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Gastropods from Small Northeastern Ontario Lakes: Their Value as Indicators of Acidification

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Gastropoda were sampled in 15 small lakes covering pH 5.0-7.5 northeast of Sudbury, Ontario. Twelve species were found among nine lakes with pH>6.0. The most widespread was a freshwater limpet, *Ferrissia* sp., which was the only one occurring in those lakes with pH 5.2-6.0. In less intensively sampled lakes in the area, other species were recorded between pH 5.5 and 6.0. In lakes with pH>6.0, there was no evidence of a relationship between the total number of gastropods, dominated by *Helisoma anceps* and *Physella gyrina*, and pH, alkalinity, or calcium ion concentration. However, the $\log_e$ total number of gastropods was significantly correlated with total phosphorous concentrations ($r=0.72$, $n=9$, $p<0.05$). Above minimum pH thresholds, gastropod densities in small oligotrophic lakes appear to be limited by food resources, and not by calcium concentrations or alkalinity.

Key Words: Gastropoda, lakes, northern Ontario, indicator, acidity, calcium, phosphorous.

Gastropoda are among the most acid-sensitive groups of freshwater organisms (Eilers et al. 1984). In an extensive survey of Norwegian lakes, Økland (1983) found that gastropods were absent from that country's acidified lakes. Many studies have related gastropod abundance or species richness to calcium ion concentrations or alkalinity, in Canada (McKillop and Harrison 1972; McKillop 1985) and elsewhere (Boycott 1936; Macan 1950; Aho 1966, 1978; Williams 1970; Dussart 1976). Because the acidification process involves a loss of alkalinity prior to a pH decline (Henriksen 1982), it might be expected that the disappearance of gastropods would be a reliable early warning indicator of acidification (Raddum and Fjellheim 1984; Mills and Schindler 1986). However, some studies have suggested that gastropods are more likely to be affected by differences in food resources than by calcium ion concentrations or alkalinity (Reavell 1980; Dillon and Benfield 1982).

In previous studies (Bendell and McNicol 1987; McNicol and Wayland 1992), we sampled the invertebrate communities of many small oligotrophic lakes as part of a project investigating the effects of acidic precipitation on waterfowl and their foods. That sampling did not accurately reflect the species distribution and composition of the gastropod community. As gastropods are a potentially important source of calcium for breeding waterfowl, we undertook a small but intensive sampling program to better document their distributions and relative abundances in headwater lakes. We also assessed their value as an indicator of the acidification of small calcium-poor lakes, typical of those used by breeding waterfowl in northern Ontario.

Methods

Invertebrates were sampled in small lakes in an area 40 to 70 km northeast of Sudbury, Ontario (see Table 1). The area is described in detail by McNicol et al. (1987). Lakes in the area occur over a wide range of pH, and include those acidified by sulphur dioxide deposition from the sulphide ore smelting operations near Sudbury, and by the long-range transport of airborne pollutants (Jeffries 1984; McNicol et al. 1987).

Twenty small (1.9–7.8 ha) headwater lakes were chosen for intensive sampling of aquatic insects that are important waterfowl food. They were chosen to include lakes with and without fish, because fish predation may have a significant impact on waterfowl foods (Bendell and McNicol 1987) including snails (Merrick et al. 1991). Benthic samples were taken from those lakes twice in 1985, between 19 June and 7 July, and between 23 July and 2 August. On each occasion, samples were taken at 10 randomly selected sites in water < 1.0 m deep. A layer of substrate 0.5 m long by 0.29 m wide was removed with a D-

TABLE 1. Water chemistry and distribution of gastropod species in visually searched lakes, scored 1-10 for the number of sites in which they were found, or B if found in benthic samples only. Lakes are ranked by pH values (summer 1985). Ca^{2+} (mg/L) and alkalinity (μeq/L) values are averages of fall 1984 and 1986 values. * indicates a fishless lake.

Lake	247*	299*	920*	005	905	409	333	016*	199*	527	197	410	922*	530*	404
Latitude	46° 54’	46° 58’	46° 51’	46° 48’	46° 51’	46° 57’	46° 55’	46° 53’	46° 52’	46° 59’	46° 51’	46° 58’	46° 57’	46° 59’	46° 56’
Longitude	80° 50’	80° 52’	80° 49’	80° 51’	80° 52’	80° 35’	80° 46’	80° 49’	80° 47’	80° 39’	80° 47’	80° 37’	80° 51’	80° 38’	80° 38’
pH	7.5	7.3	7.2	7.1	6.8	6.8	6.7	6.5	6.1	5.8	5.6	5.4	5.3	5.2	5.1
Ca^{2+}	7.0	8.9	6.2	6.8	4.8	7.8	3.9	3.5	4.1	1.9	4.2	2.9	2.9	3.0	2.2
alkalinity	389	648	210	322	100	227	143	92	69	9	0	7	0	6	0
Valvatidae															
Valvata lewisi morph *ontariensis* F. C. Baker		B													
Lymnaeidae															
Fossaria parva (Lea)		3													
Pseudosuccinea columella (Say)		1						8	2						
Bulimnea megasoma (Say)				1											
Physidae															
Physella gyrina (Say)	10	10	5		5		10	2	10						
Planorbidae															
Gyraulus deflectus (Say)		2	B	2					2						
Gyraulus parvus (Say)					7										
Promenetus exacuous (Say)	4	2		1											
Helisoma anceps (Menke)	4			1	4	3	10	6							
Planorbella campanulata (Say)				1											
Planorbella trivolvis (Say)	2	2				1									
Ancylidae															
Ferrissia sp.	7	7	7	1	9	2	3	8	B		6			4	

framed net, and sieved through 1 mm^2 screens. Macroinvertebrates, including gastropods, were removed and later identified and counted. This sampling procedure was also followed in a separate study, conducted in the same area in the summers of 1988 and 1989 (McNicol and Wayland 1992), which provided further information on pH tolerances of certain gastropod species. Between June and mid-July, ten benthic samples were collected once from eight additional lakes with pH under 5.0, 12 with pH 5.0–5.5, and 10 with pH between 5.5 and 6.0.

We found that benthic sampling did not effectively sample gastropods occurring at low densities in small oligotrophic lakes. Other studies have sampled gastropods in submerged vegetation (McKillop and Harrison 1972; McKillop 1985; Pip 1987). However, there was little submerged aquatic vegetation in our study lakes, and gastropods were often associated with woody detritus. Therefore, a more intense survey was undertaken between 20 August and 2 September, 1985. Those lakes chosen for further study were 15 of the 20 previously sampled lakes with pH>5.0. We had no realistic expectation of finding gastropods in the most highly acidic lakes. Ten 5 m sections of shoreline were randomly selected around each lake. The substrate, detritus and vegetation in the littoral zone in each sector, to a depth of 0.5 m, were visually searched by two persons until it was judged that all gastropods had been found and removed, or until 0.5 hr had passed.

The pH of surface water was determined using a portable pH meter during July 1985. In November 1984 and October 1986, surface water samples were taken for more complete chemical analysis, including pH, alkalinity, major ions, and nutrients, following procedures outlined by McNicol et al. (1987). Statistical analyses were performed using average values of fall determinations of alkalinity, total phosphorous, and calcium ion (Ca^{2+}) concentrations.

Species nomenclature follows Burch (1982). The study lakes are unnamed and are referenced here by number.

Results

Eleven species of pulmonate gastropods were found among 11 of 15 lakes sampled with the visual search technique (Table 1). A single prosobranch, *Valvata lewisi*, was the only species found solely in benthic samples from those lakes.

Using the visual search technique, 39 occurrences of species in lakes were recorded (Table 1). Benthic sampling was less effective, as only 21 occurrences of species in lakes were scored from benthic samples, of which three were not found by the visual technique. Benthic sampling commonly found *Helisoma anceps* and *Gyraulus deflectus*, but often failed to find *Physella gyrina*, a species more likely to be found by sweeping vegetation. However, neither technique adequately recorded the most widespread gastropod found in visual searches of the study lakes, a fresh-water limpet, *Ferrissia* sp.

A total of 1519 gastropods were collected by visual searches. Almost half (49%) were from lake 333, where high densities of gastropods, especially *Helisoma anceps*, made it impossible to collect all individuals in a site within the 0.5 hr sampling period. Therefore, more gastropods probably occurred in that lake than in all others combined. Lake 333 had Ca^{2+} levels lower than in most lakes with gastropods (Table 1), but had the highest total phosphorous concentrations (Figure 1).

Overall, gastropod densities were low. The average number of gastropods found in visual searches of lakes with pH>6.0, other than lake 333, was only 1.7 per metre of shoreline.

Between three and eight species of gastropods occurred in each of nine lakes with pH>6.0, and always included *Ferrissia*. It was the only gastropod occurring below pH 6.0, where it occurred in two of six lakes. Other species which characterized the gastropod fauna were the tadpole snail, *Physella gyrina*, and the ramshorn snail, *Helisoma anceps*. At least one of them occurred on each lake above pH 6.0, and together they comprised 71% of all gastropods collected by visual searches.

The number of gastropod species in visual searches increased from 3.6 per lake in five lakes between pH 6.0 and 7.0, to 5.5 per lake in four lakes with pH>7.0; but those differences were not significant ($p>0.05$, Mann-Whitney test). In lakes with pH>6.0, the $\log_e$-transformed number of gastropods per lake in visual searches was not significantly correlated ($p>0.10$) with pH ($r=0.22$), or the related chemical variables, Ca^{2+} concentration ($r=0.45$) and alkalinity ($r=0.12$). However, there was a significant correlation between mean total phosphorous concentrations and the $\log_e$-number of gastropods in visual searches ($r=0.73$, $n=9$, $p<0.05$) (Figure 1). Among lakes with pH>6.0, four lakes with fish did not differ from five without fish (Table 1), in either the number of gastropods found (t-test, $\log_e$-transformed data, $t=0.44$, $p>0.10$), or species composition.

Gastropods were not found in any benthic samples from 13 lakes with pH<5.0. In benthic samples taken in 1988-1989 from 12 lakes with pH 5.0–5.5, only *Ferrissia* was found at pH 5.5. In contrast, gastropods were found in benthic samples from six of ten lakes with pH between 5.5 and 6.0. *Amnicola limosa* was found in four of those lakes, *Gyraulus deflectus* in three, and *Ferrissia* in one. *Physella gyrina* was taken by sweep net sampling at pH 5.8.

Discussion

Intense visual searches of 15 small headwater lakes showed that gastropod distribution was limited by acidity below pH 6.0. Above pH 6.0, gastropod numbers were positively correlated with total phosphorous concentrations, which suggested a relationship to food resources.

Total phosphorous is the most important indicator of lake nutrient status and productivity, and is the most important limiting factor for the growth of algae, especially in oligotrophic lakes (Wetzel 1983). Algae and detritus were found to be the most important food items of British gastropods, and eutrophic detritus was better for growth than oligotrophic detritus (Reavell 1980). In general, gastropods have been observed to be more abundant and to have greater species richness in eutrophic compared to oligotrophic lakes (Russell-Hunter 1978). However, studies that have related gastropod abundance and diversity to water chemistry have not measured total phosphorous (Macan 1950; Aho 1966, 1978; Williams 1970; Dussart 1976; Økland 1983). North American gastropod studies (McKillop and Harrison 1972; McKillop 1985; Pip 1987; Jokinen 1991) have compared among study sites on and off the Precambrian shield and along a gradient in Ca^{2+} concentrations and alkalinity, and probably productivity, but have also not measured total phosphorous.

Økland (1983) sampled gastropods in about 1000 Norwegian lakes, including many that had become acidified, and found the greatest decline in abundance and species richness occurred below pH 6.0. In the Sudbury area and the Adirondack Mountains (Jokinen 1991), the minimum pH at which many species can be found is between pH 5.5 and 6.0. In south-central Ontario, recruitment failure of *Amnicola limosa* occurred when lake pH fell below 5.8 (Shaw and Mackie 1989).

Low pH is associated with low calcium ion concentrations, and Økland (1983) believed that either could explain the absence of gastropods. Aho (1966, 1978) and Økland (1983) found significant correlations between the diversity and abundance of gastropods, and Ca^{2+} concentration; but only among lakes with Ca^{2+} concentrations < 7.0 mg/l, which reflects the inclusion of acidic and very calcium-poor lakes in their data. However, Shaw and Mackie (1990) found that the minimum Ca^{2+} concentration for the development of *Amnicola limosa* was < 1.1 mg/l, which is lower than in most acidified lakes. Several common Ontario species have been recorded at Ca^{2+} concentrations between 2.0 and 3.0 mg/l (Rooke and Mackie 1984). In the Sudbury area, gastropods were often absent at such concentrations, and their absence was solely explained by low pH.

Macan (1950) presented statistically unanalysed data on gastropod abundances in water bodies that were similar in size to our Wanapitei study lakes, and also covered a similar range of Ca^{2+} concentration and alkalinity. Regrettably, Macan (1950) does not provide pH values. Gastropods were present in all water bodies, except those where Ca^{2+} concentrations was <3.0 mg/l. A correlation analysis of Macan's data showed no evidence of relationships between the $\log_e$-number of gastropods caught per hour in 1946 and the mean Ca^{2+} concentration ($r=0.05$) or mean alkalinity ($r=0.17$) of each water body where gastropods occurred ($n=33$, $p>0.10$). In contrast, McKillop and Harrison (1972), Dussart (1976), and McKillop (1985) covered a greater range of Ca^{2+} concentrations, including non-acidic soft waters and hard waters with Ca^{2+} concentrations > 40.0 mg/l, and found significant relationships between Ca^{2+} concentrations and gastropod species diversity or abundance. Dillon and Benfield (1982) found that the abundance of pulmonate snails, including *Helisoma anceps* and *Physella* spp., in streams was positively correlated with alkalinity, which they suggested was positively related to food resources for pulmonates.

The distributions of gastropod species suggest that they tolerate a wide range of chemical conditions (Aho et al. 1981). In Ontario, McKillop and Harrison (1972) found 14 species among nine hard-water stations (Ca^{2+} >40 mg/l), but twelve of those also occurred among seven soft-water stations (Ca^{2+} <5 mg/l). Similarly, in Manitoba, McKillop (1985) found 16 species among 11 hard-water stations (Ca^{2+} >40 mg/l), and 13 of those also occurred among six soft-water stations (Ca^{2+} <10 mg/l). Few species are likely to be found uniquely associated with hard waters.

Bendell and McNicol (1991) also sampled leeches in the Sudbury area, including lakes visually searched for gastropods. Leeches and gastropods shared a similar distribution and abundance with respect to lake pH. All lakes above critical pH values supported several species of both groups, which disappeared below critical values over a narrow range of pH. In both groups, the most widespread species in non-acidic lakes were the species that occurred at the lowest pH, and there was no evidence of a relationship between abundance and lake pH, where pH was above critical values.

Our data suggest that the response of gastropods and leeches to acidification is poorly described by a dose-response model which assumes proportional declines in populations for each decline in pH. The figures of Eilers et al. (1984) [reproduced in Mills and Schindler 1986] suggest a steady decline in species numbers over a broad range of pH. However, a better model is provided by assuming minimal pH thresholds above which populations do not respond to changes in pH, but below which they disappear over a narrow range of pH. Models predicting declines in species richness from declines in pH were developed by Schindler et al. (1989) and

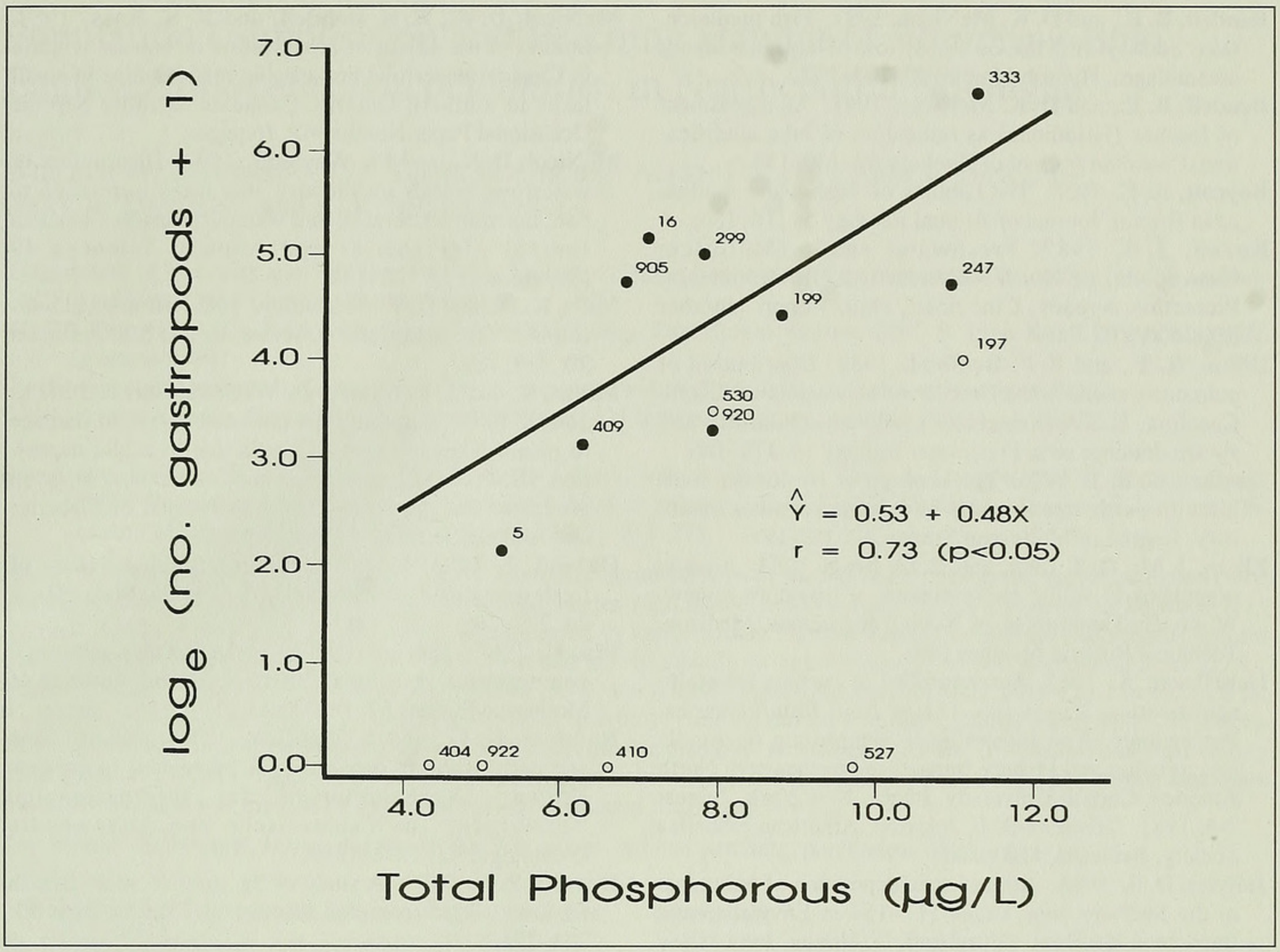

Figure 1. Log$_e$-transformed number of gastropods found in visual searches versus mean total phosphorous concentrations (μg/l). The linear regression is calculated for lakes with pH > 6.0, indicated by solid circles. Lakes with pH < 6.0 are represented by open circles, and had no gastropods or only *Ferrissia*. Numbers beside points refer to lake numbers.

Minns et al. (1990), based on Eilers et al.'s (1984) data, but they may overestimate the loss of species as pH declines from 7.0 to 6.0, and underestimate losses due to declines from pH 6.0 to 5.0.

Although gastropods are among the most acid-sensitive organisms, they are affected at pH values similar to those that affect certain fish species (Mills and Schindler 1986; Matuszek et al. 1990). The evidence presented here suggests that gastropods of small headwater lakes will not respond directly to changes in alkalinity or Ca^{2+} concentrations, and that monitoring gastropods will not provide an early warning of acidification above pH 6.0, and before other sensitive organisms are affected. Gastropod densities are low in most Precambrian shield lakes. Species are often missed in sampling programs, and may be more difficult to monitor than other acid-sensitive groups. Our data suggest that low densities of gastropods in small non-acidic oligotrophic lakes are better accounted for by low nutrients and food resources than by low alkalinity or Ca^{2+} concentrations.

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