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Comparative Effects of Sediment and Water Contamination on Benthic Invertebrates in Four Lakes

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Animals inhabiting the pelagic regions of polluted lakes are subject to only one source of contamination, the surrounding water. Because this is a relatively simple situation between organism and environment, there has been considerable progress in determining the effects of pollutants on the plankton under both field and laboratory conditions. However, benthic invertebrate communities are often exposed to two sources of contamination, the substrate and the overlying water. This may create an interaction among pollutants and consequently, there have been few attempts to determine the impacts of both polluted water and sediments on benthic invertebrates. In this investigation the concentrations of heavy metals in the sediments and waters of four lakes situated in the Canadian subarctic were determined from May 1977 to May 1978 and were correlated with differences in the species composition, diversity and density of the benthic communities. The data were also used to assess the value of indicator species as measures of water pollution.

MATERIALS AND METHODS

Collections were made in a series of shallow eutrophic lakes and in a small bay located on the north shore of Great Slave Lake at Lat. 62°24'N, Long. 114°23'W (Fig. 1). The uppermost lake on the system, Meg Lake, receives wastes from a gold mine (see below). The lake has an area of 0.1 km^2, a maximum depth of 1.5 m and discharges into Keg Lake, which is up to 2.5 m deep, with an area of 0.35 m^2. Peg Lake lies 0.8 km downstream of Keg Lake, and has an area of 0.10 km^2 and a maximum depth of 2.0 m. The terminus of the system is a bay which is 0.8 km long, 0.15 km wide and 0.5 - 0.7 m deep. Bottom deposits in all of the lakes under investigation consist of sediments with a few rocks. Although macrophytes are generally absent from Meg and Keg Lakes, most of the bottom of Peg Lake and the bay on Great Slave Lake is covered with *Chara*, *Potamogeton* and other taxa during the summer.

There is one operating gold mine (Con Mine) situated immediately upstream of Meg Lake. Liquid wastes are piped into an impoundment where solids settle to the bottom. The water fraction is periodically decanted into Meg Lake during the summer resulting in variable metal levels in the waters of the lake system.

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Water for chemical analysis was collected at a depth of 0.1 - 0.2 m every 2 weeks from May to September 1977 and at one month intervals during the winter (Fig. 1). Since Meg Lake froze completely to bottom, water was not collected during the winter. Preservation and analysis methods were conducted as outlined in LIVELY (1974). Sediments for chemical analysis were collected from several stations on each lake during August 1977 (Fig. 1). The upper 5 cm of bottom material was taken using a coring tube lined with plastic. In the laboratory, the samples were digested in perchloric and hydroflouric acids and the concentrations of copper, lead and zinc determined by plasma emission spectrometry. In addition, mercury levels were measured by flameless atomic absorption spectrometry and arsenic by hydride generation followed by colourimetric determination with silver diethyldithiocarbamate.

The zoobenthos was collected at 2 week intervals during the summer using a 15 x 15 x 23 cm Eckman dredge. In the laboratory, the benthos was sorted using screens with 0.25 mm openings. Although all species of molluscs, amphipods and oligochaetes were retained on the mesh, many of the earlier instars of chironomid larvae passed through the screen. Therefore, population estimates are restricted to fourth instar larvae.

RESULTS

Sediment and Water Quality: The concentration of arsenic in the sediments of Meg Lake was high, averaging 540 mg/kg (Table 1). Although arsenic levels in Keg Lake were statistically similar ($p<0.05$, "t" test) to those in Meg Lake, there was a significant reduction in concentrations in Peg Lake, where they averaged 76 mg/kg. At the terminus of the effluent discharge on Great Slave Lake, arsenic averaged 12 mg/kg. Copper followed roughly a similar trend, ranging from 480 to 540 mg/kg in the two upstream lakes and 82 to 102 mg/kg in the downstream areas.

TABLE 1

Average and range in concentrations (dry weight) of metals in the sediments of the study lakes.

	Meg	Keg	Peg	Great Slave
Arsenic (mg/kg)	539	349	76	12
	(10-1400)	(24-1400)	(42-105)	(3-40)
Mercury (µg/kg)	132	47	80	53
	(24-433)	(13-120)	(28-194)	(11-151)
Copper (mg/kg)	477	544	106	82
	(35-1210)	(38-1730)	(33-152)	(45-150)
Lead (mg/kg)	11	8	8	14
	(5-30)	(5-10)	(5-10)	(5-20)
Zinc (mg/kg)	112	252	185	129
	(71-216)	(93-420)	(72-410)	(96-211)

Although the levels of lead were low and consistent throughout

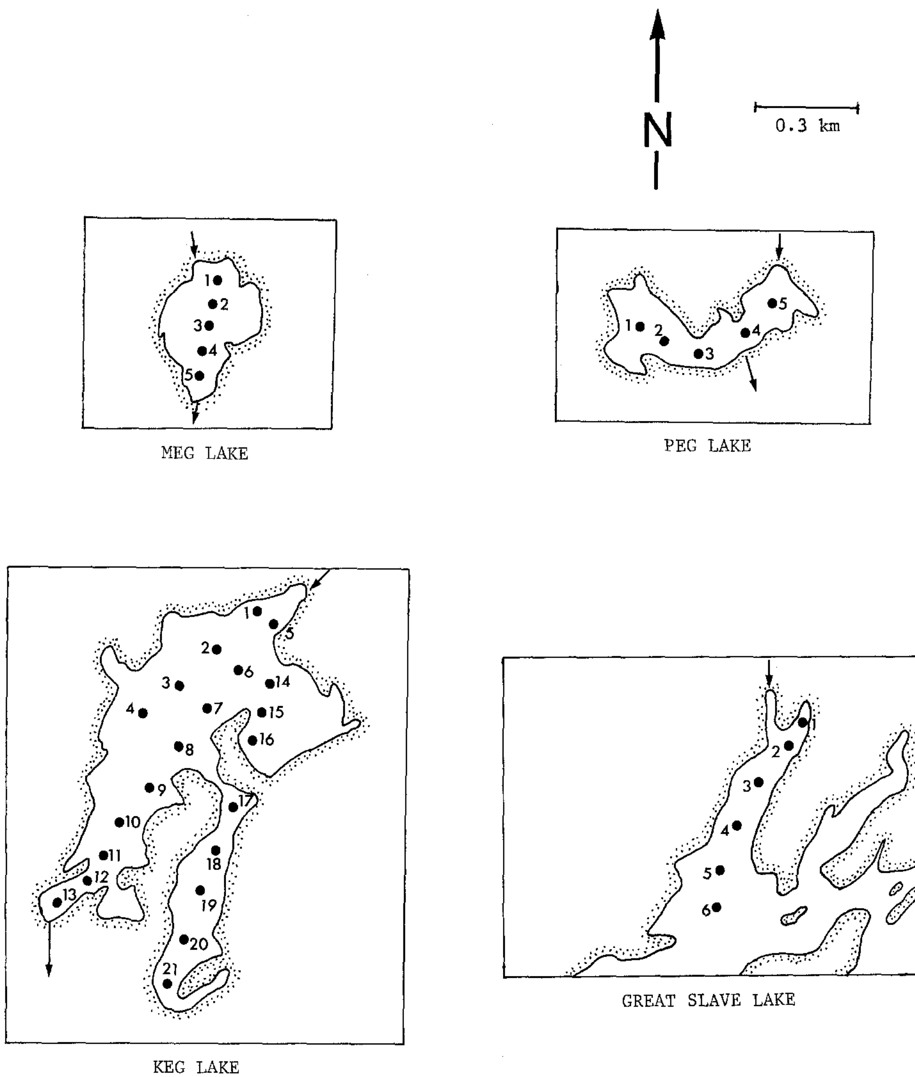

Figure 1. Location of sampling stations on study lakes. Arrows indicate path of effluent discharge from mine.

the study area, there was considerable variability in the concentrations of mercury. However, there was no significant difference ($p<0.05$) in mean values for all 4 water bodies. The only other common metal, zinc, varied from 110 to 250 mg/kg depending on the lake. Arsenic concentrations in the waters of Meg and Keg Lake were similar, averaging 2 g/m^3 (Table 2). Values decreased to <1 g/m^3 in Peg Lake and <0.02 g/m^3 in Great Slave Lake. Although the concentration of lead in Meg, Keg and Peg Lakes ranged up to 0.4 - 0.6 g/m^3, there was no contamination in Great Slave Lake. Cyanide and copper were occasionally high in Meg Lake. Total hardness in Meg Lake averaged 1800 g/m^3, compared with 2000 g/m^3 in Keg Lake and 1800 g/m^3 in Peg Lake. However, at the terminus of the effluent flow on Great Slave Lake, there was a wide range in values (50 - 2100 g/m^3). Water temperatures throughout the study area began increasing in May and reached 18 - 21^{o}C during July. Thereafter, the water cooled, falling to 0^{o}C by the middle of November. The pH was similar in all lakes ranging from 6.0 to 7.2.

TABLE 2

Average and range in total concentrations (g/m^3) of metals in the waters of the study lakes.

	Meg	Keg	Peg	Great Slave
Arsenic	2.0	1.9	0.7	0.02
	(0.5-3.4)	(0.02-3.1)	(0.09-1.1)	(<0.02-0.06)
Copper	0.2	0.05	<0.02	<0.02
	(0.02-0.7)	(0.02-0.14)	(<0.02)	(<0.02)
Lead	0.10	0.10	0.20	0.008
	(0.02-0.63)	(0.03-0.91)	(0.03-0.25)	(<0.002-0.077)
Cyanide	0.10	<0.05	<0.05	<0.05
	(<0.05-0.55)	(<0.05-0.08)	(<0.05)	(<0.05)

Zoobenthic Communities: Nine species were found in Meg Lake, of which 5 were chironomids and 4 were molluscs (Fig. 2). The total standing crop of the fauna varied from approximately 400 to 860 animals/m^2 regardless of time of year. Molluscs were dominant, accounting for more than 90% by numbers of the benthos. The most common species *Pisidium casertanum* generally occurred at densities of >300 animals/m^2.

There were 13 species in Keg Lake (7 chironomids and 6 molluscs). The density of the benthos was higher than that in Meg Lake, ranging from 330 to 1500 animals/m^2. Chironomids represented up to a maximum of 60% by numbers of the benthos. *Pisidium casertanum* was rare in Keg Lake, averaging <100 animals per m^2. It was replaced by several species, including *Physa jennessi*, *Valvata sincera*, and *Lymnaea elodes*, all of which were dominant at various times of the year. The most common chironomids were *Procladius culiciformis* and *Psectrocladius barbimanus*.

There were 14 species in Peg Lake (8 chironomids, 5 molluscs, 1 amphipod). The total density of the fauna often

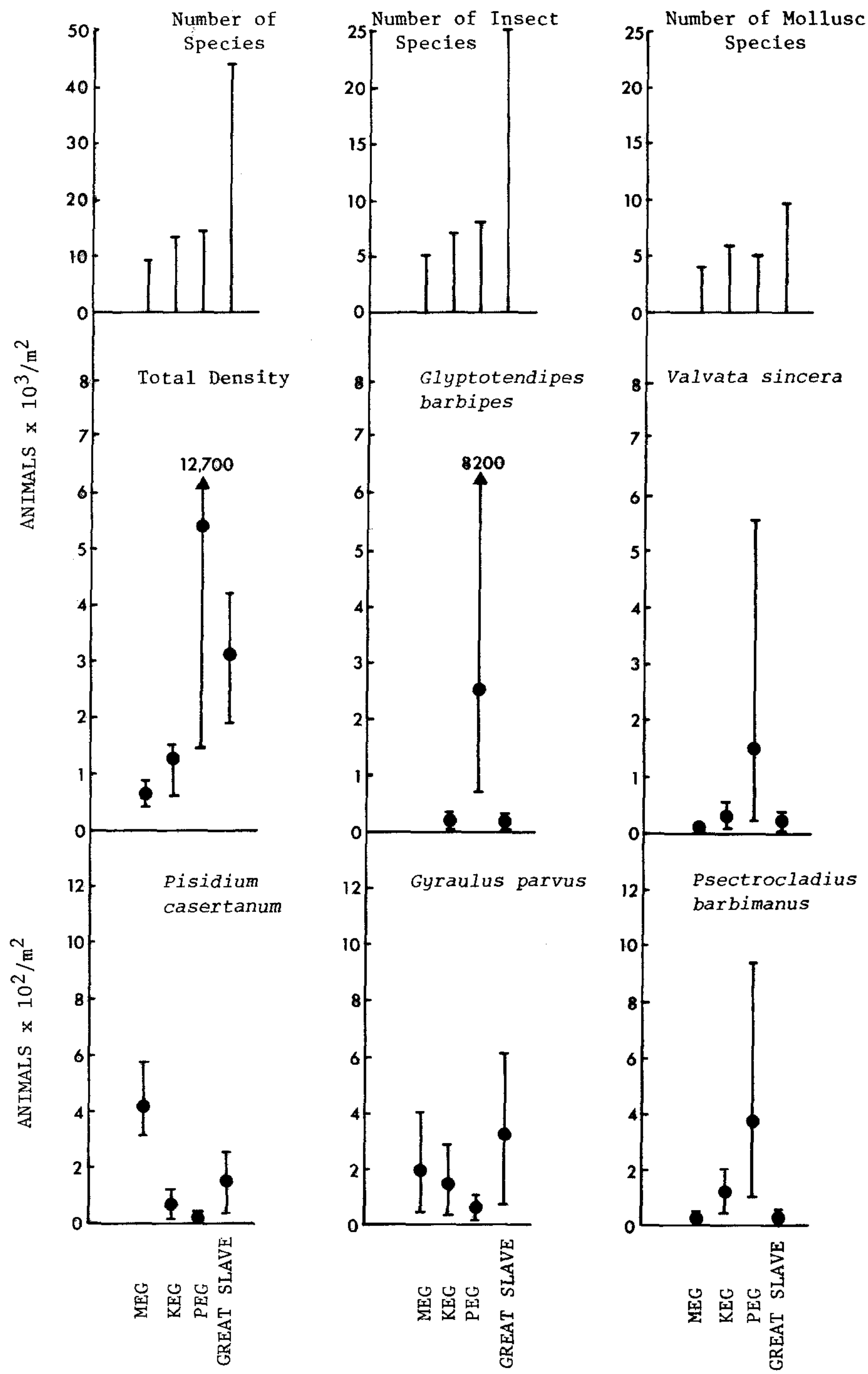

Figure 2. Number of species and average and range in densities of common benthic organisms in the study lakes.

exceeded 10,000 animals/m^2 during the summer. Larval chironomids generally accounted for 60 - 90% by numbers of the benthic community. The main species was *Glyptotendipes barbipes* followed in abundance by *Procladius culiciformis* and *Psectrocladius barbimanus*. Among the molluscs, *Valvata sincera* was dominant.

There were 44 species of invertebrates found at the terminus of the effluent discharge. Of these, 25 belonged to the Chironomidae, 10 to the Mollusca, 2 to the Amphipoda and at least 3 to the Oligochaeta. In addition, there were 4 identified species of Trichoptera and Odonata. The total standing crop of the fauna ranged from 1900 to 4300 animals/m^2 (Fig. 2). Amphipods were often predominant in the collections, followed by chironomids and molluscs. The dominant species were *Gammarus lacustris*, *Hyallela azteca*, *Procladius dentus*, *Stictochironomus sp.* and *Gyraulus parvus*.

DISCUSSION

There is one main question arising from this study: what was responsible for the reduction in the diversity and density of the benthos in the upstream lakes? Certainly, the waters of Meg Lake contained high concentrations of arsenic, cyanide, lead and copper, and based on laboratory experiments these pollutants were probably toxic to the biota. For example, WURTZ (1962) demonstrated that the 96 hour TLm for *Physa heterostropha* (Gastropoda) exposed to dissolved copper was 0.069 g/m^3, while *Physa integra* and *Campeloma decisum* were able to survive only 6 weeks at copper concentrations of 0.015 g/m^3 (ARTHUR & LEONARD 1970). Furthermore, total hardness concentrations were toxic to virtually all species of chironomids occurring within the study area (ROBACK 1974). Of the 61 species studied by Roback, only 7 were able to tolerate total hardness levels over 1000 g/m^3 and 5 species survived at >2000 g/m^3. Therefore, the poor water quality of Meg Lake probably contributed to the reduction in the diversity and density of the biota, a view which is consistent with the absence of planktonic Crustacea in the waters of Meg Lake (MOORE et al. 1979).

There are only a few laboratory studies on the toxic properties of contaminated sediments (WENTSEL et al. 1978) and consequently it is not possible to directly assess the impact of the sediments of Meg Lake on the biota. However since the concentrations of metals in the sediments of Meg Lake and Keg Lake were statistically similar, differences in the diversity and density of the benthos between the two lakes must have been due to variations in water quality. In particular, the concentrations of cyanide and copper in Meg Lake were much higher than those in Keg Lake and may have lowered diversity and density of the benthos.

The presence of large benthic populations in Peg Lake indicates that the concentrations of pollutants in the sediments and water were non-toxic to the dominant species. However, the diversity of the fauna was low and comparable to that in Keg Lake. Therefore the level of contamination probably limited the number of species, a view which is consistent with the much larger number of species found at the terminus of the effluent discharge on Great Slave Lake where contamination was slight. Since the concentrations of metals in the sediments of Peg Lake were low, even in comparison to non-impacted water-bodies (SÄRKKÄ et al. 1978, THOMAS 1972, YIM 1976) sediment contamination must have had no direct effect on the diversity of the fauna. In contrast, the total hardness of the water was high and would have prevented the development of many insect species (ROBACK 1974). In addition lead levels were similar to those in Meg Lake and arsenic was often above 1.0 g/m^3.

It should also be pointed out that the preceding discussion did not consider potential synergistic or antagonistic interactions of metals in either the water or sediments. These interactions, although well documented in laboratory studies, are much more complicated under actual field conditions and therefore their importance in the pollution-ecology of invertebrates cannot be readily assessed. Since the complexity of natural ecosystems cannot be duplicated in controlled laboratory experiments, the only way of elucidating the significance of synergism and antagonism is to collect an extensive series of field data under a variety of environmental conditions. Furthermore since Meg Lake froze to bottom, the extremely low densities may have also been related to winter mortality.

Indicator species have often been used to measure the quality of waters in various lakes and rivers. Since numerous invertebrate taxa have the ability to adapt to contaminated environments, under specific environmental conditions, the value of indicator species is considered to be limited by many authors (ROBACK 1974, CAIRNS et al. 1972). However, the presence of *Psectrocladius barbimanus* in large numbers in this study clearly indicates water of high total hardness (SAETHER 1969). Similarly *Derotanypus alaskensis* and *Glyptotendipes barbipes* are characteristic of water with moderately high hardness. Although these insects were therefore effective indicators of hard waters, there was no apparent indicator of metal contamination, as outlined below.

Most of the molluscs and insects recorded from Meg, Keg and Peg Lakes are found in unpolluted environments in North America (CLARKE 1973, ROBACK 1971, TOWNES 1945). Therefore, many other widespread species may be able to adapt to elevated metal and hardness levels. This ability for adaptation may be the reason why the indicator species concept has proved ineffective in assessing pollution in many ecosystems. For example, how can one species be designated as tolerant and hence indicative of metals if there are many other taxa with the potential capacity to adapt to the same level of contamination. It should also be pointed out that in northern environments the number of species per lake is generally much lower than that in the temperate areas of the world, where the concept of indicator species was originally applied. It is possible that species which are indicative of metal contamination are not found in arctic and subarctic lakes due to adverse food and temperature conditions. Therefore the effectiveness of the indicator species concept may be limited by the small pool of potential indicators. The marked variation in the species composition of the fauna throughout the study area can probably be related to a number of environmental factors. For example, the prevalence of *Glyptotendipes barbipes* and *Valvata sincera* in Peg Lake was clearly due to the presence of macrophytes (CLARKE 1973, ROBACK 1956). Since these growths were absent from Meg and Keg Lakes, *G. barbipes* and *V. sincera* were either rare or absent from both watercourses. Similarly, *Psectrocladius barbimanus* was most common in Peg Lake, where total hardness levels were consistently high. It was much rarer at the terminus of the effluent discharge, where total hardness was occasionally low, and in Meg Lake where metal levels probably restricted development.

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