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A Survey of Saginaw River and Saginaw Bay, Lake Huron, Sediments Using Two Bioassays with the Amphipod *Diporeia* spp.

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ABSTRACT. *The Saginaw River and Saginaw Bay ecosystem is identified as an Area of Concern by the International Joint Commission for recognized anthropogenic contamination, which includes sediments. The potential impact of sediment-associated contamination of Saginaw Bay and Saginaw River was evaluated by employing two solid phase bioassays with the amphipod* Diporeia *spp. (formerly named* Pontoporeia hoyi*). Two effects examined in the bioassays were mortality after 28 d and avoidance/preference for the sediments after 5 d. Saginaw Bay Station S-61, located off the coast of Tawas Bay, was the only location where bay sediment elicited significant mortality. Although sediment preference tended to increase from the inner bay to the outer bay with S-61 the most preferred, there were no statistical differences among stations. River sediments from all stations collected in December 1989 produced significant mortality, with sediments from Station SR-106, just below the Bay City Waste Water Treatment Plant outfall, producing the greatest response. Sediments from SR-106 were also the most avoided of the river sediments from this first collection. A subsequent collection of sediments in June 1990 from the Saginaw River produced no mortality and no significant avoidance of the sediments. The results from these two bioassay methods suggest the presence of potential contaminant problems in both the bay and river, and indicate that both lethal and sublethal effects may occur.*

INDEX WORDS: *Sediments, toxicity, bioassays, Lake Huron, Saginaw River,* Diporeia.

INTRODUCTION

The historical contamination of Great Lakes water and sediment is most evident in the 42 Areas of Concern (AOC), which include Saginaw Bay and Saginaw River, as identified by the International Joint Commission. In Saginaw Bay, the disappearance of the mayfly, *Hexagenia limbata*, was observed as a direct effect on benthic organisms. Historically *H. limbata* existed in large numbers; in 1955, *H. limbata* was found at densities of 63 organisms/m^2. By 1956, the densities had dropped to 9 organisms/m^2 and in 1965 densities were down to only 1 organism/m^2 (Schneider *et al.* 1969). *Hexagenia* are generally considered an excellent indicator of water quality (Fremling 1964, Hiltunen and Schloesser 1983).

A more recent tragedy in the Saginaw Bay area is the appearance of reproductive toxicity in the cormorant population. This response has been associated with exposure to high levels of polychlorinated biphenyls (PCB), polychlorinated dioxins, and polychlorinated dibenzofuran congeners. Recent studies have shown that these teratogenic responses are best explained by the total dioxin equivalents to which the birds are exposed (Tillet *et al.* 1988). These PCBs and dioxins are known sediment-associated contaminants in the Saginaw Bay ecosystem (Thomas and Frank 1983, Table 4) and may accumulate in the food chain (Baumann and Whittle 1988). Thus, the sediments are thought to be a major source of these contaminants to the food chain.

Sediment bioassays are useful in the assessment of the type and extent of sediment contamination. Only a few bioassays are currently recognized as

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relatively well developed for sediments, e.g., 10-d *Rhepoxynius* bioassay, *Hyalella azteca* bioassay, and *Chrionomus* bioassays (Adams *et al.* 1985; Swartz *et al.* 1985; ASTM 1990 a,b). The state-of-the-art of sediment bioassays was well reviewed (Lamberson *et al.* 1992, Burton 1991) and the authors demonstrated a clear need for development of additional solid phase bioassays for assessment of sediment contamination. To improve our assessment capability, collection and standardization of sediment bioassays continues as an ongoing effort of the American Society for Testing and Materials subcommittee E 47–03 on sediment toxicology.

Field studies have suggested that *Diporeia* spp., recently reclassified from *Pontoporeia hoyi* (Bousfield 1989), are the most abundant benthic species in the Great Lakes on a biomass basis (Nalepa 1989), and are sensitive oligotrophic organisms (Nalepa and Landrum 1988), thus making them potentially useful Great Lakes bioassay organisms. In laboratory studies (Gossiaux *et al.* 1992, Landrum and Dupuis 1990), *Diporeia* exhibited moderate sensitivity when exposed to cadmium, carbaryl, and pentachlorophenol. Further, *Diporeia* appear insensitive to sediment composition because they are found inhabiting sediments composed of coarse sand to silty muck (Nalepa *et al.* 1985). This apparent tolerance to sediment type reduces undue interference in data interpretation due to habitat considerations. *Diporeia*, collected from southern Lake Michigan, also tolerate a wide range of temperature (4–26°C) and salinity (freshwater to 20 g sea salt L^{-1} (Gossiaux *et al.* 1992). *Diporeia* have been used previously for solid phase sediment bioassays examining both avoidance and mortality responses with Great Lakes sediments (Gannon and Beeton 1969, 1971; Bahnick *et al.* 1980).

The toxicity of selected Saginaw Bay sediments collected in July 1988, and Saginaw River sediments collected in December 1989 and June 1990, was determined by examining *Diporeia* mortality and sediment avoidance/preference. In addition to the bioassays, the organic carbon, volatile solids, and particle size composition of the sediments were determined.

MATERIALS AND METHODS

Sediments

Three replicates of two Ponar grabs were collected at each of the following Saginaw Bay stations in July 1988: Bay Stations S-61, S-27, S-7 and River Mouth Station (S-RM) (Table 1, Fig. 1). The sediments were selected to reflect a transect the length of the bay including the depositional area represented by stations S-7 and S-27. They were shipped to the laboratory on ice within 48 h of collection and the bioassays initiated within one week after the arrival.

The Saginaw River sediments were collected on two different trips: December 1989 for Stations SR-103, SR-106, SR-110, and June 1990 for Stations SR-301, SR-302, SR-306, and SR-308 (Table 1, Fig. 2). Sediments designated SR-106 and SR-306 were collected at the same station but differed in collection date. The river stations were selected, based on best knowledge, to locate potential depositional contaminant hot spots and to include control areas. Large volumes of sediment (100 L) were collected with multiple Ponar grabs, homogenized in a cement mixer, sub-sampled, and shipped by overnight delivery to the laboratory on ice. These sediments were collected as part of the U.S. Environmental Protection Agency's Assessment and Remediation of Contaminated Sediments Program (ARCS). Upon arrival at the laboratory, the sediments were stored at 4°C until used. The bioassays were initiated within eight days of collection.

Lake sediments collected from 29-m and/or 45-m Lake Michigan stations, approximately 5–8 km southwest of Grand Haven, MI (Table 1), and/or Florissant, MO soil (Ingersoll and Nelson 1990) were run as control sediments with every set of bioassays. During the studies with the bay sediments, only Lake Michigan sediments were available for controls and the 45 m sediment was selected because it had been employed for multiple accumulation studies and was believed to have very low concentrations of contaminants based on the low concentrations of polycyclic aromatic hydrocarbons (Eadie *et al.* 1982). The Florissant soil was used as a control for all of the river sediment bioassays because of the known essential absence of contaminants (Ingersoll and Nelson 1990).

The sediment dry/wet ratio was determined by homogenizing the wet bulk sediment, removing and weighing a subsample, and then drying the sediment subsample to a constant dry weight at 60°C. The percent volatile solids was subsequently determined by combusting the dry sediments at 500°C for 2 h, measuring the ash weight, and calculating the fraction of weight lost (Table 1). All sediment analyses were performed in triplicate.

The amounts of sand and silt-clay in each sediment sample were determined by sieving 1 g of wet

TABLE 1. Sediment characteristics (mean ± SD, n = 3).

Station	% Volatile Solids	% Organic Carbon	% Fines (<63μm)	Location
Bay Sediments, July 1988				
S-61	0.18±0.05	0.05±0.01	0.22±0.22	44°07.6'N, 83°30.0'W
S-27	2.90±0.04	0.96±0.05	77.63±1.02	43°55.3'N, 83°41.6'W
S-7	5.32±0.06	3.44±0.05	51.64±0.56	43°44.8'N, 83°51.1'W
S-RM	1.18±0.06	0.96±0.06	4.74±0.75	43°40.7'N, 83°49.6'W
River Sediments, December 1989				
SR-103	8.94±0.02	3.24±0.06	82.02±0.94	43°37.3'N, 83°50.6'W
SR-106	3.98±0.04	1.65±0.0-7	23.52±0.13	43°36.7'N, 83°52.2'W
SR-110	2.33±0.01	1.04±0.11	17.42±0.01	43°32.7'N, 83°53.1'W
River Sediments, June 1989				
SR-301	3.65±0.03	0.97±0.08	35.9±0.1	43°45.3'N, 83°47.5'W
SR-302	3.75±0.05	1.38±0.25	15.7±0.2	43°37.4'N, 83°50.5'W
SR-306	0.69±0.02	0.13±0.06	2.4±0.3	43°36.7'N, 83°52.2'W
SR-3078	8.70-±0.02	3.81±0.33	38.9±1.2	43°35.3'N, 83°53.9'W
Control Sediments				
Florrisant Soil	4.49±0.04	1.06±0.01	78.5±2.6	
Lake Michigan 29 m	0.97±0.01	0.22±0.05	7.7±0.1	43°01.2'N, 86°17.6'W
Lake Michigan 45 m	1.76±0.08	0.42±0.05	42.0±0.3	43°02.0'N, 86°21.9'W
Combusted sand*	0.10±0.01	0.01±0.01	0.0±0.0	

*data on combusted sand gathered after bioassays but on same lot of material

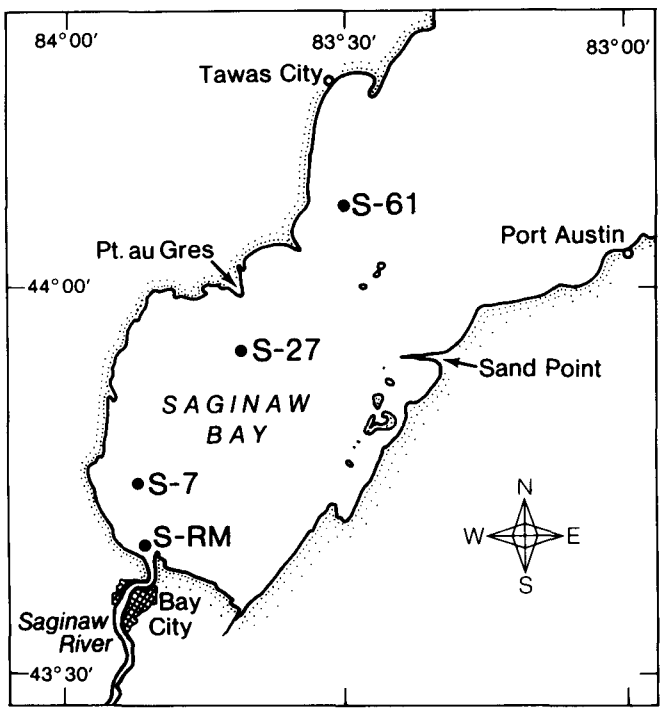

FIG. 1. Station locations for Saginaw Bay sediment collections.

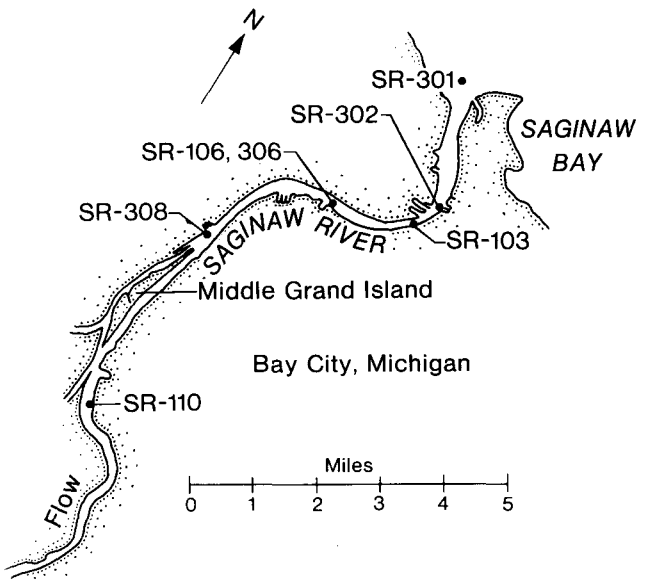

FIG. 2. Station locations for Saginaw River sediment collections.

sediment with distilled water through a 63-μ mesh screen. The sediment remaining on the screen (sand fraction) was rinsed into a petri dish and placed in a drying oven at 60°C. The sediment passing through the screen (silt-clay fraction) was collected and allowed to settle. The overlying water was aspirated off and the sediment was rinsed into a petri dish and dried. When both sediment fractions were dry, they were weighed and the fractions of sand and silt were calculated as the ratio of the total (Table 1). The mass balance for these separations resulted in an overall accountability of 98.4 ± 1.4%.

The percent organic carbon of each sediment was determined as follows: Approximately 2 g of each sediment were acidified with 2 mL of 1N HCl. The samples were shaken for 24 h and then dried to constant weight at 60°C. When dry, 20-mg samples were weighed and analyzed on a Perkin-Elmer 2400 C H N elemental analyzer (Table 1). The analyzer was calibrated using acetanilide and the calibration was confirmed using alanine.

Bioassay Species

Diporeia were collected by Ponar grab at a 29-m depth in Lake Michigan approximately 5 km southwest of Grand Haven, MI (Table 1). The animals were gently removed from the sediments with a screen and transported to the laboratory in lake water kept cool with ice. The animals were housed at 4°C in shallow aquaria containing 3–4 cm lake sediment and 10 cm lake water (Landrum 1982). Fifty percent of the water was replaced weekly in the aquaria and the sedimentary diet was supplemented with a *Chlamydomonas* culture. Bioassays were initiated no more than 1 month after amphipod collection. Lake Michigan water has a pH of 8, a hardness of 139 ± 1.6 (mean ± SD) and an alkalinity of 2.15 ± 0.1 meq L^{-1} as $CaCO^{-3}$ (Landrum and Dupuis 1990).

Bioassays

28-d Mortality Bioassay

Two types of sediment bioassays were conducted. The first was a 28-day mortality bioassay modeled after the 10-d *Rhepoxynius* bioassay (Swartz *et al.* 1985) and performed in triplicate for each sediment sample collected. Each sample was pressed through a 1-mm-mesh screen to remove large material and any indigenous macrobenthos. The sediment (2 cm) and Lake Michigan water (600 mL) were added to replicate 1-L beakers and gently aerated at 4°C for 24 h. Control sediments included: Florissant, MO soil and/or Lake Michigan sediment as described above. After aeration for 24 h, 20 juvenile *Diporeia* (weight range approximately 3–8 mg wet weight per organism based on observed size) were added to each beaker and illuminated under a red darkroom light to encourage burrowing. The animals were monitored closely, morning and afternoon, during the first 2 days and daily there after. The occasional dead *Diporeia* were replaced within the first 48 h. Any *Diporeia* trapped by the surface tension at the water-air interface were submerged. The beakers were also monitored throughout the 4-week assay period for proper aeration and water loss. Lake water was added if required. Upon termination of the bioassay, the contents of the beakers were poured onto a 1-mm-mesh screen, the sediment rinsed away, and the number of live animals recorded. The mean survival of the three replicates were compared to control survival and significance was determined using a one way Student's t test with significance at $p<0.025$. Only the pH (range 7.25–7.9) was measured at the beginning of the bioassay for water quality since the beakers were aerated and the hardness and alkalinity of Lake Michigan water had previously been shown not to change in static systems over 28 days (Landrum unpublished data).

120-h Avoidance/Preference Assay

The second bioassay, a sediment avoidance/preference test, determined the presence or absence of animals in sediment samples and the number of animals burrowed into each sample. This bioassay cannot distinguish whether an animal chooses a sediment in which to burrow because of preference or to avoid other sediments.

The field-collected sediments were assayed in triplicate with the controls described above for the mortality bioassay. Combusted sand was employed as an additional control with the other control materials described above. Sediment samples (30 g) were added to labeled petri dishes and placed randomly into a rectangular aquarium containing 6 L of lake water (approximately 10-cm depth). The aquarium was then placed into an environmental chamber at 4°C and illuminated with a red darkroom light. The sediments were allowed to settle for 24 h, after which 100 *Diporeia* were added, 20 in each corner and 20 in the center of the aquarium. To enhance test sensitivity, the number of animals added to the June 1990 collection of river sedi-

ments was doubled. As before, organisms trapped at the surface were submerged and dead animals replaced. After 5 days, each dish was removed, the sediments were sieved on a 1-mm-mesh screen, and the number of animals that burrowed into each sediment was recorded. A Waller-Duncan k-ratio t-test was performed to examine avoidance/preference differences between sediment samples (SAS 1990). Sample differences were considered significant at $p<0.05$.

RESULTS

Bay Sediments

28-d Mortality Bioassay

Relative to other sediments from Saginaw Bay, Station S-61 sediments, collected off the coast of Tawas Bay, were found to be the most toxic to *Diporeia*, 13 ± 6.7% mortality (Mean ± SD) (Table 2). These were the only Saginaw Bay sediments for which the mortality was statistically different from the controls.

Avoidance/Preference

Although toxicity was found at Station S-61, this station was the most preferred of the bay sediments (Table 2). However, despite the rank order of preference presented, the bay sediments were significantly different only from the sand and were not different from each other or the Lake Michigan 45-m control sediment.

River Sediments

28-d Mortality Bioassay

In the December 1989 sediments collected from the Saginaw River, significant mortality was found for all three stations compared to the control, with the highest mortality (55 ± 4%) observed for Station SR-106 (Table 2). For the June 1990 collections, no significant mortality was observed (Table 2), even though Station SR-306 was collected from the same location as Station SR-106. In addition to differences in *Diporeia* mortality between samples SR-106 and SR-306, the sediment characteristics were also substantially different (Table 1).

Avoidance/Preference

There was a significant avoidance of the sediments from Stations SR-106 and SR-110. Although significant mortality was observed in the bioassay for Station SR-103 sediment, it was no less preferred than the Florissant control. For the sediments collected in June 1990, preference for the various river sediments fell between that of the 29-m Lake Michigan sediment and the Florissant control (Table 2). None of the sediments from this collection could be considered avoided nor was there any statistical difference among the river sediments.

DISCUSSION

28-d Mortality Bioassays

Bay Sediments

Finding significant *Diporeia* mortality at Station S-61 is particularly surprising when contaminant concentrations and sediment characteristics are considered (Tables 1,3,4). While the bioassay result was significant compared to the control, does the result have any environmental significance? Past field surveys have shown that *Diporeia* were the most abundant benthic organisms in the outer Saginaw Bay, although density changes have been occurring. In 1965, surveys found 100 individuals/m^2 at a station near Tawas city and a range of 400–800 individuals/m^2 at stations near Station S-61 (Schuytema and Powers 1966). By 1971, only 20 individuals/m^2 were found at Station number 34 in the vicinity of Station S-61 (Batchelder 1973). Sediment samples collected in the May, July, and October 1988 averaged 3 ± 4 individuals/m^2 at Station S-61 while sediments collected July 1988, at the same time as our bioassay samples, averaged 8 ± 3 individuals/m^2 (Nalepa, T. F., Personal Communication, Great Lakes Environmental Research Laboratory, Ann Arbor, MI). Thus, the finding of significant mortality for the outer bay sediment samples assayed under laboratory conditions may provide some indication of why numbers of *Diporeia* have decreased. Additionally, a bioassay with H. limbata that used sediments collected about a year earlier than our sediments also found significant mortality at Station S-61 (Henry, M., Personal Communication, Dept. of Fish and Wildlife, University of Minnesota, St. Paul, MN.). Thus, while our mortality data were low, our data in combination with both other laboratory bioassays and field population data suggest that the toxicity may be ecologically significant.

Based on the probable significance of the mortality finding, it remains curious that toxicity occurs based on the sediment characteristics and contaminant concentrations. Compared to the other Saginaw Bay sediments, S-61 sediments are composed

TABLE 2. **Diporeia** *spp. response to Saginaw sediments.*

Avoidance/Preference (Ranked in Order of Preference)	Avoidance/Preference Animals/petri dish (% Total)[1] Mean ± SD	*Diporeia* Mortality (% Mortality ± SD, N = 3)
Bay Sediments, July 1988	1% remaining in water	
S-61	5.8±4.2 (35%), n = 6	13.6±6.7[2]
S-RM	3.7±2.9 (22%), n = 6	5.7±7.8
S-27	3.7±4.1 (22%), n = 6	2.8±3.8
S-7	2.8±5.9 (17%), n = 6	2.3±3.9
Lake Michigan 45m Sediment	1.5±0.7 (3%), n = 2	3.7±6.4
Sand	none (0%), n = 2	NT[3]
River Sediments, December 1989	12% remaining in water	
Florissant Soil	13.7±7.1 (41%), n = 3	10.0±4.1
SR-103	14±13.1 (42%), n = 3	25.0±7.1[2]
SR-110	1.6±2.1[4] (5%), n = 3	44.0±4.8[2]
SR-106	none[4] (0%), n = 3	55.0±4.1[2]
Sand	none[4] (0%), n = 3	NT
River Sediments, June 1990	3% remaining in water	
Lake Michigan 29-m Sediment	27.8±14.3 (53%), n = 4	1.7±2.8
SR-306	6.5±9 (12%), n = 4	1.7±2.8
SR-308	12.8±19.4 (24%), n = 4	0.0±0.0
SR-301	0.8±0.5 (2%), n = 4	3.3±2.8
SR-302	2.0±3.4 ()4%), n = 4	1.7±2.8
Florissant Soil	1.3±1.9 (2%), n = 4	0.0±0.0
Sand	none (0%), n = 4	NT

[1]Percent of total number of animals added to aquarium as the sum of all animals found in the dishes represented by each sediment.
[2]Significantly increased mortality compared to control, $p<0.025$
[3]Not Tested
[4]Significantly less preferred than Florissant Soil

TABLE 3. Concentrations of metals in Saginaw sediments (mg/Kg dry weight).

Station	Cadmium	Chromium	Copper	Lead	Nickel	Zinc
Bay Sediments, October 1987						
S-7	1.3	49.5	40.5	56.6	24.5	193
S-27	0.9	52.1	37.4	57.0	34.1	154
S-61	0.3	4.2	2.8	5.4	4.4	16
River Sediments, December 1989						
SR-103	0.9	90.0	49.0	55.0	37.0	352
SR-106	10.0	319.0	187.0	86.0	157.0	381
SR-110	0.2	40.0	16.0	19.0	15.0	99
River Sediments, June 1990						
SR-301	0.8	53.3	22.4	24.9	18.9	75
SR-302	0.5	24.7	24.0	29.8	15.3	166
SR-306	0.5	34.8	18.3	16.9	8.3	56
SR-308	2.0	95.0	54.8	68.7	37.9	347

Sediment Chemistry for Saginaw Bay sediments, collected from the same stations but approximately 7 months before those for bioassay, were provided by the Michigan Department of Natural Resources, Lansing, MI, and for Saginaw River by Battelle Pacific Northwest Marine Research Laboratory, Sequim, WA, as a part of the U.S. Environmental Protection Agency's Assessment and Remediation of Contaminated Sediments Program.

TABLE 4. Concentrations of polychlorinated biphenyls, polycyclic aromatic hydrocarbons, and pesticides in Saginaw sediments (μg/Kg dry weight).

	Bay Sediments, October 1987			River Sediments, December 1989			River Sediments, June 1990			
Compound	S-7	S-27	S-61	SR-103	SR-106	SR-110	SR-301	SR-302	SR-306	SR-308
Total PAH	NA	NA	NA	6,772	8,381	332	6,323	4,660	310	5,220
Dioxins	NA	NA	NA	9.18	24.1	2.9	5.1	9.9	4.8	16.3
Total PCB	316	207	8.65	ND	7,000	2,300	86	95	ND	94
Lindane	0.02	0.04	0.01	ND	ND	ND	ND	ND	ND	33.0
HCB	8.86	2.54	0.11	NA	NA	NA	NA	NA	NA	NA
Hepta-Chlor	0.03	0.04	0.01	ND	140	ND	ND	ND	ND	ND
γ-Chlordane	0.28	0.36	0.01	ND	140	ND	4.8	5.9	ND	9.0
α-Chlordane	0.32	0.04	0.03	ND	ND	ND	ND	ND	ND	ND
Trans-NonaChlor	2.53	0.04	0.01	NA	NA	NA	NA	NA	NA	NA
Cis-NonaChlor	0.18	0.16	0.01	NA	NA	NA	NA	NA	NA	NA
4,4'-DDD	8.86	5.1	0.2	ND	ND	ND	7.6	8.4	ND	ND
4,4'-DDE	0.03	3.35	0.01	ND	140	ND	3.9	5.6	ND	11.0
4,4'-DDT	0.82	1.1	0.07	ND	ND	ND	8.5	ND	ND	ND
5-Chloro-benzene	4.43	1.65	0.09	NA	NA	NA	NA	NA	NA	NA

NA = Not analyzed, ND = Not Detected.
Chemistry data for Saginaw Bay sediments, collected from the same stations but approximately 7 months before those for bioassay, were provided by the Michigan Department of Natural Resources, Lansing, MI, and for the Saginaw River sediments produced by Battelle Pacific Northwest Marine Research Laboratory, Sequim, WA, as a part of the U.S. Environmental Protection Agency's Assessment and Remediation of Contaminated Sediments Program.

of fine sand over gravel with low volatile solids and a low organic carbon content (Table 1). The sediment characteristics are very similar to the 29 m Lake Michigan sediments (Table 1) from which the *Diporeia* are collected and even subsequent exposures to pure sand produced no mortality in 28 d (n = 3) (P. F. Landrum, unpublished data). The concentrations of measured metals and organics were lower at Station S-61 than at the other bay stations (Tables 3,4) and mortality resulting from any single metal or organic contaminant is unexpected considering the moderate acute sensitivity of *Diporeia* for specific contaminants (Landrum *et al.* 1989, Landrum and Dupuis 1990, Landrum *et al.* 1991, Gossiaux *et al.* 1992). It is more reasonable to assume that toxicity results from a combination of measured contaminants, the presence of a significant but unassayed contaminant, or both. Because the concentrations of complexing materials, clays, and organic matter that reduce bioavailability were low (Table 1), the contaminant bioavailability may have been greater in this sandy sediment. Enhanced mortality with sand dilution has been observed when testing sediments from station SR-106 (Landrum *et al.* 1990) and such a dilution effect may be occurring at S-61. Hypotheses for the observed mortality in the low organic carbon environment of Station S-61 include: 1) increased foraging for food in low organic sediments results in increased exposure and relative toxicant accumulation, and 2) the amphipods may be stressed due to increased energetic demands required by foraging in such a low-resource environment. Both hypotheses, combined with reduced complexation, subsequently enhanced bioavailability, and the potential presence of an unmeasured toxicant may provide some insight on the increased toxicity of a sediment with low concentrations of contaminants and organic carbon. However, the role of organic carbon and particle size on

contaminant bioavailability and toxicity require additional investigation.

River Sediments

From the sediments collected in December 1989, all the stations produced significant mortality. Even with the high mortality, the concentrations of the organic contaminants in the sediments (Table 4) were not sufficiently high to ascribe the toxicity to any single organic contaminant even for station S-106 based on previous studies (Landrum *et al.* 1989, 1991). For the heavy metals (Table 3), it is difficult to ascertain the significance of the concentrations. For instance, the metals concentrations at station SR-103 were greater than SR-110 which exhibited significantly higher mortality. Also, the metals concentrations at SR-308 were similar to those at SR-103, but SR-308 exhibited no mortality. The main difference between SR-103 and SR-308 was the amount of fine material which was greater for station SR-103 while the other characteristics were similar. How the combination of contaminants, both organics and metals, and sediment characteristics interact to produce toxic responses remains to be defined. Further, when testing field collected sediments the potential for unmeasured contaminants remains a significant potential issue.

Of particular interest is the difference in the response of *Diporeia* at stations SR-106 and SR-306. These two samples demonstrate the type of seasonal variability that can occur in high energy environments such as a river. They also demonstrate the problem of only employing surficial grab samples for assessing sediments. Both of these samples were taken from the same location but about 6 months apart. The differences in sediment characteristics (Table 1) and contaminant concentrations (Tables 3 and 4) clearly show reductions in contaminant concentrations that correspond to reductions in the mortality response between the first and the second sample dates. Because state-of-the-art positioning equipment was employed for the ARCS program, it is likely that there was essentially no difference in the location from which the samples were taken. However, the oily character observed during the first collection was absent in the surface collection during the second collection. Just below the depth taken by the surface grab, core samples found an oily material that produced a microtox response (Rathbun, J., Personal Communication, U.S. EPA, Large Lakes Research Station, Grosse Ile, MI). These differences are thought to result, in part, from the degree of instability in the river environment. High winter and spring flow conditions could have covered the toxic sediment with a layer of sand or washed out the fine materials leaving a sand layer. Such potential dynamic changes suggest that proper assessment of sediments in energetic environments will require consideration of stocastic events that may alter the historical deposition. Thus, a temporal series of samples and the use of sampling techniques such as coring devices are suggested to obtain a proper assessment in such high energy systems.

A further possible issue that should be considered when evaluating the response of organisms is the different times of year when the bioassay organisms were collected. In December, *Diporeia* are reaching reproductive maturity and the end of their lifespan. Although fertile females were excluded from the experiments, the organisms may have been more sensitive. We doubt this explanation however, because similar relative results for the December and June river samples were observed for several other bioassays using a wide range of organisms (Burton *et al.* 1990). It is clear however that the physiological condition of the bioassay organisms should be considered and a performance based quality control should be established to evaluate the condition of organisms particularly when field collected populations must be used for assessment. To this end, the sensitivity of *Diporeia* for cadmium (Gossiaux *et al.* 1992) and pentachlorophenol (Landrum and Dupuis 1990) has been determined and a program is under development to use short-term water only exposures for such a performance base.

Avoidance/Preference Bioassays

The chemosensory ability of aquatic organisms to respond to chemical stimuli including pollutants (Brown *et al.* 1982) and to avoid environments containing high levels of contaminants is known (Kielty and White 1988). *Diporeia* are known to exhibit some avoidance of polycyclic aromatic hydrocarbon contaminated sediments (Landrum *et al.* 1991) while no avoidance of chlorinated hydrocarbon contaminated sediments was noted even at lethal concentrations (Landrum *et al.* 1989). In addition to avoiding specific contaminants, these organisms will likely be attracted to sediments containing high quality food material. Thus, when using sediment selectivity as a mechanism to distinguish between sediments, it will not be possible to

determine whether a specific sediment is avoided or another is preferred.

In general, the sediment avoidance/preference bioassay allowed ranking of the sediments by preference although there was no statistical difference among the bay sediments or the June collection of river sediments. Two of the most toxic sediments from the December river samples were strongly avoided but the third sample from that collection and Station S-61 from the bay stations both exhibited mortality but were not avoided relative to the controls.

Sediment composition will be important in the avoidance/preference response of *Diporeia*. However, these organisms inhabit a wide range of sediment types, from silty muck to course sand (Nalepa *et al.* 1985), so particle size alone is not a likely the major controlling feature. Rather, we speculate that the type and amount of organic matter is of more importance since clean combusted sand that had no organic matter was completely avoided while sandy sediments with low organic matter concentrations were preferred, e.g., Lake Michigan 29 m sediments and sediments from station S-61. When avoidance did occur, it was at high concentrations of contaminants and these concentrations tended to track with the compositional characteristics of the sediments (Tables 1,3,4).

If this bioassay is to be employed to better define the contamination of sediments then information on the range of compound classes that produce avoidance will need to be expanded. Also, the factors that elicit attraction such as food composition will need definition. Finally, the significance of the avoidance/preference assay relative to the health of an ecosystem is currently not known. Continued comparison with sediment characteristics and calibration with standard toxicants should improve our understanding of what is measured by this bioassay.

CONCLUSION

Saginaw Bay sediments in general were not acutely toxic to *Diporeia* but preponderance of evidence suggests potential acute problems could exist in the outer bay. In the river sediments, specific hot spots were observed to exist. However, in a river environment, high flow events can change site characteristics so that surface collected sediments can exhibit temporally variable indications of hazard. Thus, temporal studies should be the norm for high energy environments to properly evaluate hazard. The avoidance/preference bioassay suggested the same suite of potential problems as the mortality bioassay but it is not in complete concordance with the mortality data. Further, its significance and utility will require more substantial development before its utility can be completely appreciated.

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