BIOLOGICAL RECOVERY OF TWO PREVIOUSLY ACIDIFIED, METAL-CONTAMINATED LAKES NEAR SUDBURY ONTARIO, CANADA.

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Abstract: Studies are reported on two small lakes at Sudbury, Ontario located close to a nickel-copper smelter which closed in 1972. At that stage, Baby Lake had a pH of 4.0-4.2 while the adjacent Alice Lake had a pH 5.9-6.3. Both lakes were almost entirely devoid of algae and had neither zooplankton nor fish. Soon after the closure of the smelter, with its large airborne volume of sulphur dioxide and of copper and nickel containing particulates, the chemistry of the lakes began to change. By 1985, Baby Lake had changed from pH 4.0 to 6.8 and is now at pH 7.2. The pH of Alice Lake increased from a low of 5.9 in the early 1970s to 6.9-7.4 in the mid 1980s and is now at 7.3. Copper and nickel concentrations also decreased in both lakes during this period. The first biota found in the lakes in the post-smelter stage in the early 1980s were benthic red chironomids, planktonic rotifers, and a limited number of phytoplankton species, of which *Rhizosolenia* was the most common. By the 1990s, 13 phytoplankton species were present in each lake, with a substantial zooplankton fauna (14 species) of rotifers, copepods, and cladocerans. There are now numerous insect larvae in the sediment and some small fish in both lakes. The biological recovery, which followed substantial reductions in acidity and in soluble nickel and copper concentrations in the waters, is a slower process than chemical recovery and is initially characterized by the dominance of a few species.

Key Words: recovery, acid lake, smelter, copper, nickel, sulphate, *Rhizosolenia, Cosmarium, Bosmina, Chydorus, Chaoborus,* rotifers

1.0 Introduction

The Sudbury area has been subjected to extremely large discharges from the nickel-copper smelter located around the town, with discharges reaching almost 3 million short tons of sulphur dioxide per year in 1968-71. Large quantities of airborne particulates, containing nickel, copper, cobalt, and other smelter elements, rained down on the watersheds of the area (Hutchinson and Whitby 1974, Freedman and Hutchinson 1980). The forests were destroyed over a large area and massive soil erosion occurred. In the soils that remained, high concentrations of nickel and copper accumulated to phytotoxic levels, while soluble aluminum was also at phytotoxic levels due to extreme soil acidification to pH 3.0 (Whitby and Hutchinson 1974).

Lakes in the vicinity of Sudbury were also severely damaged by excess acidity, from direct SO_2 and sulphate fallout and by watershed drainage. Two such lakes are immediately adjacent to the Coniston smelter, which operated from 1913 to 1972 when it was permanently closed. The most severely affected was Baby Lake (surface area 11.4 hectares), which is a small deep lake in a small watershed with steep rocky slopes of Pre-Cambrian Shield granites. Run-off is directly into the lake. By 1968-72, Baby Lake had a pH of 4.0 and was almost devoid of life. It also had high concentrations of nickel (to 3.2 mg/L) and copper (to 0.8 mg/L). A few algal cells could be filtered from the lake

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(i.e. 10 to 100 L of water were filtered to obtain a few cells). These consisted of nickel or copper tolerant cells of *Chlorella* (Stokes et al. 1973).

The adjacent Alice Lake is much longer (26.7 hectares) but is shallow and has discharge streams entering it. One of these streams runs in from Baby Lake; another stream drains a large area of glacial till in the valley bottom. This stream also receives run-off directly from a slag pile of about 150 acres, which contains residual copper and nickel (see also Woodfine and Havas this volume).

While Alice Lake, even in 1968, was much less acidic than Baby Lake, its concentrations of nickel were higher (up to 7 mg/L) probably due to the drainage from the adjacent slag pile. The waters and sediments of Alice Lake were almost devoid of life in 1968-72 (Stokes, pers. comm.). To obtain a few cells of a highly nickel-tolerant alga, *Chlorella* (Alice Lake isolate not published), up to 100 L of lake water had to be filtered (Hutchinson and Stokes 1975).

Each October from 1968 until 1989, TCH took a fourth year undergraduate class to Sudbury to sample lake water for chemical analysis and for comparative lake bioassays. After the Coniston Smelter closed in 1972 and the 381 m superstack at nearby Copper Cliff was commissioned, the annual sampling and analyses were continued. It became apparent by 1976 that Baby Lake, in particular, was beginning to change chemically. This deep crystal clear small lake responded very quickly to the sharp reduction of SO_2 and heavy metal deposition on to its surface and to its small watershed. Chemical recovery of the two lakes was then followed and reported in Hutchinson and Havas (1986). Biological recovery was expected to occur over time given that the Sudbury smelter emissions of sulphur dioxide created local acidification problems from an exclusive sulphur source and given the limited soil cover in the Baby Lake watershed in particular.

This paper presents our observations of the progress of biological recovery from 1972 to 1994, by which time a relatively thriving community was present in the chemically neutralized lakes even though the composition of this community differed from those of more distance Pre-Cambrian Shield lakes.

2.0 Materials and Methods

The methods of water sampling and chemical analyses were similar to those used by us in 1970s (Stokes et al. 1973, Hutchinson and Havas 1986). We collected an integrated sample (i.e. a column of lake water from the water surface to the lake bottom using a flexible tube) for phytoplankton. These samples were preserved in Lugol's solution, settled, and counted using an inverted microscope. Zooplankton were sampled by horizontal and tows (60 um mesh) and at 1 meter depths from the surface to the sediments with a Schindler-Patalas trap. Intensive sampling was done at intervals of several years during the 22 year post-smelter phase, notably in 1976, 1980-82, 1985-86 and in 1992-94. This allowed only a series of snapshot views of biological changes but enabled us to assess long-term change with limited resources.

3.0 Results and Discussion

The dramatic reductions in SO_2 emissions in the Sudbury area over the past 22 years are shown in Table I. In the Coniston Valley, where the two study lakes are located, the reduction was even more immediate once the local smelter closed. Water quality improved markedly during this period (Table I).

TABLE I

Sulphur dioxide emissions in the Sudbury region and selected water quality parameters for Alice and Baby Lake during a 20 year period beginning in the early 1970s (Brydges 1985). [Cu and Ni in ug L^{-1}]

Period	SO2	Baby Lake			Alice Lake		
	(10^6 t y^{-1})	pH	Cu	Ni	pH	Cu	Ni
early 1970s	2.5	4.0 - 4.2	500 - 800	2700 - 3200	5.9 - 6.3	60 - 250	6400 - 6900
mid 1970s	1.25	4.5 - 4.9	280 - 340	1300-1500	6.2 - 6.5	50 - 60	2000 - 3700
mid 1980s	0.75	6.1 - 6.8	20	200-400	6.9 - 7.4	<10	1200 - 1300
early 1990s	0.4	7.0 - 7.2	20	20	7.1 - 7.3	20	1200

In a detailed assessment of the algae of the two lakes in October 1986, large differences were found between them. Baby Lake had a phytoplankton biomass of 0.079 mg/L and a species richness of 19. This was lower than that of Alice Lake with its biomass of 0.64 mg/L and species richness of 37. It was also much lower than that of other shield lakes of similar pH (6.8). In Baby Lake the Chrysophyceae dominated in 1986, comprising 94% of the cell counts based on cell number. The other two groups represented were Bacillariophyceae 3% and Chlorophyceae 3% (Fig. 1). In Alice Lake the Bacillariophyceae dominated (84%) while the Chrysophyceae represented 15% of cell counts and the Peridineae 1%. While the pHs of the two lakes were almost the same by 1986, several other chemical factors were quite different, notably the higher nickel concentrations in Alice Lake.

Amongst the more common species in Alice Lake in 1986 were *Rhizosolenia eriensis*, with 4200 cells/L; *Dinobryon bavaricum* with 800 cells/L and *Synedra acus* with 180 cells/L. Nine other species occurred at very low numbers. The composition of phytoplankton species changed from season to season and year to year at this stage of apparent re-colonization. Only *Rhizosolenia eriensis* was consistently common during five sample period in 1985-86 in Alice Lake. During this period, July 1985 to October 1986, we recorded 37 species, many only once, with densities of 40 to 50 cells/L. Nevertheless, the 37 species indicate that algae were finding the lake suitable for survival.

In this same sampling period (July 1985 to October 1986) a total of 19 algal species were recorded in Baby Lake with *Dinobryon bavaricum* being the most consistent and common over the five sample times. Its peak occurrence of 5400 cells/L in October 1985 had dropped to 600 cells/L a year later. A summer peak of 1100 cells/L was observed for *Dinobryon acuminatum* in July 1986, while *Chromulina glacialus acuminatus* reached 3600 cells/L in August 1986. Compared with the 1970-72 samplings both phytoplankton diversity and productivity had increased greatly in both lakes.

Deniseger et al. (1986) studied the recovery of Buttle Lake a copper-lead-zinc contaminated lake on Vancouver Island, Canada. They also found a persistent *Rhizosolenia* bloom and asserted this to its ability to tolerate high heavy metal concentrations while out competing other species.

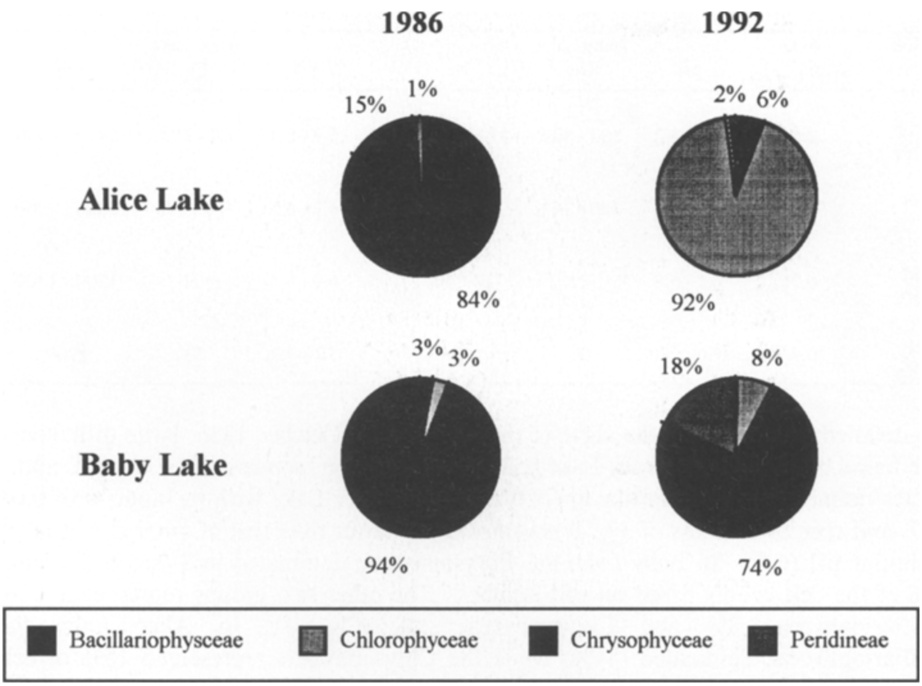

Fig. 1. Phytoplankton composition in Alice and Baby Lake in 1986 and 1992.

When the lakes were re-examined in October 1992, the lower standing crop of Baby Lake compared with Alice Lake, was maintained (i.e. 1200 cells/L compared with 8900 cells/L for Alice). In Alice Lake, *Cosmarium* dominated the system, with 87% of all cells and a count of 7800 cells/L. *Scenedesmus* accounted for 5%, various diatoms for 6%, and the Chrysophyte *Mallomonas* sp. 2%. This is a substantial change in composition. In Baby Lake another chrysophyte, *Kephyrion* sp., accounted for 69% of the total cell count but comprised only 850 cells/L. Other frequent species were of the genera *Peridinium*, *Chlorella*, and *Dinobryon*.

Zooplankton populations also re-established themselves in the lakes. The rotifers were present in significant numbers by the mid 1980s and an acid-tolerant rotifer assemblage was reported by MacIsaac et al. (1986). In 1985-86, rotifers found in Baby Lake included *Keratella taurocephala*, *Lecane tenuisela* and *Monostyle lunaris*, as were *Chydorus sphaericus*, *Bosmina* sp., and *Eubosmina*, along with copepod nauplii and cyclopoid copepods. In Alice Lake at this time, six zooplankton species were found (i.e. the rotifers *Keratella cochleans* var. *cochlearis*, *Polyarthra vulgaris*, and *P. renata* as well as *Bosmina longirostris* and *Chydorus sphaericus* (See Fig. 2 for zooplankton compositional differences).

By 1992-93, seven rotifer species were present in both Alice Lake and Baby Lake and a total zooplankton species richness of 14 in each lake. Baby Lake had made the greatest recovery of species directly between 1986 and 1992 with an increase from 4 to 14 zooplankton species during that time. In an April 1993 vertical sampling tow using a 30 cm diameter plankton net, the common species in Alice Lake were *Polyarthra*, *Mesocyclops*, copepod nauplii, *Kellicottia longispina*, and *Cyclops vernus*, while in Baby Lake the commonest species were copepod nauplii, then *Kellicottia longispina*, *Bosmina longirostris*, *Cyclops vernus*, *Mesocyclops tenuis*, *Keratella limnelais*, *Keratella cochlearis*, and *Diaptomus pygmaeus*.

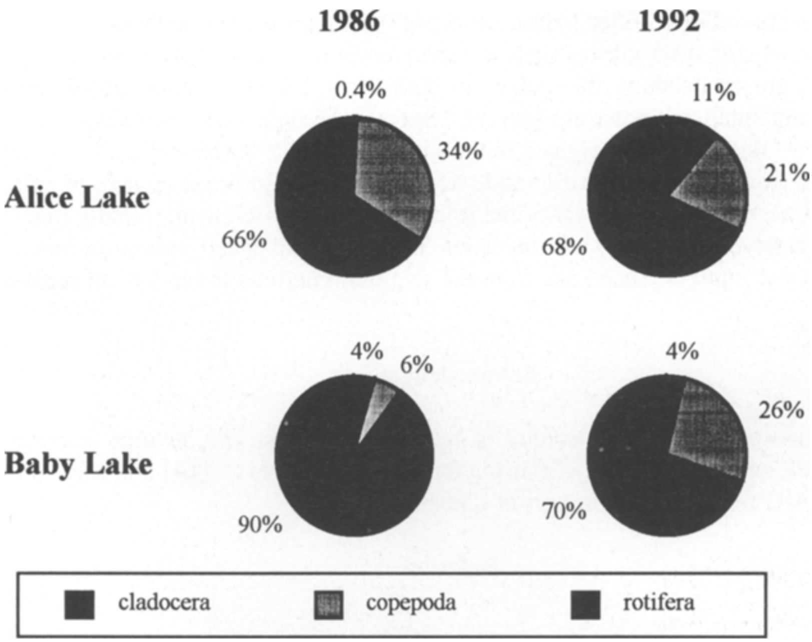

Fig. 2. Zooplankton composition in Alice and Baby Lake in 1986 and 1992.

The phantom midge, *Chaoborus*, known to be both acid and metal tolerant (Havas and Likens 1985), was first found in Alice Lake during a vertical tow in 1993. Very few specimens were found, but after subsequent sampling during the night at various depths a clearer picture of the population began to emerge. This type of sampling is necessary since some *Chaoborus* live in the sediments during the day and move up the water column to feed during the night. The population was well established but was not nearly as large as one might find in unpolluted circumneutral lakes. This species was definitely not in either Baby or Alice Lake in the early 70s, even though it might have been able to tolerate the chemical stress, presumably since its preferred food, zooplankton, were absent. We were unable to find *Chaoborus* in either lake during the mid 1980s, although diurnal sampling was not done at that time. Since *Chaoborus* cannot readily co-exist with fish, as the fish population begins to return, this insect larvae is likely to decrease in importance if not disappear entirely from these lakes.

Zooplankton species, once devoid from Alice and Baby Lake, now resemble assemblages found in acidified to circumneutral Pre-Cambrian Shield lakes.

Finally, aquatic macrophytes such as *Typha latifolia*, *T. angustifolia*, and *Phragmites communis*, are establishing themselves in both lakes, the chironomid populations are thriving, and small minnows are present. Seagulls became summer residents at Alice Lake in 1993 and a loon was sighted in the summer of 1995. Other signs of recovery are the leopard frogs in the cattails alongside Alice Lake and significant number of emergent insects. A clear re-establishment of the trophic web is now following rapidly that of the chemical changes, especially the reduction in acidity and metal concentrations. The residual nickel input to Alice Lake from the slag may continue to hinder full recovery in that lake.

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