Division Control No. ECD55

This copy is to provide information prior to publication.

DISTRIBUTION OF ARSENIC AND MERCURY IN ZOOBENTHOS FROM THE SHUBENACADIE RIVER HEADWATER LAKES IN NOVA SCOTIA

by

J.L. Metcalfe and A. Mudroch
NWRI Contribution No. 85-72

Environmental Contaminants Division
National Water Research Institute
Canada Centre for Inland Waters
Burlington, Ontario, Canada L7R 4A6

EXECUTIVE SUMMARY

The Shubenacadie River headwater lakes are contaminated with arsenic and mercury as a result of past gold mining activities in the area. Recent studies have shown that significant amounts of arsenic are transported from one lake to another, and that levels of mercury up to 2μg/g have accumulated in some fish species. This report presents the results of the first year of an investigation into the pathways of arsenic and mercury in the lake ecosystem.

Benthic organisms were collected from both the deep and nearshore areas of three contaminated lakes and two control lakes, and analyzed for tissue concentrations of arsenic and mercury. Aquatic worms and chironomids, which burrow in the sediment, accumulated higher concentrations of both arsenic and mercury than phantom midges, which spend much of their time in the water column. Snails accumulated higher concentrations of arsenic, but lower concentrations of mercury than two species of clams collected from the same locations. Small clams accumulated higher concentrations of arsenic than large clams, suggesting that arsenic accumulates by surface adsorption. Higher levels of arsenic were found in the stomach and intestines than in the other organs. Mercury concentrations were up to ten times higher in one clam species (*Elliptio complanata*) than in the other (*Anodonta cataracta*). Mercury was evenly distributed among all organs of *A. cataracta*, but was higher in the muscle tissue in *E. complanata*.

These results will be used to recommend the most suitable species for future biomonitoring in the study area and in other ecosystems contaminated with arsenic and/or mercury. Preliminary information on the pathways of arsenic and mercury in the food chain in the Shubenacadie River headwater lakes is also provided.

MANAGEMENT PERSPECTIVE

This report provides information on the distribution and bioavailability of arsenic and mercury in the Shubenacadie River headwater lakes in Nova Scotia. This information can be used to assess the potential for transfer of these toxic elements from the environment into the food chain. The most suitable organisms for future biomonitoring in the study area and in other ecosystems contaminated with arsenic and/or mercury are identified.

RÉSUMÉ ADMINISTRATIF

Les lacs en amont de la rivière Shubenacadie ont été contaminés par de l'arsenic et du mercure libérés lors de l'exploitation de mines d'or dans la région. Des études récentes ont démontré que de grandes quantités d'arsenic sont transportées d'un lac à l'autre et que l'accumulation de mercure dans certaines espèces de poissons avait atteint jusqu'à 2 ug/g. Ce rapport présente les résultats de la première année d'enquête sur les voies d'accès de l'arsenic et du mercure dans l'écosystème lacustre.

Des organismes ont été prélevés en zone profonde et près des rives de trois lacs contaminés et deux lacs témoins; ces échantillons ont ensuite été analysés afin de déterminer la concentration tissulaire d'arsenic et de mercure. On a découvert que les vers aquatiques et les chironomides, qui vivent enfouis dans les sédiments, avaient accumulé davantage d'arsenic et de mercure que les moucherons, lesquels passent une grande partie de leur vie dans la tranche d'eau. D'autre part, les gastéropodes semblent accumuler de plus grandes concentrations d'arsenic mais moins de mercure que deux espèces de bivalves prélevés aux mêmes endroits. Les petits bivalves concentrent de plus grandes quantités d'arsenic que les gros, ce qui semble indiquer que la rétention se fait par adsorption de surface. On a découvert que l'estomac et les intestins contenaient plus d'arsenic que les autres organes. La concentration de mercure était jusqu'à dix fois plus élevée dans une espèce de bivalve (*Elliptio complanata*) que dans une autre (*Anodonta cataracta*). Le mercure était également réparti dans tous les organes de *A. cataracta*, alors qu'il était plus concentré dans les tissus musculaires de *E. complanata*.

Ces résultats pourront être utilisés lorsqu'il sera question de sélectionner les espèces les plus appropriées à une surveillance biologique future dans la région à l'étude et dans d'autres écosystèmes contaminés par l'arsenic ou le mercure, ou les deux substances. L'étude présente également des renseignements préliminaires sur les voies d'accès de l'arsenic et du mercure dans la chaîne alimentaire des lacs en amont de la rivière Shubenacadie.

PERSPECTIVE-GESTION

Ce rapport fournit des renseignements sur la distribution et la biodisponibilité de l'arsenic et du mercure dans les lacs en amont de la rivière Shubenacadie en Nouvelle-Écosse. Ces données peuvent être utilisées pour déterminer les divers modes de transfert d'éléments toxiques de l'environnement à la chaîne alimentaire. Le rapport identifie également les organismes les plus appropriés à une surveillance biologique future dans la région à l'étude et dans d'autres écosystèmes contaminés par l'arsenic ou le mercure, ou les deux substances.

Distribution de l'arsenic et du mercure dans la faune benthique des lacs en amont de la rivière Shubenacadie en Nouvelle-Écosse.

J.L. Metcalfe et A. Mudroch

ABSTRACT

The Shubenacadie River headwater lakes are contaminated with arsenic and mercury as a result of past gold mining activities in the area. Recent studies have shown that significant amounts of arsenic are transported from one lake to another, and that levels of mercury up to 2 μg/g have accumulated in some fish species. To investigate the pathways of arsenic and mercury in the ecosystem, zoobenthos were collected from three contaminated lakes and two control lakes in 1984 and analyzed for tissue concentrations of arsenic and mercury by the neutron activation technique. *Chaoborus* sp., *Chironomus* sp. and Oligochaeta were obtained from the profundal zones of the lakes, while the snail, *Helisoma* sp. and the clams, *Anodonta cataracta* and *Elliptio complanata* were collected from the littoral zones. Selected specimens of clams were dissected into individual organs for separate analysis.

Chironomids and oligochaetes, which burrow in the sediment, accumulated significantly higher concentrations of both arsenic (up to 287 μg/g) and mercury (up to 6.4 μg/g) than *Chaoborus* sp., which spend much of their time in the water column. *Helisoma* sp. accumulated higher concentrations of arsenic (up to 350 μg/g) than clams, but lower concentrations of mercury. In clams, an inverse relationship between dry weight and tissue arsenic concentration was observed, suggesting surface adsorption as an important route for arsenic accumulation. Interspecific differences did not appear to be

significant. The organ distribution of arsenic was similar for both species, and was highest (23-41 μg/g) in the viscera. Tissue concentrations of mercury in A. cataracta collected from four different lakes and varying in dry weight from .04-3.24 g fell within a narrow range (<.3-1.0 μg/g), suggesting that this species is capable of regulating mercury to some extent. In contrast, tissue mercury concentrations in E. complanata increased with increasing dry weight, to a maximum of 4.6 μg/g. Based on organ analyses, concentrations of mercury in E. complanata (1.5-6.1 μg/g) were up to ten times higher than in A. cataracta (.5-.6 μg/g). Mercury was evenly distributed throughout the organs of A. cataracta, but in E. complanata levels were significantly lower in the muscle than in the mantle, gills, or viscera. A direct relationship between total mercury body burden and dry weight was observed for both species, indicating an absorptive route for mercury uptake by clams.

Significant site to site differences in arsenic and mercury contamination of the biota were apparent. However, relationships between concentrations of these elements in the organisms and in various components of their environment (water, sediment, suspended solids) were complex and remain unclear at present.

RÉSUMÉ

Les lacs en amont de la rivière Shubenacadie ont été contaminés par de l'arsenic et du mercure libérés lors de l'exploitation de mines d'or dans la région. Des études récentes démontrent que de grandes quantités d'arsenic sont transportées d'un lac à l'autre et que l'accumulation de mercure dans certaines espèces de poissons avait atteint jusqu'à 2 ug/g. En 1984, afin de déterminer les voies d'accès de l'arsenic et du mercure dans l'écosystème, on a prélevé des spécimens de la faune benthique dans trois lacs contaminés et dans deux lacs témoins; les échantillons ont ensuite été analysés selon la technique d'activation des neutrons, afin de déterminer la concentration d'arsenic et de mercure dans les tissus. Dans les zones profondes des lacs, on a prélevé des Chaoborus sp., des Chironomus sp. et des oligochètes et dans les zones littorales, on a récolté le gastéropode Helisoma sp. et les bivalves Anodonta cataracta et Elliptio companata. Certains spécimens de bivalves ont été sélectionnés, puis disséqués, afin d'en analyser individuellement chaque organe.

On a découvert que les chironomides et les oligochètes, qui vivent enfouis dans les sédiments, concentraient des quantités considérablement plus élevées d'arsenic (jusqu'à 287 ug/g) et de mercure (jusqu'à 6,4 ug/g) que les Chaoborus sp., qui passent la plus grande partie de leur vie dans la tranche d'eau. De plus, l'étude a révélé que chez Helisoma sp. l'arsenic s'accumulait en plus grandes quantités (jusqu'à 350 ug/g) que chez les bivalves, et le mercure, en moins grandes quantités. On a constaté chez les bivalves un rapport inversement proportionnel entre le poids sec des spécimens et la concentration d'arsenic dans les tissus, ce qui laisse penser que l'adsorption de surface joue un grand rôle dans l'accumulation de l'arsenic. Les différences au sein de mêmes espèces ne semblent pas avoir d'importance significative. On a noté que la distribution de l'arsenic dans les organes était semblable chez les deux espèces; le produit semble se concentrer surtout dans la masse viscérale (23 à 41 ug/g). On a découvert que la concentration de mercure dans les tissus de A. cataracta provenant de quatre lacs différents, et dont le poids sec allait de 0,04 à 3,24 g, variait faiblement (0,3 à 1,0 ug/g), ce qui laisse croire que les spécimens de cette espèce sont en mesure de régulariser le mercure jusqu'à un certain point. On a par contre remarqué que la concentration de mercure dans les tissus de E. complanata augmentait jusqu'à un maximum de 4,6 ug/g de façon proportionnelle au poids sec de l'animal. En se basant sur des analyses d'organes, on a noté que la concentration de mercure dans E. complanata (1,5 à 6,1 ug/g) était jusqu'à dix fois plus élevée que dans A. cataracta (0,5 à 0,6 ug/g). Chez A. cataracta, le mercure était distribué également dans les organes; par contre, le mercure était considérablement moins concentré dans les muscles de E. complanata que dans son manteau, ses branchies et sa masse viscérale. On a observé chez les deux espèces une relation directe entre la charge corporelle de mercure total et le poids sec, ce qui semble indiquer que la voie d'accès du mercure chez les bivalves est l'absorption.

On a noté des différences significatives d'un site à l'autre dans la contamination des biotopes par l'arsenic et le mercure. Toutefois, les relations entre la concentration de ces substances toxiques dans les organismes et dans les divers éléments de leur environnement (eau, sédiments, solides en suspension) sont complexes et encore imprécises.

Distribution de l'arsenic et du mercure dans la faune benthique des lacs en amont de la rivière Shubenacadie en Nouvelle-Écosse.

J.L. Metcalfe et A. Mudroch

INTRODUCTION

Gold mining operations in the upper Shubenacadie River drainage basin, Nova Scotia, generated large quantities of wastes containing arsenic and mercury. The arsenic occurs naturally in gold bearing ores and was released by grinding and milling of the rock and by further weathering of the milling tailings. The mercury was used in the amalgamation process to extract the gold from the ground ore. During a study carried out in 1977, it was found that bottom sediments of four of the Shubenacadie River headwater lakes contained a significant concentration of mercury and arsenic. The results suggested that industrial and urban development increased the input of material into the lakes during the past sixty years and disturbed some of the waste material which was further eroded and deposited on the bottom of the lakes (Mudroch and Sandilands, 1978).

A joint federal-provincial study undertaken in 1983-84 evaluated the ecological sensitivity and trophic status of several Shubenacadie River headwater lakes, quantified the transport of mercury and arsenic through the chain of lakes and investigated the effects of the mine wastes on the water quality of the lakes. Results of the study also showed accumulation of mercury and arsenic in fish (Eaton and Clair, 1985). The concentration of mercury in certain fish species exceeded the recommended level for human consumption (i.e. 0.5 mg/kg).

Objectives of the present study were to investigate the species composition of the benthic population in the lakes and the distribution and pathways of arsenic and mercury within the food chain. This report summarizes the results obtained during the first year of the study.

MATERIALS AND METHODS

FIELD METHODS

Biota Sampling

Eleven sites in the Shubenacadie River headwater lakes basin were sampled in 1984. They included five profundal and six littoral sites, which are shown in Figure 1. Three Mile Lake, which is situated upstream of the source of contamination, was included as a control. Sampling was conducted on two occasions: June 19-21 and July 31-August 1.

To familiarize ourselves with the benthic communities in the lakes, we collected a wide range of organisms from all of the deep sites and four of the nearshore sites in June. Deep water benthos were collected from a boat by means of a 23cm x 23cm Ekman dredge (sampled area = .05m^2/dredge). Three dredges were taken at each site

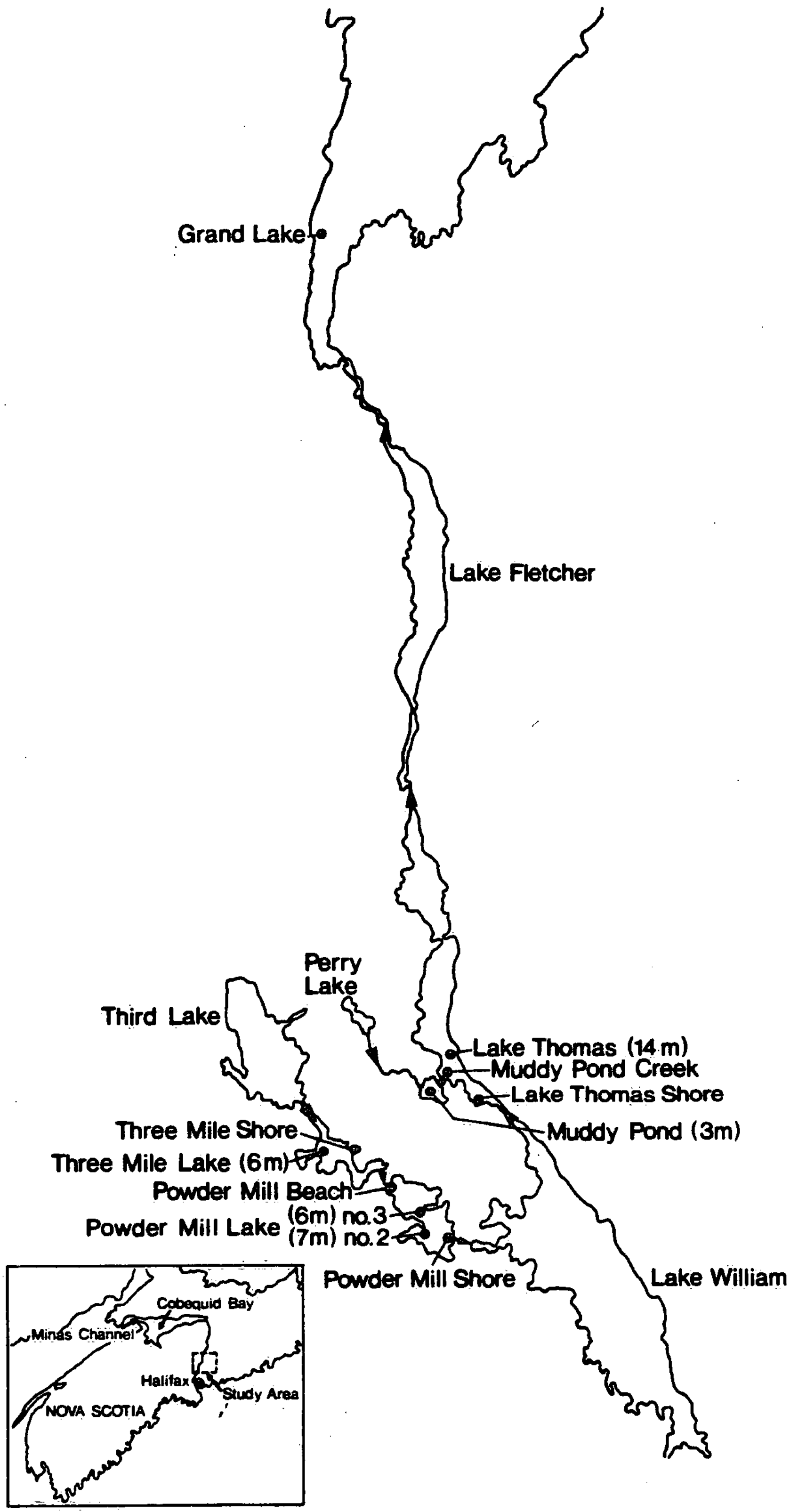

Figure 1 Profundal and littoral sites sampled in 1984. Depths of profundal sites are shown in brackets.

with the exception of Lake Thomas, where four dredges were taken. Sediment was deposited into a large cooler and transported to shore, where it was sieved and rinsed through a 700 µm mesh sieving tub. Retained organisms and debris were transferred to a large plastic jug with fresh lake water and kept cool until they could be stored in a refrigerator at 4°C. Sorting of the samples was done later the same day or the following day, to ensure that organisms were alive and in good condition. Biota samples for contaminant analysis were stored frozen in a small amount of lake water in a whirl-pac bag. Type specimens were preserved in 10% buffered formalin for later identification.

Nearshore collections were obtained from Three Mile Shore, Powder Mill Beach, Powder Mill Shore and Lake Thomas Shore, and consisted of organisms hand-picked from the substrate to a depth of about .5m. Clams were frozen whole on the day they were collected. A week later in the laboratory they were thawed, shucked, and the soft parts freeze dried and stored for quantitative determination of arsenic and mercury. Each sample consisted of 1-20 specimens from a particular site. Species were not separated. Shells were retained for species identification, and possibly for aging and contaminant analysis at a later date. Valve lengths and shell weights were recorded for each of the 29 specimens collected. Snails and fingernail clams were left whole for analysis, that is, their shells were not removed prior to freeze drying.

Based on the June collections, we decided to sample only for clams in August. A total of 82 specimens were obtained from Powder Mill Beach, Lake Thomas Shore, Muddy Pond Creek and Grand Lake. The latter site was chosen as a "background" location, as no clams could be found at the Three Mile Shore site. Clams were sorted into groups according to species. Four to six specimens within each group were shucked and combined, then frozen for storage prior to analysis. Three groups of large clams were dissected into four parts, namely, muscle (foot and adductors), mantle, gills and viscera (stomach, liver, gonads, intestines, etc.) for separate analysis. Shells were retained and processed as per the June specimens.

Water, Bottom Sediment, and Suspended Sediment Sampling

Water, bottom sediment and suspended sediment were intensively sampled in 1983 during a comprehensive study of the distribution of arsenic (As) and mercury (Hg) contamination in the Shubenacadie River headwater lakes (Mudroch and Clair, 1985). Therefore, it was not considered necessary to repeat sampling of these components in 1984.

Water was sampled from the lakes and connecting streams in April, June, August and November, 1983. Stream sampling was done from the banks, while lake water was sampled using a 2 L van Dorn bottle. The sampling depths chosen were based on the lakes' thermal profiles, with a sample being taken in the epilimnion, one in the thermocline and another in the hypolimnion, 1.5 m from the bottom. In some cases, where the thermal profile was complex, extra samples were taken for better water quality coverage. In April and November, when lakes were isothermal, samples were taken one meter below the surface, midway through the column and one meter from the bottom. Sample preservation was done according to Inland Waters Directorate, Water Quality Branch (1979).

Suspended solids were sampled from the connecting streams in April, August and November, 1983. About 3000 L of water were pumped from each stream and processed through a Westphalia continuous flow separator at a speed of 4 L/min. Collected particles were freeze dried, weighed and homogenized in preparation for analysis.

Several of our littoral biota sampling sites were located adjacent to connecting streams, and were believed to be more influenced by conditions in these streams than by those in the open lake. Therefore, water and suspended sediment values for As and Hg reported for the following sites are actually from their adjacent streams:

Site	Adjacent Stream
Powder Mill Beach	Three Mile Lake to Powder Mill Lake
Powder Mill Shore	Powder Mill Lake to Lake William
Muddy Pond Creek	Muddy Pond to Lake Thomas

Grand Lake was not sampled in either year, and suspended sediment values for the Lake Thomas Shore site are not available because there is no stream nearby.

Bottom sediment was sampled with a lightweight corer (Williams and Pashley, 1979) at the deepest points in Muddy Pond, Lake Thomas, Three Mile Lake and Powder Mill Lake. The first three locations coincided with our profundal biota sampling sites. The deepest point in Powder Mill Lake was near our Powder Mill Lake #3 biota sampling site, but was about 7 m deeper. Each sediment core was extruded and subdivided into 1 cm sections. The subsections were freeze dried and ground to 149 µm particle size for analysis.

Surface sediment grab samples were obtained from Powder Mill Beach and Grand Lake only, in August, 1984. The top 10 cm were sampled with a plastic scoop and stored at 4°C in plastic bags. For the Powder Mill Beach sample only, pore water was separated by centrifuging the sediment at 4°C at 15,000 RPM for 30 min. The separated water was filtered through a Whatman 44 filter paper, and the remaining sediment was freeze dried in preparation for analysis. Similar samples could not be obtained from the Powder Mill Shore and Lake Thomas Shore sites because they were rocky. The Muddy Pond Creek site was sandy, but no sample was collected.

ANALYTICAL METHODS

Water samples were analyzed for As and Hg according to the method described by Inland Waters Directorate, Water Quality Branch (1979). Arsenic in bottom and suspended sediment samples was determined by neutron activation and Hg by flameless atomic absorption spectrometry.

RESULTS AND DISCUSSION

DESCRIPTION OF THE BENTHIC COMMUNITIES IN THE LAKES

A list of all biota samples collected in 1984, including numbers of individuals and dry weights per sample, are presented in Tables 1, 2 and 3. Profundal sites yielded relatively little biomass; in many cases samples were of insufficient dry weight for analysis. This paucity of organisms may be partly due to season, as many aquatic insects would have reached the adult stage by mid-June. However, even the populations of Oligochaeta (aquatic worms), which are not subject to extreme seasonal fluctuations in numbers, were very low. Thus, the deep zones of the lakes appear to be unproductive. These zones are dominated by *Chaoborus* sp. (phantom midges) and *Chironomus* sp. (bloodworms). The relative abundance of these two organisms is often used to classify and compare lakes. As oxygen is depleted, *Chaoborus*

TABLE 1 Biota samples collected from Profundal Sites - June, 1984

Organism	Three Mile Lake		Powder Mill Lake #2		Powder Mill Lake #3		Muddy Pond		Lake Thomas	
	#indiv.	dry wgt.(g)	#indiv.	dry wgt.(g)	#indiv.	dry wgt.(g)	#indiv.	dry wgt.(g)	#indiv.	dry wgt.(g)
Oligochaeta			45	.0968					NC	.1353
Chaoborus sp.	174	.0548	174	.049	18	(.0057)	333	.0949	NC	(.0348)
Chironomus sp.	83	.1028	99	.1064	3	(.0030)			4	(.0060)
Other Chironomids			120	(.0163)	46	(.0128)				
Algal balls	5	(.0319)	12	(.0039)	NC	(.0047)				

Table 2. Biota samples collected from Littoral Sites - June, 1984

Organism	Three Mile Shore		Powder Mill Beach		Powder Mill Shore		Lake Thomas Shore	
	#indiv.	dry wgt.(g)	#indiv.	dry wgt.(g)	#indiv.	dry wgt.(g)	#indiv.	dry wgt.(g)
Helisoma sp.			58	2.5	40	1.6	38	1.2
A. cataracta (small)					1	.7052		
A. cataracta (med.)					4	3.7970		
A. cataracta (very large)					1	3.2409		
A. cataracta & *E. complanata*							20	31.50
A. cataracta & *A. undulata*			3	1.9161				
Hydropsychidae					150	.463		
Stenonema sp.	22	(.0350)						
Musculium sp.	27	(.0843)			22	(.0780)		

*NC = Not counted. Values in brackets are for samples too small to be analyzed.

Table 3 Biota samples collected from Littoral Sites - August, 1984

Organism	Grand Lake		Powder Mill Beach		Muddy Pond Creek		Lake Thomas Shore	
	#indiv.	dry wgt.(g)	#indiv.	dry wgt.(g)	#indiv.	dry wgt.(g)	#indiv.	dry wgt.(g)
A. cataracta (very small)			5	.20	6	1.3	6	1.0
			6	1.1				
A. cataracta (small)							4	2.93
A. cataracta (medium)			6	7.34			4	4.2
A. cataracta (large)	4	6.17	4	7.1			4	6.35*
A. cataracta (very large)			4	11.47*				
E. complanata (small)			5	4.81	1	.5		
E. complanata (medium)							5	8.9
E. complanata (large)							4	12.1
							4	12.28*
A. undulata (small)			5	.91				
A. undulata (large)			5	1.71				

* These specimens were dissected into organs.

replaces Chironomus. The presence of other species of chironomids, such as in Powder Mill Lake, usually indicates higher oxygen concentrations than in Muddy Pond, for example, where only Chaoborus is present. In fact, dissolved oxygen had already been depleted by June to 0-2 mg/L in Muddy Pond, whereas concentrations in bottom water in the remaining three lakes was still high (8-9 mg/L) (Mudroch and Clair, 1985).

Chaoborus are "sprawlers" by day, that is, they remain on the surface of the sediment; at night they enter the water column to feed on microcrustacea (Merritt and Cummins, 1978). Chironomus are "burrowers" which build tube dwellings in the sediment. Depending on the species, these detritivores are either filter-feeders or collectors. According to Oliver (1971), about 95% of chironomid larvae occur in the upper 10 cm of the substrate and most penetrate only a few centimeters. The depth to which they may burrow is directly related to the oxygen concentration in the overlying water. Oligochaetes are also burrowers, and may tunnel to a depth of 10 cm in the sediment (Brinkhurst and Jamieson, 1971). They are deposit feeders and derive their nutrition from bacteria.

The nearshore zones of the lakes were dominated by the pulmonate snail, Helisoma sp. (F. Planorbidae) and the unionid clam, Anodonta cataracta. A. cataracta was abundant at all sites except Three Mill Shore. Its apparent absence at the latter site may not be real; this was the first site visited and our search was not thorough. Another clam from the same subfamily (Anodontinae), Alasmidonta undulata, was found only at Powder Mill Beach. The unionid clam Elliptio complanata (Subf. Unioninae) was abundant at the Lake Thomas Shore site, and was also present at Powder Mill Beach and Muddy Pond Creek.

The mayfly, Stenonema sp., was quite abundant at Three Mile Shore, although the sample was too small for analysis. The fingernail clam, Musculium sp., was only found at Three Mile Shore and Powder Mill Shore - again the samples were of insufficient dry weight for analysis. Caddisfly larvae of the Family Hydropsychidae were very abundant at the Powder Mill Shore site in the vicinity of the outflow from Powder Mill Lake into the creek which connects it with Lake William. Their presence here is undoubtedly related to the riffle habitat.

LEVELS OF As and Hg IN WATER, BOTTOM SEDIMENT AND SUSPENDED SEDIMENT

Concentrations of As and Hg in the water and in bottom and suspended sediments at each site are presented in Tables 4 and 5. Water concentrations are averages of samples taken at various depths, as described previously. Levels of Hg in the water were never found to be above the detection limit of 0.02 µg/L at any site. Distribution of As and Hg at profundal and littoral sites are discussed separately.

TABLE 4. Profundal sites: Concentrations of As and Hg in the water (as mg/L) and bottom sediment (as µg/g dry weight)

Compartment Analyzed	Three Mile Lake		Powder Mill Lake		Muddy Pond		Lake Thomas	
	As	Hg	As	Hg	As	Hg	As	Hg
Water								
April	.0003	ND	.0014	ND	.0126	ND	.0027	ND
June	<.0002	ND	.0023	ND	.0091	ND	.0037	ND
August	.0006	ND	.0040	ND	.0061	ND	.0045	ND
November	.0003	ND	.0034	ND	.0074	ND	.0038	ND
Bottom Sediment								
0-1 cm	34.3	.44	272.4	38	594.3	3.78	143.3	NS
1-2	29.1	.30	319.9	NS	549.9	3.11	123.2	9.50
2-3	25.2	.37	539.6	36.2	622.6	3.32	135.6	NS
3-4	21.5	.44	945.5	NS	668.3	3.46	137.6	10.60
4-5	21.4	NS	1075.6	NS	727.4	3.46	152.3	NS
5-6	19.1	.22	1007.9	NS	711.4	3.46	157.6	NS
6-7	18.0	NS	1001.6	18.4	709.9	3.49	170.9	NS
7-8	18,4	.34	945.6	NS	676.2	3.78	181.2	9.69
8-9	18.2	NS	778.2	6.8	1417.4	3.92	204.4	NS
9-10	19.1	.20	600.3	4.49	1644.7	3.78	227.5	12.16

NS = Not sampled.
ND = Not detected (<0.02 µg/L).

TABLE 5. Littoral Sites: Concentrations of As and Hg in the water (as mg/L) and suspended sediment (as μg/g dry weight)

Compartment Analyzed	Grand Lake		Powder Mill Beach		Powder Mill Shore		Muddy Pond Creek		Lake Thomas Shore	
	As	Hg	As	Hg	As	Hg	As	Hg	As	Hg
Water										
April	NS	NS	.0002	ND	.0020	ND	.0310	ND	.0027	ND
June	NS	NS	.0011	ND	.0020	ND	.0470	ND	.0037	ND
August	NS	NS	.0041	ND	.0043	ND	.0270	ND	.0045	ND
November	NS	NS	.0005	ND	.0046	ND	.0135	ND	.0038	ND
Suspended Sediment										
April	NS	NS	NS	NS	226	.98	681	3.47	NS	
August	NS	NS	319	2.25	377	1.82	1053	15.00		NS
November	NS	NS	288	3.30	610	.83	1818	6.2		
Bottom Sediment	45	NS	1950	5.69	NS	NS	NS	NS	NS	NS
Pore Water	NS	NS	.835	.058	NS	NS	NS	NS	NS	NS

NS = Not sampled.
ND = Not detected (<0.02 μg/L).

Profundal Sites

Based on average concentrations of As in the water, Muddy Pond is the most contaminated site followed by Lake Thomas, Powder Mill Lake and Three Mile Lake, in that order. Relative contamination could be summarized as follows: Muddy Pond = 2.5x Lake Thomas = 1.5x Powder Mill Lake = 7x Three Mile Lake.

Bottom sediment concentrations of As show a slightly different pattern. Based on average concentrations in the top 10 cm, Muddy Pond is still about 30x more contaminated than Three Mile Lake, but Powder Mill Lake now appears to be more contaminated than Lake Thomas. Relative contamination would be: Muddy Pond = Powder Mill Lake = 4.5x Lake Thomas = 7.5x Three Mile Lake. However, the concentration of As in sediment is not homogeneous throughout the top 10 cm in any lake. In Three Mile Lake, levels decreased gradually within the topmost 4 cm of sediment. In contrast, levels in Lake Thomas and Muddy Pond increased with depth. In Powder Mill Lake, the greatest concentration was at about 5 cm depth and then decreased toward the bottom of the core.

The concentration profiles of Hg in the lake sediments differ from those of As. The concentration of Hg is homogeneous to a depth of 10 cm in Lake Thomas and Muddy Pond, and there is only a slight decrease with depth in the Three Mile Lake sediment. However, Hg levels decline rapidly with depth in Powder Mill Lake. Based on average Hg concentrations in the 10 cm cores, relative contamination of the lakes is: Powder Mill Lake = 2x Lake Thomas = 3x Muddy Pond = 11x Three Mile Lake.

Littoral Sites

Relative contamination of the littoral sites, as related to concentrations of As in the water are Muddy Pond Creek = 8x Lake Thomas Shore = Powder Mill Shore = 2x Powder Mill Beach. Grand Lake was not sampled. The concentration of As in suspended sediment was measured at three sites. These are, in order of declining contamination: Muddy Pond Creek = 3x Powder Mill Shore = 1.5x Powder Mill Beach. The concentration of Hg in the suspended sediment was about 3x higher in Muddy Pond Creek than at Powder Mill Beach, which in turn was about 2x more contaminated than Powder Mill Shore. Surface sediment grab samples were obtained from Powder Mill Beach and Grand Lake only. Concentrations of As and Hg were both very high at Powder Mill Beach, in fact, the As value was the highest recorded from any location including the Muddy Pond profundal site. Grand Lake sediment was only slightly more contaminated with As than that of Three Mile Lake.

LEVELS OF As and Hg IN THE BIOTA

Profundal Sites - Arsenic

Concentrations of As in biota collected from the profundal sites are given in Table 6. Despite gaps in the data, it is obvious that the three types of organisms exhibit dramatic differences in their body burdens of As. Oligochaetes from Powder Mill Lake accumulated approximately 1.5x as much As as *Chironomus*, which in turn accumulated about 18.5x as much as *Chaoborus*. Similarly, *Chironomus* from Three Mile Lake contained 14x as much As as *Chaoborus* from the same site. These differences may be due to differences in bioaccumulation capacities among the organisms and/or differences in their actual exposure regimes. As previously mentioned, *Chaoborus* larvae spend half their time in the water column and the other half at the sediment-water interface. Their exposure to As is therefore the least of the three organisms. In Powder Mill Lake, the concentrations of As in the sediment to which *Chironomus* were exposed were probably lower than for oligochaetes. This is because worms tend to burrow into the deeper, more contaminated layers. Another factor which should be considered is metal concentrations of the gut contents. Smock (1983a) found that feeding habits greatly influenced whole-body metal concentrations in aquatic insects. Whole body concentrations of five metals decreased as follows: burrowing organisms which ingest

TABLE 6. Tissue concentrations of As and Hg in biota (as µg/g dry weight) from Profundal Sites - June, 1984

Organism	Three Mile Lake		Powder Mill Lake		Muddy Pond		Lake Thomas	
	As	Hg	As	Hg	As	Hg	As	Hg
Oligochaeta			218±11	1.7±.2			287±14	1.9±.3
Chaoborus sp.	.5±.4	<.7	8.4±.5	<.7	75±4	<.7		
Chironomus sp.	7.0±.4	.5±.2	154±8	6.4±.4				

TABLE 7. Tissue concentrations of As and Hg in biota (as µg/g dry weight) from Littoral Sites - June & August, 1984

Organism	Powder Mill Beach		Powder Mill Shore		Muddy Pond Creek		Lake Thomas Shore		Grand Lake	
	As	Hg	As	Hg	As	Hg	As	Hg	As	Hg
Helisoma sp.	350±20	.95±.05	16.1±.8	.15±.03			40±2	.13±.03		
Hydropsychidae			13.2±.7	.5±.2						
A. cataracta & *A. undulata*	86±4	.7±.2								
A. cataracta & *E. complanata*							24±1	1.8±.2		
A. cataracta (very small)	103±5	1.0±.3			12.7±.7	.8±.2	31±2	.6±.07		
	83±4	.9±.2								
A. cataracta (small)			12.1±.6	<.3			25±1	.6±1		
A. cataracta (medium)	32±2	.6±.99	13.6±.7	.5±.2			21±1	.58±.08		
A. cataracta (large)	21±1	.6±.2					22.7*	.56*	7.2±.4	.5±.2
A. cataracta (very large)	45*	.81*	13.5±.7	.5±.3						
E. complanata (small)	42±2	1.2±.02			23±1	2.9±.2				
E. complanata (medium)							20±1	1.03±.06		
E. complanata (large)							16.2±.8	3.2±.2		
							30.5*	4.6*		
A. undulata (small)	60±3	1.3±.4								
A. undulata (large)	68±3	.8±.2								

* These values are back-calculated from concentrations in separately analyzed organs.

sediment > filter feeders > detritivores and herbivores > carnivores and surface feeders. Our data display the same trend: oligochaetes (burrower) > Chironomus (detritivore) > Chaoborus (carnivore). However, Smock (1983a) also found that the proportion of the whole-body burden of a metal that is associated with gut contents was significant and varied with feeding habits. These proportions were 64-88% for burrowers, 46-72% for filter feeders and detritivores, and 24-33% for carnivores. In our study, the organisms may have had time to partially clear their guts before they were frozen for analysis. However, we are unable to determine whether the As was primarily associated with the integument, body tissues, or gut contents. It should also be noted that dipteran larvae, including Chaoborus and Chironomus, undergo three to four molts prior to pupation. Namminga and Wilhm (1977) suggested molting as a route for the elimination of adsorbed zinc from chironomid larvae.

Our results suggest that biota from Three Mile Lake are by far the least contaminated with As. Based on the 75 µg/g value for Chaoborus from Muddy Pond, biota here may be the most contaminated. For Chaoborus, there is an excellent direct relationship between concentration in the organism and the water (r = +.99; Fig. 2). There is also a reasonably good correlation (r = +.94) with levels in the top layer of sediment. As expected, correlation with mean As concentration to a depth of 10 cm was poor (r = +.65). There are not enough data points to determine these relationships for bloodworms or oligochaetes.

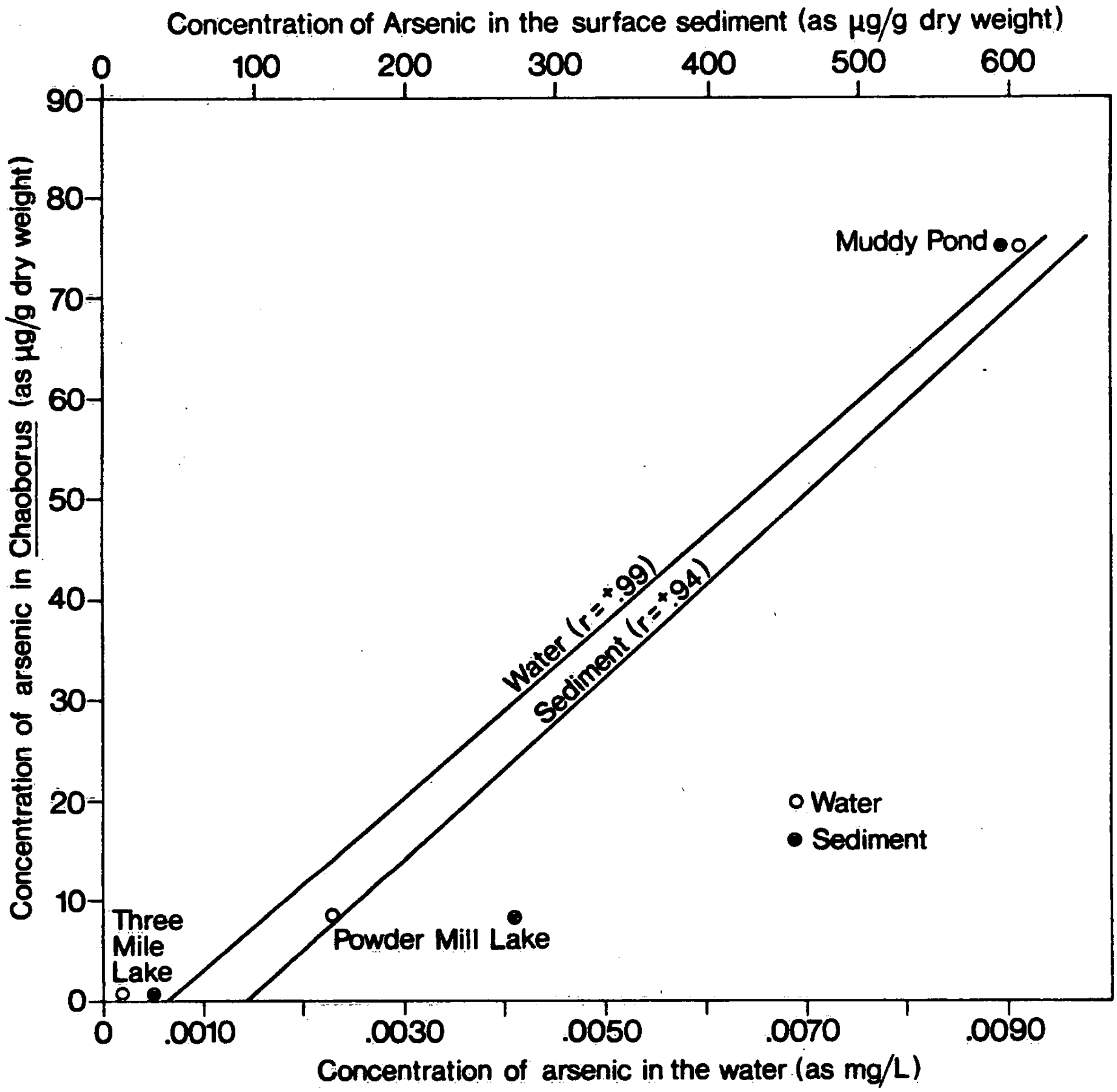

Figure 2 Concentrations of arsenic in Chaoborus, as related to concentrations of arsenic in the water and surface sediment.

Organisms do not accumulate As above levels in the sediment. In fact, concentrations in benthos ranged from 1-30% of sediment values. The exception was Lake Thomas oligochaetes which concentrated As to levels 80% higher than in the surrounding sediment. It is noteworthy that oligochaetes from this site lived in sediments which were 20% as contaminated as those from Powder Mill Lake, yet worms from both sites accumulated similar body burdens of As. It may be that the animals' tissues become saturated at concentrations in the 200 - 300 μg/g range. This translates into a maximum body burden of about .5 - .6 μg per worm.

Profundal Sites - Mercury

Concentrations of Hg in biota collected from the profundal sites are given in Table 6. The major trends are similar to those for As, that is, Chaoborus appears to accumulate the least Hg and Three Mile Lake biota are the least contaminated with Hg. It appears that Chironomus from Powder Mill Lake have a higher bioaccumulation capacity for Hg than oligochaetes. However, according to Table 4, Hg concentrations decline rapidly with sediment depth at this site. In fact, the concentration of Hg in the 10 cm sediment layer is only 10% of that in the surface layer. Therefore, oligochaetes were likely exposed to a less contaminated environment than Chironomus. How much less depends on the amount of time the worms spend in the deeper versus the shallower layers.

The relationships between levels of Hg in Chaoborus and those in the water or sediment cannot be determined because concentrations in both Chaoborus and water were near or below the limits of detection at all sites. However, because residues of Hg in Chaoborus remain very low despite differences of 1-2 orders of magnitude in sediments from the various lakes, uptake from the sediment does not appear to be an important route for this organism. In contrast, Chironomus from Powder Mill Lake showed a 13-fold increase in tissue Hg concentration in response to a 95-fold increase in sediment loading over samples from Three Mile Lake. Levels of Hg in oligochaetes from Lake Thomas and Powder Mill Lakes were similar.

It is difficult to compare the magnitude of accumulation of As with that of Hg, because in any given lake As levels in the sediment were usually 1-2 orders of magnitude higher than Hg levels. However, Chironomus from Three Mile Lake were exposed to similar levels of As as Chironomus from Powder Mill Lake were to Hg (26.3 μg/g As vs. 37.1 μg/g Hg, respectively). This organism accumulated the two metals to similar extents (7.0 μg/g As and 6.4 μg/g Hg).

Littoral Sites - Arsenic

Concentrations of As in biota collected from the littoral sites are presented in Table 7. Levels in the various organs of three samples of dissected clams are given in Table 8. The data in Table 7 show three apparent trends:

TABLE 8. Concentrations of As and Hg (as µg/g dry weight) in organs of *A. cataracta* and *E. complanata* from Lake Thomas Shore and Powder Mill Beach

	Lake Thomas Shore				Powder Mill Beach	
	E. complanata		A. cataracta		A. cataracta	
	As	Hg	As	Hg	As	Hg
Muscle	9.5±0.5	1.5±0.1	8.5±0.5	.6±0.1	17.2±0.9	.9±0.2
Mantle	33.0±3.0	6.1±0.3	16.5±0.9	.5±0.1	158.0±8.0	.7±0.2
Gills	20.0±1.0	4.0±0.4	22.0±1.0	.6±0.2	21.0±1.0	1.2±0.4
Viscera	41.0±2.0	5.3±0.6	28.0±2.0	.6±0.1	23.0±1.0	.7±0.1

Note: Each sample consisted of four specimens.

1) There are site to site differences in contamination of the biota with As.
2) There are interspecific differences in tissue As concentrations.
3) Tissue As concentrations in the soft parts of clams varies with the size of the clam.

From a visual inspection of Table 7, it appears that biota from Powder Mill Beach are the most contaminated with As, followed by Lake Thomas Shore, then Powder Mill Shore and Muddy Pond Creek (which are similar to each other), and finally Grand Lake.

The snail, Helisoma sp., accumulated the highest concentrations of As at all sites where it was collected. Although it is not known whether the As is primarily associated with the soft parts or the shells, whole snails appear to be good indicators of the presence of As in littoral zones. Langston (1984) studied the bioavailability of As in an estuary in England where As concentrations in the sediment and biota were reputed to be among the highest reported in the literature. He determined that accumulation of As by the marine gastropod, Littorina sp., was related to levels of dissolved As in the water and/or in the seaweed on which they graze. We did not find any relationship between As concentrations in Helisoma sp. and that in the unfiltered water, although our study observed concentrations of the same order.

There is an inverse relationship between clam size and tissue As concentration. This trend is most apparent in the data from the two most contaminated sites, Powder Mill Beach and Lake Thomas Shore, which were also the most intensively sampled. Tissue As concentration vs. average dry weight for each size class of clam (the latter calculated from Tables 2 and 3) is plotted for the two sites in Figure 3. The relationship is curvilinear and there may be differences among the species. In order to compare the two sites, a polynomial regression equation was calculated for _A. cataracta_ only. The value for the largest specimens collected from Powder Mill Beach was omitted. It was back-calculated from concentrations in separately analyzed organs, and one of these values was questionably high (Table 8). The two equations are:

Powder Mill Beach: $y = 103 - 89x + 25x^2$; $n = 4$; $r^2 = -.99$.

Lake Thomas Shore: $y = 34 - 20x + 8x^2$; $n = 4$; $r^2 = -.96$.

Where: x = average dry weight in grams for the size class.

y = tissue concentration of As, as µg/g dry weight.

The point at which tissue concentrations level off is similar for the two sites: 24 µg/g for Powder Mill Beach and 22 µg/g for Lake Thomas shore. This exponential decrease in concentration with increasing organism size was observed by Smock (1983b) in his work on metal accumulation by aquatic insects. He suggests that this relationship indicates surface adsorption as an important mode for accumulation. Watling and Watling (1983) also reported higher levels of nine different heavy metals in smaller individuals for both clams and snails from the South African coast. Returning to the present study, if As loadings are converted from tissue concentration to total

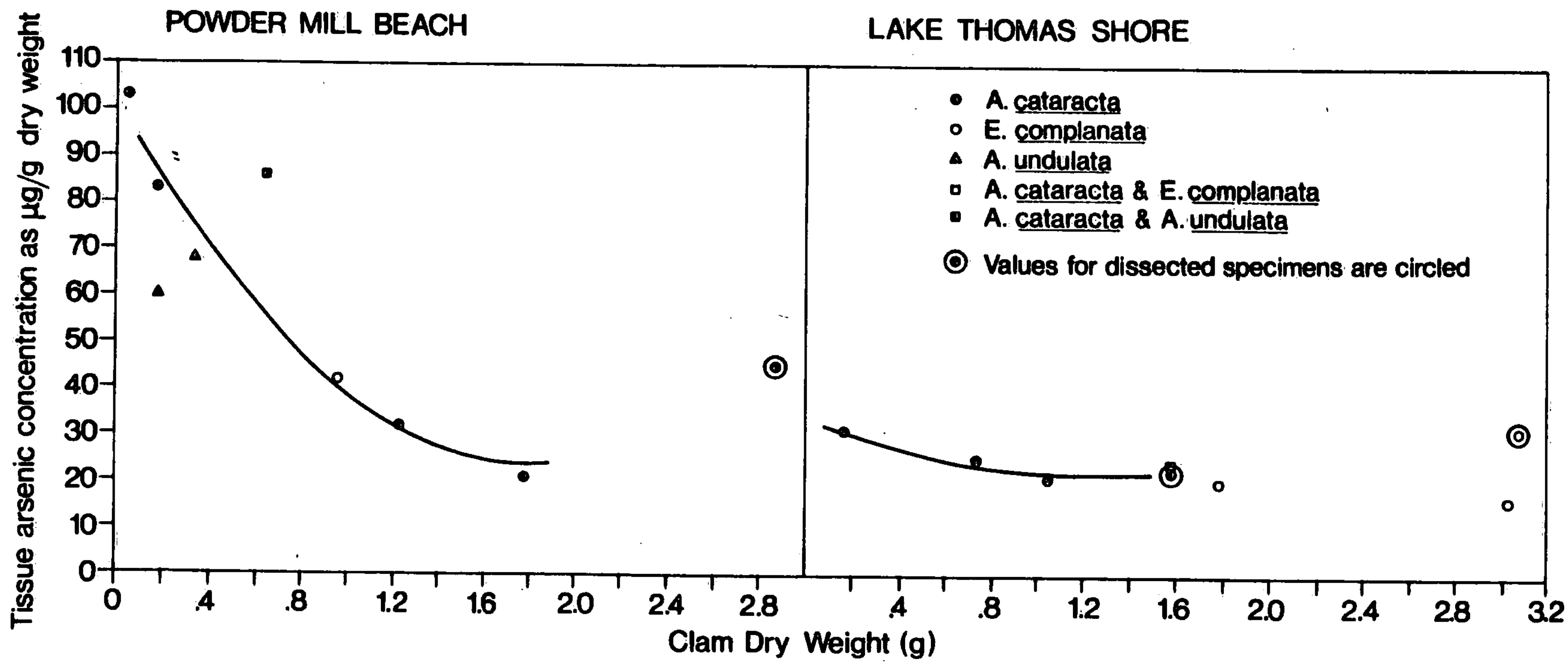

Figure 3 Relationship between tissue arsenic concentration and dry weight for clams from Powder Mill Beach and Lake Thomas Shore.

content, smaller clams naturally contain lesser amounts of As (Fig. 4). However, it appears that saturation of the binding sites for As occurs at between 36 and 40 µg. In fact, there are six values in this range for clams weighing between .96 and 1.78 g dry weight from both sites. Langston (1984) also reported tissue saturation at high As exposures in the marine bivalve Scrobicularia plana. For unknown reasons, this relationship does not hold for very large clams, especially those which had been dissected. Price and Knight (1978) noted that arsenic data for molluscs are rare, and concluded from their study on residues in clams from the Mississippi River watershed that molluscs do not accumulate As. Our results demonstrate otherwise, however, levels in both sediments and biota were one to two orders of magnitude higher in the Shubenacadie River watershed.

Interspecific differences in As accumulation cannot be demonstrated with the data available. However, at Muddy Pond Creek, small E. complanata accumulated more As than very small A. cataracta. Also, large E. complanata from Lake Thomas Shore accumulated somewhat greater concentrations of As in their organs than A. cataracta from the same site (Table 8). Unfortunately, they were not of comparable size. The results of the organ analyses suggest that concentrations of As are lowest in the muscle and highest in the viscera (Table 8). We were unable to locate any information in the literature on organ distribution of As in clams. However, Anderson (1977) reported that concentrations of Cd, Cu, Pb and Zn in two species of Anodontinae were

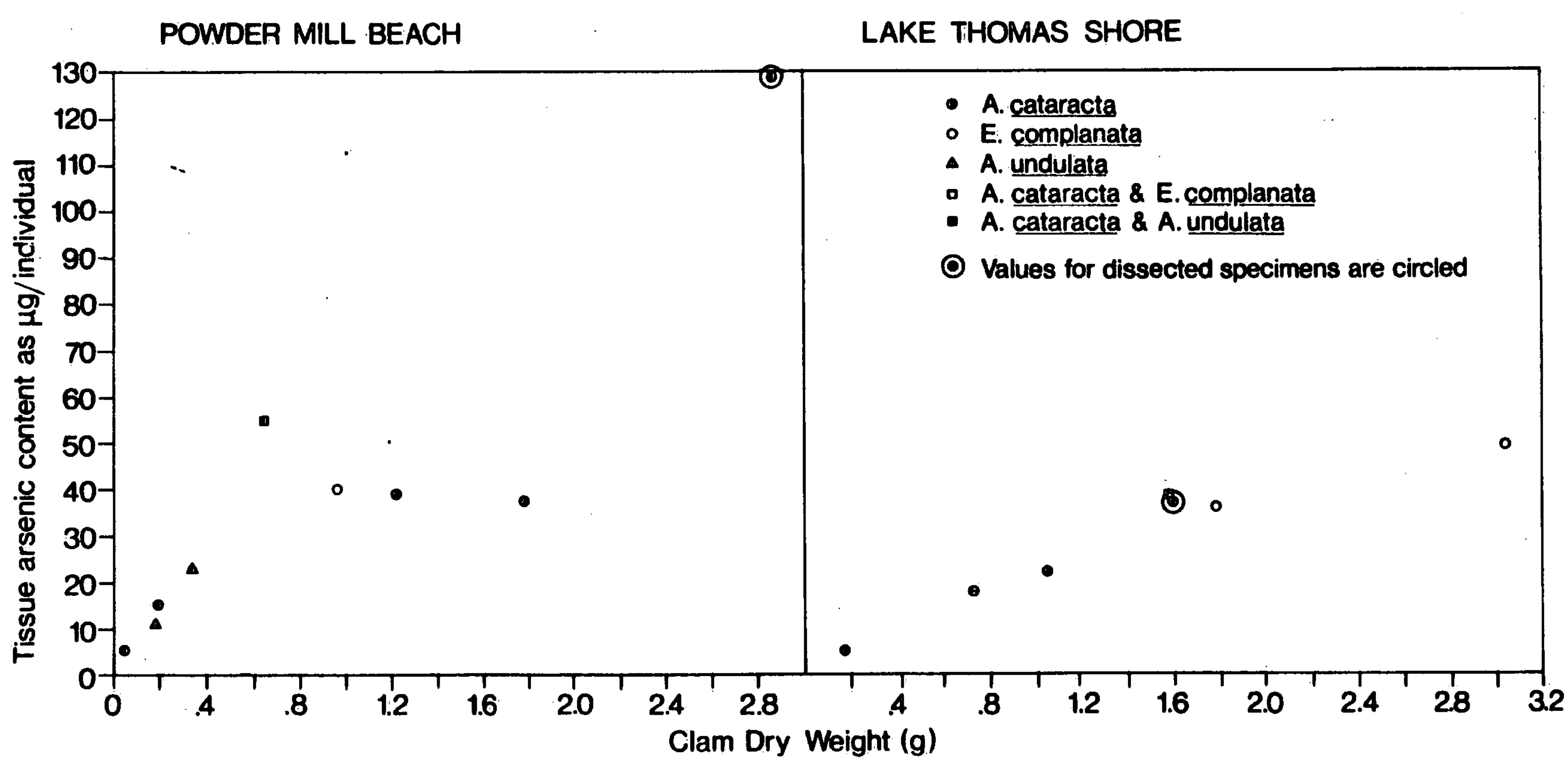

Figure 4 Relationship between tissue arsenic content and dry weight for clams from Powder Mill Beach and Lake Thomas Shore.

highest in the gills, moderate in the viscera, and very low in the muscle.

In order to compare the relative contamination of biota from the five littoral sites, the observed tissue concentrations in clams from Powder Mill Shore, Muddy Pond Creek and Grand Lake were compared with concentrations that would be expected in clams of the same size from Powder Mill Beach and Lake Thomas Shore. Expected values were calculated from the polynomial regression equations presented earlier. According to Table 9, clams from all three sites are less contaminated than those from Lake Thomas Shore and much less contaminated than those from Powder Mill Beach. It is difficult to compare the three sites with each other, but Grand Lake is probably the least contaminated.

One of the most striking findings is that concentrations of As in the biota are not related to concentrations in the water or suspended sediment. For example, Muddy Pond Creek had by far the highest concentrations of As in both water and suspended sediment, yet clams here were relatively uncontaminated. Furthermore, the Powder Mill Beach and Powder Mill Shore sites were similarly contaminated with respect to water and suspended sediment, but clams from Powder Mill Beach were much more contaminated.

Levels of As accumulated by biota may be related to levels in the bottom sediment. The concentration of As in the sediment at Powder Mill Beach was 1950 µg/g, as compared with 45 µg/g at Grand Lake. Biota from Powder Mill Beach were indeed more contaminated.

TABLE 9. Comparison of observed As concentrations in clams from Powder Mill Shore, Muddy Pond Creek and Grand Lake, as compared with expected concentrations in clams of the same size from Powder Mill Beach and Lake Thomas Shore

Site	Species	Clam Dry Weight (g)	Observed As Conc'n (μg/g)	Expected As Concentration (μg/g)	
				Powder Mill Beach	Lake Thomas Shore
Powder Mill Shore	*A. cataracta*	.71	12.1	52	24
	A. cataracta	.95	13.6	41	22
	A. cataracta	3.24	13.5	*	*
Muddy Pond Creek	*A. cataracta*	.22	12.7	85	30
	E. complanata	.50	23.0	65	26
Grand Lake	*A. cataracta*	1.54	7.2	25	22

*Not calculated; error due to extrapolation considered too large.

Pore water may also be a source of available As; pore water from Powder Mill Beach was highly contaminated (.835 mg/L). According to Tessier et al. (1984), concentrations of metals in tissues of E. complanata collected from a mining area were best related, not to total metal concentrations in the sediment, but rather to the more readily extracted fractions. Differences in As speciation in the sediments at our various sites could therefore be very important in terms of biovailability. Other environmental factors may also influence As uptake. Both Tessier et al. (1984) and Luoma and Bryan (1978) identified iron as having a significant influence on the bioavailability of As. Anoxia has been shown to increase the availability of sediment-bound copper to a burrowing estuarine bivalve (Luoma and Bryan, 1982). Finally, high concentrations of calcium may reduce heavy metal bioaccumulation (Jop and Wojtan, 1982). I would also suggest that habitat differences may be important. The substrate at Powder Mill Shore and Lake Thomas Shore was rocky, and all organisms were either attached to these rocks (snails, caddisfly larvae) or wedged between the rocks (clams). In either case, biota were minimally exposed to the bottom sediment. In contrast, the remaining three sites were sandy beaches. Snails were observed to move about on the surface of the sand, while clams were completely buried with the exception of their siphon openings.

Zaroogian and Hoffman (1982), in a laboratory study on As uptake and loss in the American oyster, found that food (phytoplankton) contributed more to As uptake than seawater As concentrations.

They suggest that inorganic As may be converted to organo arsenic compounds by phytoplankton, and that these compounds would be readily excreted by the clams. This may account for the high concentrations of As in the uncleared viscera of our dissected specimens, although the levels are not greatly elevated in relation to other organs.

Littoral Sites - Mercury

Concentrations of Hg in biota collected from the littoral sites are presented in Table 7. Levels in the various organs of dissected clams are given in Table 8. The trends associated with Hg contamination are quite different than those described for As. First of all, biota accumulated Hg to concentrations one to two orders of magnitude lower than As. This would be expected, because Hg loadings in bottom and suspended sediments are proportionately lower than As loadings.

The snail, *Helisoma* sp., appeared to accumulate lower concentrations of Hg than clams. This is the reverse of the situation for As. The relationship between clam size and tissue Hg concentration is less pronounced than for As, while species differences are more dramatic. Tissue Hg concentration vs. average dry weight for each size class of clam is plotted in Figure 5 for Powder Mill Beach and Lake Thomas Shore. The relationship appears to be insignificant for small clams, most of which are *A. cataracta*. In fact, concentrations of Hg in 14 samples of *A. cataracta* collected from all five

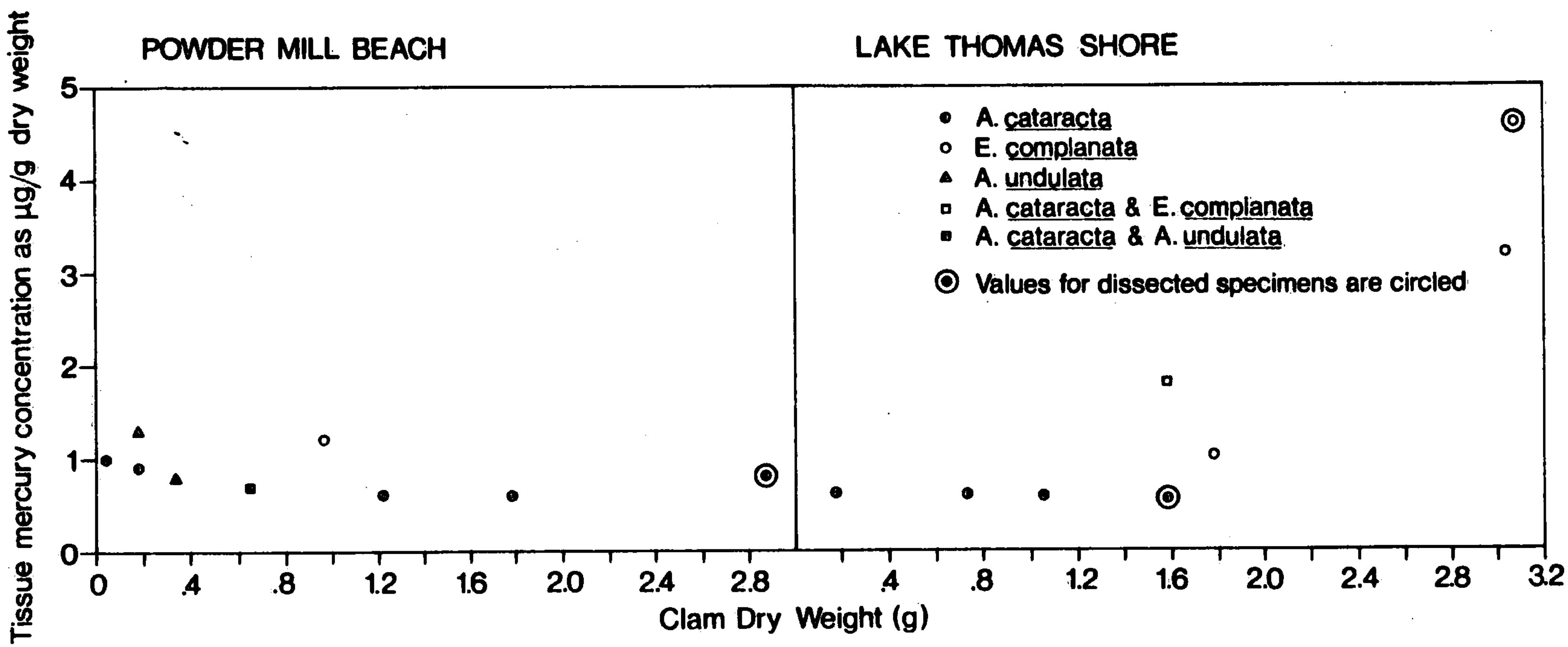

Figure 5 Relationship between tissue mercury concentration and dry weight for clams from Powder Mill Beach and Lake Thomas Shore.

sites fluctuated within a very narrow range (<.3 to 1.0 μg/g) despite a wide variation in size (.04 to 3.24 g). Manly and George (1977) observed the same phenomenon among similarly-contaminated (.1 to 2.0 μg/g dry weight) specimens of Anodonta anatina from the River Thames in England. They also found that Hg concentration decreased with increasing body weight in the more highly contaminated (2 - 11 μg/g) individuals, and concluded that body levels of Hg are moderately well regulated by A. anatina. This is clearly not the case for E. complanata in the present study. Large specimens of this species from Lake Thomas Shore demonstrated an exponential increase in Hg concentration with increasing organism size (Fig. 5).

A plot of total Hg content vs. dry weight (Fig. 6) shows that body burdens of Hg do not reach a plateau, which was the case for As. Rather the relationship appears to be direct and linear for A. cataracta and direct and exponential for E. complanata. These results suggest an absorptive route for Hg uptake. The high bioconcentration potential of E. companata for Hg is further demonstrated by the results for organ analyses (Table 8). Concentrations of Hg in E. complanata from Lake Thomas Shore were 10x higher in the mantle, gills and viscera, and 2x higher in the muscle than in A. cataracta from the same site. These differences may be age-related. One of the E. complanata specimens was found to be ten years old, while the A. cataracta may have been about six years old. This was based on the age of a similar-sized specimen from Muddy Pond Creek (Dr. R.H. Green, personal communication). However, Smith et al. (1975) also noted

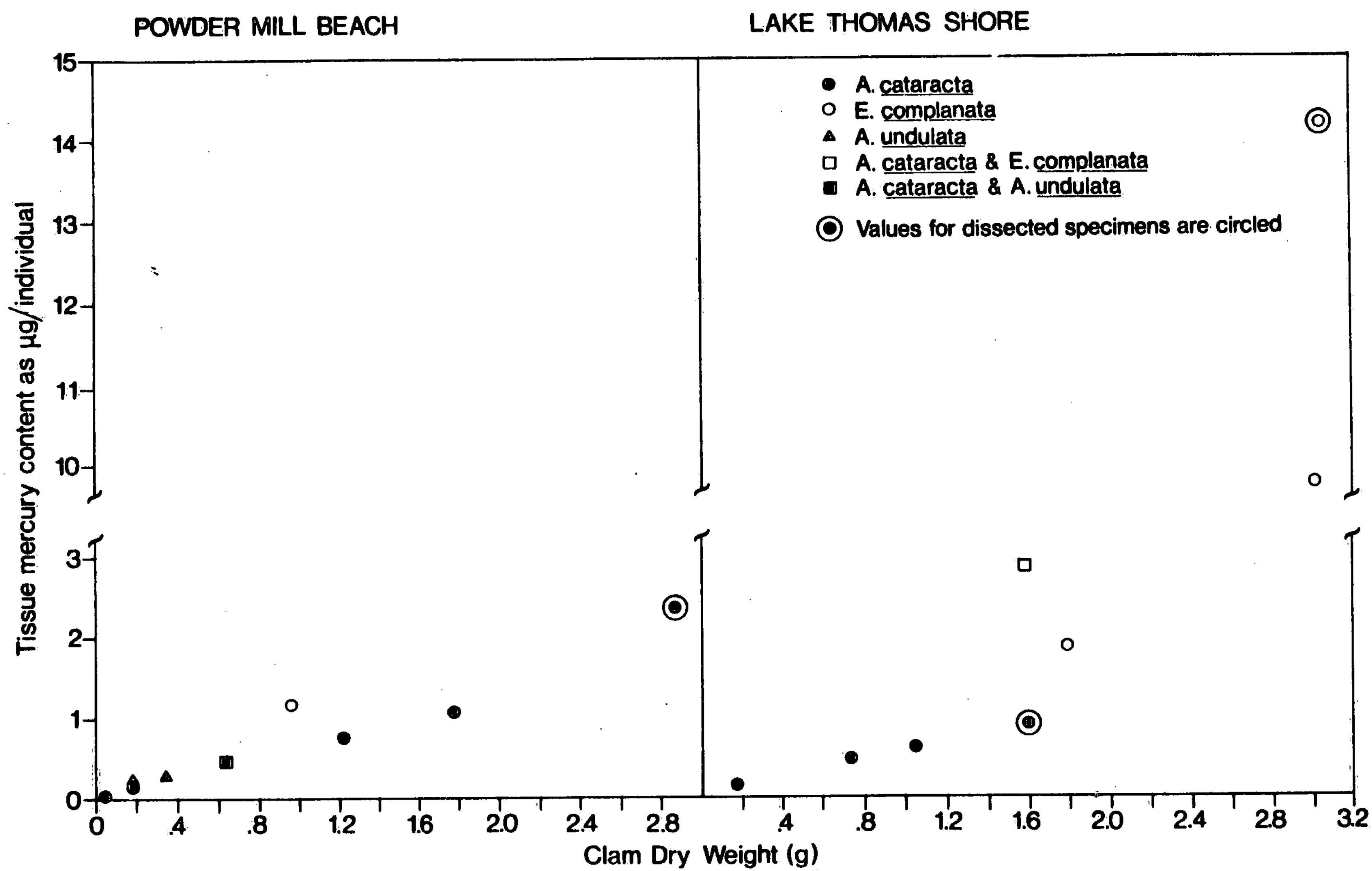

Figure 6 Relationship between tissue mercury content and dry weight for clams from Powder Mill Beach and Lake Thomas Shore.

significant interspecific differences in mercury uptake by freshwater clams. They found that Anodonta grandis accumulated less mercury than either Lampsilis radiata or Lasmigona complanata.

Mercury was found to be evenly distributed among the organs of A. cataracta (Table 8). Supportive evidence is provided by Manly and George (1977), where apart from appreciably higher concentrations in the kidneys, the levels of Hg in seven other organs of A. anatina were remarkably similar. Our results for E. complanata are contradictory. For this species, at least, the foot and adductor muscles accumulated significantly less Hg than other organs.

SUMMARY

Zoobenthos from the Shubenacadie River Headwater Lakes are contaminated with arsenic and mercury. Arsenic concentrations in the water, sediment and biota are among the highest reported in the literature, and provide a unique opportunity to assess the distribution and bioavailability of this toxic element. The selection of a suitable bioindicator for monitoring As contamination in freshwater ecosystems is an important aspect of this study.

Chaoborus appear to accumulate As directly from the water. This may also be the case for Hg, as concentrations of this metal in Chaoborus are not related to concentrations in the sediment.

Chironomus and oligochaetes accumulated higher concentrations of both As and Hg than *Chaoborus*, and there is some evidence that the primary route of uptake is from the sediment. Oligochaetes may be more suitable biomonitors than *Chironomus* because their populations are more stable and they do not undergo molting and metamorphosis.

The snail, *Helisoma* sp., appears to be an excellent indicator of As contamination in nearshore zones. Concentrations in snails were not related to concentrations in the water or suspended sediment. They were, however, correlated with concentrations in clams, which suggests a similar route of uptake for both types of molluscs.

There was an inverse relationship between clam size (dry weight) and tissue As concentration. Interspecific differences did not seem to be as important as size. This relationship suggests surface adsorption as an important mode for As accumulation. Clams from Powder Mill Beach were the most contaminated with As, followed by those from Lake Thomas Shore. There is evidence that As loadings at these sites were high enough to cause tissue saturation. Grand Lake clams appeared to be relatively clean. Levels of As in clams did not reflect those in the water and suspended sediment. Uptake via the food or bottom sediment may be more important. Differences in As speciation among the sites must also be considered. Among the various organs, muscle (foot and adductors) accumulated the least As and viscera probably accumulated the most.

The trends associated with Hg uptake by molluscs differ from those described for As. The snail, Helisoma sp., accumulated less Hg than clams. The relationship between clam size and tissue Hg concentration appeared to be insignificant for A. cataracta over a wide range of dry weights. Concentrations of Hg in this species were remarkably similar at all five sites, suggesting that A. cataracta is capable of regulating Hg to some extent under conditions of moderate Hg contamination.

Concentrations of Hg in E. complanata appeared to increase with increasing size. This suggests an absorptive route for Hg uptake. Based on organ analyses, concentrations of Hg in E. complanata were up to ten times greater than in A. cataracta. Unfortunately, the E. complanata specimens were larger and probably older than the A. cataracta. Nevertheless, E. companata has demonstrated potential as a biomonitoring organism for Hg contamination. The shells of this species have been recommended for monitoring purposes along the eastern seaboard (Imlay, 1982).

Significant site to site differences in As and Hg contamination of the biota were apparent. However, relationships between concentrations of these elements in the biota and in various components of their environment remain unclear. The bioavailability of As and Hg depends on their chemical forms, which are determined by such factors as dissolved oxygen concentration, water hardness, and the presence of organic matter and other metals. The route of uptake (via water, food, or sediment) and mode of uptake (adsorption vs. absorption) are also important. The concentrations of these elements in biota ultimately depend on the regulatory capabilities of the organisms themselves. For contaminants which are poorly regulated, age of the organism may be of significance.

This report is based on a preliminary survey of As and Hg levels in zoobenthos from selected sites in the Shubenacadie River headwater lakes. Further work is needed in order to determine the relationships between concentrations of these elements in the biota and in various components of their environment, to identify the most suitable species for biomonitoring purposes, and to describe the extent of contamination in the lake chain.

ACKNOWLEDGEMENTS

We would like to thank Ms. E. Kokotich, Inorganics Section, Environmental Contaminants Division, NWRI, for preparation of the biological samples for analyses and for her valuable assistance in collecting the biota. The assistance of G.A. Bengert, Inorganics Section, Environmental Contaminants Division, and G.D. Bruce and J.E. Tozer, Technical Operations Division, NWRI, in sampling and sorting of the biota is greatly appreciated. Many thanks to Dr. R.H. Green, associate professor, University of Western Ontario, London, Ontario, for verifying the identifications of the clam species and aging several specimens. Finally, we would like to thank Mr. Paul Schwarz, Nova Scotia Department of the Environment, for his assistance with the biota sampling and excellent logistics support.

REFERENCES

Anderson, R.V. 1977. Concentration of cadmium, copper, lead and zinc in six species of freshwater clams. Bull. Environ. Contam. Toxicol. 18(4):492-496.

Brinkhurst, R.O. and B.G.M. Jamieson. 1971. Aquatic oligochaeta of the world. University of Toronto Press, Toronto, 860 pp.

Eaton, P. and T.A. Clair. 1985. Fish contamination in Shubenacadie headwater lakes. In A. Mudroch and T.A. Clair, eds., The impact of past gold mining activities on the Shubenacadie River headwaters ecosystem, p. 146-157.

Imlay, M.J. 1982. Use of shells of freshwater mussels in monitoring heavy metals and environmental stresses: A review. Malacological Review, 15:1-14.

Inland Waters Directorate, Water Quality Branch. 1979. Analytical Methods Manual. Department of the Environment, Ottawa, Ontario.

Jop, K. and K. Wojtan. 1982. Concentrations of cadmium and lead in the body of some macrobenthos species from five streams in Southern Poland. Acta. Hydrobiol. 24(3):197-210.

Langston, W.J. 1984. Availability of arsenic to estuarine and marine organisms: a field and laboratory evaluation. Marine Biology, 80:143-154.

Luoma, S.N. and G.W. Bryan. 1978. Factors controlling the availability of sediment-bound lead to the estuarine bivalve Scrobicularia plana. J. Mar. Biol. Assoc. U.K. 58:793-802.

Luoma, S.N. and G.W. Bryan. 1982. A statistical study of environmental factors controlling concentrations of heavy metals in the burrowing bivalve Scrobicularia plana and the polychaete Nereis diversicolor. Estuarine, Coastal and Shelf Sci. 15:95-108.

Manly, R. and W.O. George. 1977. The occurrence of some heavy metals in populations of the freshwater mussel Anodonta anatina (L.) from the River Thames. Environ. Pollut. 14:139-154.

Merritt, R.W. and K.W. Cummins. 1978. An introduction to the aquatic insects of North America. Kendall/Hunt Publ. Co., Dubuque, Iowa, 441 pp.

Mudroch, A. and T.A. Clair. 1985. The impact of past gold mining activities on the Shubenacadie River headwaters ecosystem.

Mudroch A. and R.G. Sandilands. 1978. Geochemical analyses of Shubenacadie Headwater lakes bottom sediments. Shubenacadie-Stewiacke River Basin Study Group, Technical Report.

Namminga, H. and J. Wilhm. 1977. Heavy metals in water, sediments, and chironomids. J. Water Poll. Control Fed. 49:1725-1731.

Oliver, D.R. 1971. Life history of the chironomidae. Annual Review of Entomology 16:211-230.

Price, R.E. and L.A. Knight, Jr. 1978. Mercury, cadmium, lead and arsenic in sediments, plankton and clams from Lake Washington and Sardis Reservoir, Mississippi, October 1975 - May 1976. Pesticides Monitoring Journal 11(4):182-189.

Smith, A.L., R.H. Green and A.Lutz. 1975. Uptake of mercury by freshwater clams (Family Unionidae). J. Fish. Res. Board Can. 32(8):1297-1303.

Smock, L.A. 1983a. The influence of feeding habits on whole-body metal concentrations in aquatic insects. Freshwater Biology 13:301-311.

Smock, L.A. 1983b. Relationships between metal concentrations and organism size in aquatic insects. Freshwater Biology 13:313-321.

Tessier, A., P.G.C. Campbell, J.C. Auclair and M. Bisson. 1984. Relationships between the partitioning of trace metals in sediments and their accumulation in the tissues of the freshwater mollusc Elliptio complanata in a mining area. Can. J. Fish. Aquat. Sci. 41:1463-1472.

Watling, H.R. and R.J. Watling. 1983. Sandy beach molluscs as possible bioindicators of metal pollution 1. Field survey. Bull. Environ. Contam. Toxicol. 31:331-338.

Williams, J.D.H. and A.E. Pashley. 1979. Lightweight corer designed for sampling very soft sediments. J. Fish. Res. Board. Can. 36:241-246.

Zaroogian, G.E. and G.L. Hoffman. 1982. Arsenic uptake and loss in the American oyster, Crassostrea virginica. Environ. Monitoring & Assessment 1:345-358.