in Finland (cf. Kippo-Edlund & Heitto 1990).

Findlay & Kasian (1986) also list *Peridinium inconspicuum* and *Asterionella ralfsii* as good indicators of acidification. *Peridinium inconspicuum* is reported to be the most important single species (by biomass) in acidic, clear water lakes in Canada (Yan 1979), Sweden (Almer et al. 1974, Hörnström 1979, Lyden & Grahn 1985) and Finland (e.g. Ilmavirta et al. 1984, Ilmavirta & Huttunen 1989, 1990, Kippo-Edlund & Heitto 1990, Niinioja et al. 1990).

Gymnodinium spp. are abundant in clear, acidified lakes in Sweden (Almer et al. 1974, Lyden & Grahn 1985) and some species of this genus are considered acidophilic indicators (Schindler et al. 1985).

The seasonal dynamics of *Cryptomonas* sp. and *Peridinium* in the acidic pond paralleled those in the main pond, but the latter species appeared more successful in the acidic pond, possibly because of a competitive advantage over other species less tolerant of low pH. The mechanisms shaping phytoplankton communities in acidic waters are still poorly known (Stokes 1986).

5.2. Zooplankton

Many crustacean and rotifer species are pH-sensitive and disappear in the course of acidification (e.g., Sprules 1975, Sarvala & Halsinaho 1990). Nevertheless, among seven groups of freshwater biota, these two are predicted to be the least affected (Minns et al. 1990).

All Rotifera abundant in the acidic pond were common planktonic species with peak abundances occurring close to pH 7. *Keratella serrulata* is the only species with an exceptionally low pH optimum (peak abundance at pH 5.5, Berzins & Pejler 1987). *Keratella hiemalis* is a cold-stenothermal species common in spring and autumn.

The crustacean communities in both the main and acidic ponds were composed of relatively small species. This could be due to fish predation, since a considerable proportion of the diet of crucian carp consists of planktonic Crustacea (25–75 % on prey weight basis, depending on fish length, Penttinen & Holopainen 1991). In addition to eliminating large-bodied microcrustaceans, the feeding patterns of planktivorous fish often lead to decreased zooplankton density and increased phytoplankton biomass (e.g., Carpenter et al. 1985, Persson et al. 1988, Holopainen et al. 1991b).

However, both zoo- and phytoplankton densities were lower in the acidic pond, even though fish densities were the same or higher in the main pond and the main pond fish were in better condition (Holopainen & Oikari 1991). Impoverishment of the zooplankton community in the acidic pond and its reduced biomass were thus presumably due to the effects of low pH or food shortage rather than predation by fish.

Biotic interactions are often considered more important in shaping the planktonic crustacean community than pH (Sarvala & Halsinaho 1990). All of the important planktonic micro-crustaceans present in the acidic pond were filter-feeders on phytoplankton. The two dominant algal species present at low pH in late summer were probably not good food sources for the relatively small crustaceans. *Dinobryon sertularia* is a large (case length 30–40 μm), colonial form and *Peridinium inconspicuum*, although somewhat smaller (cell length 15–30 μm), has a tough case.

The difference in manipulation — the acidic pond was not subjected to the rotenone treatment in May 1985 — is unlikely to be responsible for the results given above. However, the planktonic communities were certainly affected by poisoning of the main pond, in spite of restocking with large net plankton samples from the side pond in autumn 1985, and some differences in the species composition could be due to this treatment.

Exceptional environmental conditions (e.g. drought) appeared to contribute significantly to the spatially and temporally limited edaphic acidification of the small side pond. Low pH considerably reduced both the phytoplankton species richness and community biomass, either directly, or indirectly through reduced nutrient availability. The reduced phytoplankton biovolume and changes in composition were in turn reflected in reduced zooplankton biomass, especially among micro-crustaceans.

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