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Cadmium Uptake from Cadmium-Spiked Sediments by Four Freshwater Invertebrates

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In studies of metal contaminated fresh waters and sediments, the unionid bivalve *Elliptio complanata* is commonly used as a bioaccumulator (e.g., Dermott and Lum 1986). However, the use of only single species for accumulation studies may be inappropriate. For example, Bryan et al. (1985) have data for metals that suggest that the optimal accumulator species is different for different metals. Also, the use of *E. complanata* for assessment of contaminated sediments is arguable because of its lifestyle. *E. complanata* orient in substrate with posterior siphons extended above the sediment/water interface. This effectively restricts exposure of the clams to the water column only and not to sediment interstitial water. Tessier et al. (1984) have confirmed that metal levels in *E. complanata* do not necessarily reflect metal levels in lake sediments.

In an attempt to identify other organisms that may be useful for assessing the pollution status of freshwater sediments, cadmium concentrations of four common benthic organisms exposed to cadmium-spiked sediments were examined. Organisms that accumulate cadmium to relatively higher levels are the most useful for analysis and detection. Further, organisms that have body concentrations of cadmium that are more highly correlated with sediment concentrations will also be more useful for assessing the pollution status of specific locations. Because orientation to sediments (i.e., burrowing behavior versus non-burrowing) and feeding guild (i.e., filter feeding *versus* grazing *versus* deposit feeding) are likely to affect movement of contaminants into organisms, the organisms chosen here were selected using these criteria. The benthic organisms used in this study were: (1) *Sphaerium striatinum* (deposit and filter feeding clam; burrower); (2) *Hyalella azteca* (grazing and deposit feeding amphipod; non-burrower); (3) *Physella gyrina* (grazing gastropod; non-burrower); (4) *Stichtochironomus* c.f. *flavicingula* (deposit feeding chironomid; burrower).

Cadmium was chosen because it is accumulated by aquatic organisms such as crustaceans (e.g., Stephenson 1986), insects (e.g., Nehring 1976), and molluscs (Havlik and Marking 1987), and can become toxic to aquatic life (e.g., Fennikoh et al. 1978). Also, anthropogenic sources are known that can accumulate in freshwater and sediments to excessive levels (Moore and Ramamoorthy 1984).

MATERIALS AND METHODS

Physella gyrina, *H. azteca*, *S. flavicingula* and *S. striatinum* were collected from Cox Creek (Waterloo County, Ontario, Canada, 43°34'W 80°28'N) on July 7, 1988. Ten animals of each species were exposed to each of five concentrations of cadmium-spiked sediments for 10 days at 21°C under natural photoperiod, commencing July 8, 1988. Data in Poldoski (1979) suggest that uptake of cadmium in typical benthic invertebrates reaches equilibrium levels in

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the first five days of exposure. The 10 day exposure period should, therefore, provide typical body concentrations for each species under these conditions.

Test containers consisted of 4-L acid-washed, polyethylene beakers. In each container, 200 g of sediments (47% sand, 34% silt, 19% clay, 20% organic matter) was used. Sediment composition was determined according to methods outlined by the Ontario Institute of Pedology (1983).

Sediments were spiked with cadmium solution (Fisher Scientific Co., reference standard solution in dilute nitric acid) to nominal sediment concentrations of 0, 20, 50, 100, and 200 μg Cd/g sediment. These concentrations were selected because they are representative of typical concentrations of cadmium in sediments in industrialized regions of North America (Stephenson and Mackie 1988, Moore and Ramamoorthy 1984). To spike the sediments, cadmium solution was injected directly into the sediments. Total mixing was improved by addition of deionized-distilled water. After air drying the spiked sediments, 4 L of diluted well water (50 mg $CaCO_3$/L) was added to the containers, and allowed to equilibrate with the sediments for 14 d (Chant and Cornett 1988). After this period, the containers were drained and refilled with 4 L of diluted well water (50 mg $CaCO_3$/L).

Following exposure, all animals were removed from the test containers and held in clean test water (no sediment) for 24 h for gut evacuation. Six randomly selected animals of each species and from each test container were analyzed for cadmium using flameless atomic absorption spectrophotometry (Scintrex AAZ-2 with Zeeman background correction). Animals, sediments and water were prepared for analysis following the methods described by Stephenson (1986).

Mollusc shells tend to reflect long-term (years) exposure rather than short term (weeks) exposure (e.g., Dermott and Lum 1986). Shells of *P. gyrina* and *S. striatinum* were, therefore, removed before the soft parts were analyzed for cadmium content. Clams and snails were dissected live, with stainless steel forceps, in 5% nitric acid cleaned watch glasses. The body concentrations of the molluscs, therefore, represent the cadmium content of the soft parts only.

To determine if there were significant differences in cadmium-body concentrations among the species within treatments, analysis of covariance (ACNOVA) was performed on cadmium body concentrations for each treatment. According to Luoma (1983), animal weight influences body concentrations of metals. Body weight was, therefore, used as a covariate. When significant differences in body concentrations among the species were shown, Duncan's multiple range test was used to determine which species had significantly different cadmium concentrations.

To assess the potential of the four species for predicting environmental levels of cadmium, multiple regressions between animal concentrations and water- and sediment-cadmium concentrations were generated. Type II sums of squares describe the amount of variation in the dependent variable that can only be attributed to variation in each of the independent variables alone. Consequently, type II sums of squares were used to test if water- and sediment-cadmium concentrations and body weight could account for significant amounts of variations in animal-cadmium concentrations. These statistical procedures were performed using SAS Institute Inc. (1987) software.

To determine which species could be used to make the most confident predictions of environmental cadmium levels, the mean squared error (MSE) terms from the above models were compared between the four species. Those species with the smallest MSE terms would presumably have body concentrations of cadmium that were the most predictable and, therefore, the most useful for predicting environmental levels of cadmium.

RESULTS AND DISCUSSION

Cadmium concentrations in the sediments ranged from 1.57 to 78.82 μg/g sediment (Table 1). In the container that had no cadmium added, there was a background cadmium concentration of 1.57 μg/g. Cadmium concentrations in the water ranged from 0 to 0.83 μg/L indicating that cadmium was released from the sediments into the water.

Table 1. Cadmium concentrations (μg Cd/g dry weight of body) for four freshwater invertebrates exposed to cadmium-spiked sediments for 10 d.

Initial	Final		Animal Concentrations			
Sediment	Water	Sediment	H. az	S. fl	P. gy	S. st
0	0.00	1.57	0.18[b1] (0.00-0.54)	0.37[b] (0.28-0.43)	0.83[a] (0.42-1.12)	0.92[a] (0.51-1.00)
20	0.17	11.83	0.78[b] (0.54-1.48)	0.94[b] (0.77-1.27)	1.56[a] (0.97-1.93)	1.00[a] (0.60-1.18)
50	0.33	34.72	1.01[a] (0.90-1.15)	1.51[a] (1.07-2.66)	1.61[a] (1.10-3.04)	1.41[a] (0.94-1.95)
100	0.18	60.90	2.07[b] (0.64-3.37)	2.42[b] (1,63-3.59)	4.45[a] (1.19-8.69)	1.26[b] (1.10-1.48)
200	0.83	78.82	4.45[b] (1.94-5.73)	10.25[a] (7.05-17.21)	11.08[a] (7.51-14.20)	5.23[b] (3.45-7.89)

[1] Values are means; ranges are presented in parentheses. The species are: *Hyalella azteca* (H. az); *Stichtochironomus flavicingula* (S. fl); *Physella gyrina* (P. gy); and *Sphaerium striatinum* (S. st). Initial and final concentrations of cadmium in sediments (μg Cd/g dry weight of sediment) and water (μg Cd/L water) are also given. Animal body concentrations in the same row, and with the same letter superscript are not significantly different.

Body concentrations of cadmium were lowest in the amphipod, *H. azteca* (0.18-4.45 μg Cd/g) than the other three species. Body concentrations ranged from 0.37-10.25 μg Cd/g in *S. flavicingula*, from 0.83 to 11.08 μg Cd/g in *P. gyrina*, and from 0.92 to 5.23 μg Cd/g in *S. striatinum*. In the treatment with no cadmium added, *P. gyrina* and *S. striatinum* had the highest body concentrations. This suggests that these two species had higher initial cadmium concentrations prior to the test, and that their body concentrations are probably a function of cadmium levels in the environment they were collected from.

Differences in body concentrations among the four species in treatments with cadmium added suggest that orientation to the sediments, behavior, and physiology were important in determining body concentrations. In the treatment with the highest cadmium levels, the burrowing chironomid, *S. flavicingula*, and the non-burrowing snail, *P. gyrina*, had the highest body concentrations (Table 1). These two species clearly have a greater ability to accumulate cadmium than the other two species. If orientation to the sediment were important in determining body concentrations, then concentrations in *S. flavicingula* and *S. striatinum* would have been the highest. However, *P. gyrina* had the highest concentrations, and individuals of this species were consistently observed grazing along the sides of the containers suggesting that cadmium was accumulated from the water column. Because water concentrations of cadmium were much lower than concentrations in the sediments, either *P. gyrina* has physiological mechanisms that are more highly suited for accumulating cadmium or cadmium in the water was more bioavailable than in the sediments. In contrast, high concentrations of cadmium in the chironomid, *S. flavicingula* were less attributable to the water column, and while this potential route of uptake cannot be excluded, body burdens may be a function of its close proximity to the sediments (due to burrowing), its feeding strategy (consumes detritus), or more suitable physiological mechanisms.

The data indicate that body concentrations of burrowing species are more predictable than non-burrowing species, and that water-cadmium concentrations are important to body concentrations of the two molluscs, *P. gyrina* and *S. striatinum*. *Stichtochironomus flavicingula* and *S. striatinum* had the most predictable body concentrations of the four species tested (Table 2). Cadmium concentrations in individuals of these two species may, therefore, be more useful for predicting environmental concentrations of cadmium.

Mortimer and Kudo (1979) have shown that the orientation of animals relative to the sediment can influence metal concentrations. Throughout the study, *S. flavicingula* were below the surface of the sediment, building cases out of the sediment. *Sphaerium striatinum* were generally located just below the surface of the sediments; some had siphons just visible, and others were completely out of sight. In contrast, the other species had more variable activity patterns. The snails (*P. gyrina*) and the amphipods (*H. azteca*) were usually located in the water column; however, they were occasionally observed on the surface of the sediments.

The more variable cadmium levels in *H. azteca* and *P. gyrina* were probably a result of these two species having a more variable orientation to the sediments. Variability in body concentrations of *H. azteca* and *S. flavicingula* were related to both water- and sediment-cadmium concentrations (Table 2). Neither *P. gyrina* nor *S. striatinum* had variability in body concentrations of cadmium that could be explained by sediment levels. *H. azteca* and *S. flavicingula* may accumulate at least part of their body burdens from the sediments, while *P. gyrina* and *S. striatinum* probably accumulate cadmium from the water column only. Mode of feeding, specifically ingestion of sediments, may influence body concentrations of *H. azteca* and *S. flavicingula*. Both species are detritivorous, a feeding behavior that can increase metal concentrations of aquatic organisms (Luoma 1983).

In summary, of the species tested, *S. flavicingula* and *H. azteca* appear to be useful for monitoring cadmium levels of sediments. *S. flavicingula* appears to be the most useful species for assessing the cadmium levels of sediments, since body levels of this species were related to sediment levels and body concentrations were the most predictable.

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Table 2. Results of ANCOVA to show the relationships between water and sediment cadmium concentrations, and body cadmium concentrations in four freshwater invertebrates.

Species	Source	df	Type II SS	MS	F	P	r^2
Hyalella azteca	water	1	0.163	0.163	8.22	0.009	
	sediment	1	0.107	0.107	5.38	0.029	
	weight	1	0.041	0.041	2.05	0.165	
	error	24	0.478	0.020			
	total	27	1.584				0.699
Stichtochironomus flavicingula	water	1	0.380	0.380	35.29	<0.0001	
	sediment	1	0.039	0.039	3.62	0.069	
	weight	1	0.173	0.173	16.06	0.001	
	error	24	0.258	0.011			
	total	27	2.655				0.903
Physella gyrina	water	1	0.425	0.425	12.15	0.002	
	sediment	1	0.073	0.073	2.09	0.160	
	weight	1	0.024	0.024	0.70		
	error	25	0.875	0.034			
	total	28	2.657				0.671
Sphaerium striatinum	water	1	0.557	0.557	62.35	<0.0001	
	sediment	1	0.020	0.020	2.29	0.143	
	weight	1	0.006	0.006	0.69	0.414	
	error	24	0.214	0.009			
	total	27	1.176				0.818

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