

TRACE ELEMENTS IN WATER, SEDIMENT, AND BIOTA OF THREE OLIGOTROPHIC LAKES IN QUEENS AND ANNAPOLIS COUNTIES, NOVA SCOTIA

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Concentrations of a range of elements have been measured in water, sediment, plankton, benthos, macrophytes and fish of three oligotrophic lakes in Kejimikujik National Park, Nova Scotia. Lead appeared to be concentrated in the top centimeter of undisturbed sediment cores; probably due to anthropomorphic use of leaded gasoline. The low concentrations of calcium and magnesium in these waters are probably due to the substratum of impoverished basement rocks and glacial moraine. High concentrations of sodium and chloride reflect the influence of atmospheric aerosols of marine origin.

Les concentrations d'une gamme d'éléments ont été mesurés dans l'eau, dans le sédiment, dans le plancton, dans le benthos, dans les macrophytes, et dans les poissons de trois lacs oligotrophiques dans le Parc National Kejimikujik en Nouvelle-Ecosse. Le plomb s'est avéré le plus concentré dans le cm. superficiel de noyaux de sédiment non-dérangés; ceci démontre une influence anthropogénique probablement reliée à l'usage d'essence au plomb. Les concentrations relativement basses du calcium et du magnésium dans ces eaux (comparées à des lacs oligotrophiques situés ailleurs) sont probablement une conséquence d'un fond de roche appauvri et de moraines glaciales. Les concentrations élevées du sodium et de la chlorure réfléchissent une influence d'aérosols atmosphériques provenant de la mer.

Introduction

Metals and other trace elements are emitted from various anthropogenic sources such as power plants, smelters and automobiles, and these contaminants are known to be transported in the atmosphere over long distances, after which they may deposit on forests or waterbodies (Freedman, 1989). In order to determine whether such atmospheric depositions cause measurable increases in the concentrations of potentially toxic trace elements in ecosystems, information is required on their background concentrations in the environment. To provide such background information, multi-elemental biogeochemical surveys have been made of putatively uncontaminated environments. Reviews of such data may be found in Bowen (1979) and Forstner and Wittmann (1981). Here we summarize the results of a study of the concentrations of

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26 elements in water, sediment, and biological compartments of three oligotrophic lakes in southwestern Nova Scotia, though not all elements were found in every compartment. The purposes of this study were to provide baseline data against which future changes in elemental concentrations might be assessed and to determine whether any of the elements were present in unusually large or small levels in these waterbodies.

Methods

Study area

The three lakes examined were Beaverskin, Pebbleloggitch and Kejimkujik, all located in Kejimkujik National Park in southwestern Nova Scotia. The physical, chemical and biological characteristics of the lakes and their watersheds have been described in detail (Kerekes and Freedman, 1989). Beaverskin and Pebbleloggitch Lakes are small, shallow, oligotrophic lakes in small headwater watersheds (Table I). Pebbleloggitch Lake has relatively dark and acidic water (87 Hazen units, pH 4.3), while Beaverskin Lake is clear and less acidic (5 Hazen units, pH 5.3). Kejimkujik Lake is larger and deeper, drains a large watershed and its colour and acidity (65 Hazen units, pH 4.9) is between the other two smaller lakes (Table I). The watersheds of the lakes are largely forested, but about 33% of the Pebbleloggitch watershed is a poor-fen dominated by heaths and *Sphagnum*. Parts of the Kejimkujik watershed are similar wetlands. It is because of the brownwater drainage from these wetlands that these two lakes are dystrophic.

Table I Location and selected morphometrics of the three study lakes.

	Beaverskin	Pebbleloggitch	Kejimkujik
location (grid reference)	140 085	124 078	
latitude	44°18' N	44°18' N	44°23' N
longitude	65°20' W	65°21' W	65°15' W
elevation (m a.s.l.)	120	120	90
lake area (km ²)	0.443	0.338	24.35
drainage basin & lake (km ²)	1.0	1.6	723
maximum depth (m)	6.8	2.5	19.2
mean depth (m)	2.8	1.6	4.4
water retention time (y)	1.36	0.38	0.17

Collection and preparation of samples Field sampling was done in mid-July, 1980, except for undisturbed sediment cores, which were collected in July 1986.

Water samples The lakes were sampled at their outflow. An acid-washed nalgene bottle of capacity 1 L was rinsed several times with lake water, filled, and the sample was preserved by adding nitric acid to pH ~2.

Sediment samples Duplicate samples of sediment were collected from a mid-lake deep water station, using an Ekman dredge. The sediment was taken from the center of the sampler, passed through a 0.5 mm nylon mesh sieve, and dried at 100°C. Subsamples of 5 g dry weight (d.w.) were digested in nitric-perchloric acids (5:2) to prepare them for chemical analysis. In addition, undisturbed sediment cores were collected from two of the lakes (Beaverskin and Pebbleloggitch) in 1986, by using divers to carefully insert and extract a 7.5 cm diameter, acid-washed, plexiglass tube

at deepwater stations of the lakes. The sediment from these cores was sectioned into 1 cm depth segments, dried at 100°C, sieved through 1 mm sieves and subsamples (5 g, d.w.) digested in a teflon vessel in nitric-hydrofluoric-perchloric acids (3:3:1) at 100°C, prior to chemical analysis.

Plankton Duplicate plankton tows were made, using a 0.15 mm nylon mesh net. Samples were dried at 100°C, and subsamples (0.5 g d.w.) were digested in nitric-perchloric acids (5:2) to prepare for chemical analysis.

Benthos Benthic invertebrates were sorted from the sediment samples. Composite samples of various taxa (mostly *Asellus*, Diptera, *Hexagenia*, Odonata and Trichoptera) were dried at 100°C and subsamples (0.5 g d.w.) digested in the same way as the plankton samples.

Macrophytes Samples of *Eriocaulon septangulare*, *Nuphar variegatum* and *Utricularia vulgaris* were collected, rinsed to remove sediment, freeze-dried, homogenized in a powder mill and subsamples (0.5 g) digested as described.

Fish Individuals of brown bullhead (*Ictalurus nebulosus*), golden shiner (*Notemigonus crysoleucas*) and yellow perch (*Perca flavescens*) were collected by gillnetting. Composite samples of 3-5 individuals per species were homogenized in a blender, dried at 100°C, and subsamples (0.5 g d.w.) digested in nitric-perchloric acids (5:2) for chemical analysis. Samples for mercury analysis were kept frozen and were then digested and analysed.

Chemical analyses All chemical analyses of the samples collected in 1980 were made by Barringer Magenta Limited, Rexdale, Ontario. Analyses were done on a total of 17 samples of water, 16 of sediment, 94 of fish, 8 of benthic invertebrates, 15 of plankton, and 46 of macrophytes. Most determinations were by inductively coupled plasma emission spectroscopy using standard procedures. Cadmium, mercury and lead were analyzed by atomic absorption spectroscopy. Chromium in sediments was also analyzed by atomic absorption. Determinations were made of blank digests and all analytical data were corrected for these blank values. The ratio of sample:blank analyses was 8:1 for water and sediment, and 1:17 for biological samples. Standard reference materials: a syenite rock sample (S4-3) from Canada Center for Mineral and Energy Technology; a bovine liver standard and an orchard leaf standard from U.S. Bureau of Standards were analyzed as controls and to indicate analytical accuracy. The results are given in Table II.

The sediment core samples collected in 1986 were analyzed in the laboratories of OceanChem Ltd. Lead was determined by atomic absorption spectroscopy and the remaining elements by inductively coupled plasma atomic emission spectroscopy.

Data analysis Descriptive statistics were computed for each of the elements determined for the various samples from each lake (Ag was not detected). In cases where the concentration of an element was below the detection limit, the values were treated as 'missing' for the statistical analysis and are indicated in Tables III to VII with a blank.

Results and Discussion

The analyses of standard reference materials given in Table II indicate that the results obtained were generally within experimental error of the certified values; large percentage differences were generally found only for those elements present in very small quantities (<5 mg kg⁻¹). The exceptions to this rule were analyses of orchard

Table II Replicate (7) analyses of elements (mg kg⁻¹) in standard reference materials and comparison with their certified values (σ = standard deviation; n.a. = not available; % difference between certified and analytical values given in parentheses when > 5%)

Element	Orchard leaves			Bovine liver			Syenite rock		
	mean	σ	certified value	mean	σ	certified value	mean	σ	certified value
Al	174	11	n.a.	2.9	.3	2	59300	540	62400
Be				<.01		.017	18.4	1	20(8)
Ca	18600	460	20900(11)	125	3	124	56700	590	59000
Cd				<.25	.27				
Co	<.5		.2	1.3	.3	.21(!)	90	1	82(9)
Cr	1.4	.1	2.6(46)	.6	.2	.6	3.3	1.2	11(70)
Cu	10.3	.2	12(14)	178	3	193(8)	27	7	17(37)
Fe	240	5	300(20)	270	3	268	44700	500	44900
Hg				15	1	16			
K	13600	520	14700(7)	9870	200	9960	34640	240	34900
Mg	5800	100	6200	630	12	604	16150	170	16100
Mn	81	2	91(10)	10	.1	10.3	2320	20	2480
Mo				3.0	0	3.5(14)			
Na	63	7	82(23)	2470	30	2430	30830	220	30800
Ni	2.3	.1	1.3(77)	.7	.2	n.a.	7.3	.7	11(34)
P	1880	20	2100(10)	11600	200	11100	2410	30	2360
Pb	38	2	45(16)	<.5		.34	150	2	133(10)
Sr	25	1	37(34)	.07	.01	.14(50)	250	2	300(17)
Th	<.6		.064	.033	.016	.05	1240	3	1003(19)
Ti	4.9	.5	n.a.				970	15	900(7)
V				.13	.04	.1	56	1	50(11)
Zn	20	1	25(20)	136	3	130	233	5	244
Zr							520	8	320(38)

leaves where lower values for Ca, Fe, Mn, Na, P, Pb, Sr and Zn than the certified concentrations, were obtained. An explanation for these discrepancies is unknown but requires further investigation and may mean that the values given in this paper for plant material should be revised upwards. Standard analyses for Ba, Si and Sn were not obtained.

The analytical values for 20 elements in water samples from the three lakes are given in Table III; values for Cd, Co, Mo, Sn, Th, and Zr were below the detection limits. These analyses, when compared with those of benthic invertebrates (Table IV, Si not detected), plankton (Table V, Ba, Be, Pb & Si not detected), macrophytes (Table VI, Ba, Be & Si not detected) and fish (Table VII, Ba, Be & Si not detected), show that there was bioaccumulation of elements in all these compartments. However the biota did not have consistently greater or smaller elemental concentration than the sediments (Table IV).

Other than the general biomagnification of elemental concentrations compared with water, there was little food chain accumulation of the elements. In relatively uncontaminated environments like the lakes examined in this study, the relative concentrations among the various biological compartments depend more on element specific physiological requirements or sequestering mechanisms than on trophic level. For example cyanoglobin, is a copper containing respiratory protein found e.g. in molluscs, which species therefore, have a relatively high content of this element (Bryan, 1968; Hutchinson et al., 1976).

Table III Concentrations ($\mu\text{g kg}^{-1}$) of elements in the water of Kejimikujik, Pebbleloggitch and Beaverskin Lakes (σ = standard deviation; n = number of analyses)

Element	Kejimikujik			Pebbleloggitch		Beaverskin	
	Mean	σ	n	Mean	n	Mean	n
Al	100	0	7	190	3	50	3
Ba	2.4	.8	7	2	2	2.5	2
Be	.1		1				
Ca	670	80	9	340	4	350	4
Cr				1	1	.9	1
Cu	11		1				
Fe	200	60	9	105	2		
Hg	.1	.04	5	.09	3	.07	3
K	100	0	5	150	2	100	2
Mg	480	40	9	390	4	410	4
Mn	37	2	9	8	2	16	4
Na	3000	50	9	3000	4	2900	4
Ni	23	8	8				
P	9	1	9	14	4	5	4
Pb	2.2	.1	9	2.3	4	2.3	4
Si	473	160	9	600	4	150	3
Sr	5.2	1.6	8	4.5	3	3.7	2
Ti	1		1				
V						6	1
Zn	8	1	8	4	2	4.5	2

The trace element concentrations reported are similar to those of uncontaminated fresh waters [c.f. data in reviews of Bowen (1979); Forstner and Wittman (1981)], and as might be expected, differences between specific compartments were small, though some (see e.g. Table VII) were statistically significant. There were, however, several cases where the data diverged from that recorded for other pristine fresh waters and these are discussed below in greater detail.

Lead in sediments Uncontaminated soil typically contains about 35 mg kg⁻¹ of lead (Bowen, 1979). The mean lead concentration found in the bulk sediments collected from the three lakes lay in the range 18 - 47 mg kg⁻¹, with a maximum of 65 mg kg⁻¹ (Table IV). However values of 123 mg kg⁻¹ were obtained on samples taken from the top centimeter of the sediment and the mean value for this horizon in Beaverskin Lake was 96 mg kg⁻¹. There was a pronounced vertical stratification in the sediments of Beaverskin and Pebbleloggitch Lakes (Table IV) where values >40 mg kg⁻¹ were found in the upper 5 cm of the sediment horizons and <10 mg kg⁻¹ at depths in the range 9-23 cm. Similar stratification was also found in nearby Big Dam Lake. This pattern of elevated concentrations of Pb in the surface sediments of remote lakes is probably caused by increases in the rate of atmospheric deposition of this element as a result of the long-range transport of emissions associated with automobile exhaust (Freedman, 1989). Enhanced deposition of lead to remote ecosystems has previously been attributed to automobile emissions, e.g. deposition to forested watersheds at relatively high elevation in the N.E. United States (Siccama and Smith, 1978; Andresen et al., 1980; Friedland and Johnson, 1985).

Elements of groups I and II The cations: Ca⁺², K⁺ and Mg⁺² are present in relatively small concentrations in the water and sediments of the three lakes. Most notably, Ca⁺² in water is present in the range .34 - .67 mg kg⁻¹ (Table III), compared with Bowen's (1979) 'typical' value of 15 mg kg⁻¹ for fresh water, or compared with continental soft

Table IV Concentrations of elements in the sediments and benthos of Kejimikujik, Pebbleloggitch and Beaverskin Lakes (σ = standard deviation; n = number of analyses)

Element (mg g ⁻¹)	Kejimikujik					Pebbleloggitch				Beaverskin		
	Sediment			Benthos		Sediment		Benthos		Sediment		Benthos
	Mean	σ	n	Mean	n	Mean bulk (n=4)	Mean top 5 cm (n=3)	Mean	n	Mean bulk (n=4)	Mean top 5 cm (n=3)	n=1
Al	85.6	7.4	8	.86	3	15.4	10.8	.1	2	27.5	18.0	.12
Ca	2.9	.19	8	.35	3	2.5	1.02	.17	2	2.2	1.37	.39
Fe	40.8	2	8	1.5	3	2.8	2.97	.13	2	6.8	5.5	.31
K	27.3	1.9	8	1.8	3	4.7		.75	2	8.8		2.08
Mg	9.7	.9	8	.43	3	.92	.49	.16	2	1.03	.77	.24
Mn	1.13	.13	8	.031	3	.057	.035	.002	2	.21	.243	.01
Na	11.8	.5	8	1.39	3	4.3		.68	2	6.7		1.78
P	.9	.06	8	1.88	3	.67	.73	.98	2	1.2	1.38	1.69
Ti	4.4	.5	8	.03	3	.73	.69	.007	2	.73	.63	.004
Zn	.12	.005	8	.04	3	.014	.006	.022	2	.051	.006	.027
($\mu\text{g } 10\text{g}^{-1}$)												
Ba							510					810
Be						5	<10			8		13
Cd							<10					<10
Co	160	120	7	29	3		18	19	2			29 30
Cr	810	120	8	15	3	100	87	7	2	88	130	7
Cu	230	60	8	47	3	60	210	28	2	430	150	61
Hg	.22	.13	8	.42	1	.26		.23	1	.21		
Ni	4	4	6	13	3	43	49	18	2	50	71	13
Pb	180	40	8	25	1	340	430	20	2	470	560	
Sn							29				70	
Sr	1200	90	8	16	3	320	150	5	2	370	180	14
Th				17	3			10	1			30
V	880	120	8	18	3	97	150	5	2	160	220	
Zr	1040	50	8	10	1	200	220					

water lakes e.g. the Experimental Lakes Area (ELA) of N.W. Ontario (1.6 mg kg⁻¹; Armstrong and Schindler, 1971). This observation is related to the small quantities of calcium in the thin mantle of soil and till overlying the hard oligotrophic bedrock in this part of Nova Scotia (Freedman and Morash, 1985; Kerekes and Freedman, 1989). Because of the sparse quantities of these cations in the study lakes, their waters have little acid neutralizing capacity and are therefore susceptible to acidification caused by deposition of acidifying substances from the atmosphere and by input of organic acids from the sphagnaceous wetlands of their watersheds (Clymo, 1984; Gorham et al., 1984; Kerekes and Freedman, 1989).

The concentrations of Na⁺ in the study lakes (range 2.9 - 3.0 mg kg⁻¹; Table III) are large compared with about .9 mg kg⁻¹ for softwater lakes of the ELA (Armstrong and Schindler, 1971). This observation possibly reflects the facts that the lakes are less than 60 km from the Atlantic Ocean, so there is a relatively large deposition of marine derived aerosols (Freedman and Clair, 1987; Kerekes and Freedman, 1989).

Elements mobilized by acidity Aluminium is abundant as an insoluble constituent of various minerals of watershed soils and aquatic sediments (in which its 'typical total' concentration is ca. 7%) and it is known that acidic water can solubilize the element

Table V Concentrations ($\mu\text{g kg}^{-1}$) of elements in the plankton of Kejimikujik, Pebbleloggitch and Beaverskin Lakes (σ = standard deviation; n = number of analyses)

Element	Kejimikujik			Pebbleloggitch		Beaverskin	
	Mean	σ	n	Mean	n	Mean	n
Al	11	1	7	9.8	4	7.8	4
Ca	110	15	7	82	4	72	4
Co	.7	.2	5	.8	3	.9	1
Cr	.2	.1	6	.1	4	.2	4
Cu	1.9	2.3	7	2.6	4	1	4
Fe	25	4	7	18	4	17	4
Hg($\mu\text{g kg}^{-1}$)	7	2	7	10	4	8	4
K	91	27	7	190	4	160	4
Mg	40	7	7	43	4	34	4
Mn	1.4	.3	7	.6	4	1	4
Na	76	13	7	100	4	95	4
Ni				.2	4	.2	2
P	320	70	7	360	4	250	4
Sr				.2	4	.2	4
Ti				.4	4	.3	4
V				.1	4	.1	4
Zn				10	4	5.2	4

from these compartments (Freedman and Hutchinson, 1986; Havas, 1986). Of the 3 lakes under study, the highest mean concentration of Al in water occurred in the most acidic lake (Pebbleloggitch; pH 4.3, .19 mg kg⁻¹, Table III), whilst the smallest concentration was in the most alkaline lake (Beaverskin; pH 5.3, .05 mg kg⁻¹, Table III). Aluminium concentrations in sediments (15.4 - 85.6 mg g⁻¹, Table IV) and in biota (3 - 860 mg kg⁻¹, Tables IV - VII) were present in much larger concentrations.

Mercury in fish The Hg concentrations in water (.07 - .1 mg kg⁻¹) were lower than the recommended limit for protection of aquatic wildlife (.2 mg kg⁻¹; CCREM, 1987). The maximum observed concentration of Hg in *Notemigonus crysoleucas* in this study was .2 mg kg⁻¹ d.w. but the mean value, .15 mg kg⁻¹ (n=18), was corresponding to .038 mg kg⁻¹ on a fresh weight basis (Bowen, 1979, p. 85), was much lower than the recommended upper limit for the protection of fish-eating birds and other wildlife (.5 mg kg⁻¹ d.w.; International Joint Commission, 1977). Some other studies of mercury in fish of lakes in Eastern Canada have found higher concentrations than these, e.g. .3 - 1.3 mg kg⁻¹ in 3 species in 11 lakes in N.W. Ontario; .1 - .4 mg kg⁻¹ in 3 species in Lake of the Woods, Ontario; a mean of 2 mg kg⁻¹ (maximum 5 mg kg⁻¹) in *Esox lucius* in northern Manitoba (Fimreite and Reynolds, 1973). Other studies have found similar mercury concentrations (e.g. mean values of <2 mg kg⁻¹ in juvenile yellow perch of 10 Ontario lakes; Suns et al., 1980). However, Fimreite et al., (1973) reported analyses of relatively large and/or old fish of different species than the ones studied here. These and other factors are known to affect the mercury concentration of fish (Scheider et al., 1978; Suns et al., 1980; MacCrimmon et al., 1983). Water pH is another important factor, with acidic waters generally favouring the formation of bioavailable methylmercury compounds compared to dimethylmercury in less acidic waters (Tsai et al., 1975; Brouzes et al., 1977; Scheider et al., 1978).

All of the determinations reported are for total elemental concentrations, no analytical distinctions are made between e.g. ionic and organically bound forms. In terms of ecotoxicology, this is an important point, since ionic forms of toxic elements

Table VI Concentrations of elements in *Eriocaulon septangulare*, *Nuphar variegatum* and *Utricularia vulgaris* collected in Kejimikujik, Pebbleloggitch and Beaverskin Lakes (σ = standard deviation; n = number of analyses)

Element	Kejimikujik		Pebbleloggitch			Beaverskin			σ
	Eriocaulon Utricularia	Nuphar	Eriocaulon	Nuphar	Utricularia	Eriocaulon	Utricularia	Eriocaulon	
	(n=1)	mean (n=4)	mean (n=5)	mean (n=8)	σ	mean (n=5)	mean (n=4)	mean (n=7)	
(mg g ⁻¹)									
Al	.7	.2	.52	.09	.041	3.27	.52	5.65	.12
Ca	1.15	10.3	.38	12.3	1.1	3.97	.79	5.2	.3
Fe	3.4	.77	1.89	.49	.18	6.4	3.94	16.9	.7
K	4.9	10.3	1.14	10.8	1.3	.85	3.65	1.02	.11
Mg	.66	1.13	.34	1.4	.04	3.46	.46	2.73	.1
Mn	.225	.57	.044	.15	.004	.05	.3	3.54	.64
Na	5.34	4.85	1.71	5.98	.16	2.01	6.6	.656	.011
P	.83	2.43	.79	1.93	.1	1.65	.39	1	.03
Zn	.144	.024	.02	.02	.001	.064	.04	.076	.002
($\mu\text{g } 10\text{g}^{-1}$)									
Cd	7.5	11	8	11	1	10	20	24	1
Co	33	27	16	9	2	20	13	34	7
Cr	160	34	67	10	1	120	64	110	30
Cu	590	28	70	9	1	66	100	78	4
Hg	.09	.05	.09	.05	n=2	.18	.05	.27	n=2
Ni	31	35	33	20	2	75	44	91	3
Pb	120	26	260	140	20	540	210	460	50
Sr	68	710	51	380	60	420	79	540	30
Th	13		9			14	8	19	4
Ti	160	57	230	19	15	930	87	870	160
V	26	5	27	5	3	68	32	140	10
Zr	9	6	5			14	7	36	?

Table VII Element concentrations (mg kg⁻¹ dry weight) in *Perca flavescens* (yellow perch) caught in Kejimikujik, Pebbleloggitch and Beaverskin Lakes (σ = standard deviation, n = number of analyses)

Element	Kejimikujik			Pebbleloggitch			Beaverskin		
	mean	σ	n	mean	σ	n	mean	σ	n
Al	6.1	3.4	11	3.3	1.9	9	17	6	6
Ca	13500	2100	14	11700	1900	20	11700	2500	18
Cr	.4	.2	14	.3	.1	20	.3	.1	18
Cu	.9	.4	14	.6	.2	20	.7	.3	18
Fe	21	7	14	17	3	20	35	4	18
K	2800	300	14	2440	310	20	2260	700	18
Mg	470	40	14	410	40	20	440	60	18
Mn	16	7	14	3	.8	20	18	11	18
Na	880	100	14	720	200	20	610	110	18
Ni	1.1	.6	12	1.1	.2	20	1.1	.8	18
P	8000	950	14	7010	980	20	7100	1200	18
Pb	.7	.2	14	2.4	.6	20	1.1	.2	18
Sr	29	13	14	33	7	20	32	7	18
Ti	.2	.1	8	.2	.1	17	.3	.3	12
Zn	24	6	14	17	2	20	23	6	18

are more readily bioavailable and toxic than are equivalent concentrations that are bound to dissolved organic materials or colloids such as suspended clays (Pagenkopf et al., 1974; Sunda and Lewis, 1978; Chau et al., 1974; Bowen, 1979; McKnight, 1981; Havas, 1986). Pebbleloggitch and Kejimikujik Lakes have large total concentrations of dissolved organic substances (Kerekes and Freedman, 1989) and these serve as complexing agents for metals, greatly reducing the relative concentration of the ionic fraction and thus the potential toxic effects.

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