Monitoring the Bioavailability of Toxic Metals in Acid-Stressed Shield Lakes Using Pelecypod Molluscs (Clams, Mussels)

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ABSTRACT

Measurement of total or nominal pollutant concentration in the physical compartments of the aquatic environment (water, sediments, etc.) seldom gives a valid indication of the ultimate threat to the ecosystem. An alternative is to use a living organism to reflect the biological availability of the contaminant and to integrate its changing levels in the environment by monitoring over an extended period.

Pelecypods have been used as indicators of marine, coastal pollution but have received relatively little attention in freshwaters. The large unionacean clams and mussels show a number of features which suggest that they would be useful as monitors of biological availability of freshwater pollutants: ability to accumulate a wide variety of contaminants; mode of feeding; position on food chain; longevity; sedentary habits; facility with which their age can be determined; abundance; distribution; size and hardiness.

The current programme is concerned with: 1) evaluating unionaceans as potential indicators and the factors that affect pollutant uptake, 2) development of the methodology for monitoring, 3) characterisation of the pollutant status of Ontario shield lakes which are subject to both direct inputs of toxic metals with precipitation and their mobilisation through the ecosystem as a secondary function of environmental acidification.

INTRODUCTION

Demands for energy and current economic and political trends favour the increasing exploitation of native fossil fuels. The prognosis with respect to acidification of the environment and its pollution by the associated emission of toxic metals is not an optimistic one. Precipitation on the poorly buffered lakes of the Ontario shield is now at least as acidic as that in the worst affected regions of the U.S., Scandinavia, and the Sudbury (Ont.) region and the acid is accompanied by an increasing burden of toxic metals. Whether as a result of this direct input, or as a secondary effect of acidification and the consequent mobilisation of cations from soils and sediments through the aquatic ecosystem, metal concentrations are increasing in the lakes (5,6). Copper, nickel, zinc, manganese and aluminum concentrations are higher than those of shield lakes which are not influenced by urban-industrial emissions and, although they are less than levels found in the most severely polluted Sudbury lakes, they approximate those of the La Cloche system and badly stressed regions of Norway (Table I).

TABLE I. METAL CONCENTRATIONS IN SOUTH-CENTRAL ONTARIO LAKE WATER COMPARED WITH OTHER SYSTEMS*

LAKE SYSTEMS	CONCENTRATION ppb Cu	Ni	Zn	Mn	Fe	Al
SCO 14 Lakes	6	4	13	51		49
SCO Blue Chalk L.	8	3	9	40	41	13
ELA 1C2 Lakes	2	3	1	3		3
La Cloche 4 Lakes	2-4	8-12	24-36	220-260		
Sudbury Clearwater L.	97	275	46	300	110	487
SE Norway	1-10		3-35			

*Data from South-Central Ontario shield lakes compared with values from the Experimental Lakes Area (ELA), unpolluted shield lakes from N.W. Ontario, highly stressed lakes from Sudbury, Killarney and the La Cloche system of Ontario and Norway. Data summarised from (5,6,19).

The magnitude of these changes and the rate at which they are happening suggests that the majority of south central Ontario shield lakes will be irreversibly damaged within 10 years and all of them within 3 decades (5,6,19). The lakes are in transition and the nature and rate of this decline must be quantified if there is to be corrective management of the watershed. But 'the diagnostic protocols are at a primitive state for most ecosystems' (7) and will have to become increasingly sophisticated to account for the effects of low levels of persistent toxic substances entering the aquatic ecosystem continuously over protracted periods. Because of complexity of factors that govern the cycling of metals through lakes and rivers, estimates of their nominal concentration in the compartments of the physical environment are often of limited value in assessing impact on the biota. It has been argued (17,18) that the use of living indicators reflecting the biological availability of pollutants - particularly when they are able to integrate changing environmental levels over a period of time at a given location - represents a major advance in the study of aquatic pollution.

UNIONACEAN CLAMS AND MUSSELS AS INDICATORS

Despite many general biological similarities to marine pelecypods which are used extensively as indicators of coastal pollution (1,10), freshwater clams and mussels have received little attention. But there exists a considerable literature (8) which suggests that a wide variety of substances - approximately 19 metals and trace elements, 36 radionuclides and 17 persistent organic compounds - form appreciable residues in the tissues where they may be concentrated to levels several orders of magnitude greater than those in the water (Table II). Studies in which tissue burden has been related to environmental conditions in general support the use of these organisms in monitoring freshwaters (4,9,11,13-16,22).

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TABLE II. CONCENTRATION FACTORS AND CONCENTRATIONS FOR VARIOUS TRACE ELEMENTS IN UNIONACEAN MOLLUSCS

Element	CF	Conc. ppm (dry wt)
Al	2139	200-1500
Cr	210-3100	0.6-12(88)
	440[a]	
Mn	3259	500-3500
	2380-2.2x10^5[a]	
Fe	---	2000-5000
Co	233-267	0.2-1.5
	790[a]	
Ni	450-6300	0.4-15(25)
Cu	1200-6000	2-20(103)
		1.4-2.4[c]
Zn	1548-9000	6-300(600)
	4080[a]	24-34[c]
As	---	0.4-11.7[c]
Se	---	2-4
Ag	---	0.3
Cd	633-1150[b]	0.5-10(17)
		0.2-0.4[c]
Sn	---	0.05
Cs	90-300[a]	---
Ce	900[a]	---
Hg	900-3000	1.0(8.2)
		0.02-0.03[c]
Pb	1100-1856	0.5-20(50)
		0.68-0.70[c]

CF is wet weight concentration in tissue/concentration in water.
(a) radiotracer studies (b) some Cd CF values reported up to 8.7 x 10^3
(c) concentrations expressed as ppm wet wt. Data summarised from a no. of sources (8).

Their suitability in relation to the criteria for a monitoring agent proposed by Butler *et al.* (2), Goldberg (10) and Phillips (17,18), may be summarised:

1. They feed on suspended material, accumulating a wide spectrum of pollutants which may be concentrated in their tissues many thousands of times.
2. Their low position in the food chain results in a direct reflection of environmental conditions compared with the use of organisms at higher trophic levels.
3. They are long-lived (~5-10 years), sedentary or with only limited motility, and so integrate environmental levels over a period of time at one location.
4. Growth lines on the shell enable them to be readily aged, facilitating corrections for size/age variations in samples.
5. They are locally abundant, widely distributed and have an established and stable taxonomy which permits collection of comparable data from different areas.
6. They are hardy and adaptable to being transported for both field and laboratory experiments.

7. Their large size provides adequate material for whole animal and individual organ analyses.

THE CURRENT RESEARCH PROGRAMME

Unionaceans are able to form appreciable tissue burdens of a variety of toxic metals and trace elements (Table II) and preliminary evidence (Table III) shows that samples from south-central Ontario shield lakes are no exceptions. Of particular interest are the high levels of

TABLE III. METALS IN UNIONACEAN CLAMS (*Anodonta* sp.) FROM SOUTH-CENTRAL ONTARIO SHIELD LAKES, 1978

METAL	CONCENTRATION ppm (wet wt) $\bar{x} \pm$ SD (range n = 20)	
Mr	3507.1 ± 3067.3	(386.4 - 11,363.6)
Al	1508.0 ± 1409.0	(78.6 - 5318.3)
Ni	1.2 ± 0.7	(nd - 2.3)
Cu	5.9 ± 1.7	(2.6 - 8.3)
Zn	208.2 ± 80.5	(70.3 - 447.4)
Cd	16.9 ± 8.7	(6.7 - 40.1)
Pb	17.6 ± 17.1	(0.1 - 53.0)

Zn (ca 400 ppm), Al (ca 1500 ppm) and Mn (ca 3500 ppm) in the soft tissues. It has been known for some time that freshwater pelecypods have high affinities for these metals, particularly Zn and Mn (8) and it is becoming more evident that these 3 elements are also the most readily mobilised in acidified watersheds (3,12,20,21). Unionaceans therefore appear to be ideally suited as monitors of the bioavailability of metals in lakes and rivers currently under stress from acid precipitation and its secondary effects.

The programme is primarily directed toward developing protocols with particular reference to identifying and quantifying factors which introduce variability and compromise the comparability of the data. Some of these are summarised below:

1. Are data from different species comparable?
2. Do age and size affect weight-specific concentration and influence sampling strategy?
3. Do the organisms have differing affinities for individual metals and are they equally suitable as monitors in all cases?
4. Would the residues in individual organ systems give a better indication of environmental levels than whole tissue samples?
5. How do kinetic constants (biological half-life, turnover times, uptake/excretion kinetics) affect the organism's suitability as a monitoring agent?
6. How do sampling strategies affect variability of the data?

7. Is it necessary to allow the organism to purge the alimentary canal before analysis?

The combined laboratory-field study will cover Cu, Ni, Zn, Cd, Pb, Al and Mn. Tissue burdens will be related to the water concentration (filtered and unfiltered), sediment concentration and pH and will also be integrated with a detailed limnological data base generated by the Ontario Ministry of the Environment. Shield lakes and off-shield lakes having similar atmospheric loadings of metals and acid but differing buffer capacities will be compared together with biosphere controls (23) taken from other lakes remote from urban-industrial emissions.

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