Species Composition and Biomass of the Macrophyte Vegetation of one Acidified and two Acid-sensitive Lakes in Ontario

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The composition and biomass of the aquatic macrophyte community of Clearwater Lake, an acidified (pH 4.3), metal-contaminated lake near Sudbury, Ontario were compared with those of two lakes (Harp and Red Chalk) with floras typical of non-acidic oligotrophic lakes in south-central Ontario. Clearwater Lake had far fewer species of macrophytes than the other two lakes, probably because of its high trace metal levels. Average macrophyte biomass, however, was not only much higher in Clearwater Lake than in Harp and Red Chalk Lakes, but exceeded all previous records of biomass for oligotrophic, soft water lakes.

Key Words: Macrophyte biomass, acid lakes, metals, Sudbury.

Field surveys of acidified Precambrian Shield lakes in Scandinavia and in northeastern North America have demonstrated that phytoplankton, zooplankton, benthic macroinvertebrate and fish communities are negatively affected by depression of lake water pH to levels ≤ 5.5 (reviewed by Harvey et al. 1981; Haines 1981; and Dillon et al. 1984, among others). Impacts of acidification on aquatic macrophytes have received comparatively less attention. In Swedish acidified lakes the bryophyte *Sphagnum* often replaces various isoetid species as a community dominant (Grahn 1977; Hultberg and Grahn 1976; Hultberg 1977). In Lake Orvattnet, for example, bottom cover by *Sphagnum* in the 0–2 m depth zone increased from 8% in 1967 to 63% in 1974 while pH levels declined by 0.8 units. Dense monospecific beds of *Sphagnum* have also been observed in acidic (pH 4.9) Colden Lake in the Adirondack Mountains in New York State (Hendrey and Vertucci 1980), but such accumulations do not appear to be characteristic of acidic lakes in North America (Singer et al. 1983; Wile and Miller 1983).

Gorham and Gordon (1963) were the first to indicate that vascular macrophytes might be affected by acidification of Canadian lakes. In a survey of 29 lakes near Sudbury, Ontario, they found that macrophyte species richness increased with distance from Sudbury. They suggested that elevated metal levels rather than the high acidity of lakes near Sudbury were responsible for the poor floras of lakes near the city. In a survey including several acidic lakes at greater distances from Sudbury, Wile and Miller (1983) found floras to be impoverished only in those acidic lakes which also had elevated metal levels. This was consistent with Gorham and Gordon's hypothesis.

While acidification of lakes affects the vertical zonation of macrophyte species (Singer et al. 1983), it is not yet known if changes in total or relative abundance of aquatic macrophytes are to be anticipated in lakes in North America that have acidified. In this report the submersed and floating-leafed flora of an acidified, metal-contaminated lake near Sudbury (Clearwater Lake) is compared with those of Harp and Red Chalk Lakes, two acid-sensitive soft water lakes in the Muskoka District of Ontario. Differences between the lakes are examined to see if acidification and/or contamination with trace metals might influence total macrophyte biomass or the relative abundance of macrophyte species.

Description of the Study Lakes

Extensive hydrological, chemical and planktonic data for the study lakes have been reported elsewhere (e.g. Dillon et al. 1978, 1979). Lake location and selected morphometric parameters are indicated in Table 1. Clearwater Lake is located 13 km south of the copper-nickel smelting complex at Copper Cliff, just west of Sudbury, Ontario. The lake has been acidic (pH < 4.5) for at least two decades (Yan 1979). Levels of several trace metals are greatly elevated (Table 1) as a result of unusually high rates of atmospheric loading (e.g. Cu and Ni: Jeffries and Snyder 1981), or high rates of mobilization of metals (e.g. Al and Mn) from watershed materials (Dillon et al. 1980).

Typical of most Precambrian Shield lakes, the three lakes had low levels of total phosphorus (Table 1). Conductivity and Ca levels in Clearwater Lake were somewhat greater than in the other two lakes because high levels of acid deposition have increased weathering rates of materials in the watershed of the lake (Dillon et al. 1980). While precipitation in the

TABLE 1. Location and selected morphometric and chemical data for the study lakes (from Dillon unpublished data, and Yan and Miller 1984).

Parameter		Harp	Red Chalk	Clearwater
Latitude	(°N)	45°23′	45°11′	45°22′
Longitude	(°W)	79°08′	78°56′	81°03′
Area	(ha)	66.9	56.9	76.5
Mean depth	(m)	12.4	14.2	8.1
Maximum depth	(m)	40	38	22
Secchi transparency	(m)	3.4	6.1	9.7
pH		6.7	6.6	4.4
Conductivity	(u S cm^{-1})	34	29	86
Alkalinity	(ueq L^{-1})	92	95	<0
Total phosphorus	(ug L^{-1})	5	5	4
Calcium	(mg L^{-1})	3	3	6
Sulphate	(mg L^{-1})	9	8	24
Copper	(ug L^{-1})	<2	<2	76
Nickel	(ug L^{-1})	<2	<2	255
Zinc	(ug L^{-1})	7	6	37
Manganese	(ug L^{-1})	12	12	303
Iron	(ug L^{-1})	38	51	57
Aluminum	(ug L^{-1})	56	24	332

watersheds of Harp and Red Chalk Lakes is very acidic (Dillon et al. 1978) and temporary reductions in lake pH have been observed (Jeffries et al. 1979; Scheider et al. 1979), the average pH of the lakes remains circumneutral (Table 1).

Human usage of the three lakes is entirely recreational. There are 36 dwellings on the shores of Clearwater Lake, 83 on Harp Lake and three on Red Chalk Lake. Most are used in the summer only. The watersheds of the lakes are virtually continuously forested.

The greatest biomass of isoetid vegetation (the dominant plants in soft water lakes) is found in waters < 4 m deep (Moeller 1975; Nygaard 1958; Sand-Jensen and Sondergaard 1979). Harp and Red Chalk Lakes have steeply sloping bottoms, consequently only 25% and 21% respectively, of their bottom area is overlain by waters < 4 m deep. Clearwater Lake has several extensive shallow areas with gently sloping bottoms and 33% of its bottom area falls within the 0–4 m depth zone. Hence, Clearwater Lake has a greater area potentially suitable for good growth of isoetid vegetation.

Methods

In May 1978, divers using snorkelling gear or S.C.U.B.A. swam the entire perimeter of Harp, Red Chalk and Clearwater Lakes, and mapped macrophytic vegetation from the shore to the maximum depth of colonization. Samples of all species of submersed and floating-leafed macrophytes (tracheophytes, bryophytes and charaphytes) were collected and subsequently identified using Fasset (1957). The percentage bottom cover of each species was visually estimated.

Biomass was determined on a monthly basis from May through August, 1978 using a destructive harvesting technique. Quadrats (0.25 m^2) were positioned using a stratified random design. The total number of quadrats was distributed equally among areas determined by divers to have similar floras and relative and total cover estimates. The quadrats were positioned randomly within each area. All enclosed plant material including roots was removed from each quadrat. Plants were washed free of sediment and dried at 105°C to a constant weight. Through the season a total of 44 quadrats were collected from 11 sites in Harp Lake and 56 quadrats from 14 sites in each of Red Chalk and Clearwater Lakes.

As visual estimates of bottom cover are subjective, the data were used conservatively to aid in the calculation of plant biomass. A relative frequency histogram of cover estimates in the lakes was constructed. The distribution was bimodal. Therefore, a weighted total plant biomass was generated on each date by summing the products of average biomass in low and high cover zones (less than and greater than 50% cover) with the proportion of the vegetated area of the lake exhibiting low and high cover, respectively.

Results and Discussion

Macrophyte Distribution, Species Composition and Dominance

Macrophytes colonized less than 10% of the total surface areas of Harp and Red Chalk Lakes. Areas of dense growth were generally found adjacent to inflow-

TABLE 2. Species composition and abundance[a] of macrophytes in the study lakes. The abundance ratings, based on the frequency of occurrence at the sampling sites are A (85–100% occurrence), C (50–84% occurrence), 0 (< 50% occurrence) and R (1 occurrence). Average biomass estimates in vegetated zone for the study lakes (± 95% confidence limits) are indicated.

	Harp	Red Chalk	Clearwater
Vascular Plants			
Eleocharis acicularis	O	R	O
Eriocaulon septangulare	A	A	A
Isoetes sp.	C	O	—
Juncus pelocarpus	O	O	O
Lobelia dortmanna	O	C	—
Lycopus sp.	—	—	R
Myriophyllum tenellum	—	O	O
Sparganium angustifolium	R	—	—
Utricularia minor	R	—	—
Utricularia purpurea	—	R	—
Utricularia vulgaris	O	R	—
Utricularia resupinata	—	R	—
Potamogeton natans	R	—	—
Potamogeton epihydrus	R	—	—
Nymphaea odorata	O	O	—
Brasenia schreberi	O	O	—
Pontederia cordata	O	O	—
Stoneworts			
Nitella flexilis	O	—	—
Mosses and Liverworts			
Cladopodiella fluitans	—	—	O
Drepanocladus exannulatus	—	—	C
Fontinalis antipyretica	O	O	—
Sphagnum subsecundum Nees *ex* sturm.	R	—	—
Mnium pseudopunctatum	R	—	—
Eurhynchium riparioides	R	—	—
Total Biomass (g m^{-2} dry wt.)	73.6 ± 16.0	59.2 ± 7.2	326 ± 83.2

[a]Abundance estimates were confirmed in a subsequent survey in 1982.

ing streams. The vegetation was dominated by pipewort, *Eriocaulon septangulare*. In Clearwater Lake, in contrast, macrophytes colonized some 15% of the lake and the nearshore areas were characterized by very dense mats of pipewort.

In all three lakes maximum depth of plant occurrence approximated the Secchi transparency (Table 1). Harp and Red Chalk Lakes supported vegetation to depths of 3 and 4 m, respectively. In Clearwater Lake, scattered patches of the bryophyte *Drepanocladus exannulatus* were observed at depths of 8 m.

Floristically, Harp and Red Chalk Lakes were similar (Table 2). They supported 18 and 13 plant species, respectively, and of these, 10 were common to both lakes. Both the species richness and species composition were comparable to other soft water lakes of Ontario (Miller 1977). In comparison there were only eight plant species in Clearwater Lake.

Without pre-acidification floristic descriptions of Clearwater Lake, it cannot be concluded that species richness decreased in the lake when it acidified and became contaminated with metals. Nevertheless, extensive surveys of lakes in the area indicate that such a reduction has almost certainly occurred. It is probably attributable to high metal levels rather than to low lake water pH (Gorham and Gordon 1963; Wile and Miller 1983).

Although there are floristic differences between Clearwater Lake and the two Muskoka lakes some similarities also existed. The floras of the three lakes were predominantly isoetid in character and each was dominated by *E. septangulare*. There was a general paucity of bryophytes, with only *D. exannulatus* abundant in Clearwater Lake and *Fontinalis antipyretica* in Harp and Red Chalk Lakes. *Sphagnum subsecundum* was found at only one site in Harp Lake. Major perturbations of the flora, such as extensive *Sphagnum* invasions and losses of isoetid vegetation were not apparent in any of the lakes although they have been observed elsewhere (Grahn 1977).

Macrophyte Biomass

There was no trend in macrophyte biomass in any of the lakes over the ice-free season. This is consistent with other investigations (Sand-Jensen and Sondergaard 1979; Moeller 1975). Average macrophyte biomass in Red Chalk and Harp Lakes was similar at 59.2 and 73.6 g m^{-2} of vegetated zone, respectively. A much higher average value of 326 g m^{-2} was calculated for Clearwater Lake (Table 2).

A very wide range of average macrophyte biomass has been recorded for oligotrophic lakes. Lowest values of 0.085 to 0.52 g m^{-2} (dry weight for the vegetated zone) were reported by Wilson (1935 in Hutchinson 1975) for three lakes in Wisconsin. Levels in Mirror Lake in New Hampshire were much higher, at 7.1 g m^{-2} (Moeller 1975). The highest recorded value for an oligotrophic lake is for Lake Kalgaard in Denmark. Sand-Jensen and Sondergaard (1979) reported an average biomass of 188 g ash free dry weight m^{-2} of vegetated zone for the lake, or 221 g m^{-2} assuming a plant ash content of 15% of dry weight (Moeller 1975).

The macrophyte biomasses of Harp and Red Chalk Lakes were within this recorded range for oligotrophic lakes. The biomass of Clearwater Lake was not only much higher than that of the other two study lakes, but it exceeds all previously recorded biomass estimates for oligotrophic lakes. The biomass of Clearwater Lake is actually comparable to the midsummer peak in biomass of the vittate macrophyte communities characteristic of hard water, eutrophic environments (200–400 g m^{-2}: Rickett 1922 and 1924, Carpenter 1979). The exceptionally high biomass in Clearwater Lake is surprising in view of the lake's elevated metal levels and very acidic waters. Obviously, *E. septangulare* and *D. exannulatus* are highly tolerant of such conditions.

The spatial (vertical and horizontal) distribution of biomass and of productivity of primary producers (benthic and planktonic algae and macrophytes) is probably influenced by the acidification of lakes. The great clarity of acidic lakes allows for the development of subthermocline production maxima of phytoplankton (Schindler 1980; Yan and Miller 1984) and may explain the successful invasion of profundal sediments by vascular macrophytes (Singer et al. 1983). Shifts in relative abundance of primary producers from the pelagic to the littoral are indicated by frequent reports of dense accumulations of benthic algae in the littoral zone of acidified lakes both with and without elevated levels of trace metals (Stokes 1981). This report presents the first indication that the biomass of aquatic macrophytes may also be much greater in the littoral zone of an acidified, metal-contaminated lake than in circumneutral lakes of similar nutrient status. Whether this observation is applicable to acid or acid and metal contaminated lakes in general must await the results of additional surveys.

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Literature Cited

Carpenter, S. R. 1979. Invasion and decline of *Myriophyllum spicatum* in a eutrophic Wisconsin lake. Pp. 1–32 *in* Proceedings of Conference on Aquatic Plants, Lake Management, and Ecosystem Consequences of Lake Harvesting, Madison, Wisconsin. February 14–16.

Dillon, P. J., D. S. Jeffries, W. Snyder, R. Reid, N. D. Yan, D. Evans, J. Moss, and **W. A. Scheider.** 1978. Acid precipitation in south-central Ontario: recent observations. Journal Fisheries Research Board of Canada 35: 809–815.

Dillon, P. J., N. D. Yan, W. A. Scheider, and **N. Conroy.** 1979. Acidic lakes in Ontario, Canada: Characterization, extent and responses to base and nutrient additions. Archiv fur Hydrobiologie Beiheft Ergebnisse der Limnologie 13: 317–336.

Dillon, P. J., D. S. Jerries, W. A. Scheider, and **N. D. Yan.** 1980. Some aspects of acidification in southern Ontario. Pp. 212–213 *in* Ecological impact of acid precipitation. *Edited by* D. Drablos and A. Tollan. SNSF project, Oslo, Norway.

Dillon, P. J., N. D. Yan, and **H. H. Harvey.** 1984. Acidic deposition: effects on aquatic ecosystems. CRC Critical Reviews in Environmental Control 13: 167–194.

Fasset, N. C. 1957. A manual of aquatic plants. With revised appendix by E. C. Ogden. University of Wisconsin Press. 405 pp.

Gorham, E., and **A. G. Gordon.** 1963. Some effects of smelter polution upon aquatic vegetation near Sudbury, Ontario. Canadian Journal Botany 41: 371–378.

Grahn, O. 1977. Macrophyte succession in Swedish lakes caused by deposition of airborne acid substances. Water, Air and Soil Pollution 7: 295–306.

Haines, T. 1981. Acidic precipitation and its consequences for aquatic ecosystems: a review. Transactions of the American Fisheries Society 110: 669–707.

Harvey, H. H., R. C. Pierce, P. J. Dillon, J. P. Kramer, and **D. M. Whelpdale.** 1981. Acidification in the Canadian aquatic environment. Publication NRCC 18475, Environmental Secretariat, National Research Council of Canada. 369 pp.

Hendrey, G. R., and **F. Vertucci.** 1980. Benthic plant communities in acidic Lake Colden, New York: Sphagnum and the algal mat. Pp 314–315 *in* Ecological Impact of Acid Precipitation. *Edited by* D. Drabløs and A. Tollan. SNSF project, Oslo, Norway.

Hultberg, H. 1977. Thermally stratified acid water in late winter — A key factor inducing self-accelerating processes which increase acidification. Water, Air and Soil Pollution 7: 279–294.

Hultberg, H., and **O. Grahn.** 1976. Effects of acid precipitation on macrophytes in oligotrophic Swedish lakes. Journal of Great Lakes Research 2: 208–217.

Hutchinson, G. E. 1975. A Treatise on Limnology III.

Limnological Botany. Wiley-Interscience, New York. 660 pp.

Jeffries, D. S., C. M. Cox, and **P. J. Dillon.** 1979. Depression of pH in lakes and streams in central Ontario during snowmelt. Journal of the Fisheries Research Board of Canada 36: 640–646.

Jeffries, D. S., and **W. R. Snyder.** 1981. Atmospheric deposition of heavy metals in central Ontario. Water, Air and Soil Pollution 15: 127–152.

Miller, G. 1977. A classification of Ontario lakes based on their submersed and floating macrophyte flora. M.Sc. thesis, University of Guelph, Guelph, Ontario. 97 pp.

Moeller, R. E. 1975. Hydrophyte biomass and community structure in a small, oligotrophic New Hampshire lake. Verhandlungen Internationale Vereinigung Limnologie 19: 1004–1012.

Nygaard, G. 1958. On the productivity of the bottom vegetation in Lake Grane Langso. Verhandlungen Internationale Vereinigung Limnologie 13: 144–155.

Rickett, H. W. 1922. A quantitative study of the larger aquatic plants of Lake Mendota. Transactions of the Wisconsin Academy Arts, Sciences and Letters 20: 501–527.

Rickett, H. W. 1924. A quantitative study of the larger aquatic plants of Green Lake, Wisconsin. Transactions of the Wisconsin Academy Arts, Sciences and Letters 21: 381–414.

Sand-Jensen, K., and **M. Sondergaard.** 1979. Distribution and quantitative development of aquatic macrophytes in relation to sediment characteristics in oligotrophic Lake Kalgaard, Denmark. Freshwater Biology 9: 1–11.

Scheider, W. A., W. R. Snyder, and **B. Clark.** 1979. Deposition of nutrients and major ions by precipitation in south-central Ontario. Water, Air and Soil Pollution 12: 171–185.

Schindler, D. W. 1980. Experimental acidification of a whole lake: a test of the oligotrophication hypothesis. Pp. 370–374 *in* Ecological Impact of acid precipitation. *Edited by* D. Drabløs and A. Tollan. SNSF project, Oslo, Norway.

Singer, R., D. A. Roberts, and **C. W. Boylen.** 1983. The macrophytic community of an acidic lake in Adirondack (New York, U.S.A.): a new depth record for aquatic angiosperms. Aquatic Botany 16: 49–57.

Stokes, P. M. 1981. Benthic algal communities in acidic lakes. Pp. 119–138 *in* Effects of acid rain on benthos. *Edited by* R. Singer. North American Benthological Society, Colgate University.

Wile, I., and **G. Miller.** 1983. The macrophyte flora of 46 acidified and acid-sensitive soft water lakes in Ontario. Ontario Ministry of the Environment Report. 35 pp.

Yan, N. D. 1979. Phytoplankton community of an acidified, heavy metal-contaminated lake near Sudbury, Ontario: 1973–1977. Water, Air and Soil Pollution 11: 43–55.

Yan, N. D., and **G. E. Miller.** 1984. Effects of deposition of acids and metals on chemistry and biology of lakes near Sudbury, Ontario. Pp. 243–282 *in* Environmental Impacts of Smelters. *Edited by* J. Nriagu. John Wiley and Sons, Inc.

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