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Biological and Physical Factors Affecting the Body Burden of Organic Contaminants in Freshwater Mussels

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Abstract. Biological and physical factors affecting the body burdens of hexachlorobenzene, octachlorostyrene, and four polychlorobiphenyl (PCB) congeners in freshwater mussels from Lake St. Clair, Ontario, Canada were investigated. Specimens of *Lampsilis radiata* (Barnes) and the non-native *Elliptio complanata* (Lightfoot) were deployed for forty days at four Lake St. Clair sites, to investigate whether the water or the sediment phase represented the primary source of contaminants and to examine the effect of enclosure of the mussels on contaminant uptake. No significant differences in body burdens were detected for any of the compounds between mussels placed in corrals containing uncontaminated sand and those with natural sediment, suggesting the water phase represents the xenobiotic source. Among three enclosure types of varying restriction there were no significant differences in the body burden of each compound indicating the effect of confinement on uptake is minimal. Weak negative correlations between body burden and body length existed for all compounds, although there were no significant differences between the sexes or, with the exception of PCB congener 118, among five indigenous species.

The ability of the soft tissue of freshwater mussels to accumulate levels of toxic compounds far in excess of those in the surrounding water or sediments has been well documented (Bedford *et al.* 1968; Foster and Bates 1978; Adams *et al.* 1981; Hartley and Johnston 1983). Thus, the analysis of these organisms can provide information of greater environmental relevance than studies which examine levels of contaminants in water or sediments. The usefulness of sediment measurements is attenuated, since contaminants bound to the substrate may not be bioavailable and varying concentrations may reflect changes in the sediment's binding properties rather than variation in ambient contaminant loadings (Oliver 1984; Boon *et al.* 1985; McCrea *et al.* 1985). The value of direct analysis of water is limited because contaminant levels are usually below detection limits, and since irregular discharges may go undetected (Curry 1977/78; Kuntz and Chan 1982). By contrast, the body burdens of mussels reflect concentrations integrated over a period of time. The sedentary nature of these organisms results in continual exposure within a specific microhabitat as opposed to fish, which tend to migrate over a much greater distance, or insects, which may emerge during their life cycle. The abundance and wide distribution of several unionid species adds to their general usefulness as biomonitors. Moreover, a single adult provides sufficient tissue to permit analysis for both organic and inorganic contaminants. This eliminates the need to pool samples, allowing for a measure of individual variability. As a result of these advantages, molluscs have been widely used to monitor contaminants (Leard *et al.* 1980; de Kock 1983; Greig and Sennefelder 1985; Duursma *et al.* 1986).

The first efforts employing unionids to monitor toxic compounds in the Great Lakes involved the deployment of caged *Elliptio complanata* at sites in Lake Ontario, and the Niagara, Detroit, and St. Clair Rivers (Curry 1977/78; Kauss *et al.* 1983; Kauss and Hamdy 1985). Pugsley *et al.* (1985) surveyed contaminant levels in natural populations of *Lampsilis radiata* throughout the Huron-Erie corridor. In contrast to the Niagara River where inputs of contaminants occur on the American shore, Kauss and Hamdy (1985) determined that the sources of organic contaminant discharge into the St. Clair River were primarily on the Canadian side. The river shows little horizontal mixing, resulting in a plume of contaminants that hugs the Canadian shoreline of the St. Clair River, and ultimately enters Lake St. Clair via the South Channel. Analysis of natural mussel populations in Lake St. Clair revealed that this plume extended from the St. Clair River delta into the central portion of the lake (Pugsley *et al.* 1985). Modelling studies have supported the biological findings, indicating little horizontal mixing of water in the St. Clair River or of the river plume once it enters the lake (Leach 1980; Ibrahim and McCorquodale 1985). Body burdens in the mussels delineated the contaminant plume much more clearly than did sediment concentrations (Pugsley *et al.* 1985) confirming the value of biological monitors.

While these studies have demonstrated the usefulness of unionids in identifying the source and movement of contaminants, there is a lack of knowledge on the influence of biological parameters (size, age, and sex) on the body burden of molluscs. Although surveys of contaminant levels in mussels and the adjacent sediment have been performed, no

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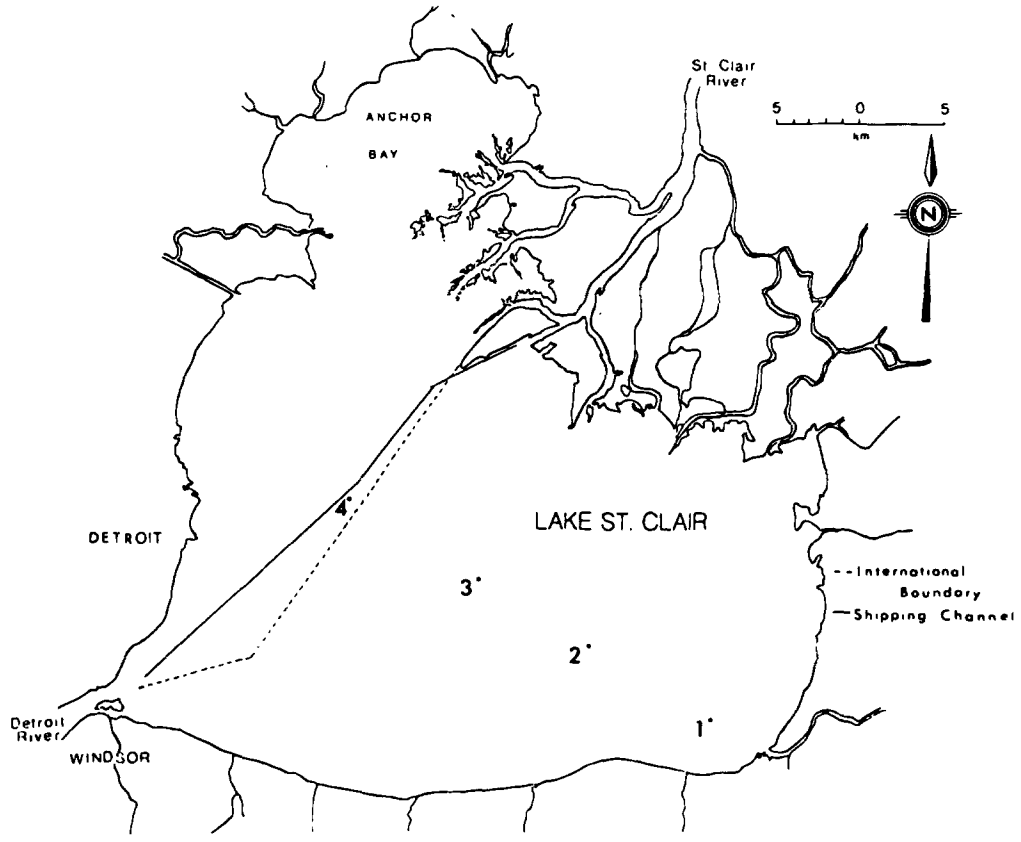

Fig. 1. Location of sampling stations in Lake St. Clair, Canada

studies have directly addressed whether the sediment or water phase is the primary source of organic contaminants accumulated by mussels. Most biomonitoring studies involve holding mussels in enclosures, but there is no information concerning the effect of containment on the body burdens of these organisms. Cage design might, for example, have an indirect effect on contaminant uptake through an alteration of filtration rates (Adams *et al.* 1981).

The goal of this investigation was to examine the role of these factors in determining contaminant burdens in mussels. A sample of native unionids from the contaminant plume of Lake St. Clair was examined to establish the relationship between biological characteristics and body burdens, and differences in contaminant levels among several species. To investigate the source of toxic compounds and the effect of containment on contaminant uptake, mussels were deployed in three enclosure types at four Lake St. Clair sites in and adjacent to the plume. Both locally occurring *Lampsilis radiata* (Barnes) and the non-native *Elliptio complanata* (Lightfoot) were employed in the latter study to examine the possibility of alteration in body burden associated with the additional stress of introduction.

Materials and Methods

Mussel Collection and Deployment

Individuals of *L. radiata* with low contaminant concentrations (Pugsley *et al.* 1985) were collected by diver from Anchor Bay, Lake St. Clair (Figure 1), while individuals of *E. complanata* were obtained from Balsam Lake, thirty km north of Lindsay, Ontario. The mussels ranged in size from 6.5–7.2 cm and 6.5–7.5 cm for *E. complanata* and *L. radiata* respectively.

The mussels were held in bags of lake water at 10°C and deployed within 36 hr of collection. At the conclusion of an experiment, specimens were shucked, excess fluid drained, and tissues wrapped in hexane-rinsed aluminum foil. Samples were frozen at −50°C until analysis, on average four weeks after collection. Shell length was measured, and individuals sexed. *L. radiata* is sexually dimorphic (Kat 1983), while gill micro-structure was used to sex *E. complanata* (Mackie 1984).

To ascertain whether the contaminants in the mussels were obtained from water or sediment, contaminant levels of mussels placed in stainless-steel 'corrals' (0.8 m diameter) with natural sediment were compared with those of mussels placed in corrals containing seven cm of contaminant-free sand.

To study the effect of enclosure type on contaminant uptake, three forms of containment were employed: 0.8 m corrals, wire-mesh 'pillow' cages (Kauss and Hamdy 1985), and mussels individually leashed to a 3 m monofilament line (Figure 2). Resident mussels from each site were collected at the start of the experiment except at site 4 where they were absent.

Mussels were deployed, using divers, on 8 September 1985 for forty days at four Lake St. Clair sites which transected the contaminant plume extending from the delta of the St. Clair River (Figure 1). The sites were expected to represent a wide range of organic contaminant levels as indicated by prior studies (Pugsley *et al.* 1985). Each enclosure contained five mussels of one species of which three replicates were analyzed, except three of the leash treatments (site 1 (1), site 2 (2), site 4 (2)).

The relationship between body burden and shell length was examined in a sample of 26 native *L. radiata* collected from site three in Lake St. Clair on 4 September 1986. From the same site, specimens of five other species ((*Anodonta grandis* (Say), *Lampsilis ventri-*

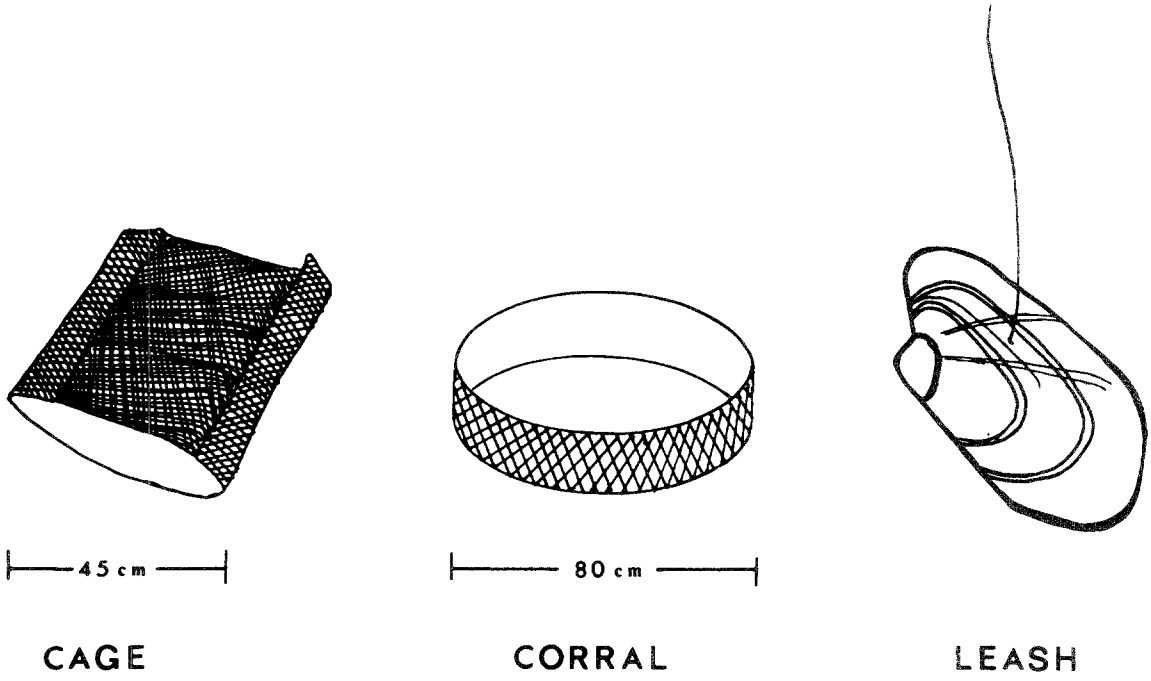

Fig. 2. The three enclosure types used to study the effects of containment on body burden

cosa (Barnes), *Leptodea fragilis* (Rafinesque), *Ligumia nasuta* (Say), and *Ligumia recta* (Lamarck)) were collected to permit an examination of interspecific variation in body burdens.

Analysis for Organic Contaminants

All samples were analyzed for levels of octachlorostyrene (OCS), hexachlorobenzene (HCB) and four polychlorobiphenyl (PCB) congeners (three pentachlorobiphenyl congeners, 87 (2,2',3,4,5'), 110 (2,3,3',4',6), and 118 (2,3',4,4',5), and a heptachlorobiphenyl congener, 180 (2,2',3,4,4',5,5')) in the Great Lakes Institute organics laboratory. Congener 118 is a toxic PCB of environmental interest, while congeners 110 and 180 make up the largest percentage of Aroclors® 1254 and 1260, respectively (Albro *et al.* 1981). Congener 87 was chosen for analysis in the present study because it displayed a different accumulation pattern than the other PCB congeners in caddisflies from the Huron-Erie corridor (Ciborowski and Corkum 1988).

All glassware was washed with hot, soapy water (Contrad 70, Canlab) and rinsed well with hot water. Immediately prior to use, glassware was rinsed in succession with three portions of acetone, three portions of petroleum ether, and a final rinse of pesticide-grade hexane. All solvents that were in direct contact with the samples were of pesticide grade.

Mussel tissue was thawed and, when necessary, gill tissue removed for sex determination. The remaining tissue was weighed (typical weight of 9 g) and ground with a Polytron homogenizer for 90 sec in 120 ml acetonitrile and 40 ml distilled water. The homogenate was filtered with suction through a sintered glass funnel, followed by a second homogenization with 50 ml acetonitrile and rinsing with two 20 ml portions of acetonitrile. The combined filtrates were extracted with 300 ml of petroleum ether in three portions; 150 ml, 75 ml, and 75 ml. One ml of sulphuric acid was added to the initial extraction to hydrolyze lipids. The combined petroleum ether extracts were washed with 200 ml of distilled water and dried by passage through 20 mm × 40 cm glass columns containing 15 g anhydrous sodium sulphate. The dried extracts were concentrated to 5 ml with a Kuderna-Danish evaporator and passed through columns with 30 g Florisil® under 8 g anhydrous sodium sulphate. The column was eluted with 200 ml of petroleum ether, which was concentrated to 5 ml. The concentrate was diluted to 10 ml with hexane, of which 1.0 µl was injected into a Hewlett-Packard 5790A capillary column gas chromatograph with an electron-capture detector fitted with a 30 m × 0.25 mm fused silica column containing a cross-linked DB-5 stationary phase (J & W Scientific, Folsom, CA). The following conditions were employed:

Injector temperature: 250°C
Column temperature programming: 0.5 min at 50°C, 50–250°C at 2°C per min, 20.0 min at 250°C
Detector temperature: 300°C
Carrier gas: helium at 1.5 ml per min
Detector make-up gas: 5% methane/95% argon at 60 ml per min
Injection mode: splitless

Quantification was performed by comparing peak areas against a set of standards containing known concentrations of the compounds. For PCB congeners, individual peaks were compared to those of a mixture of equal parts of Aroclors 1242, 1254, and 1260. The percent composition of each congener in the Aroclors was determined from data by Tuinstra and Traag (1983). Individual congener standards were later compared to the Aroclor standards. The standards of specific congeners produced peak areas ranging from 37–74% of the total area representing the congener in the Aroclor mixture for a similar concentration. Since it was impossible to determine whether this represented a different percent composition in our Aroclor standards relative to those described in the literature, or an error in interpolation, no correction factors were used.

The limits of quantification for HCB and OCS were 0.2 ng/g and 0.5 ng/g for individual PCB congeners. Recovery efficiencies were estimated by adding known quantities of compounds to uncontaminated mussel tissues and solvents. Recoveries for spiked tissue ranged from 87–93%, while recoveries from solvents ranged from 79–95%. No corrections were made for recovery efficiency. All chromatograms were visually inspected before data summary. Concentrations were ordinarily determined by comparing integrated peak values with those of a standard of a known concentration. In a few cases, the integrator failed to report an area for a peak that had

Table 1. Organic contaminants in mussels from the source locations, and after forty day deployment (all treatments) at four Lake St. Clair sites

Species	Contaminant[a]	Mean burden (±1 S.E.) Source	Site 1	Site 2	Site 3	Site 4
Lampsilis radiata	HCB	1.30 (±0.34)	0.66 (±0.06)	1.87 (±0.26)	3.13 (±0.42)	1.58 (±0.17)
	OCS	0.74 (±0.42)	0.83 (±0.11)	2.16 (±0.23)	5.08 (±0.58)	3.49 (±0.30)
	PCB 87	0.04 (±0.01)	0.04 (±0.01)	0.04 (±0.01)	0.05 (±0.01)	0.05 (±0.01)
	PCB 110	0.21 (±0.05)	0.24 (±0.02)	0.22 (±0.05)	0.31 (±0.05)	0.28 (±0.03)
	PCB 118	0.17 (±0.03)	0.20 (±0.02)	0.23 (±0.02)	0.26 (±0.03)	0.23 (±0.02)
	PCB 180	0.21 (±0.04)	0.20 (±0.02)	0.22 (±0.02)	0.28 (±0.03)	0.24 (±0.03)
Elliptio complanata	HCB	0.34 (±0.24)	0.55 (±0.06)	2.15 (±0.31)	3.45 (±0.34)	1.63 (±0.11)
	OCS	0.21 (±0.16)	0.42 (±0.06)	1.58 (±0.10)	2.19 (±0.26)	1.98 (±0.26)
	PCB 87	0.03 (±0.02)	0.03 (±0.01)	0.03 (±0.01)	0.03 (±0.01)	0.01 (±0.01)
	PCB 110	0.03 (±0.03)	0.17 (±0.04)	0.23 (±0.03)	0.20 (±0.01)	0.15 (±0.03)
	PCB 118	0.07 (±0.03)	0.17 (±0.01)	0.30 (±0.12)	0.19 (±0.02)	0.17 (±0.01)
	PCB 180	0.09 (±0.01)	0.12 (±0.01)	0.15 (±0.01)	0.14 (±0.02)	0.12 (±0.01)

[a] HCB = hexachlorobenzene, OCS = octachlorostyrene, PCB 87–180 = PCB congeners 87–180 (polychlorobiphenyls)

exceeded the baseline. In such cases the peak area was estimated by comparison with reported peaks of a similar size. If the peak area as defined by the integrator clearly had penetrated or failed to reach the baseline, an approximation of the positive peak area was made by comparison with peaks of a similar size on the same chromatogram.

Each set of five samples was accompanied by a solvent blank, subjected to the entire extraction procedure, to check the cleanliness of glassware and reagent purity and a standard run to account for changes in machine sensitivity.

All concentrations are expressed as parts per billion (ng/g) wet weight. The mean water content of twelve *E. complanata* specimens was 89% (S.E. = .003). Thus body burdens can be expressed on a dry weight basis using a conversion factor of 9.09. Lipid concentrations (expressed as a % of dry weight) were determined by extraction with petroleum ether and heating at 120°C for 24 hr. Lipid contents were determined for fifteen *E. complanata* individuals, and ranged from 1.8–3.4% (mean = 2.6%, S.E. = 0.5%). Values may be expressed on a lipid basis by multiplying dry weight concentrations by 38.5, although spatial and seasonal variation in lipid content may occur among individuals (Boon *et al.* 1985).

Statistical Analysis

Correlation coefficients are simple Pearson product-moment correlations. Difference between sexes were tested by Tukey's HSD procedure.

The source and enclosure experiments were analyzed by a 2 (species) × 2 (corral types) × 4 (sites) and a 2 (species) × 3 (enclosures) × 4 (sites) three-way factorial ANOVA with replication, respectively. The confidence intervals used represent two standard errors. Muncaster presented full ANOVA tables and the raw data in a prior publication (1987).

Table 2. Comparison of organic contaminants, using a three-way ANOVA, in *Lampsilis radiata* and *Elliptio complanata* placed in corrals with natural sediment or in corrals with uncontaminated sand after a forty day exposure period at four Lake St. Clair sites

Compound[a]	R^2	Treatment	F-ratio	Probability
HCB	.62	Site	16.14	<0.001
		Sediment type	0.09	0.76
		Species	0.32	0.58
OCS	.78	Site	19.45	<0.001
		Sediment type	0.24	0.63
		Species	24.85	<0.001
PCB 87	.30	Site	0.33	0.81
		Sediment type	0.01	0.94
		Species	5.55	0.02
PCB 110	.36	Site	1.19	0.33
		Sediment type	1.45	0.24
		Species	7.13	0.01
PCB 118	.49	Site	2.74	0.06
		Sediment type	0.92	0.34
		Species	11.01	0.002
PCB 180	.51	Site	0.78	0.51
		Sediment type	0.34	0.56
		Species	22.81	<0.001

[a] HCB = hexachlorobenzene, OCS = octachlorostyrene, PCB 87–180 = PCB congeners 87–180 (polychlorobiphenyls)

Results

Source of Contaminants

Both *L. radiata* and *E. complanata* individuals contained detectable levels of all of the study compounds prior to their deployment (Table 1). As the mussels equilibrate their body

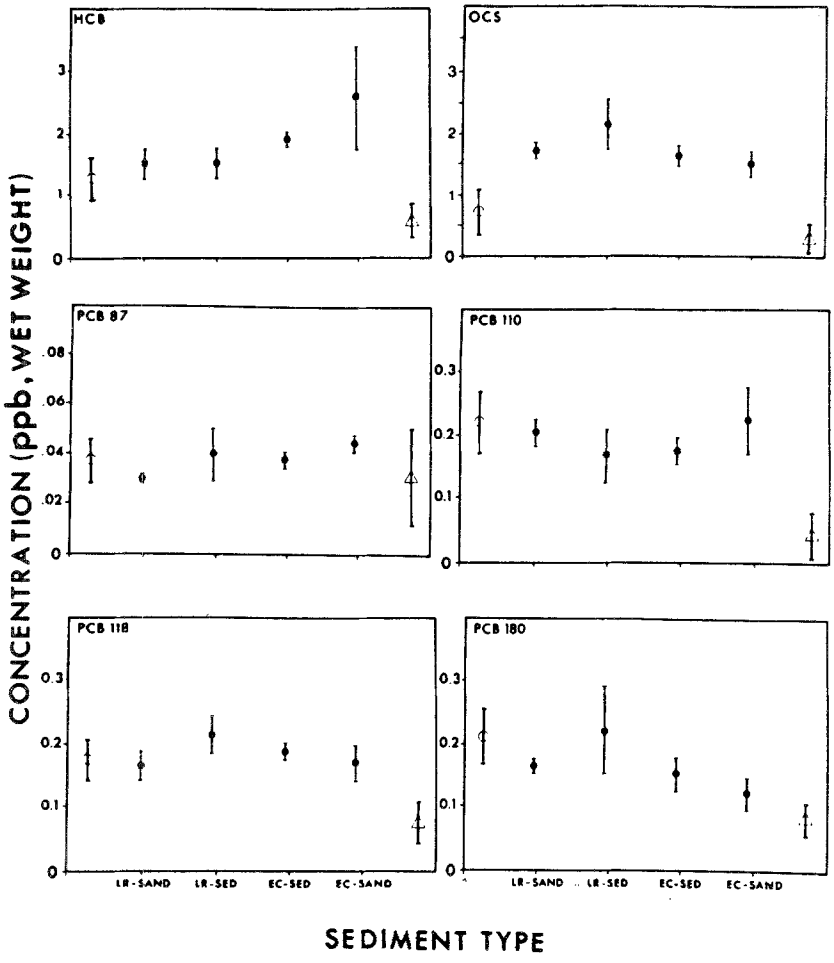

Fig. 3. Mean body burden (±1 S.E.) of *Lampsilis radiata* (LR) and *Elliptio complanata* (EC) individuals placed in corrals with uncontaminated sand (SAND) and natural sediment (SED) for forty days at site two in Lake St. Clair. Open circles and triangles represent the mean burden of *L. radiata* and *E. complanata* control mussels respectively

burden relatively quickly with the ambient water loadings (Muncaster *et al.* 1989), background levels were not subtracted from the body burdens after the forty day exposure period (Table 1).

There were highly significant differences among mussels deployed at four Lake St. Clair sites for OCS and HCB, but not for any of the PCB congeners (Table 2). After a forty day exposure *L. radiata* and *E. complanata* from corrals with natural sediment showed similar body burdens of all contaminants to individuals held in sand-filled corrals (Figure 3). The two species showed similar responses except for OCS, where *L. radiata* had higher levels (Table 2). The site by species interaction for OCS was the only significant interaction.

Effect of Enclosure

Individuals of *L. radiata* and *E. complanata* in three different enclosure types—cages, corrals, and leashes (*L. radiata* only)-showed no differences in their body burdens for any compound after a forty day exposure period (Table 3). Only the site by species interaction for OCS was significant. When compared to *L. radiata* mussels sampled from the study sites ('free' treatment), body burdens were generally lower in the enclosed specimens than those *in situ* (Figure

Table 3. Effect of three enclosure types (cage, corral, and leash) on contaminant uptake of *Lampsilis radiata* and *Elliptio complanata* individuals after a forty day exposure period at four Lake St. Clair sites, using a three-way ANOVA. No *E. complanata* specimens were used with the leash treatment

Contaminant[a]	R^2	Treatment	F-ratio	Probability
HCB	.72	Site	18.11	<0.001
		Enclosure	0.12	0.88
		Species	0.00	1.00
OCS	.74	Site	13.42	<0.001
		Enclosure	0.01	0.99
		Species	0.00	1.00
PCB 87	.22	Site	0.52	0.67
		Enclosure	0.80	0.46
		Species	0.00	1.00
PCB 110	.18	Site	0.57	0.64
		Enclosure	0.22	0.81
		Species	0.00	1.00
PCB 118	.25	Site	1.50	0.23
		Enclosure	0.33	0.72
		Species	0.00	1.00
PCB 180	.44	Site	1.98	0.13
		Enclosure	0.03	0.97
		Species	0.00	1.00

[a] HCB = hexachlorobenzene, OCS = octachlorostyrene, PCB 87–180 = PCB congeners 87–180 (Polychlorobiphenyls)

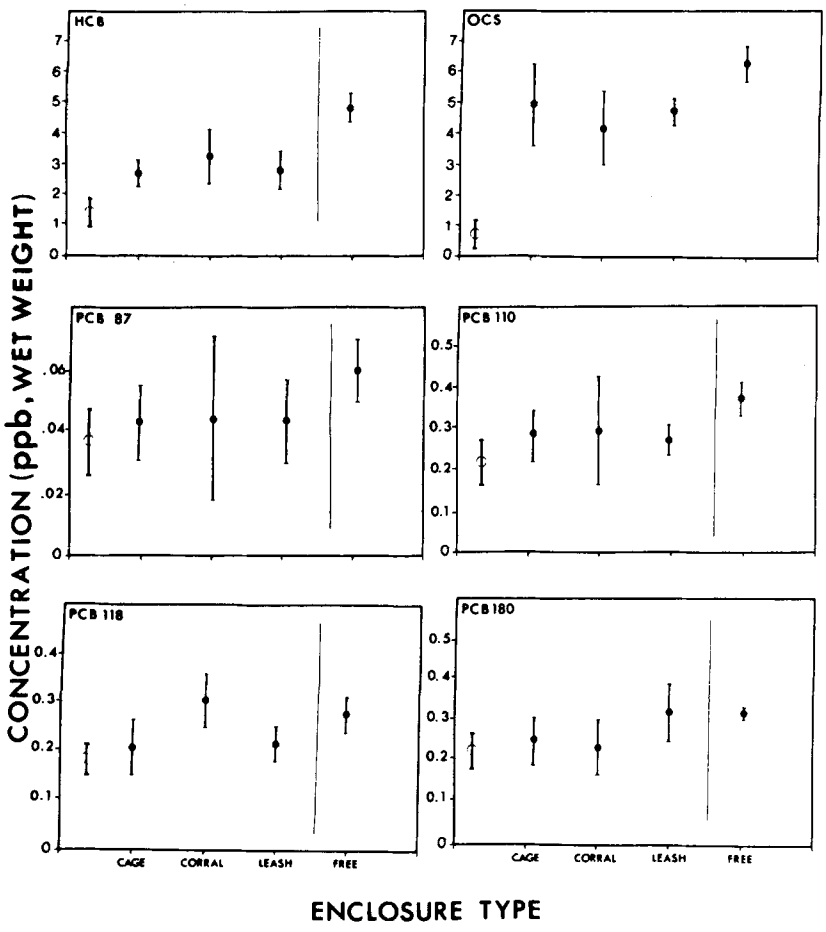

Fig. 4. Mean body burden (±1 S.E.) of *Lampsilis radiata* specimens deployed in three enclosures for forty days at site three in Lake St. Clair. Free mussels were sampled at site three at the beginning of the experiment. Open circles indicate mean body burdens of *L. radiata* mussels from Anchor Bay, Lake St. Clair

4). In 56% of the observations, the mean body burden in the native *L. radiata* mussels was greater than the mean contaminant levels in all of the enclosed *L. radiata* treatments. No significant differences existed between the body burdens of *L. radiata* and *E. complanata* among the enclosure treatments (Table 3).

Logarithmic transformation of the data produced no differences in the significance of variables for both the source of contaminant and the enclosure studies.

Relationship between Body Size and Body Burden

L. radiata from the contaminant plume in Lake St. Clair showed a negative relationship between body burden and shell length (Figure 5). Concentrations of HCB and the PCB congeners 110 and 118 were significantly negatively correlated with shell length, while OCS and PCB congeners 87 and 180 showed a similar, though not significant, trend between contaminant levels and length (Figure 5). Females tended to have greater body burdens than males, although the difference was not significant (Table 4).

Interspecific Comparison

Among six Lake St. Clair species (*Anodonta grandis, Lampsilis radiata, Lampsilis ventricosa, Leptodea fragilis, Ligumia nasuta,* and *Ligumia recta*) collected at site three, there were no significant differences in body burdens except for PCB congener 118. This difference was due to higher concentrations in *L. nasuta,* which had greater body burdens than the other species for all contaminants except PCB congeners 87 and 180 (Figure 6).

Discussion

Contaminants may be present in the bodies of freshwater mussels as a result of direct contact with the sediment or via absorption from the water column during filter feeding. The similarity of body burdens among mussels placed in corrals with uncontaminated sand and those with natural sediment gives direct evidence that the water column is the primary contaminant source. This study does not, however, reveal whether the contaminants are dissolved or absorbed to detrital and food particles suspended in the water column. Past studies have shown that contaminants bound to sediments are far less bioavailable than those in solution (Roesijadi *et al.* 1978a; Platford *et al.* 1985). For example, Fowler (1978) determined bioaccumulation factors of 800 vs 3.5 for water vs sediment-bound PCBs, respectively. Similarly, Roesijadi *et al.* (1978b) found that concentration factors for PAHs in the marine mussel *Macoma inquinata* ranged from 10–1, 349 for seawater, but less than 0.2 from sediments. Despite their low bioavailability, contaminants in sediments are often regarded as making an important contribution to the body burdens of benthic invertebrates because contaminant

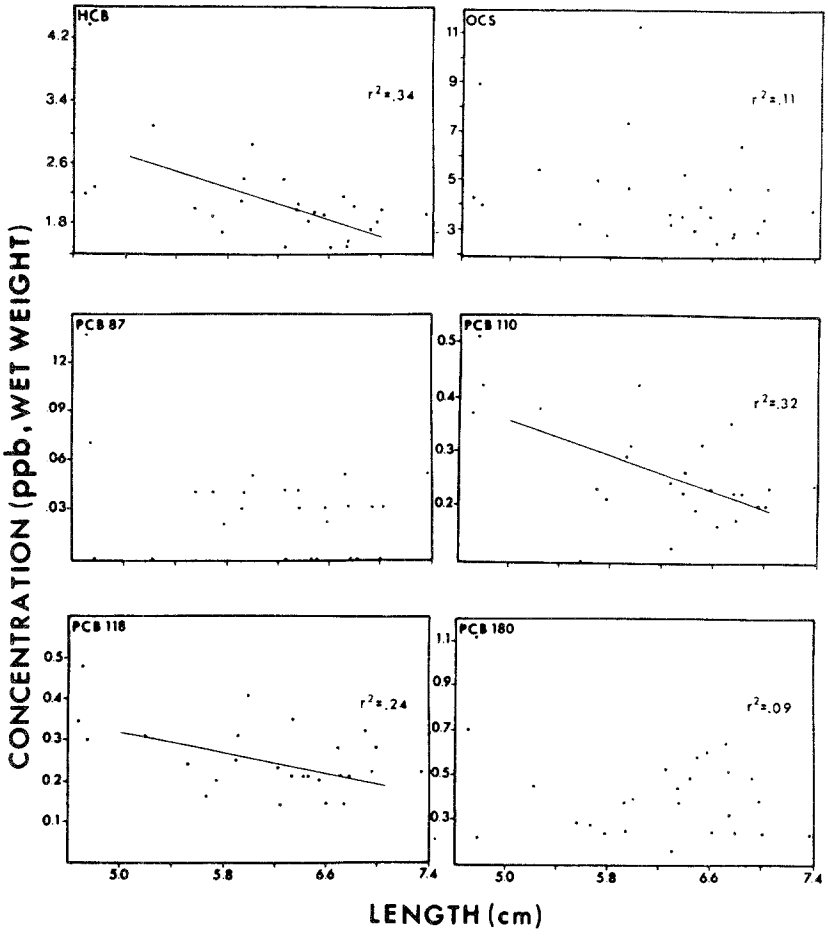

Fig. 5. Concentration of contaminants vs body length of 26 *Lampsilis radiata* individuals from site three in Lake St. Clair

concentrations are so much greater in sediments than water. The present study has shown, however, that an inconsequential portion of the body burden of bivalve molluscs is derived from sediment exposures. These results are concordant with prior work on Lake St. Clair which showed that contaminant concentrations in native mussels were only weakly correlated with levels of the sediment (Pugsley *et al.* 1985).

Enclosure type had no impact on contaminant uptake, a result which may not be surprising as unionids tend to be relatively sedentary. Bedford *et al.* (1968) noted that *L. radiata* with a sufficient quantity of food moved an average of only 2.3 m (total distance) per week. The similarity of contaminant levels in experimental and resident mussels further suggests that animals in the enclosures respond similarly to native individuals, a result which confirms the usefulness of experimentally deployed mussels as monitors of organic contaminants.

For each of the contaminants, a negative relationship was observed between the body burden and size of *L. radiata,* but with R^2 values ranging from 0.09–0.34, the negative relationship though significant, was weak. Although Kuwabara *et al.* (1986) reported a significant positive correlation between shell length of *Mytilus edulis* and PCB levels, the inverse relationship between size and contaminant levels noted in this study is consistent with prior work showing a negative relationship between heavy metal burdens and body size. Copper accumulation in the freshwater mussel *Quadrula quadrula* was negatively related to body weight; mussels three to four years of age had three times more copper than older animals (Foster and Bates 1978). Manly and George (1977) found no correlation between metal concentration and body weight at low levels in the freshwater mussel *Anodonta anatina,* but with higher body burdens, negative relationships between copper and mercury concentrations and body weight were noted. Cadmium and lead concentrations were directly correlated with body weight, while no significant relationship was observed for nickel. For *Mytilus edulis* and other invertebrates, the greatest burdens of trace elements (copper, lead, and zinc) were noted in the smallest specimens (Boyden 1974).

Ecological studies have shown that small mussels have relatively greater filtration rates and gill areas than their larger conspecifics and should hence have an increased potential to accumulate water borne contaminants. Vahl (1973), for example, showed a negative allometric relationship between both gill area and filtration rate and body size in *Mytilus edulis*. Bayne and Widdows (1978) confirmed that smaller *M. edulis* had a greater filtration rate per unit biomass. Larger individuals of this species do not compensate for their lower relative filtration rate with a more efficient utilization of the food (Vahl 1973). In conjunction with their greater relative filtration rate, this may imply a greater assimilation rate of contaminants attached to the suspended sediment by the smaller mussels.

With the exception of PCB congener 87, which showed an

Table 4. Mean body burden (±1 S.E.) based on sex of *Lampsilis radiata* specimens from Lake St. Clair (Site 3, n = 26). Difference between sexes was tested, using Tukey's procedure

Contaminant[a]	Females (N = 14)	Males (N = 12)	t-Stat	Probability
HCB	2.23 (±0.19)	2.00 (±0.15)	0.94	.36
OCS	6.73 (±0.65)	6.43 (±1.22)	0.22	.82
PCB 87	0.04 (±0.01)	0.02 (±0.01)	1.32	.20
PCB 110	0.28 (±0.03)	0.24 (±0.03)	1.06	.30
PCB 118	0.26 (±0.02)	0.25 (±0.02)	0.16	.87
PCB 180	0.44 (±0.07)	0.40 (±0.04)	0.45	.66

[a] HCB = hexachlorobenzene, OCS = octachlorostyrene, PCB 87–180 = PCB congeners 87–180 (Polychlorobiphenyls)

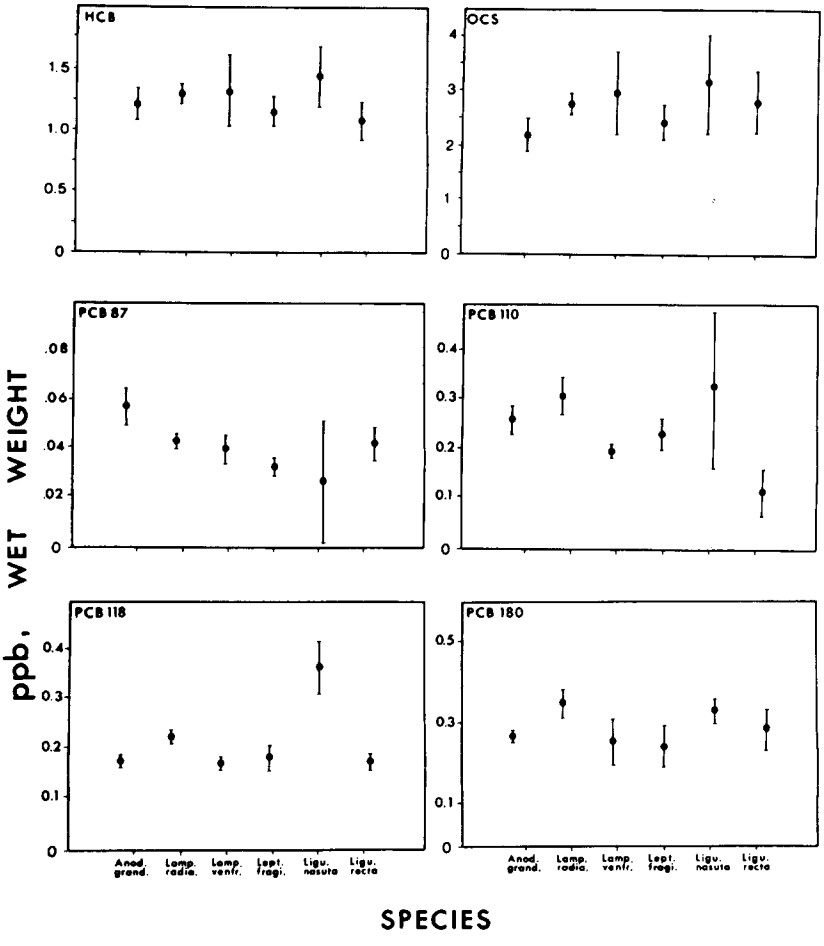

Fig. 6. Mean body burden (±1 S.E., n = 3) of contaminants among six unionid species sampled at site three in Lake St. Clair

even greater elevation, female *L. radiata* had body burdens that were on average 10% greater than the males. Prior work on marine mussels has shown that female mussels tend to have a greater body burden of contaminants, perhaps as a result of higher lipid contents prior to spawning (Hartley and Johnston 1983) or greater tissue accumulation due to gametogenesis (Watling and Watling 1976; Latouche and Mix 1982).

There was generally little difference in the body burden of the six Lake St. Clair species for each of the contaminants. The ambient PCB levels in Lake St. Clair are relatively low as suggested by the similarity between concentrations of PCBs in mussels after forty days of exposure in Lake St. Clair and those found in the control mussels. The low levels may have made some trends more difficult to observe. PCB congener 118 varied significantly among the species, due to its relatively high concentration in *Ligumia nasuta*. In all study compounds, except PCB congeners 87 and 180, *L. nasuta* had the highest mean body burden of the species studied. This perhaps reflects the relatively small size of *L. nasuta* (average weight of 5.44 g vs 11.44 g for *Lampsilis radiata*, the second smallest species) and the tendency for smaller mussels to have greater body burdens.

Bedford *et al.* (1968) noted no differences in the body burden of DDT and its metabolites among six native species (including *Anodonta grandis* and *Lampsilis ventricosa*) in a southern Michigan stream. In the same study, *Lampsilis radiata* and *Lampsilis ventricosa* individuals displayed no dif-

ferences in the body burdens of pesticides after exposure periods of up to ten weeks. Heit *et al.* (1980) similarly observed no differences in the levels of metals (including cadmium, mercury, and nickel) for the mussels *Anodonta grandis, Elliptio complanata,* and *Lampsilis radiata.* However, variation within and among taxa has been noted. Lobel (1987) described large variability in zinc concentrations among similarly sized individuals of *Mytilus edulis,* apparently as a result of variation in the concentration of a natural chelating agent. A differential ability to metabolize compounds may result in variation in body burdens among taxa. Leard *et al.* (1980) noted, for example, that species of fingernail clams have varying abilities to eliminate pesticides. The varying physiological cycles and body sizes of polychaete worms were suggested as causes of the diversity in body burdens among taxa (Boon *et al.* 1985).

In summary, the present study has shown that both inter and intraspecific variation in contaminant levels among freshwater mussels are small. The study further showed that experimentally deployed mussels accumulate body burdens similar to those in resident organisms, and indicated that the water column represents the primary source of these contaminants. The results confirm the general usefulness of freshwater mussels as monitors of contaminants in aquatic systems.

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