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COMPARATIVE HEAVY METAL UPTAKE BY SOIL-DWELLING
INVERTEBRATES AND THE BIOASSAY EARTHWORM
EISENIA FOETIDA

Final technical report
by
Elizabeth A. Stafford

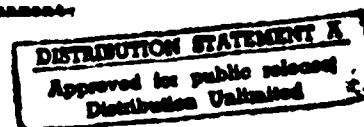
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Entomology Department.
Rothamsted Experimental Station.
Harpenden, Hertfordshire, U.K.

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by pitfall trapping) and native earthworms (collected by formalin vermifuge). Metal concentrations in earthworms exposed to substrates from each of the sites for 28 days under laboratory conditions were also measured.

Concentrations measured in invertebrates from the field sites also provided information on target organisms for metal uptake at the sites. The spiders (Araneida) and the detritivorous groups: millipedes (Diplopoda), woodlice (Isopoda), and earthworms (Oligochaeta) had the greatest metal concentrations. Earthworms contained the greatest Zn concentrations, Cu concentrations were greater in the Diplopoda, and Cd concentrations similar in range between earthworms and Isopoda. Pb concentrations were within a similar range in earthworms and invertebrates in the pitfall traps. Results suggest that earthworms colonizing the field sites do provide a good indication of the "worst case" of metal uptake by the soil-dwelling invertebrates.

Results of the laboratory uptake studies using E. foetida generally reflected the trends observed in metal concentrations measured in invertebrates naturally colonizing the Times Beach CDF, Black Rock CDF, and Grand Island reference site and in most cases provided a valid indication of the relative hazard posed by the elements Zn, Cu, Cd, and Pb. However, metal concentrations in invertebrates at the Ottawa mine spoil reclamation site did not correspond with those expected from the laboratory uptake study.



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Abstract

The use of invertebrates as indicators of soil pollution has been approached from two directions: either as a predictive laboratory test or as an indicator of field conditions. Under the present contract, the two approaches were compared by measuring concentrations of Zn, Cu, Ni, Cd, Cr and Pb in soil macro-invertebrates (including native earthworms) collected at field sites and by conducting laboratory uptake studies using the earthworm Eisenia foetida exposed to dredged material and soil from the field sites.

Three upland dredged material disposal sites on which ecosystems had developed to a greater or lesser degree and a reference area of low metal contamination were studied. These were: Times Beach Confined Disposal Facility (CDF), Buffalo, NY, Black Rock Harbor CDF, Bridgeport, CT and Ottawa Mine Spoil Reclamation Site, Ottawa, IL. The reference area was at Grand Island, Buffalo, NY. At each of the four sites measurements were made of heavy metal concentrations in dredged material/soil, soil-dwelling macro-invertebrates (collected by pitfall trapping) and native earthworms (collected by formalin vermifuge). Metal concentrations in earthworms exposed to substrates from each of the sites for 28 days under laboratory conditions were also measured (earthworm bioassay procedure).

Concentrations measured in invertebrates from the field sites also provided information on target organisms for metal uptake at the sites. The spiders (Araneida) and the detritivorous groups: millipedes (Diplopoda), woodlice (Isopoda) and earthworms (Oligochaeta) had the greatest metal concentrations. Earthworms contained the greatest Zn concentrations, Cu concentrations were greater in the Diplopoda and Cd concentrations similar between earthworms and Isopoda. Pb concentrations were within a similar range in earthworms and invertebrates in the pitfall traps. Results suggest that earthworms colonizing the field sites do provide a good indication of the 'worst case' of metal uptake by the soil-dwelling invertebrates.

Results of the laboratory uptake studies using E. foetida generally reflected the trends observed in metal concentrations measured in invertebrates naturally colonizing the Times Beach CDF, Black Rock CDF and Grand Island reference site and in most cases provided a valid indication of the relative hazard posed by the elements Zn, Cu, Cd and Pb. However, metal concentrations in invertebrates at the Ottawa mine spoil reclamation site did not correspond with the pattern expected from the laboratory uptake study.

1. INTRODUCTION

The United States Army Corps of Engineers (USACE) is responsible for the maintenance of navigable channels through the waterways of the United States. As a result, each year they are required to dispose of large quantities of dredged material which may be contaminated as a result of industrial and sewage effluent and run off from agricultural land and mining operations. The choice of areas onto which the dredged material is disposed and their subsequent management depends upon the mobility of contaminants in the material. To assess contaminant mobility and bioavailability, the USACE, Environmental Laboratory at Waterways Experiment Station (WES), Vicksburg, Mississippi, has laboratory procedures, measuring plant and animal uptake from dredged material, to indicate the potential hazard at dredged material disposal facilities (Folsom et al., 1981, Simmers et al., 1986, Lee et al., 1984). The use of earthworms for this purpose has been suggested by the USACE in relation to the environmental effects of dredging (Marquenie & Simmers, 1984, Simmers et al., 1986) and by the US Environmental Protection Agency (EPA) in relation to the assessment of hazardous waste disposal sites (Callahan et al., 1985, Miller et al., 1985).

At WES, a laboratory procedure measuring uptake of contaminants from dredged material under oxidized conditions (to simulate upland disposal) has used the earthworm Eisenia foetida (Rhett et al., 1984). This procedure was modified from a test developed at Rothamsted Experimental Station (Harpندن, Herts.) for use by the European Economic Community (EEC) in eco-toxicological testing of agro- and industrial chemicals entering the market (CEC Directive 79/81, 1984). In the field, earthworms have been collected and their tissues analyzed and found to provide an indication of metal concentrations in the soils (van Rhee, 1975, 1977, Helmke et al., 1979, Curry & Cotton, 1980, Beyer et al., 1982, Martin & Coughtrey, 1982). Other organisms, naturally colonizing contaminated sites, for example woodlice (Weiser et al., 1976, Coughtrey et al., 1977, Williamson, 1979), snails (Meinckee & Schaller, 1974) and surface dwelling invertebrates in general (Wade et al., 1980) have also been used to indicate the presence of bioavailable contaminants.

To investigate the ability of the WES laboratory test procedure to assess relative hazard posed by the elements: Zn, Cu, Cd and Pb in dredged material at upland confined disposal facilities (CDF), results of laboratory earthworm uptake studies were compared with measurements of these elements in invertebrates naturally colonizing CDFs containing contaminated dredged material.

The research objectives may be summarized as follows:-

- (1) To compare heavy metal uptake by the earthworm E. foetida exposed to dredged material under laboratory conditions with metal concentrations measured in native earthworms and soil-dwelling invertebrates naturally colonizing dredged material disposal facilities. To thereby assess the validity of using E. foetida to indicate contaminant bio-availability in dredged materials at upland dredged material disposal facilities.
- (2) To identify 'target organisms' among soil-dwelling invertebrates in terms of abundance at the CDFs and heavy metal uptake into the tissues and to assess their future significance as indicator species/groups/niches in the study of potential hazard posed by dredged material disposal facilities.

To achieve these objectives three CDFs and a reference site were selected for study. Elevated concentrations of metals have been recorded in dredged material from the Times Beach CDF (Marquenie et al. 1987), Black Rock Harbor CDF (Rogerson et al., 1985) and Ottawa mine spoil reclamation site (Rhett and Richards, 1986, Rhett et al., 1987). Preliminary assessments of the mobility of contaminants indicated a potential for movement into plant and animal tissues from the Times Beach dredged material (Folsom, 1981, Simmers & Rhett, 1983), Black Rock Harbor dredged material (Yevich et al., 1987) and Ottawa mine spoil dredged material (Rhett & Richards, 1986, Rhett et al., 1987). From each of the CDFs and the reference site dredged material/soil were collected and returned to the laboratory to conduct earthworm uptake studies. Each of the sites were naturally colonized to some degree by vegetation and associated fauna and samples of invertebrates, including native earthworms, were collected and returned to the laboratory for identification and metal analysis.

2. MATERIALS AND METHODS.

2.1 SITE SELECTION AND DESCRIPTION.

Three upland, dredged material confined disposal facilities (CDF) and one reference site, known to contain low concentrations of heavy metals, were selected.

2.1.1 Times Beach CDF: Times Beach CDF, Buffalo NY was created by the Buffalo District Army Corps of Engineers to contain sediment dredged from the Buffalo Harbor, known to be contaminated by effluent from industries along the Buffalo River. Disposal of dredged material ceased at Times Beach in 1976 and the upper layer of dredged material has consolidated to produce a soil-like layer supporting the growth of vegetation. Beneath the upper consolidated layer, the unconsolidated dredged material remains close to its original form. Depth of the consolidated soil-like layer depends upon its elevation relative to the water table. A woodland ecosystem has developed in the upland area of the CDF (Figure 1) and three distinct vegetation zones (A, B, C) were defined (see reports by Wilhelm in Stafford et al., 1987):

Vegetation zone A is the highest and driest of the zones. It is wooded, almost entirely by Populus deltoides (Cottonwood) and dominated beneath by the perennial Solidago altissima (Tall Goldenrod).

Vegetation zone B is, on the whole, 0.6 to 0.9 m lower in elevation than zone A; the canopy is also dominated by Cottonwood, but there is a lower story characterized by Cornus stolonifera (Red Osier Dogwood) and a few Salix spp. (Willows). The ground cover is relatively diverse, dominated by Impatiens capensis (Common Jewel Weed), Lythrum salicaria (Purple Loosestrife) and Goldenrods.

Vegetation zone C is the lowest of the zones in the upland area. It is also characterized by a canopy of Cottonwoods but there is no significant middle shrub story. The ground cover is dominated by Common Jewel Weed.

In association with the colonizing vegetation a diversity of invertebrate fauna and vertebrates, resident and migratory, have been recorded (see reports by Stafford, Bater and Andrie in Stafford et al., 1987).

2.1.2 Grand Island reference site: A woodland ecosystem established on soil derived from river sediments was selected by the Buffalo District Corps of Engineers for comparison with Times Beach CDF. Dominant tree species at Grand Island, Buffalo NY, were Fraxinus pennsylvanica (Pennsylvania Ash), Quercus macrocarpa and Quercus palustris (Oak spp.), and Salix fragilis (Willow). A more complete description of the vegetation at Grand Island is given by Wilhelm in Stafford et al. (1987).

2.1.3 Black Rock Harbor CDF: The Black Rock Harbor CDF, Bridgeport CT, was created under the Field Verification Program (FVP) of the U.S. Army Engineer Waterways Experiment Station (WES) Dredged Material Research Program (DMRP). Dredged material from the harbor was pumped into the CDF in 1981. After some consolidation of the material had occurred, the central area was divided into twenty sub-plots (in 1983) each treated with different combinations of lime, sand, manure and gravel (Figure 2). Grass seed was applied and a sparse cover of grasses have colonized the consolidating sediment at the site. Further details of the construction and development of the site are given elsewhere (Pedicord, 1987).

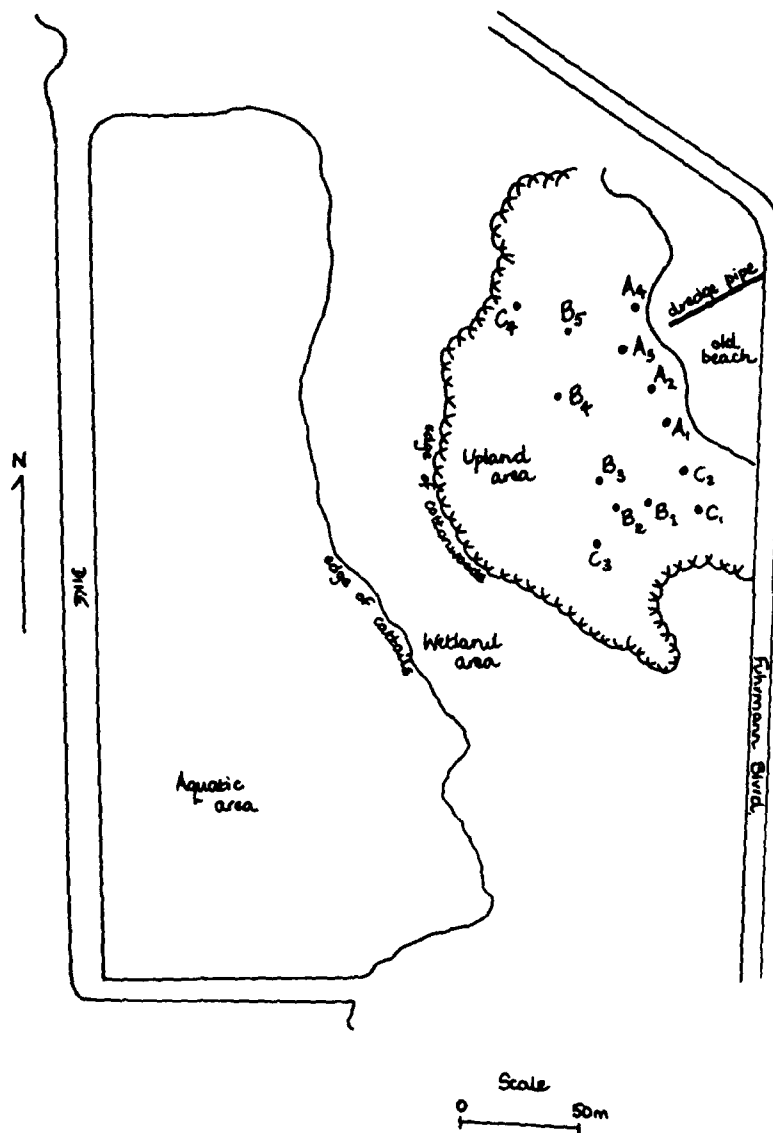


Figure 1: Times Beach CDF: positions of pitfall traps for collection of invertebrates

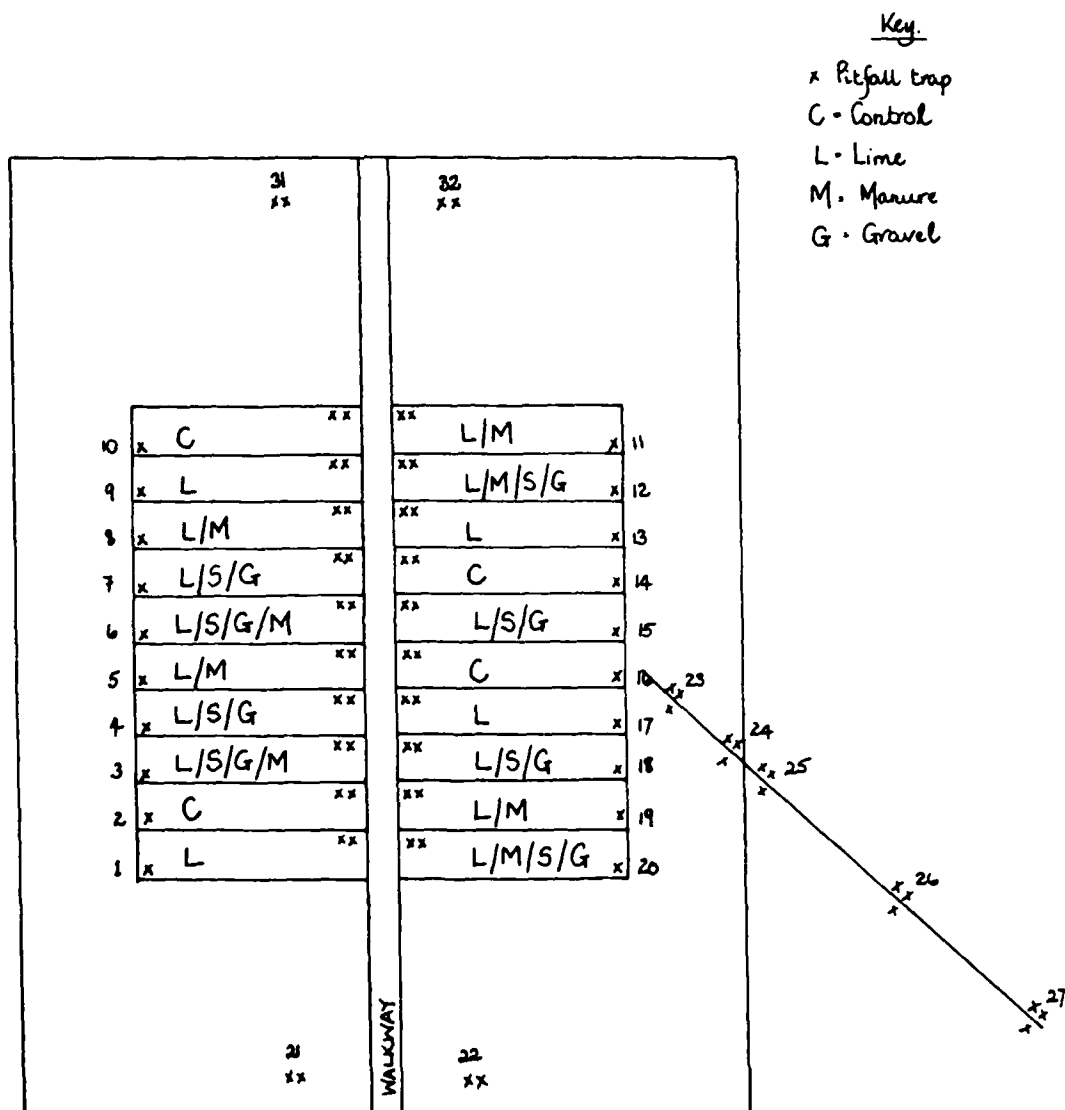


Figure 2: Black Rock Harbor CDF: position of pitfall traps for the collection of invertebrates

2.1.4 Ottawa mine spoil reclamation site: Pilot studies using dredged material for the reclamation of land used for strip mining were initiated in 1978 as a Productive Uses Project (PUP) of the U.S. Army Engineer, Waterways Experiment Station (WES) Dredged Material Research Program (DMRP). Within a 0.5 hectare site at Ottawa IL., pyritic mine spoil was levelled and divided into four plots (Figure 3). Plots were separated from each other by impervious dikes. In plot 1, (the control plot) pyritic mine spoil remained untreated, in plot 2, a meter depth of dewatered dredged material was added and in plots 3 and 4 crushed agricultural limestone (11 metric tons/ha and 17 metric tons/ha, respectively) was mixed with the top 15cm of mine spoil before addition of the dewatered dredged material (1 meter depth). Construction of the site has been described by Perrier et al., (1978). In 1978, all plots were seeded with a mixture of grass species. Development of vegetation at the Ottawa site is described by Simmers et al. (1984). In each plot, five sub-plots were delineated for management of vegetative cover. Sub-plot (a) was mown and the organic matter removed, sub-plot (b) was planted with a commercial crop (soybeans or corn) sub-plots (c) and (d) were left alone and sub-plot (e) was burned annually. Vegetation was managed to exclude trees.

2.2 DREDGED MATERIAL AND SOIL SAMPLES.

2.2.1 Times Beach CDF and Black Rock Harbor CDF. Forty liters of unconsolidated dredged material were collected, in May 1985, from below 1 meter depth at Times Beach CDF and from Black Rock Harbor CDF and returned to the laboratory for use in earthworm uptake studies. Sub-samples of these materials were finely ground and oven dried for chemical analysis.

2.2.2 Times Beach CDF and Grand Island reference site. In November 1986, oxidized, surface layer material was collected using a 15cm depth by 5cm diameter soil corer from each of the thirteen sampling plots in vegetation zones A, B and C at Times Beach (Figure 1) and from each of the five sampling plots at Grand Island. These plots correspond with those used for collection of soil invertebrates. After extraction of the soil dwelling micro-invertebrates using a Tullgren funnel apparatus the material from four cores at each plot was mixed, finely ground and oven dried prior to chemical analysis.

2.2.3 Ottawa mine spoil reclamation site. Samples of dredged material from this site were collected in 1985 for analysis (Rhett & Richards, 1986).

2.3 LABORATORY UPTAKE STUDIES USING EISENIA FOETIDA.

Dredged material collected at the CDFs and soil from the reference site were returned to the laboratory for measuring metal uptake by earthworms. In each case a standard laboratory procedure was followed: 7.5 liter sub-samples of dredged material/soil were placed in replicate plexiglass cylinders and rewetted to field capacity. The plexiglass cylinders were covered at each end with muslin and one end was placed in a tray of de-ionized water. Capillary action produced a gradation in moisture content up the cylinder and earthworms could seek out their optimum conditions. Twenty grams (live weight) of mature, clitellate *Eisenia foetida* were added to each cylinder and held at 15°C under low light conditions for 28 days. Earthworms for use in the studies were grown in manure containing low concentrations of heavy metals and initial samples of the *E. foetida* were analyzed to ensure low metal concentrations. After 28 days exposure, earthworms were hand separated from the substrate and held on moist filter paper for 48 hours for evacuation of gut contents before preparation for metal analysis.

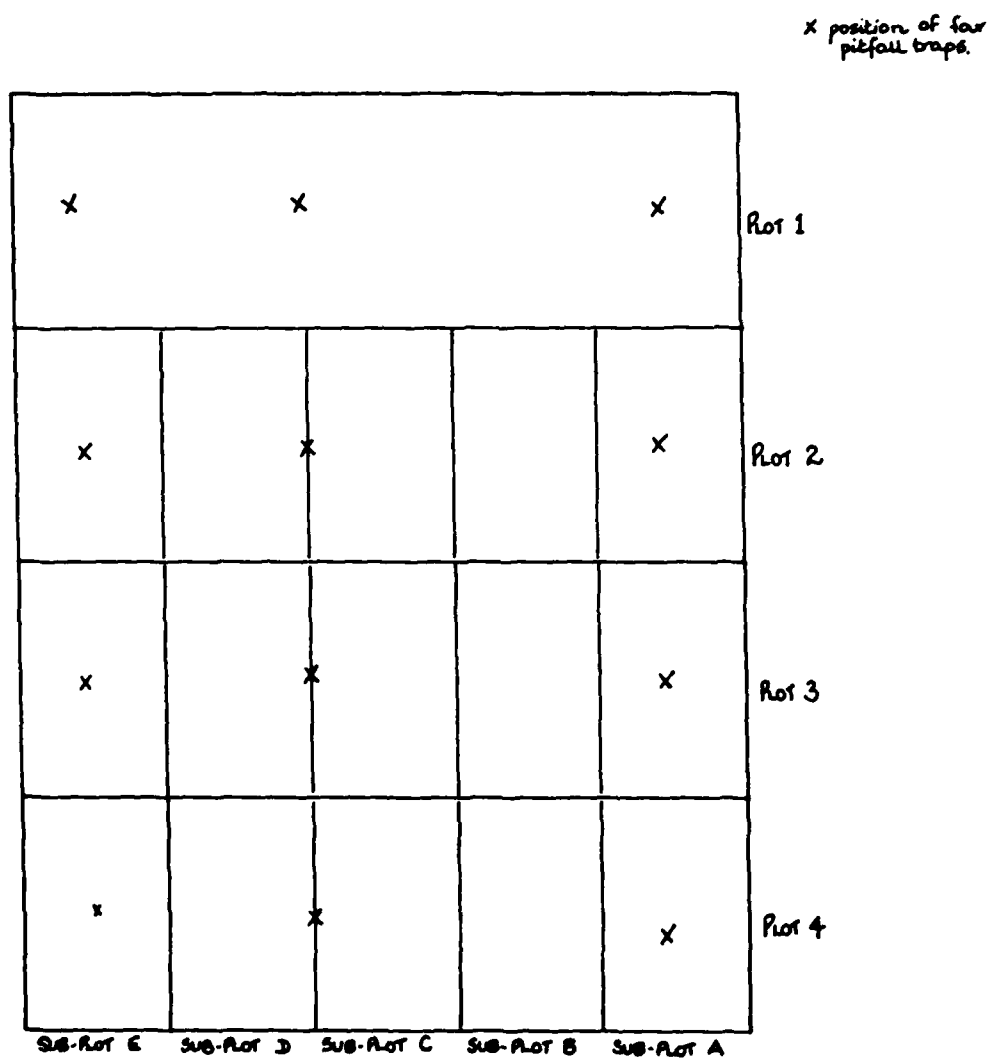


Figure 3: Ottawa, IL strip mine reclamation site - pitfall traps for the collection of invertebrates

2.3.1 Times Beach CDF. Dredged material has been collected on several occasions for use in laboratory uptake studies using the earthworm E. foetida. Under the present contract two studies were made:-

Study 1: In May 1985, 40 liters of deep layer (> 1 meter) unconsolidated dredged material were collected, returned to the laboratory and stored in sealed containers at 4°C until August 1985. Preliminary screening tests demonstrated that the material was toxic to E. foetida. Treatment of the dredged material by simulated weathering processes of leaching and drying was necessary before earthworms survived the 28 day exposure period. Dredged material was placed on polythene sheets in thin layers in a greenhouse to dry. Ten liters of water were poured through ten liter batches of dried sediment held on muslin. Fine sediment in the washings was removed by filtration and re-mixed with the re-dried sediment. After each leaching and drying earthworm survival was tested. Dredged material leached and dried five times was used for earthworm uptake studies.

Study 2: Dredged material was collected from thirteen plots in the upland area at Times Beach. Material collected from successive depths at each plot was held separately and earthworm uptake studies conducted using each layer. Successive layers were defined as follows: Level 0 = Litter layer; Level 1 = Humic layer; Level 2 = Oxidized Layer; Levels 3,4,5 = Oxidized/Reduced layers. Levels 3,4 and 5 are oxidized/reduced depending on seasonal changes in the water level of Lake Erie.

2.3.2 Grand Island reference area. Surface layer soil (to 30cm depth) was collected from four plots at Grand Island and returned to the laboratory for conducting earthworm uptake studies using the standard procedure.

2.3.3 Black Rock Harbor CDF. In preliminary tests, dredged material collected here was toxic to E. foetida. Simulated weathering processes as described in Section 2.3.1 were carried out. Earthworms then survived the standard procedure of 28 days exposure to the dredged material.

2.3.4 Ottawa mine spoil reclamation site. Earthworm uptake studies had been conducted previously at this site in 1981 and 1983. In 1981, uptake studies were conducted under field conditions within each plot at the site (Simmers et al., 1984) and in 1983, laboratory uptake studies were conducted using material collected from different depths at each plot. Results for plots 2 - 4 were then combined (Rhett et al., 1987). These results are referred to for comparison in the present report.

2.4 FIELD COLLECTION OF INVERTEBRATES.

Plots used for the collection of invertebrates were chosen to coincide with the different vegetation types at each of the sites.

Pitfall traps were placed in the dredged material/soil, at each plot, so that the top rim of the plastic cup was level with the surface of the soil. To each pitfall trap approximately 20 ml of 5% formaldehyde solution was added and the traps left in position for three to ten days. Invertebrates collected in the traps from each plot were rinsed free of debris and taxonomic groups identified. Invertebrates collected at the sites were identified by Mr John Bator of the Entomology Department, Ohio State University, USA and Mr James Ashby of the Entomology Department, Rothamsted Experimental Station.

Harpenden, UK. The following taxonomic groups were used: Diplopoda (millipedes) and Chilopoda (centipedes) were grouped according to Class. the Class Arachnida was further divided into the Orders: Araneida (spiders) and Opiliones (harvestmen). The Class Insecta was further divided into the Orders Orthoptera (grasshoppers) and Coleoptera (beetles), and the Isopoda (woodlice) were grouped as an Order within the Class Crustacea. These groupings were chosen on the basis of biomass and numerical abundance of specimens collected in the traps and the diversity of species within the group. Within each group, further identification was carried out where expertise was available. In order to obtain sufficient biomass for chemical analysis, individuals of the same taxonomic group from the four traps at each plot were pooled. Invertebrates of each taxonomic group from each plot were oven-dried to constant weight at 80°C and their dry weight biomass recorded.

Native earthworms were collected using a dilute (0.5%) formaldehyde vermifuge applied to the surface (Raw, 1959). Emerging earthworms were immediately rinsed in clean water, separated according to species and prepared for analysis. The method of Stafford and McGrath (1986) was used to correct measurements of metal concentrations for the presence of soil within the earthworm gut. Earthworms were identified by Mr J. Reece Lofty of the Entomology Department, Rothamsted Experimental Station, Harpenden, Herts.

2.4.1 Times Beach CDF. For the collection of soil-dwelling invertebrates four plots were used in vegetation zones A and C (A1, A2, A3, A4, C1, C2, C3, C4) and five plots in vegetation zone B (B1, B2, B3, B4, B5) (Figure 1). In each plot, pitfall traps were positioned on the four corners of a meter square quadrat. Samples were collected in the spring and fall of 1985 and 1986. In spring 1985, for the initial investigation, seven of the thirteen possible plots were used and pitfall traps were left in position for three days before the contents were collected. For subsequent collections traps were left in position at all plots for ten days. A preliminary assessment of the native earthworm population was made in May 1985 and collection from within all plots was made in November 1986.

2.4.2 Grand Island reference site. In May and November 1986, pitfall traps were placed on the four corners of five, meter square plots at the Grand Island reference site, for ten days, to collect soil-dwelling invertebrates. In November 1986, dilute formaldehyde solution was applied at each plot to collect native earthworms.

2.4.3 Black Rock Harbor CDF. Within each of the twenty plots three pitfall traps were placed: two close to the walkway and one in the farther extremity of the plot (Figure 2). Pitfall traps were also placed outside the treated plots and along a transect running from the CDF across the dike and into the nearby vegetation (Figure 2). Pitfall traps were placed at Black Rock Harbor CDF for ten days in May and November 1986. There was no native earthworm population due to unfavorable conditions at the Black Rock Harbor CDF.

2.4.4 Ottawa mine spoil reclamation site. Within each of the differently managed subplots, except for sub-plot (b), pitfall traps were placed at the four corners of a meter square quadrat (Figure 3). Invertebrate collections were made over a ten day period in May 1986 and in November 1986. In May 1986 formalin vermifuge was applied in each sub-plot for the collection of native earthworms.

2.5 CHEMICAL ANALYSIS.

In preparation for metal analysis samples were oven dried at 80°C to constant weight. Total metal concentrations in the dredged material/soil and invertebrates were determined after a wet-ashing digestion procedure. Sample weights of less than or equal to 0.5g (dry weight) were digested in 'AnalaR' grade concentrated HNO₃ (5 ml) at room temperature for 48 hours, then refluxed at 125°C for 5 hours. After cooling, 'AnalaR' grade 70% HClO₄ was added before re-heating to 200°C, taking samples almost to dryness. Samples were then re-extracted in hot 25% HCl and made up to final volume (5% HCl). Concentrations of Zn, Cu, Ni, Cd, Cr and Pb were determined using inductively coupled plasma (ICP) emission spectrometry (ARL 34000 instrument). Standard solutions of these elements were prepared using the same extractant solution and reagent blanks were also run. In some cases (mostly invertebrates) insufficient biomass was available for analysis. In all circumstances due care was taken to avoid contamination by metals in the analytical procedures.

When making an assessment of the bioavailability of heavy metals, it is essential to distinguish between metal concentrations within the animal tissue and metal concentrations present as a result of soil in the sample, for example soil within the earthworm gut. For preliminary investigations and laboratory uptake studies, earthworms were held on moist filter paper for 48 hours (changed once after 24 hours) for gut evacuation. As this was not practicable in the field, a new method was developed using acid insoluble residue (AIR) as an inert marker to enable the quantity of soil present in any earthworm sample to be calculated. A correction factor could then be applied to eliminate heavy metal concentrations resulting from soil within the earthworm gut, leaving only the concentrations of heavy metals in the earthworm tissue. Full details of this method have been published elsewhere (Stafford and McGrath 1986).

2.6 STATISTICAL ANALYSIS.

Data comparisons were made using analysis of variance. Prior to this, the homogeneity of variance between the plots was tested using Cochran's test for homogeneity of variance. Where necessary, data transformations were carried out until valid comparisons could be made. Statistical comparisons between the means were achieved using Waller-Duncan k-ratio t-test. Where homogeneity of variance was not achieved by data transformation, comparisons between the means were carried out using non-parametric tests. Two non-parametric tests were applied as appropriate: if $k = 2$ the Mann-Whitney U test was applied, and if $k > 2$ the Kruskal-Wallis test was employed (Winer, 1979, Sokal and Rohlf, 1981). Where relevant, the method of comparison between the means has been indicated at the base of the appropriate table.

3. RESULTS.

3.1 DREDGED MATERIAL AND SOIL ANALYSIS.

3.1.1 Times Beach CDF and Black Rock Harbor CDF. Concentrations of heavy metals measured in the partly consolidated dredged material collected at Black Rock Harbor CDF and unconsolidated dredged material collected at Times Beach CDF for use in the laboratory earthworm uptake studies are given in Table 1. Although no statistical comparisons were possible because material was collected from only one plot at each site, major differences in metal concentrations were evident between the two CDFs.

Table 1
Metal Concentrations Measured in Dredged Material from Times Beach
(Unconsolidated, Deep Layer) and Black Rock CDF (ug/g, dry weight).

SITE	Element					
	Zn	Cu	Ni	Cd	Cr	Pb
Times Beach	2,002	432	73	13	606	1.073
Black Rock	1,413	2,606	187	21	1,575	406

3.1.2 Times Beach CDF and Grand Island reference site. Concentrations of Zn, Cu, Ni, Cd, Cr and Pb in oxidized, surface layer dredged material from vegetation zones A, B and C, at Times Beach and in soil from the Grand Island reference site are given in Table 2.

Table 2
Metal Concentrations Measured in Dredged Material and Soil
from Times Beach (Surface Layer) and Grand Island.
Mean values per zone expressed as ug/g, dry weight.

SITE/ZONE	Element					
	Zn	Cu	Ni	Cd	Cr	Pb
Times Beach						
Vegetation zone						
A	289 ^b	51 ^a	28 ^c	3.3 ^b	57 ^a	161 ^a
B	480 ^a	95 ^a	49 ^b	6.4 ^a	137 ^a	212 ^a
C	426 ^{a,b}	83 ^a	35 ^b	5.0 ^{a,b}	100 ^a	172 ^a
Grand Island						
R	227 ^b	68 ^a	55 ^a	2.5 ^c	37 ^b	44 ^b

a,b,c - mean values in a column followed by the same letter are not significantly different at $p < 0.05$.
Non-parametric statistical comparison of the means was employed.

Concentrations of metals measured in dredged material from Times Beach and soil from Grand Island were statistically compared between vegetation zones at Times Beach and between each of the vegetation zones at Times Beach and the Grand Island site (Table 2). All comparisons were made at the 0.05 level of significance. Within Times Beach, Cu, Cr and Pb concentrations were not statistically different between the three vegetation zones. Cd and Zn concentrations were significantly lower in zone A compared with zone B but not zone C. Ni concentrations were significantly lower in zone A compared with zones B and C. Comparisons between Times Beach plots and Grand Island plots indicated significantly greater Cd, Cr and Pb concentrations in the Times Beach dredged material and significantly greater Ni concentrations in the Grand Island soil (Table 2). Concentrations of Cu at Times Beach and Grand Island were not statistically different.

3.1.3 Ottawa mine spoil reclamation site. Metal concentrations measured in dredged material placed at this site were compared (Table 3, from Rhett & Richards, 1986). Only Pb concentrations differed between the plots.

Table 3
Metal Concentrations Measured in Dredged Material
from Ottawa Mine Spoil Reclamation Site.
Mean values expressed as ug/g, dry weight.

PLOT	Element					
	Zn	Cu	Ni	Cd	Cr	Pb
Plot 2	1,003 ^a	85 ^a	38 ^a	6.9 ^a	83 ^a	412 ^a
Plot 3	1,088 ^a	95 ^a	41 ^a	7.4 ^a	113 ^a	475 ^{ab}
Plot 4	1,043 ^a	96 ^a	41 ^a	7.8 ^a	104 ^a	536 ^b

ab = values followed by different letters within each column are significantly different at the 95% confidence limit according to Bayes LSD test.

3.2 RESULTS OF LABORATORY UPTAKE STUDIES.

3.2.1 Times Beach (unconsolidated layer) and Black Rock dredged material.

Preliminary investigations demonstrated that survival of E. foetida in these materials was poor (LT₅₀ of <2 days and <3 hours in Times Beach and Black Rock materials, respectively, Table 4). To conduct a 28 day uptake study, some pretreatment of the materials was necessary. Leaching and drying of the material aimed to simulate natural weathering processes and increase acceptability of the materials to the earthworms. Results of successive tests for earthworm mortality after each leaching and drying are given in Table 4. Once suitable for 28 day earthworm survival, materials were used to conduct the uptake study. After 28 days exposure to the dredged material, 50% of the earthworm biomass was recovered from the Times Beach material and 56% from the Black Rock material (mean values of four replicates). Results of metal concentrations in E. foetida are given in Table 5.

Table 4
LT₅₀ and LT₁₀₀ of E. foetida after Successive Leaching and Drying
of the Dredged Material

Treatment	TIMES BEACH		BLACK ROCK
No treatment	LT ₅₀	1 - 4 days	
	LT ₁₀₀	(0% mortality after 1 day) (100% mortality after 4 days)	< 3 hours
Once leached and dried	LT ₅₀	< 2 days	
	LT ₁₀₀	(92% mortality after 4 days)	< 3 hours
Twice leached and dried	LT ₅₀	2 - 3 days (33% mortality after 2 days) (58% mortality after 3 days)	3 - 7 days (42% mortality after 3 days) (75% mortality after 7 days)
	LT ₁₀₀	< 7 days (92% mortality after 7 days)	> 7 days
Thrice leached and dried	LT ₅₀	7 - 12 days (0% mortality after 7 days) (92% mortality after 12 days)	> 12 days (42% mortality after 12 days)
	LT ₁₀₀	> 12 days	> 12 days
Four times leached/dried	LT ₅₀	17 - 28 days (33% mortality after 17 days) (50% mortality after 28 days)	17 - 28 days (17% mortality after 17 days) (92% mortality after 28 days)
	LT ₁₀₀	> 28 days	> 28 days
Five times leached/dried	-----	> 80% survival after 28 days	-----

Earthworms were considered dead if they failed to respond to a sharp stimulus to the anterior end.

Table 5
Metal Concentrations (ug/g, dry weight) in E. foetida at the Start of the
Study (Initial) and After 28 Days Exposure to the Dredged Materials.

ELEMENT	Zn	Cu	Ni	Cd	Cr	Pb
Initial worms	120 (1.9)	17 (0.93)	1.4 (0.97)	2.8 (0.32)	1.4 (0.67)	2.7 (0.21)
After 28 days: Times Beach	135 (5.6)	41 (2.2)	27 (5.3)	5.4 (0.45)	2.0 (1.9)	13 (4.3)
Black Rock	152 (8.1)	145 (7.6)	33 (6.7)	8.0 (1.6)	7.2 (5.5)	4.5 (0.31)

Mean value and standard deviation (in parenthesis) of four replicates.

3.2.2 Times Beach consolidated dredged material. E. foetida were exposed for 28 days to dredged material from Times Beach CDF, and to a control substrate of uncontaminated horse manure. Dredged material was excavated from increasing depths at Times Beach and earthworm uptake studies conducted using each of the different levels separately. Metal concentrations measured in the earthworms after 28 days are given in Table 6.

Table 6
Metal Concentrations Measured in E. foetida Exposed to Times Beach
Dredged Material and an Uncontaminated Control Substrate.

Substrate	Zn	Cu	Ni	Cd	Cr	Pb
Control: n=3	110 (11)	9.9 (0.46)	1.3 (0.50)	4.0 (2.2)	5.5 (4.1)	<2.7 -
<u>Vegetation zone A</u>						
Level:0(litter) n=3	179 (97)	15 (1.1)	5.9 (5.7)	15 (7.3)	3.4 (0.91)	5.5 (0.15)
Level:1(humic) n=3	114 (7.9)	18 (1.2)	8.3 (9.5)	13 (5.5)	6.9 (4.2)	9.1 (5.4)
Level:2(oxidized) n=3	112 (2.8)	29 (5.2)	2.9 (0.96)	6.1 (0.84)	7.7 (3.7)	8.7 (3.5)
Level:3 n=2	107	22	3.6	6.4	12	13
<u>Vegetation zone B</u>						
Level:0(litter) n=3	113 (7.1)	12 (1.8)	1.7 (0.82)	17 (4.1)	1.5 (0.53)	2.7 (0.07)
Level:1(humic) n=3	110 (0.60)	18 (3.4)	2.9 (0.76)	12 (2.9)	5.1 (0.80)	4.9 (0.93)
Level:2(oxidized) n=3	115 (4.8)	23 (1.5)	3.5 (0.35)	6.4 (1.3)	11 (3.4)	9.7 (1.7)
Level:3 n=3	133 (16)	35 (0.61)	4.9 (0.64)	5.6 (0.60)	19 (4.5)	24 (6.5)
<u>Vegetation zone C</u>						
Level:0(litter) n=4	112 (7.8)	12 (1.2)	3.3 (3.2)	17 (10)	6.1 (9.0)	3.5 (0.76)
Level:1(humic) n=4	126 (22)	14 (1.2)	3.6 (1.7)	11 (2.9)	5.2 (1.2)	6.4 (2.3)
Level:2(oxidized) n=4	114 (11)	24 (3.7)	3.5 (0.83)	7.3 (2.3)	14 (5.6)	11 (8.7)
Level:3 n=2	138	34	3.1	7.2	24	26
Level:4 n=2	116	34	2.9	5.8	10	14

Mean values and standard deviation (in parenthesis) in ug/g, dry weight.

These results are compared statistically between vegetation types at Times Beach in Table 7a and between successive levels in the substrate in Table 7b.

Table 7a
Metal Concentrations Measured in E. foetida Exposed to
Dredged Material from Different Vegetation Types at Times Beach CDF.
 All values expressed as ug/g. dry weight.

Level/Veg. type	Zn	Cu	Cd	Pb
Level 0				
Veg. type A	179 _a	15 _a	15 _a	5.5 _a
Veg. type B	113 _a	12 _a	17 _a	2.7 _a
Veg. type C	112 _a	12 _a	17 _a	3.5 _a
Level 1				
Veg. type A	114 _a	18 _a	13 _a	9.1 _a
Veg. type B	110 _a	18 _a	12 _a	4.9 _a
Veg. type C	126 _a	14 _b	11 _a	6.4 _a
Level 2				
Veg. type A	112 _a	29 _a	6.1 _a	8.7 _a
Veg. type B	115 _a	23 _a	6.4 _a	9.7 _a
Veg. type C	114 _a	24 _a	7.3 _a	11 _a

a = mean values in a column within each level with the same subscript are not significantly different ($p < 0.05$).

Table 7b
Metal Concentrations Measured in E. foetida Exposed to
Dredged Material from Different Depths at Times Beach CDF.
 All values expressed as ug/g. dry weight.

Veg. type/Level	Zn	Cu	Cd	Pb
Vegetation type A				
Level 0	179 _a	15 _a	15 _a	5.5 _a
Level 1	114 _a	18 _a	13 _a	9.1 _a
Level 2	112 _a	29 _a	6.1 _a	8.7 _a
Vegetation type B				
Level 0	113 _a	12 _b	17 _a	2.7 _a
Level 1	110 _a	18 _b	12 _b	4.9 _a
Level 2	115 _a	23 _a	6.4 _b	9.7 _a
Vegetation type C				
Level 0	112 _a	12 _b	17 _a	3.5 _b
Level 1	126 _a	14 _b	11 _a	6.4 _b
Level 2	114 _a	24 _a	7.3 _a	11 _a

ab = mean values in a column within each vegetation type with different subscripts are significantly different ($p < 0.05$)

3.2.3 Grand Island reference site. Over 50% of the biomass of E. foetida exposed to soil from the Grand Island site were recovered at the end of the 28 days. Metal concentrations in these earthworms and those sampled at the start of the 28 day study (T = 0) are given in Table 8.

Table 8
Metal Concentrations Measured in E. foetida at the Beginning and End of 28 Days Exposure to the Grand Island Soil.
Mean values and standard deviations (in parenthesis) in ug/g, dry weight.

Sample	Zn	Cu	Ni	Cd	Cr	Pb
T = 0	98 (4.2)	9.0 (0.62)	2.5 (0.31)	2.7 (0.23)	2.1 (0.93)	<4.2
T = 28 days	101 (4.5)	10 (0.56)	5.9 (5.5)	4.4 (0.19)	2.1 (0.47)	<2.7

T = 0 = mean value and standard deviation of three replicate samples.

T = 28 = mean value and standard deviation of four replicate samples.

3.2.4 Ottawa mine spoil reclamation site. Results of earthworm uptake studies conducted in the field in 1981 (Simmers et al., 1984) and in the laboratory in 1983 (Rhett et al., 1987) are given in Tables 9a and b, respectively.

Table 9a
Metal Concentrations in E. foetida Exposed to Dredged Material in the Field at the Ottawa Site.
Mean values $\pm$ standard deviations in ug/g, dry weight.

Plot	Cu	Ni	Cd	Pb
Control*	7.5 $\pm$ 1.1	5.6 $\pm$ 2.5	3.1 $\pm$ 0.34	1.3 $\pm$ 0.85
2	14 $\pm$ 1.7	5.2 $\pm$ 1.4	2.9 $\pm$ 0.70	2.2 $\pm$ 0.65
3	11 $\pm$ 0.5	5.5 $\pm$ 0.21	3.0 $\pm$ 0.39	5.4 $\pm$ 1.1
4	21 $\pm$ 0.5	7.6 $\pm$ 0.83	9.7 $\pm$ 0.39	3.6 $\pm$ 0.42

Control* = earthworms from a manure/peat moss substrate of low metal concentrations.

From Simmers et al., 1984.

Table 9b
Metal Concentrations in Earthworms Exposed to Leaf Litter
and Dredged Material from Plots 2-4 at the Ottawa Site.
Mean values $\pm$ standard deviations in ug/g. dry weight.

Test Material	Cu	Ni	Cd	Pb
Initial worms	9.6 $\pm$ 1.0	2.0 $\pm$ 0.77	3.7 $\pm$ 0.51	1.5 $\pm$ 0.65
<u>After 28 days exposure:</u>				
<u>E. foetida</u>	9.2 $\pm$ 1.6	1.9 $\pm$ 0.46	14 $\pm$ 5.4	2.2 $\pm$ 0.46
Leaf litter	16 $\pm$ 1.7	5.9 $\pm$ 0.20	3.3 $\pm$ 0.73	<
<u>E. foetida</u>	26 $\pm$ 4.2	5.2 $\pm$ 0.61	9.0 $\pm$ 0.89	2.9 $\pm$ 0.69
30cm depth*	127 $\pm$ 8.6	52 $\pm$ 3.2	10 $\pm$ 0.50	620 $\pm$ 70
<u>E. foetida</u>	25 $\pm$ 1.0	5.3 $\pm$ 0.31	8.2 $\pm$ 0.21	5.3 $\pm$ 2.0
100cm depth*	117 $\pm$ 10	50 $\pm$ 2.2	9.2 $\pm$ 1.6	585 $\pm$ 23

depth* = defines depth below the surface from which dredged material was collected.

From Rhett et al., 1987.

3.3 IDENTIFICATION AND ANALYSIS OF NATIVE INVERTEBRATES.

3.3.1 Times Beach CDF. Individuals from most of the major invertebrate taxa were represented in the pitfall traps. Specimens of Coleoptera (beetles), Araneida (spiders), Opiliones (harvestmen), Chilopoda (centipedes), Diplopoda (millipedes), Isopoda (woodlice) and Orthoptera (grasshoppers) collected in the pitfall traps were identified and counted. Eleven families of Coleoptera were represented dominated numerically by the Carabidae (Ground Beetles); four families of Isopoda were present dominated numerically by Trichoniscus (Woodlice); two families of Diplopoda and one family each of Chilopoda and Araneida were recorded in the samples collected at each sampling time. A full record of species collected and identified is included in Appendix A, to this report. In composition the invertebrate fauna collected in the pitfall traps was dominated both numerically and in terms of dry matter contribution to the total biomass by Coleoptera, Diplopoda and Isopoda. Relative percent biomass of each group in the pitfall traps is given in Appendix A, Tables 1c, 2c, 3b and 4b. Pitfall traps collect proportionally more of the active groups, such as predatory species, actively seeking prey, and detritivores moving about in the litter and on the soil surface. Herbivorous invertebrates are poorly represented. Pitfall trapping is not intended to provide a means of estimating absolute invertebrate populations.

Invertebrates were sampled using pitfall traps in spring and fall for two consecutive years. Seasonal differences between samples in terms of species abundance and composition were evident for some taxonomic groups, for example, Opiliones and Orthoptera were collected in greater abundance in the pitfall traps collected in the fall compared with the spring. Snails were present in larger numbers in the sample collected in November compared to other samples. Within taxonomic groups (where further identification to genus level was possible) some differences between seasons were also observed, for

example, in the May 1985 sample there were no Nitidulidae (Sap Beetles) or Chrysomelidae (Leaf Beetles) among the Coleoptera, while in the October 1985 sample the Elateridae (Click Beetles), Tachyporidae (Carrion Beetles) and Oxytelinidae (Carrion Beetles) which were present in May were absent. These differences in composition between the samples are most likely to be due to seasonal breeding cycles of the different species of invertebrates.

The greatest numbers and percentage biomass by weight collected in the traps were the Coleoptera, followed by the Isopoda. A similar total dry weight biomass was collected in all the pitfall traps across the site. The composition of invertebrate fauna in the traps was then examined for changes in taxonomic composition which could be related to vegetation type. A similar relative biomass of Coleoptera was collected from all plots across the upland area at the site. Some indication of an increase in relative percent by weight of Araneida and decrease in relative percent by weight of Diplopoda and Isopoda in the pitfall traps may have occurred with increasing proximity to the water edge. This may be related to the changing vegetation type, or may be directly due to higher moisture levels in the substrate.

3.3.2 Grand Island reference site. Pitfall traps placed at the Grand Island site collected a similar taxonomic composition of soil-dwelling invertebrates to those identified from the Times Beach traps (Appendix B, Tables 1 and 2). In similarity to the Times Beach results, numbers and biomass of invertebrates were dominated by the Coleoptera and Isopoda and similar seasonal differences were noted, for example Opiolones and Orthoptera were present in the November sample and not in the May sample.

Measurements of metal concentrations in invertebrates collected at Times Beach CDF and Grand Island reference site are presented in full detail in Appendices A and B. For each taxonomic group, mean metal concentrations were calculated and statistically compared at each of the four sampling times (1985, spring and fall and 1986, spring and fall). The results of these statistical analyses are shown in Tables 10a-d.

In 1985, the Grand Island reference site was not sampled by pitfall trapping; however, statistically significant differences in metal concentrations were noted between the vegetation zones at Times Beach. In the spring sample (Table 10a), Zn and Cd concentrations in the Coleoptera were significantly lower in vegetation zone A compared with zones B and C. Cd concentrations in the Diplopoda were significantly greater in vegetation zone B compared with zones A and C and a similar pattern was noted for Cu concentrations in the Araneida. In fall 1985 (Table 10b), no statistically significant differences were noted between the vegetation zones at Times Beach for any of the four taxa, with the exception of the Isopoda, where Cu concentrations were significantly greater in Isopoda from vegetation zone A compared with zones B and C.

Table 10a
Metal Concentrations Measured in Invertebrates Collected
in Pitfall Traps, Times Beach, Spring 1985.
Mean values per vegetation zone¹ expressed in ug/g, dry weight.

SPECIES/ ZONE	Element			
	Zn	Cu	Cd	Pb
ARANEIDA				
Veg. zone A	415 ^a	169 ^b	27 ^a	26 ^{a*}
B	461 ^a	230 ^a	76 ^a	17 ^{a*}
C	307 ^a	182 ^b	111 ^a	6.8 ^{a*}
COLEOPTERA				
Veg. zone A	90 ^b	14 ^{a*}	1.1 ^b	0.68 ^a
B	108 ^a	15 ^{a*}	2.7 ^a	2.4 ^a
C	113 ^a	15 ^{a*}	2.2 ^a	2.9 ^a
DIPLOPODA				
Veg. zone A	211 ^a	641 ^a	2.8 ^b	7.5 ^a
B	242 ^a	660 ^a	3.7 ^a	6.1 ^a
C	174 ^a	634 ^a	2.2 ^b	5.8 ^a
ISOPODA				
Veg. zone A	180 ^a	182 ^a	33 ^{a*}	14 ^{a*}
B	191 ^a	142 ^a	45 ^{a*}	14 ^{a*}
C	180 ^a	144 ^a	29 ^{a*}	11 ^{a*}

a,b - mean values in a column within each taxon followed by the same letter are not significantly different at $p < 0.05$.

* = Non-parametric statistical comparison of the means was employed.

1. Mean values of two replicates for vegetation zones A and B, and three replicates for vegetation zone C.

Table 10b
Metal Concentrations Measured in Invertebrates Collected
in Pitfall Traps, Times Beach, Fall 1985.
Mean values per vegetation zone¹ expressed in ug/g. dry weight.

SPECIES/ ZONE	Element			
	Zn	Cu	Cd	Pb
ARANEIDA				
Veg. zone A	166 ^a	111 ^a	15 ^a	9.0 ^a
B	140 ^a	77 ^a	8.8 ^a	14 ^a
C	142 ^a	103 ^a	18 ^a	8.5 ^a
COLEOPTERA				
Veg. zone A	99 ^a	18 ^a	2.1 ^a	7.1 ^a
B	111 ^a	19 ^a	2.6 ^a	5.0 ^a
C	104 ^a	16 ^a	1.6 ^a	4.5 ^a
DIPLOPODA				
Veg. zone A	195 ^{a*}	728 ^a	2.7 ^a	12 ^a
B	235 ^{a*}	787 ^a	3.1 ^a	12 ^a
C	210 ^{a*}	723 ^a	3.0 ^a	12 ^a
ISOPODA				
Veg. zone A	314 ^a	310 ^a	23 ^a	17 ^a
B	326 ^a	223 ^b	22 ^a	16 ^a
C	281 ^a	208 ^b	23 ^a	13 ^a

a,b - mean values in a column within each taxon followed by the same letter are not significantly different at $p < 0.05$.

* = Non-parametric statistical comparison of the means was employed.

1. Mean values of four replicates in vegetation zones A and C, and five replicates in vegetation zone B.

s - insufficient data available for statistical analysis.

In 1986, pitfall traps were placed at both the Times Beach CDF and the Grand Island reference site and the results of metal analysis of these samples are statistically compared in Tables 10c and 10d. At Times Beach, there were no statistically significant differences between the vegetation zones, with the exception of significantly greater Zn concentrations were measured in the Coleoptera from vegetation zone A compared with vegetation zones B and C (Table 10c) and significantly greater Cu concentrations in the Araneida from vegetation zone A compared with vegetation zone C, but not B (Table 10d).

Table 10c
Metal Concentrations Measured in Invertebrates Collected
in Pitfall Traps, Times Beach (A,B,C) and Grand Island (R), Spring 1986.
Mean values per vegetation zone¹ expressed in ug/g. dry weight.

SPECIES/ ZONE	Element			
	Zn	Cu	Cd	Pb
ARANEIDA				
Veg. zone A	325 ^a	230 ^a	71 ^a	s
B	311 ^a	177 ^a	36 ^a	s
C	299 ^a	114 ^a	29 ^a	s
R	238 ^a	202 ^a	13 ^a	s
COLEOPTERA				
Veg. zone A	147 ^a	18 ^a	4.7 ^a	s
B	109 ^b	18 ^a	4.4 ^a	s
C	105 ^b	19 ^a	3.5 ^a	s
R	102 ^b	15 ^a	2.0 ^a	s
DIPLOPODA				
Veg. zone A	269 ^{a*}	683 ^a	3.9 ^a	22 ^a
B	227 ^{a*}	681 ^a	4.0 ^a	16 ^a
C	254 ^{a*}	755 ^a	4.1 ^a	14 ^a
R	198 ^{a*}	218 ^b	2.7 ^a	s
ISOPODA				
Veg. zone A	341 ^a	224 ^a	21 ^a	21 ^a
B	307 ^a	221 ^a	s	s
C	272 ^a	185 ^{a*}	20 ^a	16 ^a
R	260 ^a	153 ^b	3.3 ^b	6.5 ^a

a,b - mean values in a column within each taxon followed by the same letter are not significantly different at $p < 0.05$.

* = Non-parametric statistical comparison of the means was employed.

1. Mean values of four replicates for vegetation zones A and B, and five replicates for vegetation zone C and the Grand Island site: R.

s = insufficient sample size for statistical analysis.

Table 10d
Metal Concentrations Measured in Invertebrates Collected
in Pitfall Traps, Times Beach (A,B,C) and Grand Island (R), Fall 1986.
Mean values per vegetation zone¹ expressed in ug/g, dry weight.

SPECIES/ ZONE	Element			
	Zn	Cu	Cd	Pb
ARANEIDA				
Veg. zone A	213 ^a	85 ^a	8.6 ^{a*}	6.7 ^a
B	215 ^a	78 ^{a*}	14 ^{a*}	7.2 ^a
C	209 ^a	64 ^b	7.3 ^{a*}	6.6 ^a
R	194 ^a	64 ^b	3.9 ^{b*}	17 ^a
COLEOPTERA				
Veg. zone A	114 ^{a*}	31 ^{a*}	2.7 ^a	2.5 ^a
B	100 ^{a*}	18 ^{a*}	2.7 ^a	5.0 ^a
C	90 ^{a*}	19 ^{a*}	2.5 ^a	7.1 ^a
R	63 ^{a*}	16 ^{a*}	1.1 ^a	3.8 ^a
DIPLOPODA				
Veg. zone A	235 ^a	522 ^a	4.5 ^a	14 ^a
B	260 ^a	557 ^a	4.5 ^a	19 ^a
C	222 ^a	469 ^a	4.2 ^a	12 ^a
R	160 ^a	133 ^b	2.4 ^a	6.3 ^b
ISOPODA				
Veg. zone A	234 ^a	130 ^{a*}	30 ^a	18 ^a
B	297 ^a	101 ^{a*}	27 ^a	17 ^a
C	332 ^a	186 ^{a*}	23 ^a	17 ^a
R	219 ^a	79 ^{a*}	8.2 ^b	14 ^a

a,b - mean values in a column within each taxon followed by the same letter are not significantly different at $p < 0.05$.

* = Non-parametric statistical comparison of the means was employed.

1. Mean values of four replicates for vegetation zones A and B, and five replicates for vegetation zone C and the Grand Island site: R.

Statistically significant differences between the samples collected at Times Beach and those collected at Grand Island could be assessed in the 1986 samples (Tables 10c and d). In both the spring and fall samples Cu concentrations in the Diplopoda and Cd concentrations in the Isopoda were significantly greater at Times Beach compared with Grand Island. In spring 1986, Zn concentrations measured in Coleoptera from the Grand Island site were significantly lower than those measured in Coleoptera collected in vegetation zone A but not B and C at Times Beach, and Cu concentrations in the Isopoda were significantly lower at Grand Island compared to vegetation zones A and B, but not C at Times Beach. Araneida, collected in fall 1986, had significantly lower Cd concentrations at Grand Island compared to Times Beach, and significantly lower Cu concentrations at Grand Island compared to vegetation zone A at Times Beach. Also in fall 1986, Diplopoda collected at Grand Island had significantly lower Pb concentrations compared with those collected at Times Beach.

In summary, Tables 10a-d indicated no significant differences in Pb concentrations within each taxon, between the vegetation zones at Times Beach or (with the sole exception of the Diplopoda collected in fall 1986) between Times Beach and Grand Island. Concentrations of Cu in the Diplopoda and Cd in the Isopoda were consistently greater ($p < 0.05$) in the Times Beach samples compared with the Grand Island samples. Patterns of metal concentrations measured in the various taxa at the two sites were clearly repeated at each time of sampling. Figures 4a-d show the metal concentrations measured within each group of invertebrates, by metal element, for each sampling period.

In general, concentrations did not appear to differ according to the time of year that the sample was collected. The most notable exception was concentrations of Zn, Cu and Cd in the Araneida which were elevated in the spring sample compared with the fall sample in both 1985 and 1986. This pattern was clearly evident from Figures 4a-d. Since expertise was not available to identify the Araneida to genus or species level, it was not possible to ascertain whether this was due to a variation in species composition at the different times of year. However, some assessment of inter-generic and intra-specific variation was made using the Isopoda and the Lumbricus rubellus collected at Times Beach. The results of this study are given in Appendix E and demonstrate the importance of accurate identification of target/indicator organisms in making an assessment of the mobility of metals into the food chains. Over the two year sampling period there may have been an increase in the Cd concentrations present in the Coleoptera, Opiolones and Diplopoda collected; however, this increase would need to be validated through analysis of further samples as time progresses.

Differences in metal concentrations between taxonomic groups were clearly evident from the results of chemical analysis and are shown in Figures 4a-d. Within the carnivorous species, the predatory Coleoptera contained the lowest concentrations of metals and Araneida the highest. Other carnivorous groups (Chilopoda and Opiolones) also contained high concentrations of the elements Zn, Cu, and Cd. The detritivorous species (Diplopoda and Isopoda), had high concentrations of the elements Zn, Cu and Cd, and greater Cd, and lower Cu concentrations were observed in the Isopoda compared with the Diplopoda. With the exception of Cd concentrations, the two herbivorous groups analyzed (herbivorous Coleoptera and Orthoptera) had similar tissue metal concentrations. Cd concentrations were greater in the Orthoptera. All metal concentrations in herbivorous groups were low compared with the carnivorous and detritivorous groups. Of the taxonomic groups collected in sufficient quantities for metal analysis the Araneida, Diplopoda and Isopoda contained the greatest concentrations of heavy metals.

3.3.3 Black Rock Harbor CDF. Due to the relatively recent disposal of dredged material, invertebrates collected in pitfall traps placed at this site were relatively mobile groups (Coleoptera and Araneida) likely to be moving in and out of the site to feed. No soil-inhabiting invertebrates and very few detritivores were collected within the CDF. Details of the invertebrates collected within Black Rock Harbor CDF and along the transect out of the site and metal concentrations measured in each of the taxonomic groups are given in Appendix C. Due to the high mobility of the organisms collected, it was unlikely that individuals remained within any specific sub-plot and therefore mean concentrations for each taxonomic group collected within the CDF are

Figure 4 a-d: Metal Concentrations in Invertebrates
Captured in Pitfall Traps at Times Beach and Grand Island.

Key to symbols:

Taxon: A = ARANEIDA
C = COLEOPTERA
D = DIPLOPODA
I = ISOPODA

Season: F = Fall
S = Spring

Zone: A = Vegetation zone A, Times Beach
B = Vegetation zone B, Times Beach
C = Vegetation zone C, Times Beach
R = Reference site, Grand Island

All concentrations expressed as ug/g, dry weight.

Figure 4a Zinc concentrations in Invertebrates in 1985 and 1986
Figure 4b Copper concentrations in Invertebrates in 1985 and 1986
Figure 4c Cadmium concentrations in Invertebrates in 1985 and 1986
Figure 4d Lead concentrations in Invertebrates in 1985 and 1986

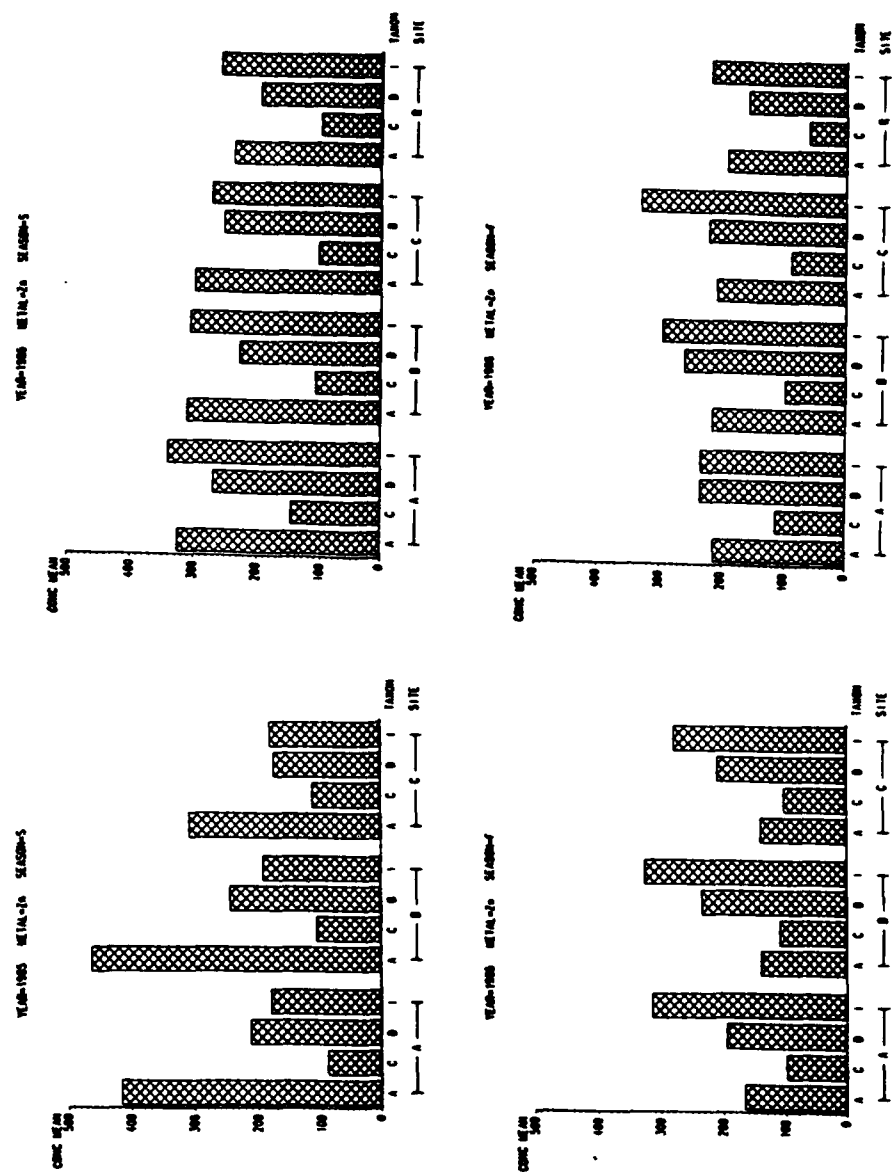


Figure 4a: Zinc

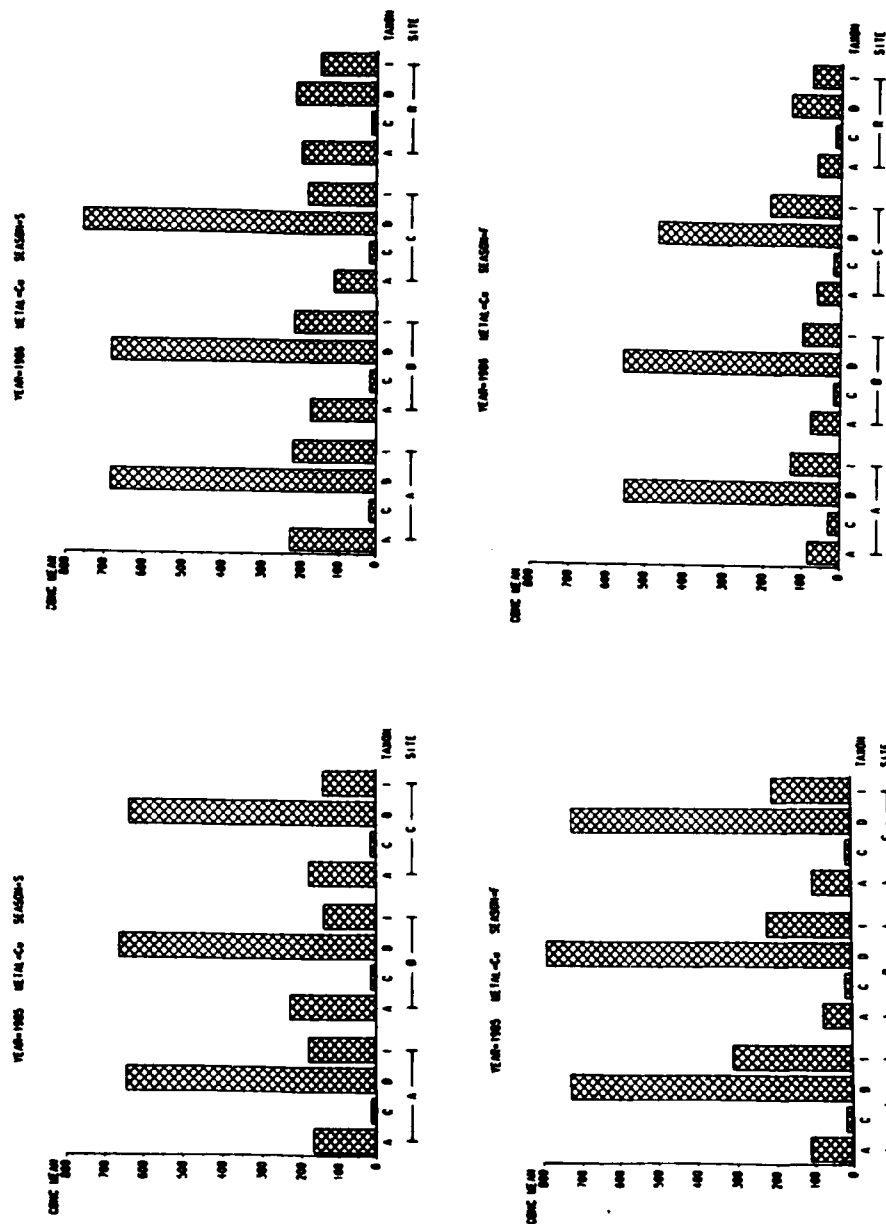


Figure 4b; Copper

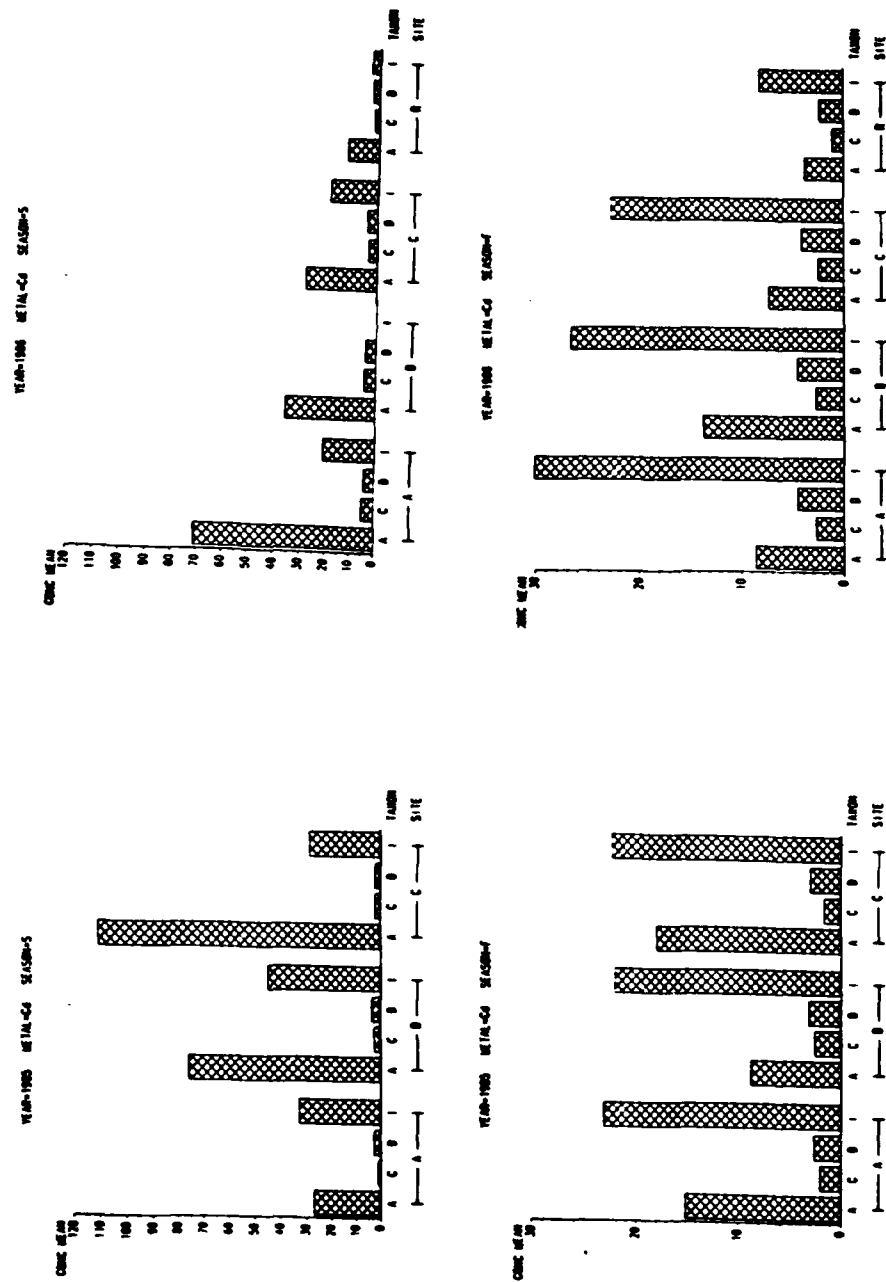
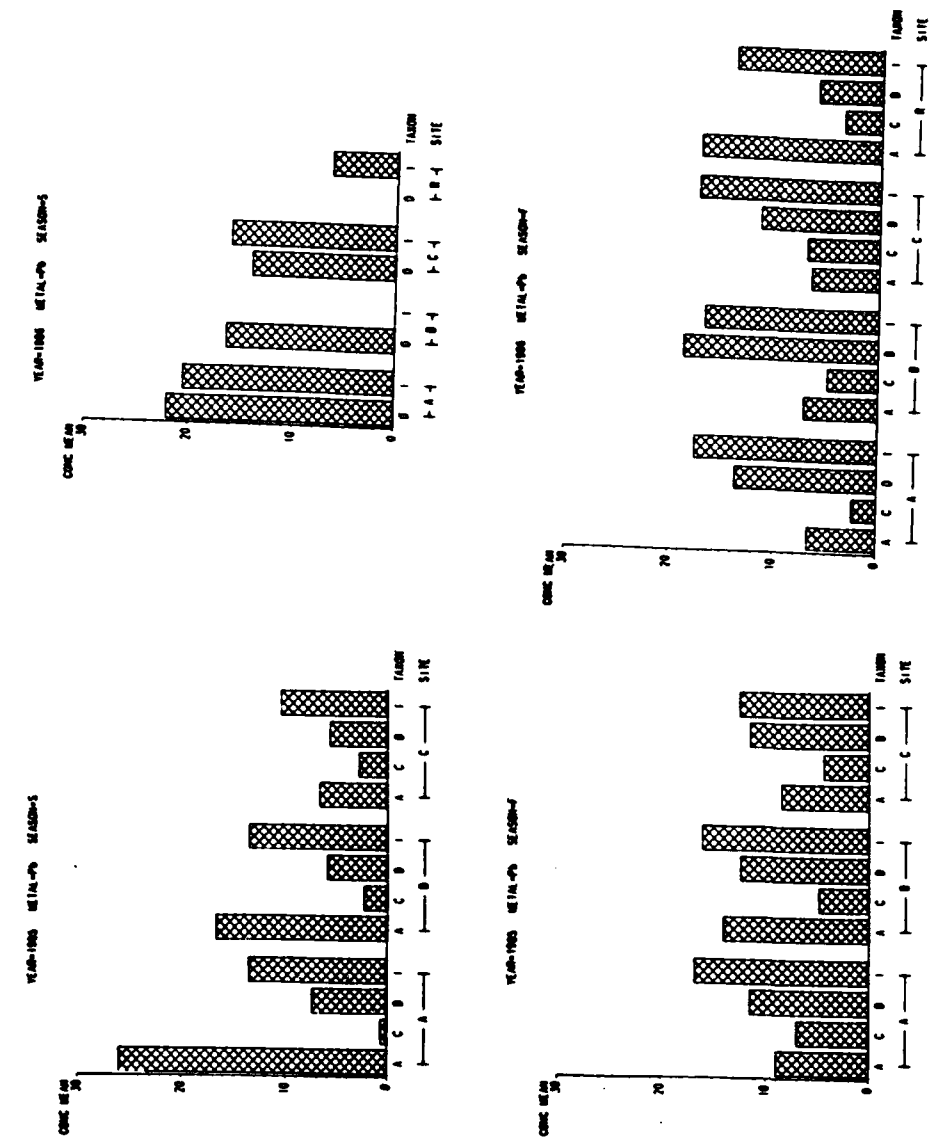


Figure 4c; Cadmium



given in Table 11. The major difference between invertebrates collected in May and November was the abundance of Coleoptera larvae collected in November. These larvae are likely to have remained only within the CDF and metal concentrations (particularly Cu) did reflect the high metal concentrations at this CDF (Table 11). The seasonal differences noted in metal concentrations in Araneida collected at Times Beach (Tables 10a-d) were observed for Ni and Cd at Black Rock, but not for Zn or Cu, however high metal concentrations did reflect high metal concentrations at this CDF (Tables 1 and 11).

Table 11
Metal Concentrations in Soil Invertebrates Collected
within the Black Rock CDF in Spring and Fall 1986.
 All concentrations in ug/g, dry weight.

Species/Sample	Zn	Cu	Ni	Cd	Cr	Pb
Predatory Coleoptera						
May 1986	80 (13)	64 (17)	4.4 (1.9)	1.1 (0.46)	33 (14)	9.3 (3.3)
November 1986*	131	80	4.3	1.3	34	6.4
Coleoptera Larvae						
November 1986	121 (30)	208 (53)	13 (5.6)	2.7 (1.1)	32 (13)	17 (6.9)
Araneida						
May 1986	330 (99)	367 (160)	25 (33)	13 (3.0)	24 (4.7)	12 (3.1)
November 1986	326 (87)	442 (109)	9.2 (2.1)	8.7 (2.5)	37 (9.3)	12 (6.1)
Herbivorous Coleoptera						
May 1986	211 (101)	84 (25)	9.3 (5.6)	1.6 (0.91)	37 (17)	25 (14)

Mean values (n = 6) and standard deviations in parenthesis.

November 1986* Predatory Coleoptera - All specimens pooled from entire CDF.

3.3.4 Ottawa mine spoil reclamation site. Details of invertebrates collected in pitfall traps placed at the Ottawa site and metal concentrations measured in each of the taxonomic groups are given in Appendix D. Individuals of most of the major invertebrate taxa were present and their composition was similar to that recorded at Times Beach and Grand Island (Appendix A and B). Dredged material placed at the Ottawa site was from one source and metal concentrations (except Pb) in dredged material from plots 2-4 were not statistically different (Table 3) (Rhett & Richards, 1986). Insufficient data was available to make comparisons between the differently managed sub-plots and therefore mean metal concentrations measured in each of the taxonomic groups are presented (Table 12). In general, similar metal concentrations were measured in groups sampled in May and November (Table 12).

Table 12
Metal Concentrations in Soil Invertebrates Collected in Plots 2 - 4
at the Ottawa Mine Spoil Reclamation Site in Spring and Fall 1986.
 All concentrations in ug/g, dry weight.

Species/Sample	Zn	Cu	Ni	Cd	Cr	Pb
Predatory Coleoptera						
May 1986	101 (23)	17 (6.0)	-	0.85	6.2 (1.6)	8.6 (3.9)
November 1986	154 (71)	17 (1.5)	3.3 (1.9)	2.1 (2.0)	4.4 (2.8)	17 (7.2)
Araneida						
May 1986	326 (48)	91 (31)	5.5 (4.9)	6.5 (1.5)	4.9 (1.5)	20 (11)
November 1986	263 (80)	112 (65)	2.6 (1.5)	6.4 (2.8)	6.7 (3.7)	10 (6.0)
Herbivorous Coleoptera						
May 1986	145 (36)	31 (5.6)	11 (6.3)	1.3 (0.34)	7.5 (2.2)	30 (14)
November 1986	s	s	s	s	s	s
Orthoptera						
May 1986	183 (53)	47 (22)	2.1 (1.5)	1.4 (0.70)	1.4 (0.72)	8.0 (3.7)
November 1986	204 (56)	40 (14)	2.0 (1.0)	2.2 (1.3)	5.9 (4.7)	11 (8.3)
Lepidoptera L.						
May 1986	159 (32)	25 (7.9)	1.9 (0.91)	1.6 (0.99)	4.0 (3.1)	9.0 (4.4)
November 1986	s	s	s	s	s	s
Diplopoda						
May 1986	393 (72)	98 (20)	6.2 (4.2)	2.0 (0.70)	4.1 (1.3)	25 (17)
November 1986	298 (119)	102 (26)	2.3 (2.0)	1.8 (1.4)	4.7 (3.1)	6.4 (4.3)
Isopoda						
May 1986	582 (267)	219 (77)	6.5 (3.1)	8.0 (3.1)	9.0 (2.4)	33 (4.7)
November 1986	441 (76)	160 (25)	3.8 (2.9)	5.1 (1.7)	11 (5.9)	19 (7.4)

Mean values and standard deviations in parenthesis.
 s = insufficient sample size for analysis.

3.4 NATIVE EARTHWORMS.

Earthworms of the species Lumbricus terrestris; Allolobophora caliginosa; Allolobophora chlorotica and Lumbricus rubellus were present at the Times Beach CDF, Ottawa and Grand Island sites. At Times Beach, the deep burrowing species L. terrestris were found only in the higher, drier plots, where the top soil-like layer had developed to sufficient depth for burrowing. The lower, wetter plots were dominated by L. rubellus.

3.4.1 Times Beach CDF and Grand Island reference site. Earthworm species collected at both the Times Beach and Grand Island sites and metal concentrations in earthworm tissue are given in Appendix A, Tables 5 and 6 and Appendix B, Table 3. High concentrations of Zn and Cd were measured in all of the earthworm species collected. Inter-specific differences were clearly evident from the results, for example A. chlorotica contained lower concentrations of Zn compared with the remaining species. Within each species similar concentrations of each of the elements (except Cu) were present in the vegetation zones A, B and C at Times Beach (Table 13a). This agrees with measurements of metal concentrations in invertebrates collected in pitfall traps (Tables 10a-d) and results of laboratory uptake studies using E. foetida where no significant differences were noted in metal uptake between vegetation zones (Table 7a).

Table 13a
Comparative Metal Concentrations in Earthworms Collected
from the Different Vegetation Zones at Times Beach.
Mean values expressed as ug/g, dry weight.

Species/ Vegetation zone	Element			
	Zn	Cu	Cd	Pb
<u>L. rubellus</u>				
zone A	1809 ^a	16 ^{a,b}	57 ^a	0.34 ^a
zone B	1302 ^a	18 ^a	67 ^a	0.31 ^a
zone C	1332 ^a	11 ^b	58 ^a	s
<u>A. caliginosa</u>				
zone A	1115 ^{a,*}	26 ^a	27 ^a	1.2 ^a
zone B	1059 ^{a,*}	21 ^{a,b}	30 ^a	4.3 ^a
zone C	995 ^{a,*}	16 ^b	37 ^a	s
<u>A. chlorotica</u>				
zone A	412 ^{a,*}	23 ^a	32 ^{a,*}	5.9 ^a
zone B	467 ^{a,*}	25 ^a	51 ^{a,*}	8.9 ^a
zone C	417 ^{a,*}	21 ^a	45 ^{a,*}	3.6 ^a

a,b - means values in a column within each species followed by the same letter are not significantly different at $p < 0.05$.

* = Non-parametric statistical comparison of the means was employed.

s = insufficient sample size for statistical analysis.

Results for each species collected at Times Beach, were pooled and the mean value compared with the metal concentrations measured in each species collected at the Grand Island site (Table 13b). Generally, greater concentrations of Zn, Cu and Cd were present in earthworms collected at Times Beach compared with those collected at Grand Island. Cu concentrations in L. terrestris, Zn concentrations in A. chlorotica and Cd concentrations in

A. caliginosa were exceptions, similar concentrations were present in earthworms collected at each site. With the exception of Pb concentrations measured in L. rubellus, Pb concentrations were similar in earthworms collected at Times Beach and Grand Island indicating little difference in the bio-availability of this element between the two sites.

Table 13b
Comparative Metal Concentrations in Earthworms from
Grand Island and Times Beach.
Mean values expressed in ug/g, dry weight.

Species/ Site	Zn	Element Cu	Cd	Pb
<u>L. terrestris</u>				
Times Beach	2775 ^a	16 ^{a*}	48 ^a	2.6 ^a
Grand Island ^{a*}	350 ^b	2.1 ^{a*}	8.9 ^b	4.0 ^a
<u>L. rubellus</u>				
Times Beach	1436 ^a	16 ^a	62 ^a	1.5 ^a
Grand Island	430 ^b	4.6 ^b	13 ^b	0.32 ^b
<u>A. caliginosa</u>				
Times Beach	1064 ^a	22 ^a	34 ^a	2.8 ^a
Grand Island	479 ^b	5.5 ^b	31 ^a	2.5 ^a
<u>A. chlorotica</u>				
Times Beach	434 ^{a*}	23 ^a	43 ^a	7.0 ^a
Grand Island	304 ^{a*}	7.7 ^b	18 ^b	2.3 ^a

a, b - means values in a column within each species followed by the same letter are not significantly different at $p < 0.05$.

* = Non-parametric statistical comparison of the means was employed.

3.4.2 Ottawa mine spoil reclamation site. Metal concentrations measured in native earthworms collected at the Ottawa mine spoil reclamation site are given in Appendix D, Table 3. Unusually dry conditions prevented collection of native earthworms by the formalin vermifuge method and these earthworms were collected incidentally in the pitfall traps. The use of these results for comparative purposes was limited since no correction to the metal concentrations was possible to eliminate the effect of soil within the gut.

3.5 COMPARATIVE METAL CONCENTRATIONS BETWEEN THE FOUR SITES.

For each of the elements Zn, Cu, Cd and Pb, metal concentrations in samples collected from the field sites are compared with the results of laboratory studies using E. foetida (Tables 14 - 17).

Table 14
Zinc Concentrations at the Four Sites.

Sample	Unconsol.		Times Beach			Grand	Ottawa		
	TB	BR	TB-A	TB-B	TB-C	Island	OT-2	OT-3	OT-4
DM/Soil	2,002	1,413	289	480	426	227	1,003	1,008	1,043
<u>E. foetida</u>									
Field uptake study:									
Lab. uptake study:									
Day 0	120	120	110	110	110	98	-	-	-
Day 28	135	152	litter: 179	113	112	litter:	-	-	-
Day 28			humic: 114	110	126	101	30cm:	-	-
Day 28			oxid.: 112	115	114		100cm:	-	-
<u>Invertebrates</u>									
<u>Pred. Coleoptera</u>									
Spring '85			90	108	113				
Fall '85			99	111	104				
Spring '86		80	147	109	105	102		101	
Fall '86		131 (121 L.)	114	100	90	63		154	
<u>Araneida</u>									
Spring '85			415	461	307				
Fall '85			166	140	142				
Spring '86		330	325	311	299	238		326	
Fall '86		326	213	215	209	194		263	
<u>Herb. Coleoptera</u>									
Spring '85			-	-	-				
Fall '85			222	153	167				
Spring '86		211	127	204	190			145	
Fall '86			222	171	-			-	
<u>Diplopoda</u>									
Spring '85			211	242	174				
Fall '85			195	235	210				
Spring '86			269	227	254	198		393	
Fall '86			235	260	222	160		298	
<u>Isopoda</u>									
Spring '85			180	191	180				
Fall '85			314	326	281				
Spring '86			341	307	272	260		582	
Fall '86			234	297	332	219		441	
<u>Native earthworms</u>									
<u>L. terrestris</u>			2,775			350			
<u>A. caliginosa</u>			1,115	1,059	995	479			
<u>A. chlorotica</u>			412	467	417	304			
<u>L. rubellus</u>			1,809	1,302	1,332	430			

DM = Dredged Material; TB = Times Beach, A,B,C = Vegetation types; Times Beach
BR = Black Rock CDF; OT = Ottawa site, 2,3,4 = plots at the Ottawa site;
L. = Coleoptera larvae.

Table 15
Copper Concentrations at the Four Sites.

Sample	Unconsol.		Times Beach			Grand	Ottawa		
	TB	BR	TB-A	TB-B	TB-C	Island	OT-2	OT-3	OT-4
DM/Soil	432	2,606	51	95	83	68	85	95	96
<u>E. foetida</u>									
<u>Field uptake study:</u>									
<u>Lab. uptake study:</u>									
Day 0	17	17	9.9	9.9	9.9	9.0		9.6	
Day 28	41	145	litter: 15	12	12		litter:	9.2	
Day 28			humic: 18	18	14	10	30cm:	26	
Day 28			oxid: 29	23	24		100cm:	25	
<u>Invertebrates</u>									
<u>Pred. Coleoptera</u>									
Spring '85			14	15	15				
Fall '85			18	19	16				
Spring '86		64	18	18	19	15		17	
Fall '86		80 (208L.)	31	18	19	16		17	
<u>Araneida</u>									
Spring '85			169	230	182				
Fall '85			111	77	103				
Spring '86		367	230	177	114	202		91	
Fall '86		442	85	78	64	64		112	
<u>Herb. Coleoptera</u>									
Spring '85			-	-	-				
Fall '85			42	35	26				
Spring '86		84	33	34	33	-		31	
Fall '86			46	78	-	-		-	
<u>Diplopoda</u>									
Spring '85			641	660	634				
Fall '85			728	787	723				
Spring '86			683	681	755	218		98	
Fall '86			522	557	469	133		102	
<u>Isopoda</u>									
Spring '85			182	142	144				
Fall '85			310	223	208				
Spring '86			224	221	185	153		219	
Fall '86			130	101	186	79		160	
<u>Native earthworms</u>									
<u>L. terrestris</u>			16			2.1			
<u>A. caliginosa</u>			26	21	16	5.5			
<u>A. chlorotica</u>			23	25	21	7.7			
<u>L. rubellus</u>			16	18	11	4.6			

DM = Dredged Material; TB = Times Beach, A,B,C = Vegetation types; Times Beach
BR = Black Rock CDF; OT = Ottawa site, 2,3,4 = plots at the Ottawa site;
L. = Coleoptera larvae.

Table 16
Cadmium Concentrations at the Four Sites.

Sample	Unconsol.		Times Beach			Grand	Ottawa		
	TB	BR	TB-A	TB-B	TB-C	Island	OT-2	OT-3	OT-4
DM/Soil	13	21	3.3	6.4	5.0	2.5	6.9	7.4	7.8
<u>E.foetida</u>									
<u>Field uptake study:</u>									
<u>Lab. uptake study:</u>									
Day 0	2.8	2.8	4.0	4.0	4.0	2.7		3.7	
Day 28	5.4	8.0	litter: 15	17	17		litter: 14		
Day 28			humic: 13	12	11	4.4	30cm: 9.0		
Day 28			oxid: 6.1	6.4	7.3		100cm: 8.2		
<u>Invertebrates</u>									
<u>Pred. Coleoptera</u>									
Spring'85			1.1	2.7	2.2				
Fall'85			2.1	2.6	1.6				
Spring'86		1.1	4.7	4.4	3.5	2.0		0.85	
Fall'86		1.3(2.7L.)	2.7	2.7	2.5	1.1		2.1	
<u>Araneida</u>									
Spring'85			27	76	111				
Fall'85			15	8.8	18				
Spring'86		13	71	36	29	13		6.5	
Fall'86		8.7	8.6	14	7.3	3.9		6.4	
<u>Herb. Coleoptera</u>									
Spring'85			-	-	-				
Fall'85			0.99	0.69	0.72				
Spring'86		1.6	-	-	-	-		1.3	
Fall'86			1.1	2.9	-	-		-	
<u>Diplopoda</u>									
Spring'85			2.8	3.7	2.2				
Fall'85			2.7	3.1	3.0				
Spring'86			3.9	4.0	4.1	2.7		2.0	
Fall'86			4.5	4.5	4.2	2.4		1.8	
<u>Isopoda</u>									
Spring'85			33	45	29				
Fall'85			23	22	23				
Spring'86			21	20	20	3.3		8.0	
Fall'86			30	27	23	8.2		5.1	
<u>Native earthworms</u>									
<u>L. terrestris</u>			48			8.9			
<u>A. caliginosa</u>			27	30	37	31			
<u>A. chlorotica</u>			32	51	45	18			
<u>L. rubellus</u>			57	67	58	13			

DM = Dredged Material; TB = Times Beach, A,B,C = Vegetation types: Times Beach
BR = Black Rock CDF; OT = Ottawa site, 2,3,4 = plots at the Ottawa site;
L. = Coleoptera larvae.

Table 17
Lead Concentrations at the Four Sites.

Sample	Unconsoi.		Times Beach			Grand	Ottawa		
	TB	BR	TB-A	TB-B	TB-C	Island	OT-2	OT-3	OT-4
DM/Soil	1,073	406	161	212	172	44	412	475	536

E. foetida

Field uptake study:

Lab. uptake study:

Day 0	2.7	2.7	<2.7	<2.7	<2.7	<4.2		1.5	
Day 28	13	4.5	litter: 5.5	2.7	3.5	<2.7	litter: 2.2		
Day 28			humic: 9.1	4.9	6.4		30cm: 2.9		
Day 28			oxid: 8.7	9.7	11		100cm: 5.3		

Invertebrates

Pred. Coleoptera

Spring'85			0.68	2.4	2.9				
Fall'85			7.1	5.0	4.5				
Spring'86	9.3		-	-	-			8.6	
Fall'86	6.4 (17L.)		2.5	5.0	7.1	3.8		17	

Araneida

Spring'85			26	17	6.8				
Fall'85			9.0	14	8.5				
Spring'86	12		-	-	-	-		20	
Fall'86	12		6.7	7.2	6.6	17		10	

Herb. Coleoptera

Spring'85			-	-	-				
Fall'85			13	13	<7.9				
Spring'86	25		-	-	-	-		30	
Fall'86			<11	<57	-	-		-	

Diplopoda

Spring'85			7.5	6.1	5.8				
Fall'85			12	12	12				
Spring'86			22	16	14	-		25	
Fall'86			14	19	12	6.3		6.4	

Isopoda

Spring'85			14	14	11				
Fall'85			17	16	13				
Spring'86			21	-	16	6.5		33	
Fall'86			18	17	17	14		19	

Native earthworms

<u>L. terrestris</u>			2.6			4.0			
<u>A. caliginosa</u>			1.2	4.3	-	2.5			
<u>A. chlorotica</u>			5.9	8.9	3.6	2.3			
<u>L. rubellus</u>			0.34	0.31	-	0.32			

DM = Dredged Material; TB = Times Beach, A,B,C = Vegetation types: Times Beach
BR = Black Rock CDF; OT = Ottawa site, 2,3,4 = plots at the Ottawa site;
L. = Coleoptera larvae.

4. DISCUSSION.

4.1 COMPARISONS BETWEEN LABORATORY AND FIELD RESULTS.

4.1.1 Unconsolidated dredged material: Times Beach CDF and Black Rock CDF.

Results of the laboratory uptake study indicated elevated concentrations of Zn, Cu, Ni, Cd, Cr and Pb in *E. foetida* after 28 days exposure to the dredged material (Table 5). Similar increases in concentrations of Zn and Ni were observed in earthworms exposed to Times Beach and Black Rock dredged materials. Concentrations of Cd, Cr and particularly Cu, suggested greater uptake from Black Rock compared with Times Beach dredged material, while Pb concentrations suggested greater uptake by earthworms exposed to the Times Beach dredged material (Table 5).

Comparisons of metal concentrations in invertebrates naturally colonizing the Times Beach and Black Rock CDF are limited due to the lack of detritivorous and soil inhabiting species at Black Rock. Zn concentrations in spiders (present at both sites in sufficient quantities for analysis) were within a similar range at Times Beach and Black Rock CDFs (Table 14) and Cu concentrations were greater in spiders collected at Black Rock compared with Times Beach (Table 15). For both elements the field situation reflected results of the laboratory uptake study. However, compared with Times Beach, Cd concentrations were lower in spiders from Black Rock (Table 16) and Pb concentrations were higher in spiders from Black Rock (Table 17), these results were contrary to those expected from the uptake study. Although earthworm uptake studies were conducted using unconsolidated dredged material considered to represent the original dredged material placed at the sites, the CDFs from which invertebrates were collected differed in age and degree of colonization by vegetation and this may have influenced the species compositions within the taxonomic groups. Differences in metal concentrations between species from the same site have previously been reported for Pb in spiders (Clausen, 1984), and metals in earthworms (Ireland, 1979, 1983, Ash & Lee, 1980). Metal concentrations measured in Isopoda collected at Times Beach in the present study also demonstrated the variation in metal concentrations between different genus of the same taxonomic group (Appendix E). This may explain the lack of correlation between laboratory and field results and further identification of individuals before analysis would be necessary to clarify this. Alternatively, since dredged materials are highly heterogeneous, the single sample from each plot used in laboratory studies may have been inadequate to represent the whole site.

4.1.2 Surface material: Times Beach CDF and Grand Island reference site.

Results of the laboratory uptake study using soil from Grand Island were compared with results of uptake by *E. foetida* exposed to dredged material from the humic layer at Times Beach (level 1, Tables 6 & 7). Very little uptake of Zn was observed over the 28 day period by earthworms exposed to either materials (Table 14). After 28 days, Cu concentrations were greater in *E. foetida* exposed to Times Beach dredged material compared with Grand Island soil (Table 15). Earthworms at the start of both studies contained similar concentrations of Cu but not Cd, those worms used for the Times Beach study had lower Cd concentrations compared with those used in the Grand Island study (Table 16). However, after 28 days, there was proportionally greater uptake of Cd by earthworms in the Times Beach dredged material (3 x the initial concentration) compared with the Grand Island soil (2 x the initial concentration) suggesting higher bio-availability of Cd in the Times Beach

material (Table 16). Results suggested some uptake of Pb by E. foetida from the Times Beach but not the Grand Island material (Table 17). In summary, results of the laboratory study suggested greater bio-availability of Cu, Cd and Pb but not Zn at Times Beach compared with Grand Island.

Comparisons between metal concentrations measured in invertebrates collected at the Times Beach CDF and Grand Island reference site (Tables 10c & 10d, Table 13b) indicated a similar range in Zn concentrations in the Coleoptera, Araneida, Diplopoda and Isopoda. However, the native earthworms from Times Beach had consistently higher Zn concentrations compared with those from Grand Island. Diplopoda and native earthworms had greater Cu concentrations at Times Beach compared with Grand Island. Cd concentrations in the Araneida (Fall 1986), Isopoda and native earthworms (except A. caliginosa) were lower at Grand Island compared with Times Beach. Pb concentrations in the invertebrates were generally within a similar range at the two sites (Table 17).

Results of the laboratory study were supported by measurements in the field as follows: The laboratory study indicated very little uptake of Zn by E. foetida, from both Times Beach dredged material and Grand Island soil. Zn concentrations measured in invertebrates collected at the two field sites were not statistically different, with the exception of Zn concentrations measured in the native earthworm species (L. terrestris, A. caliginosa and L. rubellus, Table 13b) and in Coleoptera collected in spring 1986 (Table 10c). The laboratory uptake study suggested higher bio-availability of Cu, Cd and Pb from the Times Beach dredged material than the Grand Island soil. In the field, greater concentrations of both Cu and Cd were evident in at least one group of organisms at the Times Beach CDF compared with the Grand Island site. Native earthworms contained significantly higher concentrations of both Cu and Cd at Times Beach compared with Grand Island (Table 13b). Some bioavailability of Pb from the Times Beach dredged material but not the Grand Island soil was indicated by the results of the laboratory uptake study. However, measurements of invertebrates, including native earthworms, collected in the field showed no significant difference in Pb concentrations at Times Beach CDF compared with Grand Island reference site with the exception of Diplopoda collected in fall 1986 (Table 10d) and the earthworm species L. rubellus (Table 13b). In general, results suggested that the earthworms did provide a good indication of the 'worst case' for uptake of the elements Zn, Cu, Cd and Pb at each of the sites studied.

Differences in metal concentrations between native earthworm species may be a reflection of feeding preferences and of variation in the bioavailability of metals present in the different horizons of the substrate. Of the earthworms species collected, A. caliginosa predominantly ingests mineral soil, burrowing within the mineral soil horizons, while the other three species either predominantly inhabit the litter layer (L. rubellus and A. chlorotica) or feed mainly on leaf litter (L. terrestris). Results of the laboratory uptake study using E. foetida demonstrated significant differences in the availability of metals with changing depth within the dredged material (Table 7b). Cadmium concentrations were significantly greater in litter dwelling and litter feeding earthworm species at Times Beach compared with Grand Island while there was no significant difference between the two sites in Cd concentrations in A. caliginosa (Table 13b). This may indicate that Cd more bio-available in the litter layer compared with the lower horizons.

Results of the laboratory uptake study (Table 7b) also demonstrate an decrease in uptake of Cd with increasing depth in the dredged material.

4.1.3 Ottawa mine spoil reclamation site. General comparisons between the results of earthworm uptake studies using dredged material (depth 30 cm) from Ottawa and those from Times Beach and Grand Island suggested greater bioavailability of Cu in the Ottawa material, similar bioavailability of Cd compared with Times Beach and less available Pb compared with Times Beach but not Grand Island (Tables 15 - 17). The general pattern observed in invertebrates collected at Ottawa did not correspond with these results. Cu concentrations in invertebrates from Ottawa were within a similar range to those from Times Beach and Grand Island and Cu concentrations in the Diplopoda were lower at Ottawa compared with Times Beach and Grand Island (Table 15). Cd concentrations were lower in invertebrates from Ottawa (Table 16) and Pb concentrations were higher in invertebrates from Ottawa (Table 17) compared with the other sites. These were contrary to the expected results based on the laboratory study. Further standardization of the laboratory earthworm bioassay procedure measuring metal uptake may be necessary before valid comparisons can be made between tests. *E. foetida* used in the studies may need to be more standardized in terms of age and previous exposure to contaminants (i.e. all grown in the same substrate with careful separation of cocoons to maintain groups of the same age). Both factors have been demonstrated to influence metal uptake by Annelids (Bryan & Hummerstone, 1973, Ma, 1982a). In addition, soil physical properties have been shown to affect metal uptake by earthworms (Ma, 1982a) and it may be necessary to more closely define the physical and chemical properties of the dredged material. Repeatability of the laboratory procedure could be checked by using a standard reference substrate for which the earthworms response is known.

4.2 TARGET ORGANISMS FOR METAL UPTAKE.

Any taxonomic group to be used as an indicator of heavy metal mobility in the upland zone of confined disposal sites such as those studied here must fulfill certain requirements:-

(i) It must be easily collected in sufficient quantities both numerically and in terms of dry matter biomass across the range of vegetation types and soil moisture conditions at the sites for chemical analysis.

(ii) Results of analysis of tissue heavy metal concentrations should reflect the maximum bioavailability of heavy metals to that trophic level.

Invertebrate fauna collected in the pitfall traps placed at the Times Beach CDF and Grand Island reference site were dominated both numerically and in terms of dry matter contribution to the total biomass by Coleoptera, Diplopoda and Isopoda (Appendix A, Tables 1c, 2c, 3b & 4b, Appendix B, Tables 1b & 2b), and at the Ottawa mine spoil reclamation site by these groups as well as Orthoptera (Appendix D, Table 1c). At Black Rock Harbor CDF the Araneida and Coleoptera dominated the composition of the pitfall trap collections (Appendix C, Table 1c). These groups were present in all vegetation types across the sites. Dominance of these active groups reflects the sampling technique, collecting species seeking prey and detritivores moving in the litter and at the soil surface.

Generally, smallest metal concentrations were evident in the

herbivorous species. Of the predatory species, Coleoptera showed little evidence of metal uptake and the Araneida reflected maximum uptake of metals at the carnivore trophic level, suggesting some movement of metals up the food chain (Tables 14 - 17). Wade et al. (1980) measuring Pb and Zn concentrations in invertebrates at increasing distances from a major road also recorded higher Pb concentrations in Arachnida compared with Carabidae. Seasonal differences recorded in the metal concentrations of Araneida reduce their usefulness as an indicator group and further investigations are required to clarify the reasons for this variability.

For each of the sites, greatest metal concentrations were measured in detritivorous species including native earthworms. Soils and associated decomposing matter have been recognised as the ultimate sink for metal contaminants present in the ecosystem (Martin et al., 1982). Therefore metal concentrations in the detritivorous organisms should provide most relevant information for movement of metals into the food chain. Of the detritivores collected the Diplopoda, Isopoda and native earthworms were sufficiently abundant for chemical analysis at all sites except Black Rock CDF. Isopoda have been shown to accumulate Zn, Cu, Cd and Pb from their food to a greater extent than other terrestrial arthropods (Weiser et al., 1976, Coughtrey et al., 1977) and have been proposed as an ideal indicator of the bio-availability of these elements from the leaf litter which comprises their diet (Hopkin and Martin, 1982). Earthworms are also useful as indicators of heavy metal bio-availability since they are present in most soils, are intimately in contact with the soil and decomposing material and form a vital link in many food chains. They represent the site from which they were collected because they are relatively sedentary and they almost always provide sufficient material for analysis (Ma, 1982b, Dierckx et al., 1985). Compared with the other soil dwelling invertebrates collected at the four sites, the native earthworms contained the greatest Zn concentrations. Cu concentrations were greater in the Diplopoda and Cd concentrations were similar between the earthworms and the Isopoda. Pb concentrations were within a similar range in the earthworms as in the other invertebrate fauna collected in the pitfall traps.

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APPENDICES

APPENDIX A: Times Beach CDF.

Table 1	May 1985	Pitfall traps	(a) Numerical record.....1 (b) Identification.....2 (c) Relative composition...6 (d) Metal concentrations...7
Table 2	October 1985	Pitfall traps	(a) Numerical record.....9 (b) Identification.....10 (c) Relative composition...16 (d) Metal concentrations...17
Table 3	May 1986	Pitfall traps	(a) Numerical record.....20 (b) Relative composition...21 (c) Metal concentrations...22
Table 4	November 1986	Pitfall traps	(a) Numerical record.....25 (b) Relative composition...26 (c) Metal concentrations...27
Table 5	May 1985	Native earthworms	Metal concentrations...30
Table 6	November 1986	Native earthworms	Metal concentrations...31

APPENDIX B: Grand Island Reference Site.

Table 1	May 1986	Pitfall traps	(a) Numerical record.....34 (b) Relative composition...34 (c) Metal concentrations...35
Table 2	November 1986	Pitfall traps	(a) Numerical record.....36 (b) Relative composition...36 (c) Metal concentrations...37
Table 3	November 1986	Native earthworms	Metal concentrations...38

APPENDIX C: Black Rock Harbour CDF.

Table 1	May 1986	Pitfall traps	(a) Numerical record.....39 (b) Identification.....41 (c) Relative composition...43 (d) Metal concentrations...45
Table 2	November 1986	Pitfall traps	(a) Numerical record.....46 (b) Metal concentrations...48

APPENDIX D: Ottawa Mine Spoil Reclamation Site.

Table 1	May 1986	Pitfall traps	(a) Numerical record.....49 (b) Identification.....50 (c) Relative composition...52 (d) Metal concentrations...53
Table 2	November 1986	Pitfall traps	(a) Numerical record.....56 (b) Metal concentrations...57
Table 3	May/November 1986	Native earthworms	Metal concentrations...60

APPENDIX E: Comparison of Metal Concentrations Within the Same Species and Between Different Genus of the Same Order.....61

Appendix A TIMES BEACH CDF.

Surface active invertebrates collected at the Times Beach CDF in spring and fall (1985 and 1986) were identified, and a record of the relative abundance calculated. Where sufficient material was available metal analysis was carried out.

TABLE 1 MAY 1985

TABLE 1(a) Record of numbers of soil dwelling invertebrates collected in pitfall traps.

PLOT	COL.	ARAN.	CHIL.	DIPL.	ISOP.	OTHERS
A1	9	4	3	23	148	2 Oligochaeta/2 Orthoptera/1 Diptera 2 Hymenoptera/1 Coleoptera L.
A4	9	3	3	29	120	10 Oligochaeta/5 Coleoptera L.
B4	26	11	1	19	244	4 Oligochaeta/3 Coleoptera L. 3 Hymenoptera/3 Thysanoptera/1 Diptera
B5	10	2	2	19	183	17 Oligochaeta/5 Coleoptera L.
C1	23	8	-	11	44	2 Diptera/1 Acarina 1 Thysanoptera/2 Hymenoptera
C2	8	2	-	8	124	6 Oligochaeta/2 Acarina 2 Hemiptera
C4	51	6	-	6	19	1 Oligochaeta/2 Hymenoptera/ 2 Hemiptera/1 Lepidoptera L.

TABLE 1(b) Identification of major groups of soil dwelling invertebrate fauna collected in pitfall traps. MAY 1985

1. COLEOPTERA

PLOT	SUB-ORDER	FAMILY	GENUS	NUMBER IN POOLED SAMPLE AT EACH PLOT
A1	Geodephaga	Carabidae	<u>Carabus</u> sp	2
	Geodephaga	Carabidae	<u>Pterostichus</u> sp	1
	Sternoxia	Elatiderae	<u>Agriotes</u> sp	1
	Rhynchophora	Curculionidae		
		Otiorrhynchinae		2
	Rhynchophora	Curculionidae		1
	Brachelytra	Staphylinidae		1
	Geodephaga	Carabidae	<u>Bradycellus</u> sp	1
A4	Geodephaga	Carabidae	<u>Carabus</u> sp	8
	Geodephaga	Carabidae	<u>Pterostichus</u> sp	1
	Brachelytra	Staphylinidae		
		Tachyporidae	<u>Tachyporus</u> sp	1
	Rhynchophora	Curculionidae		
		Otiorrhynchinae	<u>Barypithes</u> sp?	1
B4	Geodephaga	Carabidae	<u>Carabus</u> sp	2
	Geodephaga	Carabidae	<u>Chlaenius</u> sp	2
	Geodephaga	Carabidae	<u>Pterostichus</u> sp	17
	Lamellicornia	Scarabidae		1
	Brachelytra	Staphylinidae	<u>Staphylinius</u> sp	1
	Brachelytra	Staphylinidae		
		Tachyporinae	<u>Tachyporus</u> sp	2
B5	Geodephaga	Carabidae	<u>Carabus</u> sp	4
	Geodephaga	Carabidae	<u>Pterostichus</u> sp	5
	Lamellicornia	Trogidae	<u>Trox</u> sp	2

TABLE 1(b) contd...

PLOT	SUB-ORDER	FAMILY	GENUS	NUMBER IN POOLED SAMPLE AT EACH PLOT
C1	Geodephaga	Carabidae	<u>Chlaenius</u> sp	10
	Geodephaga	Carabidae	<u>Pterostichus</u> sp	10
	Sternoxia	Elatiderae	<u>Agriotes</u>	1
	Brachelytra	Staphylinidae		
		Oxytelinidae		1
C2	Geodephaga	Carabidae	<u>Carabus</u>	1
	Geodephaga	Carabidae	<u>Pterostichus</u> sp	1
	Brachelytra	Staphylinidae		
		Tachyporidae		1
	Geodephaga	Carabidae	<u>Chlaenius</u> sp	2
	Brachelytra	Staphylinidae		
		Oxytelinidae		1
	Clavicornia	Nitidulidae		
		Nitidulinae		2
C4	Geodephaga	Carabidae	<u>Chlaenius</u> sp	19
	Geodephaga	Carabidae	<u>Pterostichus</u> sp	9
	Geodephaga	Carabidae	<u>Bembidion</u> sp	2
	Geodephaga	Carabidae	<u>Agonum</u> sp	2
	Clavicornia	Nitidulidae		
		Nitidulinae		1
	Brachelytra	Staphylinidae		17

2. All Araneida identified as belonging to the Family Agriopoidea.

3. All Chilopoda identified as belonging to the Family Scutigerae.

TABLE 1(b) contd...

4. DIPLOPODA

PLOT	FAMILY	NUMBER IN POOLED SAMPLE AT EACH PLOT
A1	Blaniulidae	20
	Polydesmidae	3
A4	Blaniulidae	29
	Polydesmidae	4
B4	Blaniulidae	14
	Polydesmidae	6
B5	Blaniulidae	17
	Polydesmidae	4
C1	Blaniulidae	12
C2	Blaniulidae	8
C4	Blaniulidae	6

TABLE 1(b) contd...

5. ISOPODA

PLOT	FAMILY	ABUNDANCE	
		least common	most common
A1	Porcellionidae	***	
	Trichoniscidae	****	
	Oniscidae	**	
A4	Porcellionidae	***	
	Oniscidae	**	
	Trichoniscidae	****	
	Armadillidiidae	*	
B4	Porcellionidae	***	
	Trichoniscidae	****	
	Oniscidae	**	
B5	Porcellionidae	***	
	Trichoniscidae	****	
C1	Porcellionidae	***	
	Trichoniscidae	****	
	Oniscidae	**	
C2	Porcellionidae	***	
	Trichoniscidae	****	
	Oniscidae	**	
C4	Porcellionidae	***	
	Trichoniscidae	****	

TABLE 1 contd...

TABLE 1(c) Composition of soil dwelling invertebrate fauna sampled using pitfall traps over a three day period at Times Beach. Total dry matter (g) and relative percentage dry matter (%) of four pooled samples per plot. MAY 1985.

PLOT	PRED. COL.	ARAM.	CHIL.	DIPL.	ISOP.	OTHERS
A1 (g)	0.3479	0.0080	0.0700	0.1063	0.2774	0.12
(%)	37.26	0.64	7.51	11.41	29.77	13.40
A4 (g)	1.5008	0.0091	0.0615	0.1995	0.2500	0.14
(%)	69.50	0.42	2.85	9.24	11.58	6.41
B4 (g)	0.9868	0.0391	0.0187	0.1345	0.1988	1.74
(%)	31.65	1.25	0.60	4.31	6.38	55.81
B5 (g)	0.9064	0.0045	0.0531	0.2237	0.1331	0.26
(%)	57.36	0.28	3.36	14.16	8.42	16.42
C1 (g)	0.5727	0.0170	-	0.1053	0.0626	0.01
(%)	48.74	1.45	-	9.01	5.33	0.85
C2 (g)	0.2547	0.0125	-	0.029	0.1049	0.05
(%)	24.25	1.19	-	9.01	5.33	0.85
C4 (g)	1.0407	0.1063	-	0.054	0.0395	-
(%)	83.22	8.50	-	4.32	3.16	-

TABLE 1 contd...

TABLE 1(d) Metal concentrations in major groups of invertebrate fauna, four pooled samples per plot (ug/g. dry weight). MAY 1985

CARNIVOROUS SPECIES

(1) Predatory COLEOPTERA

PLOT	Zn	Cu	Mn	Cd	Cr	Pb
A1	92	14	<0.43	0.85	2.6	<1.5
A4	87	14	<0.35	1.3	1.7	<1.2
B4	115	16	1.1	2.6	5.5	4.2
B5	100	13	<0.34	2.8	1.7	<1.2
C1	114	17	0.74	2.1	4.7	5.1
C2	108	11	<0.59	1.9	3.0	<2.1
C4	118	18	<0.72	2.6	3.5	2.6

(2) ARANEIDA

PLOT	Zn	Cu	Mn	Cd	Cr	Pb
A1	369	165	<13	28	117	<44
A4	461	172	<8.3	26	52	30
B4	411	253	<1.9	112	14	<6.8
B5	511	207	17	40	85	<59
C1	336	182	<4.5	114	30	<16
C2	342	190	<6.1	148	37	<21
C4	244	174	<0.71	70	6.1	<2.5

(3) CHILOPODA

PLOT	Zn	Cu	Mn	Cd	Cr	Pb
A1	279	60	<1.1	6.0	6.8	<3.8
A4	283	57	<1.2	12	7.3	<4.3
B4	193	45	<4.0	25	22	<14
B5	272	28	<1.4	4.2	8.9	<5.0

TABLE 1(d) contd...

DETRITIVOROUS SPECIES

(4) DIPLOPODA

PLOT	Zn	Cu	Mn	Cd	Cr	Pb
A1	228	630	<2.5	2.9	5.8	10.4
A4	194	652	<1.5	2.6	4.3	<9.7
B4	280	693	1.9	3.5	8.7	7.9
B5	204	626	<1.7	3.8	4.2	<8.4
C1	158	581	1.0	1.8	5.8	6.2
C2	178	731	<2.6	2.4	9.2	<9.2
C4	187	591	<1.4	2.3	7.1	6.6

(5) ISOPODA

PLOT	Zn	Cu	Mn	Cd	Cr	Pb
A1	195	192	3.5	31	13	13
A4	164	171	2.9	35	7.6	14
B4	209	157	2.3	41	14	13
B5	173	127	3.9	49	11	14
C1	113	110	2.4	21	9.3	12
C2	179	149	2.9	45	12	16
C4	249	173	<1.9	21	15	<6.7

TABLE 2 OCTOBER 1985

TABLE 2(a) Record of numbers of soil dwelling invertebrates collected in pitfall traps.

PLOT	COL.	ARAN.	CHIL.	DIPL.	ISOP.	ORTH.	OTHERS
A1	20	18	3	26	196	5	5 Diptera/1 Dermaptera/1 Mollusc 4 Hemiptera/15 Hymenoptera 7 Neuroptera/2 Lepidoptera/1 Olig.
A2	14	11	2	20	118	7	1 Acarina/1 Diptera/2 Hemiptera/ 22 Hymenoptera/1 Mollusca 1 Oligochaeta
A3	5	5	2	31	102	7	2 Acarina/4 Diptera/37 Hymenoptera 1 Neuroptera/2 Oligochaeta
A4	19	35	8	49	161	28	7 Acarina/4 Diptera/1 Hemiptera 27 Hymenoptera/1 Mollusca/ 6 Oligochaeta
B1	23	29	1	12	261	10	7 Acarina/1 Diptera/2 Hemiptera 8 Hymenoptera/2 Mollusca 2 Oligochaeta
B2	29	51	2	5	121	34	6 Acarina/2 Dermaptera/2 Diptera 6 Hemiptera/8 Hymenoptera
B3	23	32	5	60	211	8	4 Acarina/10 Hymenoptera 1 Oligochaeta
B4	15	36	2	33	105	9	5 Acarina/5 Hemiptera/ 13 Hymenoptera/2 Lepidoptera 3 Oligochaeta
B5	26	25	2	17	54	14	4 Acarina/1 Dermaptera/5 Hemiptera 16 Hymenoptera/1 Thysanoptera 8 Oligochaeta
C1	69	33	1	7	301	62	6 Acarina/3 Diptera/1 Hemiptera 14 Hymenoptera/1 Mollusca 5 Oligochaeta
C2	107	28	5	16	243	58	15 Acarina/1 Dermaptera/4 Diptera 20 Hymenoptera/2 Neuroptera/ 5 Oligochaeta
C3	31	33	5	27	181	28	5 Acarina/4 Diptera/15 Hymenoptera 1 Lepidoptera/2 Mollusca 1 Oligochaeta
C4	16	38	6	6	142	17	10 Acarina/2 Diptera/1 Hemiptera 18 Hymenoptera/1 Mollusca 5 Oligochaeta

TABLE 2 contd...

TABLE 2(b) Identification of major groups of soil dwelling invertebrate fauna. OCTOBER 1985

1. COLEOPTERA

PLOT	SUB-ORDER	FAMILY	GENUS	NUMBER IN POOLED SAMPLE AT EACH PLOT
A1	Geodephaga	Carabidae	<u>Amara</u> sp	12
	Lamellicornia	Trogidae	<u>Trox</u> sp	2
	Rhynchophora	Curculionidae		1
	Rhynchophora	Otiorynchinae		1
	Clavicornia	Nitidulidae		2
	Lamellicornia	Scarabidae	<u>Aphodius</u> ?	1
	Brachelytra	Staphylinidae	<u>Tachyporus</u> sp	1
A2	Geodephaga	Carabidae	<u>Pterostichus</u>	2
	Geodephaga	Carabidae	<u>Amara</u>	5
	Clavicornia	Nitidulinidae	?	3
	Rhynchophora	Curculionidae	?	4
A3	Geodephaga	Carabidae	<u>Calathus</u> sp	1
	Geodephaga	Carabidae	<u>Amara</u> sp	1
	Clavicornia	Nitidulinidae	?	1
	Rhynchophora	Curculionidae	?	2
A4	Geodephaga	Carabidae	<u>Carabus</u> sp	1
	Geodephaga	Carabidae	<u>Pterostichus</u> sp	1
	Geodephaga	Carabidae	<u>Amara</u> sp	10
	Geodephaga	Carabidae	<u>Harpalus</u> sp	1
	Geodephaga	Carabidae	<u>Bembidion</u> sp	1
	Geodephaga	Carabidae		1
	Lamellicornia	Trogidae	<u>Trox</u> sp	1
	Rhynchophora	Curculionidae		3

TABLE 2(b) contd...

PLOT	SUB-ORDER	FAMILY	GENUS	NUMBER IN POOLED SAMPLE AT EACH PLOT
B1	Geodephaga	Carabidae	<u>Pterostichus</u> sp	5
	Geodephaga	Carabidae	<u>Harpalus</u> sp	1
	Geodephaga	Carabidae	<u>Amara</u> sp	12
	Geodephaga	Carabidae	<u>Clivina</u> ? sp	1
	Geodephaga	Carabidae		1
	Rhynchophora	Curculionidae		2
	Brachelytra	Staphylinidae	<u>Aleocharinae</u>	1
B2	Geodephaga	Carabidae	<u>Carabus</u> sp	1
	Geodephaga	Carabidae	<u>Amara</u> sp	15
	Geodephaga	Carabidae	<u>Pterostichus</u>	1
	Geodephaga	Carabidae		3
	Clavicornia	Nitidulinidae		1
	Rhynchophora	Curculionidae		1
	?	Chrysomelidae	<u>Altica</u> ?	3
	Brachelytra	Staphylinidae	<u>Aleocharinae</u>	2
	Brachelytra	Staphylinidae	<u>Omalinae</u>	1
	Brachelytra	Staphylinidae	<u>Staphylininae</u>	1
B3	Geodephaga	Carabidae	<u>Carabus</u> sp	1
	Geodephaga	Carabidae	<u>Amara</u> sp	15
	Geodephaga	Carabidae	<u>Pterostichus</u>	1
	Geodephaga	Carabidae	?	3
	Clavicornia	Nitidulinidae	?	1
	Rhynchophora	Curculionidae	?	1
	?	Chrysomelidae	<u>Altica</u> ?	3
	Brachelytra	Staphylinidae	<u>Aleocharinae</u>	2
	Brachelytra	Staphylinidae	<u>Omalinae</u>	1
	Brachelytra	Staphylinidae	<u>Staphylininae</u>	1
B4	Geodephaga	Carabidae	<u>Amara</u> sp	11
	Lamellicornia	Trogidae	<u>Trox</u> sp	1
	Brachelytra	Staphylinidae	<u>Tachyporus</u> sp	1
	Clavicornia	Nitidulinidae	?	2
B5	Geodephaga	Carabidae	<u>Amara</u> sp	19
	Lamellicornia	Trogidae	<u>Trox</u> sp	1
	Clavicornia	Nitidulinidae		1
	Brachelytra	Staphylinidae	<u>Aleocharinae</u>	1
	Brachelytra	Staphylinidae	<u>Tachyporus</u> sp	1
	Brachelytra	Staphylinidae	<u>Omalinae</u>	2
	Brachelytra	Staphylinidae		1

TABLE 2(b) contd...

PLOT	SUB-ORDER	FAMILY	GENUS	NUMBER IN POOLED SAMPLE AT EACH PLOT
C1	Geodephaga	Carabidae	<u>Carabus</u> sp	1
	Geodephaga	Carabidae	<u>Amara</u> sp	57
	Geodephaga	Carabidae	<u>Pterostichus</u> sp	3
	Geodephaga	Carabidae	<u>Agonus</u>	1
	Geodephaga	Carabidae	<u>Clivina</u> sp	1
	Geodephaga	Carabidae	?	2
	Clavicornia	Nitidulidae	?	1
	?	Chrysomelidae	?	1
	Brachelytra	Staphylinidae	<u>Tachyporus</u> sp	2
C2	Geodephaga	Carabidae	<u>Carabus</u>	1
	Geodephaga	Carabidae	<u>Amara</u>	76
	Geodephaga	Carabidae	<u>Pterostichus</u>	14
	Geodephaga	Carabidae	?	1
	Clavicornia	Nitidulidae	?	1
	Lamellicornia	Trogidae	<u>Trox</u> sp	2
	Rhynchophora	Curculionidae	?	2
	Geodephaga	Carabidae	<u>Bembidion</u> sp	1
	Brachelytra	Staphylinidae	<u>Omaliniinae</u>	1
	Brachelytra	Staphylinidae	<u>Tachyporus</u> sp	2
	Brachelytra	Staphylinidae	<u>Aleocharinae</u>	4
	?	Chrysomelidae	<u>Halticinae</u>	2
C3	Geodephaga	Carabidae	<u>Amara</u> sp	7
	Geodephaga	Carabidae	<u>Pterostichus</u> sp	1
	Geodephaga	Carabidae	?	6
		Otiorynchinae	?	1
	Clavicornia	Nitidulidae	?	4
	Geodephaga	Carabidae	<u>Bembidion</u> sp	2
	Brachelytra	Staphylinidae	<u>Tachyporus</u> sp	6
	Brachelytra	Staphylinidae	<u>Aleocharine</u>	2
	?	Chrysomelidae	?	1
	?			1
C4	Geodephaga	Carabidae	<u>Amara</u> sp	3
	Geodephaga	Carabidae	<u>Pterostichus</u> sp	1
	Geodephaga	Carabidae	<u>Agonus</u> sp	2
	Geodephaga	Carabidae	<u>Harpalus</u> sp	2
	Geodephaga	Carabidae	?	3
	Clavicornia	Nitidulidae	?	1
	Brachelytra	Staphylinidae	<u>Omaliniinae</u>	3
	Brachelytra	Staphylinidae	<u>Tachyporus</u> sp	1
	Brachelytra	Staphylinidae	<u>Philonthius</u> sp	1
	Brachelytra	Staphylinidae	<u>Aleocharinae</u>	1

TABLE 2(b) contd...

4. DIPLOPODA

PLOT	FAMILY	GENUS	SPECIES	NUMBER IN POOLED SAMPLE AT EACH PLOT
A1	Blaniulidae	<u>Isobates</u>	<u>littoralis</u>	6
	Blaniulidae	<u>Choneiulus</u>	<u>palmatus</u>	19
	Polydesmidae	<u>Brachydesmus</u>	sp	1
A2	Blaniulidae	<u>Isobates</u>	<u>littoralis</u>	7
	Blaniulidae	<u>Choneiulus</u>	<u>palmatus</u>	13
A3	Blaniulidae	<u>Isobates</u>	<u>littoralis</u>	7
	Blaniulidae	<u>Choneiulus</u>	<u>palmatus</u>	23
	Polydesmidae	<u>Brachydesmus</u>	sp	1
A4	Blaniulidae	<u>Isobates</u>	<u>littoralis</u>	13
	Blaniulidae	<u>Choneiulus</u>	<u>palmatus</u>	24
	Polydesmidae	<u>Brachydesmus</u>	sp	12
B1	Blaniulidae	<u>Isobates</u>	<u>littoralis</u>	3
	Blaniulidae	<u>Choneiulus</u>	<u>palmatus</u>	9
B2	Blaniulidae	<u>Choneiulus</u>	<u>littoralis</u>	4
	Polydesmidae	<u>Brachydesmus</u>	sp	1
B3	Blaniulidae	<u>Isobates</u>	<u>littoralis</u>	17
	Blaniulidae	<u>Choneiulus</u>	<u>palmatus</u>	40
	Polydesmidae	<u>Brachydesmus</u>	sp	3
B4	Blaniulidae	<u>Isobates</u>	<u>littoralis</u>	20
	Polydesmidae	<u>Brachydesmus</u>	sp	13
B5	Blaniulidae	<u>Choneiulus</u>	<u>palmatus</u>	17
C1	Blaniulidae	<u>Isobates</u>	<u>littoralis</u>	1
	Blaniulidae	<u>Choneiulus</u>	<u>palmatus</u>	6
C2	Blaniulidae	<u>Isobates</u>	<u>littoralis</u>	3
	Blaniulidae	<u>Choneiulus</u>	<u>palmatus</u>	9
	Polydesmidae	<u>Brachydesmus</u>	sp	12
C3	Blaniulidae	<u>Isobates</u>	<u>littoralis</u>	1
	Blaniulidae	<u>Choneiulus</u>	<u>palmatus</u>	6
C4	Blaniulidae	<u>Choneiulus</u>	<u>palmatus</u>	6

TABLE 2(b) contd...

5. ISOPODA

PLOT	FAMILY	GENUS	NUMBER IN POOLED SAMPLE AT EACH PLOT
A1	Oniscidae	<u>Oniscus</u>	44
	Porcellionidae	<u>Porcellio</u>	98
	Trichoniscidae	<u>Trichoniscus</u>	48
	Armadillidiidae	<u>Armadillidium</u>	6
A2	Oniscidae	<u>Oniscus</u>	17
	Porcellionidae	<u>Porcellio</u>	72
	Trichoniscidae	<u>Trichoniscus</u>	16
	Armadillidiidae	<u>Armadillidium</u>	13
A3	Oniscidae	<u>Oniscus</u>	3
	Porcellionidae	<u>Porcellio</u>	67
	Trichoniscidae	<u>Trichoniscus</u>	6
	Armadillidiidae	<u>Armadillidium</u>	26
A4	Oniscidae	<u>Oniscus</u>	10
	Porcellionidae	<u>Porcellio</u>	74
	Trichoniscidae	<u>Trichoniscus</u>	65
	Armadillidiidae	<u>Armadillidium</u>	12
B1	Oniscidae	<u>Oniscus</u>	3
	Porcellionidae	<u>Porcellio</u>	46
	Trichoniscidae	<u>Trichoniscus</u>	211
	Armadillidiidae	<u>Armadillidium</u>	1
B2	Oniscidae	<u>Oniscus</u>	3
	Porcellionidae	<u>Porcellio</u>	36
	Trichoniscidae	<u>Trichoniscus</u>	81
	Armadillidiidae	<u>Armadillidium</u>	1
B3	Oniscidae	<u>Oniscus</u>	1
	Porcellionidae	<u>Porcellio</u>	40
	Trichoniscidae	<u>Trichoniscus</u>	169
	Armadillidiidae	<u>Armadillidium</u>	1
B4	Oniscidae	<u>Oniscus</u>	11
	Porcellionidae	<u>Porcellio</u>	36
	Trichoniscidae	<u>Trichoniscus</u>	57
	Armadillidiidae	<u>Armadillidium</u>	1
B5	Oniscidae	<u>Oniscus</u>	2
	Porcellionidae	<u>Porcellio</u>	23
	Trichoniscidae	<u>Trichoniscus</u>	29
	Armadillidiidae	<u>Armadillidium</u>	0

TABLE 2(b) contd...

PLOT	FAMILY	GENUS	NUMBER IN POOLED SAMPLE AT EACH PLOT
C1	Oniscidae	<u>Oniscus</u>	1
	Porcellionidae	<u>Porcellio</u>	25
	Trichoniscidae	<u>Trichoniscus</u>	274
	Armadillidiidae	<u>Armadillidium</u>	1
C2	Oniscidae	<u>Oniscus</u>	15
	Porcellionidae	<u>Porcellio</u>	80
	Trichoniscidae	<u>Trichoniscus</u>	147
	Armadillidiidae	<u>Armadillidium</u>	0
C3	Oniscidae	<u>Oniscus</u>	1
	Porcellionidae	<u>Porcellio</u>	40
	Trichoniscidae	<u>Trichoniscus</u>	140
	Armadillidiidae	<u>Armadillidium</u>	0
C4	Oniscidae	<u>Oniscus</u>	0
	Porcellionidae	<u>Porcellio</u>	27
	Trichoniscidae	<u>Trichoniscus</u>	115
	Armadillidiidae	<u>Armadillidium</u>	0

6. ORTHOPTERA

PLOT	FAMILY	NUMBER IN POOLED SAMPLE AT EACH PLOT
A1	Tettigoniidae	5
A2	Tettigoniidae	7
A3	Tettigoniidae	7
A4	Tettigoniidae	28
B1	Tettigoniidae	10
B2	Tettigoniidae	34
B3	Tettigoniidae	8
B4	Tettigoniidae	9
B5	Tettigoniidae	14
C1	Tettigoniidae	61
	Acridiidae	1
C2	Tettigoniidae	58
C3	Tettigoniidae	28
C4	Tettigoniidae	17

TABLE 2 contd...

TABLE 2(c) Composition of soil dwelling invertebrate fauna sampled by pitfall traps over a ten day period at Times Beach. Total dry matter (g) and relative percentage dry matter contribution (%) of four pooled samples per plot.
OCTOBER 1985

PLOT	PRED. COL.	ARAN.	OPIO.	CHIL.	HERB. COL.	ORTH.	DIPL.	ISOP.	OTHERS
A1 (g)	0.068	0.016	0.055	0.035	0.028	0.069	0.126	1.343	0.054
(%)	3.8	0.89	3.1	2.0	1.6	3.8	7.0	74.9	3.0
A2 (g)	0.102	0.094	0.073	0.019	0.008	0.089	0.108	0.873	0.034
(%)	7.3	6.7	5.2	1.4	0.57	6.4	7.7	62.4	2.4
A3 (g)	0.008	0.113	0.030	0.001	0.003	0.092	0.135	0.673	0.038
(%)	0.73	10.3	2.7	0.09	0.27	8.4	12.4	61.6	3.5
A4 (g)	0.373	0.013	0.177	0.029	0.020	0.273	0.705	0.221	0.197
(%)	18.6	0.6	8.8	1.4	1.0	13.6	35.1	11.0	9.8
B1 (g)	0.401	0.006	0.095	0.002	0.005	0.128	0.102	0.441	0.029
(%)	33.2	0.50	7.9	0.17	0.41	10.6	8.4	36.5	2.4
B2 (g)	0.543	0.011	0.113	0.027	0.005	0.342	0.040	0.334	0.078
(%)	36.4	0.74	7.6	1.8	0.33	22.9	2.7	22.4	5.2
B3 (g)	0.314	0.005	0.107	0.084	0.003	0.077	0.285	0.444	0.093
(%)	2.2	0.35	7.5	5.9	0.21	0.50	20.2	31.4	6.6
B4 (g)	0.108	0.040	0.120	0.005	0.003	0.062	0.165	0.363	0.070
(%)	11.5	4.3	12.8	0.5	0.3	6.6	0.2	38.8	7.5
B5 (g)	0.343	0.030	0.092	0.017	0.009	0.163	0.142	0.178	0.104
(%)	31.8	2.8	8.5	1.6	0.8	15.1	13.2	16.5	9.6
C1 (g)	1.270	0.071	0.086	0.002	0.001	0.867	0.117	0.478	0.278
(%)	40.1	2.2	2.7	0.63	0.03	27.4	3.7	15.1	8.8
C2 (g)	2.222	0.038	0.134	0.111	0.034	0.690	0.107	0.772	0.154
(%)	52.1	0.9	3.1	2.6	0.8	16.2	2.5	18.1	3.6
C3 (g)	0.153	0.071	0.086	0.037	0.034	0.308	0.207	0.337	0.061
(%)	11.86	5.5	6.6	2.9	2.6	23.8	16.0	26.0	4.7
C4 (g)	0.185	0.089	0.062	0.026	<0.001	0.164	0.052	0.333	0.082
(%)	18.6	9.0	6.2	2.6	-	16.5	5.2	33.5	8.3

TABLE 2 contd...

TABLE 2(d) Metal concentrations in major groups of invertebrate fauna, four pooled samples per plot (ug/g, dry weight). OCTOBER 1985

CARNIVOROUS SPECIES

(1) Predatory COLEOPTERA

PLOT	Zn	Cu	Ni	Cd	Cr	Pb
A1	77	15	<1.1	0.56	6.1	<3.9
A2	104	22	1.4	4.0	10	9.5
A3	-	-	-	-	-	-
A4	117	16	1.1	1.6	6.6	9.7
B1	103	17	1.3	2.6	4.1	5.3
B2	103	16	<0.69	1.0	4.1	5.2
B3	143	21	0.87	4.0	3.1	4.0
B4	122	21	1.8	4.5	8.6	7.0
B5	82	18	0.48	0.82	2.3	3.2
C1	108	15	0.97	1.6	2.4	2.6
C2	123	18	1.4	2.3	2.4	2.9
C3	108	16	1.9	1.7	7.7	8.2
C4	76	14	2.7	0.89	8.4	4.2

(2) ARANEIDA

PLOT	Zn	Cu	Ni	Cd	Cr	Pb
Veg. A	166	111	18	15	-	9.0
Veg. B	140	77	4.8	8.8	11	14
Veg. C	142	103	2.4	18	21	8.5

(3) OPIOLONES

PLOT	Zn	Cu	Ni	Cd	Cr	Pb
Veg. A	165	37	1.9	14	3.9	8.5
Veg. B	121	38	2.1	12	2.6	8.6
Veg. C	132	39	1.5	16	4.2	8.1

TABLE 2(d) contd. . .

(4) CHILOPODA

PLOT	Zn	Cu	Ni	Cd	Cr	Pb
Veg. A	152	48	32	4.2	3.5	<2.9
Veg. B	152	37	3.8	3.5	8.5	9.1
Veg. C	138	30	2.1	5.0	1.3	<7.9

HERBIVOROUS SPECIES

(5) Herbivorous COLEOPTERA

PLOT	Zn	Cu	Ni	Cd	Cr	Pb
Veg. A	222	42	3.1	0.99	19	13
Veg. B	153	35	2.2	0.69	11	13
Veg. C	167	26	3.6	0.72	22	<7.9

(6) ORTHOPTERA

PLOT	Zn	Cu	Ni	Cd	Cr	Pb
A1	175	31	2.3	12	7.4	11
A2	217	36	4.4	9.8	9.9	16
A3	182	45	6.7	11	8.6	15
A4	186	34	3.3	6.8	7.9	17
B1	164	28	3.7	17	7.3	10
B2	192	31	2.5	14	5.0	8.9
B3	168	35	3.3	9.1	8.1	14
B4	155	30	2.5	5.5	12	11
B5	150	23	1.7	10	3.3	5.6
C1	229	28	2.0	12	1.9	5.2
C2	250	32	5.2	11	2.8	6.3
C3	183	33	3.9	6.8	14	9.4
C4	120	19	2.2	8.6	3.0	6.6

TABLE 2(d) contd...

DETRITIVOROUS SPECIES

(7) DIPLOPODA

PLOT	Zn	Cu	Ni	Cd	Cr	Pb
A1	186	784	2.7	2.8	6.6	12
A2	176	706	2.7	2.3	6.6	12
A3	188	662	1.8	2.3	6.9	11
A4	229	760	1.7	3.2	3.5	11
B1	222	632	2.1	2.8	8.5	13
B2	243	839	<1.8	2.8	12	10
B3	248	901	2.9	3.5	6.1	16
B4	244	765	2.9	3.2	6.3	11
B5	216	798	2.2	3.4	5.2	12
C1	124	494	1.3	1.9	4.0	8.0
C2	248	718	2.5	2.8	7.1	12
C3	252	962	3.6	4.0	7.8	17
C4	217	716	<1.4	3.3	7.9	9.1

(8) ISOPODA

PLOT	Zn	Cu	Ni	Cd	Cr	Pb
A1	243	328	2.1	33	7.8	16
A2	291	305	3.8	22	14	20
A3	373	285	2.4	14	7.9	15
A4	349	320	2.8	24	10	16
B1	402	239	4.3	23	15	21
B2	291	198	3.3	21	11	16
B3	283	201	3.5	27	9	20
B4	318	261	2.4	21	6.9	12
B5	335	216	4.4	19	6.2	11
C1	274	136	1.6	22	6.8	9.0
C2	292	263	2.1	29	11	12
C3	286	226	3.5	20	13	19
C4	270	206	2.2	19	6.7	10

TABLE 3. MAY 1986

TABLE 3(a) Record of numbers of soil dwelling invertebrates collected in four pitfall traps per plot.

PLOT	COL.	ARAN.	CHIL.	DIP.	ISOP.	OTHERS
A1	9	2	5	98	17	1 Homoptera/5 Hymenoptera/1 Diptera 1 Mollusca
A2	48	3	2	53	17	3 Hymenoptera/1 Acarina
A3	20	5	1	11	11	6 Hymenoptera/2 Diptera/5 Acarina 1 Lepidoptera
A4	14	6	-	59	10	3 Hymenoptera/3 Acarina/1 Neuroptera 1 Orthoptera
B1	39	6	-	20	5	1 Orthoptera/1 Oligochaeta
B2	13	7	-	34	14	3 Hymenoptera/1 Diptera
B3	3	2	1	39	13	1 Hymenoptera/2 Hemiptera
B4	42	15	3	14	28	8 Hymenoptera/4 Acarina/1 Orthoptera
B5	32	12	1	48	12	3 Hymenoptera/4 Acarina 1 Oligochaeta
C1	59	7	5	14	2	1 Acarina/1 Orthoptera/2 Oligochaeta
C2	11	7	3	65	124	1 Hymenoptera/2 Oligochaeta
C3	42	18	-	12	1	1 Hymenoptera/7 Diptera/2 Acarina 1 Hemiptera/2 Orthoptera/1 Olig.
C4	43	8	2	30	37	6 Hymenoptera/5 Diptera/3 Acarina

TABLE 3 contd...

TABLE 3(b) Composition of soil dwelling invertebrate fauna sampled by pitfall trapping over a ten day period at Times Beach. Total dry matter (g) and percentage dry matter contribution (%) four pooled samples per plot. MAY 1986

PLOT	PRED. COL.	ARANEIDA	CHILOPODA	HERB. COL.	DIPLOPODA	ISOPODA	OTHERS
A1 (g)	1.056	-	0.010	0.002	0.371	0.128	0.024
(%)	66.4	-	0.06	0.10	23.3	8.0	1.5
A2 (g)	4.369	0.018	-	-	0.234	0.069	0.004
(%)	93.5	0.4	-	-	4.7	1.4	0.1
A3 (g)	0.222	0.001	-	0.014	0.031	0.046	0.239
(%)	40.1	0.2	-	2.5	5.6	8.3	43.2
A4 (g)	0.706	0.002	-	0.003	0.247	0.036	0.018
(%)	69.8	0.2	-	0.3	24.4	3.6	1.8
B1 (g)	0.578	0.049	-	-	0.122	0.022	0.153
(%)	62.6	5.3	-	-	13.2	2.4	16.6
B2 (g)	0.188	0.097	-	-	0.168	0.052	0.002
(%)	37.1	19.1	-	-	33.1	10.3	0.4
B3 (g)	0.018	0.005	-	-	0.161	0.015	0.001
(%)	9.0	2.5	-	-	80.5	7.5	0.5
B4 (g)	0.439	0.008	0.002	0.025	0.080	0.060	0.028
(%)	66.3	1.2	3.3	3.8	12.1	9.1	4.2
B5 (g)	0.620	0.125	0.001	0.003	0.212	0.046	0.071
(%)	57.5	11.6	0.1	0.3	19.6	4.3	6.6
C1 (g)	1.056	-	0.010	0.002	0.371	0.128	0.024
(%)	66.4	-	0.6	0.1	23.3	8.0	1.5
C2 (g)	0.131	0.029	0.076	0.041	0.274	0.235	0.011
(%)	16.4	3.6	9.5	5.1	34.4	29.5	1.4
C3 (g)	0.159	0.030	0.141	-	0.089	0.019	0.060
(%)	61.9	3.6	16.8	-	8.2	2.3	7.2
C4 (g)	0.314	0.020	0.048	0.008	0.445	0.116	0.047
(%)	48.7	3.1	7.4	1.2	21.9	16.0	1.7

TABLE 3 contd...

TABLE 3(c) Metal concentrations in major groups of invertebrate fauna, four pooled samples per plot (ug/g. dry weight). MAY 1986

CARNIVOROUS SPECIES

(1) Predatory COLEOPTERA

PLOT	Zn	Cu	Mn	Cd	Cr	Pb
A1	148	19	-	2.0	4.3	-
A2	140	19	-	7.1	1.4	-
A3	149	18	-	3.5	2.0	-
A4	151	16	-	6.1	-	-
B1	123	15	-	3.8	4.0	-
B2	83	14	-	3.2	2.2	-
B3						
B4	112	22	-	4.1	3.4	-
B5	119	19	-	6.6	-	-
C1	120	21	-	3.4	4.3	-
C2	84	15	-	1.0	2.0	-
C3	109	21	-	5.0	6.5	-
C4	106	18	-	4.6	2.9	-

(2) ARANEIDA

PLOT	Zn	Cu	Mn	Cd	Cr	Pb
Veg. A	325	230	-	71	5.9	-
Veg. B	311	177	23	36	4.6	-
Veg. C	299	114	10	29	5.3	-

(3) CHILOPODA

PLOT	Zn	Cu	Mn	Cd	Cr	Pb
Veg. A	818	67	-	-	-	-
Veg. B	193	47	-	9.0	-	-
Veg. C	212	50	12	5.2	2.9	-

TABLE 3(c) contd...

HERBIVOROUS SPECIES

(4) Herbivorous COLEOPTERA

PLOT	Zn	Cu	Ni	Cd	Cr	Pb
Veg. A	127	33	-	-	-	-
Veg. B	204	34	-	-	-	-
Veg. C	190	33	-	-	7.7	-

(5) ORTHOPTERA

PLOT	Zn	Cu	Ni	Cd	Cr	Pb
All plots.	188	56	-	3.2	7.0	8.3

TABLE 3(c) contd...

DETRITIVOROUS SPECIES

(6) DIPLOPODA

PLOT	Zn	Cu	Mn	Cd	Cr	Pb
A1	213	839	3.3	3.9	6.2	15
A2	393	551	-	2.2	8.3	29
A3	304	639	-	5.4	5.2	-
A4	167	702	-	4.1	3.6	-
B1	266	689	-	6.9	6.9	23
B2	218	851	3.3	3.1	5.6	18
B3	176	556	4.4	2.8	5.3	15
B4	242	683	4.3	3.3	5.1	14
B5	235	628	3.0	3.9	3.7	12
C1	323	876	-	5.0	8.4	-
C2	238	705	4.2	3.7	5.0	-
C3	241	756	-	4.5	6.3	-
C4	214	683	4.3	3.3	5.1	14

(7) ISOPODA

PLOT	Zn	Cu	Mn	Cd	Cr	Pb
A1	226	242	4.3	20	5.5	15
A2	501	223	7.6	27	12	26
A3	374	243	-	11	7.2	-
A4	263	186	-	27	5.8	-
B1	251	189	-	17	7.8	-
B2	343	194	-	14	11	-
B3	326	295	-	22	19	-
B4	290	237	-	29	7.6	-
B5	323	192	-	24	6.6	-
C1 & 3	421	221	-	11	12	-
C2	167	142	16	28	6.1	-
C4	232	192	7.1	20	6.1	16

TABLE 4 NOVEMBER 1986

TABLE 4(a) Record of numbers of soil dwelling invertebrates collected in pitfall traps.

PLOT	COL.	ARAN.	OPIO.	CHIL.	DIPL.	ISOP.	ORTH.	OTHERS
A1	9	8	5	1	11	43	-	12 Diptera/ 3 Hemiptera 1 Mollusca/ 2 Hymenoptera
A2	14	21	3	-	19	84	-	13 Diptera/21 Hymenoptera 4 Dermaptera/3 Hemiptera 4 Acarina/1 Mollusc/10lig
A3	6	12	18	6	62	421	2	12 Diptera/1 Hemiptera 9 Hymenoptera/3 Mollusca 9 Oligochaeta
A4	9	4	3	3	34	62	-	4 Diptera/1 Hemiptera 1 Mollusca/1 Hymenoptera 6 Oligochaeta
B1	12	11	1	1	4	5	1	6 Diptera/4 Hymenoptera 8 Mollusca
B2	12	19	4	1	4	6	1	9 Diptera/2 Hymenoptera 15 Mollusca/4 Hemiptera
B3	9	14	11	1	13	94	4	9 Diptera/1 Hemiptera 2 Neuroptera/1 Mollusca
B4	10	14	3	2	5	11	3	4 Diptera/8 Hymenoptera 37 Mollusca/1 Acarina 1 Oligochaeta
B5	12	5	8	1	2	260	1	6 Diptera/9 Hymenoptera 7 Mollusca/1 Oligochaeta
C1	7	18	2	-	2	20	-	2 Diptera/4 Mollusca 1 Oligochaeta
C2	16	16	4	-	7	82	5	12 Diptera/1 Hymenoptera 4 Dermaptera/4 Mollusca
C3	13	26	2	-	2	3	7	19 Diptera/1 Hymenoptera 2 Mollusca/1 Lepidoptera
C4	15	25	2	1	2	2	2	9 Diptera/1 Hymenoptera 1 Hemiptera/1 Acarina 1 Mollusca/1 Lepidoptera

TABLE 4 contd...

TABLE 4(b) Composition of soil dwelling invertebrate fauna sampled by pitfall trapping over a ten day period at Times Beach. Total dry matter (g) and percentage dry matter contribution (%), four samples per plot.
NOVEMBER 1986.

PLOT	PRED. COL.	ARAW.	OPIO.	CHIL.	HERB. COL.	DIPL.	ISOP.	ORTH.	OTHERS
A1 (g)	0.289	0.011	0.036	0.001	-	0.013	0.119	-	0.090
(%)	51.69	1.97	6.44	0.18	-	2.33	21.29	-	16.10
A2 (g)	0.253	0.025	0.013	0.112	0.006	0.061	0.232	-	0.190
(%)	28.36	2.80	1.46	12.56	0.67	6.84	26.01	-	21.30
A3 (g)	0.066	0.021	0.110	0.029	0.001	0.169	0.303	0.021	0.110
(%)	7.95	2.53	13.25	3.49	0.12	20.36	36.51	2.53	13.25
A4 (g)	0.109	0.006	0.025	0.109	0.016	0.004	0.561	-	0.210
(%)	10.48	0.58	2.40	10.48	1.54	0.38	53.94	-	20.19
B1 (g)	0.074	0.037	0.009	0.024	0.001	0.009	0.004	0.016	0.020
(%)	38.14	19.07	4.64	12.37	0.52	4.64	2.06	8.25	10.31
B2 (g)	0.044	0.076	0.026	0.003	0.004	0.007	0.016	0.016	0.020
(%)	20.75	35.85	12.26	1.42	1.89	3.30	7.55	7.55	9.43
B3 (g)	0.112	0.038	0.088	0.001	-	0.031	0.100	0.038	0.030
(%)	25.57	8.68	20.09	0.23	-	7.08	22.83	8.68	6.85
B4 (g)	0.121	0.009	0.016	0.004	0.001	0.020	0.017	0.044	0.140
(%)	32.53	2.42	4.30	1.08	0.27	5.38	4.57	11.83	37.63
B5 (g)	0.108	0.009	0.044	0.005	-	0.053	0.230	0.011	0.080
(%)	20.00	1.67	8.15	0.93	-	9.81	42.59	2.04	14.81
C1 (g)	0.038	0.084	0.017	-	-	0.016	0.037	-	0.270
(%)	8.23	18.18	3.68	-	-	3.46	8.01	-	58.44
C2 (g)	0.202	0.031	0.017	-	-	0.044	0.058	0.075	0.160
(%)	34.41	5.28	2.89	-	-	7.49	9.88	12.78	27.26
C3 (g)	0.072	0.099	0.017	-	-	0.005	0.003	0.087	0.130
(%)	17.43	23.97	4.12	-	-	1.21	0.73	21.07	31.47
C4 (g)	0.147	0.124	0.021	-	-	0.029	0.016	0.027	0.150
(%)	28.59	24.12	4.09	-	-	5.64	3.11	5.25	29.18

TABLE 4 contd...

TABLE 4(c) Metal concentrations in major groups of invertebrate fauna, four pooled samples per plot (ug/g, dry weight). NOVEMBER 1986

CARNIVOROUS SPECIES

(1) Predatory COLEOPTERA

PLOT	Zn	Cu	Mn	Cd	Cr	Pb
A1	179	54	3.0	4.9	2.4	2.4
A2	120	36	1.3	-	7.5	2.4
A3	78	17	1.4	1.1	8.9	<4.0
A4	80	17	2.3	2.1	5.6	3.1
B1	96	22	4.1	1.5	7.6	10
B2	139	20	4.6	4.3	4.3	<6.0
B3	86	16	2.3	2.4	2.3	5.8
B4	85	14	1.4	2.4	2.7	2.2
B5	95	16	3.3	3.0	4.4	4.1
C1	98	23	5.2	1.9	6.5	14
C2	86	17	2.5	3.0	1.0	4.2
C3	82	16	2.9	2.0	6.4	5.0
C4	94	20	5.5	3.2	6.4	5.0

(2) ARANEIDA

PLOT	Zn	Cu	Mn	Cd	Cr	Pb
A1 & A4	221	82	7.2	8.8	8.1	<16
A2	231	93	4.9	8.0	2.8	<11
A3	188	79	5.4	9.0	7.0	<13
B1	207	89	5.1	18	6.5	9.5
B2	193	60	1.5	14	<0.26	3.8
B3	213	74	9.2	7.1	0.56	8.0
B4 & B5	248	90	<4.4	15	4.1	<15
C1	215	57	3.0	7.2	7.2	14
C2	208	71	<2.4	7.1	5.3	<8.6
C3	205	67	1.4	8.2	1.9	4.6
C4	208	59	2.5	6.8	3.7	3.6

TABLE 4(c) contd...

(3) OPIOLONES

ZONE	Zn	Cu	Ni	Cd	Cr	Pb
Veg. A	526	53	5.4	31	15	7.1
Veg. B	483	44	3.9	28	4.2	11
Veg. C	414	33	18	17	11	18

(4) CHILOPODA

ZONE	Zn	Cu	Ni	Cd	Cr	Pb
Veg. A	281	40	6.9	3.3	2.5	2.8
Veg. B	454	121	33	8.6	16	18
Veg. C	Insufficient sample					

HERBIVOROUS SPECIES

(5) Herbivorous COLEOPTERA

ZONE	Zn	Cu	Ni	Cd	Cr	Pb
Veg. A	222	46	7.9	1.1	18	<11
Veg. B	171	78	35	2.9	76	<57
Veg. C	Insufficient sample					

(6) ORTHOPTERA

PLOT	Zn	Cu	Ni	Cd	Cr	Pb
A1, A2 & A4	Insufficient sample					
A3	122	32	9.5	6.5	-	<13
B1 & B2	174	35	8.1	9.5	16	16
B3	143	32	5.6	4.1	6.0	11
B4 & B5	154	23	7.1	8.4	5.4	9.7
C1	Insufficient sample					
C2	133	22	3.2	9.2	4.1	9.7
C3	141	23	2.8	4.7	2.1	7.6
C4	146	34	8.1	4.4	8.8	12

TABLE 4(d) contd...

DETRITIVOROUS SPECIES

(7) DIPLOPODA

PLOT	Zn	Cu	Ni	Cd	Cr	Pb
A1 & A4	236	461	12	4.8	6.8	16
A2	267	611	10.4	4.9	5.2	11
A3	201	586	7.0	3.8	5.9	14
B1 & B2	335	711	29	5.8	18	22
B3	291	555	19	4.7	11	21
B4 & B5	154	405	6.0	3.1	5.0	13
C1, C3 & C4	270	518	8.0	5.0	10.1	13
C2	174	419	8.1	3.3	5.0	10

(8) ISOPODA

PLOT	Zn	Cu	Ni	Cd	Cr	Pb
A1	229	110	5.2	24	6.4	17
A2	305	150	4.1	24	5.3	16
A3	235	118	3.7	37	4.6	24
A4	166	142	3.3	35	3.0	13
B1 & B2	320	106	18	16	12	25
B3	290	124	5.9	18	6.2	16
B4	369	84	20	31	17	<15
B5	207	89	5.6	41	6.8	18
C1	235	148	5.4	25	6.9	16
C2	280	96	6.4	28	7.0	17
C3 & C4	481	314	16	15	10.3	19

TABLE 5 MAY 1985

Native earthworms.

Metal concentrations measured in the native earthworms collected using formalin vermifuge from the defined vegetation zones at Times Beach. All concentrations expressed as ug/g, dry weight.

TABLE 5 Native earthworms collected at Times Beach. MAY 1985

All species, from each plot pooled for analysis and no correction made for the presence of substrate within the earthworm gut.

Plot	Zn	Cu	Ni	Cd	Cr	Pb
A1	1089	65	9.0	43	27	44
A4	1139	159	13	91	42	77
B5	530	79	9.1	101	18	31
C2	517	78	16	18	70	77

TABLE 6 NOVEMBER 1986

TABLE 6 Native earthworms.

Species from each plot pooled for analysis and concentrations corrected to eliminate the effect of substrate within the earthworm gut (Stafford & McGrath, 1986). All concentrations expressed as ug/g, dry weight.

Vegetation type A

Species/Plot	Zn	Cu	Ni	Cd	Cr	Pb
<u>Lumbricus terrestris</u>						
A1	2921	23	8.8	39	-	-
A2	2790	13	0.80	60	-	2.5
A3	3604	12	1.4	45	1.6	2.7
A4	2994	12	2.5	46	-	-
<u>Lumbricus rubellus</u>						
A3	2050	15	2.5	69	-	0.34
A4	1567	17	2.3	44	-	-
<u>Allolobophora caliginosa</u>						
A1	1115	23	-	28	-	-
A2	1220	25	1.7	24	1.0	-
A4	1010	30	4.1	30	15	1.2
<u>Allolobophora chlorotica</u>						
A1	461	22	0.57	35	-	-
A2	467	21	4.6	36	14	6.8
A4	309	26	8.7	26	-	5.0
Means for vegetation type A by earthworm species:						
<u>L. terrestris</u>	3077	15	3.4	48	1.6	18
<u>L. rubellus</u>	1809	16	2.4	57	-	0.34
<u>A. caliginosa</u>	1115	26	2.9	27	7.8	1.2
<u>A. chlorotica</u>	412	23	4.6	35	14	27

TABLE 6 contd...

Vegetation type B

Species/Plot	Zn	Cu	Ni	Cd	Cr	Pb
<u>Lumbricus rubellus</u>						
B1	945	15	2.5	69	-	0.36
B2	1149	22	3.1	64	3.6	0.25
B3	1490	16	0.05	67	-	-
B4	1625	20	-	68	-	-
<u>Allolobophora caliginosa</u>						
B1	789	19	2.85	34	-	4.3
B3	1328	22	-	26	-	-
<u>Allolobophora chlorotica</u>						
B1	477	23	11	53	1.1	8.7
B2	544	32	13	58	30	6.0
B3	381	20	3.0	43	6.5	12
Means for vegetation type B by earthworm species:						
<u>L.rubellus</u>	1302	19	1.9	67	3.6	0.31
<u>A.caliginosa</u>	1059	21	2.9	30	-	4.3
<u>A.chlorotica</u>	467	25	9.1	51	13	8.9

TABLE 6 contd...

Vegetation type C

<u>Species/Plot</u>	<u>Zn</u>	<u>Cu</u>	<u>Ni</u>	<u>Cd</u>	<u>Cr</u>	<u>Pb</u>
<u>Lumbricus rubellus</u>						
C2	1580	13	2.9	73	-	-
C3	1084	9	-	42	-	-
<u>Allolobophora caliginosa</u>						
C1	975	19	0.10	39	-	-
C3	1014	13	3.2	35	-	-
<u>Allolobophora chlorotica</u>						
C2	678	30	6.3	67	5.8	3.6
C3	155	12	2.4	22	-	-
Means for vegetation type C by earthworm species:						
<u>L. terrestris</u>	1565	18	-	48	-	-
<u>L. rubellus</u>	1332	11	2.9	57	-	-
<u>A. caliginosa</u>	995	16	1.6	37	-	-
<u>A. chlorotica</u>	417	28	4.3	44	5.8	3.6

Appendix B GRAND ISLAND REFERENCE SITE.

TABLE 1 MAY 1986

TABLE 1(a) Record of numbers of soil dwelling fauna sampled in pitfall traps, four pooled samples per plot.

PLOT	COL.	ARAN.	CHIL.	DIPL.	ISOP.	OTHERS
Ref 1	61	6	-	1	21	1 Acarina
Ref 2	26	1	-	6	27	1 Acarina/1 Diptera 1 Opiolones/1 Hymenoptera 1 Homoptera/1 Homoptera
Ref 3	14	-	-	5	37	1 Acarina/1 Diptera
Ref 4	11	-	-	4	58	2 Acarina/2 Opiolones 2 Hemiptera/1 Homoptera
Ref 5	12	1	-	4	37	1 Acarina/1 Diptera 2 Hemiptera

TABLE 1(b) Composition of soil dwelling invertebrate fauna sampled by pitfall traps over a ten day period at Grand Island. Total dry matter (g) and percentage dry matter contribution (%), four pooled samples per plot. MAY 1986.

PLOT	PRED. COL.	ARAN.	CHIL.	HERB. COL.	DIPL.	ISOP.	OTHERS
Ref 1 (g)	0.853	0.051	-	0.011	0.024	0.084	0.001
(%)	83.3	5.0	-	1.1	2.3	8.2	0.1
Ref 2 (g)	1.370	0.016	-	0.027	0.031	0.212	0.019
(%)	81.8	1.0	-	1.6	1.9	12.7	1.1
Ref 3 (g)	0.655	-	-	0.013	0.011	0.247	0.001
(%)	70.7	-	-	1.4	1.2	26.6	0.1
Ref 4 (g)	0.871	-	-	0.011	0.040	0.291	0.019
(%)	70.7	-	-	1.0	3.2	23.6	1.5
Ref 5 (g)	0.293	0.003	-	0.005	0.011	0.208	0.013
(%)	55.0	0.6	-	0.9	2.1	39.0	2.4

TABLE 1 contd...

TABLE 1(c) Metal concentrations in major groups of invertebrate fauna collected in pitfall traps at Grand Island. Four pooled samples from each plot. MAY 1986.

Species/Plot	Zn	Cu	Ni	Cd	Cr	Pb
CARNIVOROUS SPECIES						
Predatory COLEOPTERA						
Ref 1	109	17	-	-	-	-
Ref 2	107	17	-	2.2	-	-
Ref 3	109	15	-	1.7	-	-
Ref 4	108	16	-	-	-	-
Ref 5	77	11	-	-	-	-
ARANEIDA						
Ref 1 - 5	238	202	-	13	3.5	-
OPIOLONES						
Ref 1 - 5	311	58	-	7.1	-	-
HERBIVOROUS SPECIES						
Herbivorous COLEOPTERA						
Ref 1	113	38	-	-	9.3	-
Ref 2	96	31	-	-	7.1	-
Ref 3	246	60	-	-	-	-
DETRITIVOROUS SPECIES						
DIPLOPODA						
Ref 1	189	231	-	-	5.3	-
Ref 2 - 5	206	205	17	2.7	12	-
ISOPODA						
Ref 1	240	175	-	4.3	4.5	-
Ref 2	144	123	6.3	3.0	3.7	-
Ref 3	512	179	4.7	3.3	3.5	-
Ref 4	281	152	4.9	3.5	3.1	-
Ref 5	123	138	6.8	2.4	3.5	6.5

TABLE 2 NOVEMBER 1986

TABLE 2(a) Record of numbers of soil dwelling invertebrates sampled in pitfall traps, Grand Island.

PLOT	COL.	ARAN.	OPIO.	CHIL.	DIPL.	ISOP.	ORTH.	Others
Ref 1	5	3	21	-	1	7	1	1 Diptera
Ref 2	11	2	15	-	4	15	-	1 Diptera/1Hymenoptera 1 Lepidoptera L.
Ref 3	8	2	19	1	5	13	-	1 Acarina/2 Mollusca 2 Hymenoptera
Ref 4	10	2	24	-	1	58	-	1 Acarina/1 Mollusca 6 Hymenoptera
Ref 5	2	2	5	-	-	26	1	4 Diptera/2Hymenoptera 7 Mollusca/2 Lumb.

TABLE 2(b) Composition of soil dwelling invertebrate fauna sampled by pitfall trapping over a seven day period at Grand Island. Total dry matter (g) and percentage dry matter contribution (%), four pooled samples per plot. NOVEMBER 1986

PLOT	PRED. COL.	ARAN.	OPIO.	HERB. COL.	CHIL.	DIPL.	ISOP.	OTHERS
Ref 1(g)	0.0926	0.0143	0.1148	-	-	0.0494	0.0242	0.0161
(%)	29.74	4.59	36.87	-	-	15.86	7.77	5.17
Ref 2(g)	0.1402	0.0082	0.0713	-	-	0.0991	0.0872	0.0510
(%)	30.68	1.79	15.60	-	-	21.68	19.08	11.16
Ref 3(g)	0.0686	0.0191	0.1018	0.0356	0.0298	0.0887	0.0265	0.0848
(%)	15.08	4.20	22.38	7.82	6.51	19.50	5.83	18.52
Ref 4(g)	0.1120	0.0053	0.0846	0.0022	-	0.0666	0.2372	0.0423
(%)	20.36	0.96	15.38	0.40	-	12.10	43.11	7.69
Ref 5(g)	0.0312	0.0027	0.0300	-	-	-	0.0883	0.2092
(%)	8.63	0.75	8.30	-	-	-	24.43	57.89

TABLE 2 contd...

TABLE 2(c) Metal concentrations in major groups of invertebrate fauna collected in pitfall traps at Grand Island. Four pooled samples per plot (ug/g, dry weight). NOVEMBER 1986

Species/Plot	Zn	Cu	Mn	Cd	Cr	Pb
CARNIVOROUS SPECIES						
Predatory COLEOPTERA						
Ref 1	59	18	1.4	1.2	29	3.1
Ref 2	52	13	0.84	0.46	6.2	<1.9
Ref 3	71	13	1.9	0.66	5.9	<3.8
Ref 4	69	19	4.1	2.2	1.0	9.0
ARANEIDA						
Ref 1	196	68	<5.3	2.7	10	<18
Ref 2	206	58	18	7.7	18	37
Ref 3	173	57	5.1	2.9	9.8	<14
Ref 4 & 5	199	74	9.2	2.1	31	<32
OPIOLONES						
Ref 1	194	34	4.9	6.9	6.1	5.7
Ref 2	197	30	3.9	5.4	4.2	5.3
Ref 3	170	36	4.0	6.3	2.9	<2.6
Ref 4	246	38	4.4	7.1	4.9	5.7
Ref 5	315	58	4.9	9.4	2.5	14
CHILOPODA						
Ref 3	148	41	3.2	1.5	<0.65	<8.9
HERBIVOROUS SPECIES						
Herbivorous COLEOPTERA						
Ref 1 - 5	86	34	2.6	0.65	2.3	<7.4
DETRITIVOROUS SPECIES						
DIPLOPODA						
Ref 1	142	288	6.7	4.2	8.1	8.5
Ref 2	225	112	4.7	1.9	4.8	7.8
Ref 3	167	75	5.2	2.3	2.6	6.8
Ref 4	106	56	1.8	1.1	0.59	<4.0
ISOPODA						
Ref 1	303	85	17	13	21	27
Ref 2	214	57	6.4	7.8	3.8	7.8
Ref 3	229	41	12	7.0	4.2	16
Ref 4	242	136	11	7.5	5.9	13
Ref 5	107	74	5.5	5.7	2.6	6.6

TABLE 3 NOVEMBER 1986

TABLE 3 Native earthworms.

Composite samples of each species per plot expresses as ug/g. dry weight. All results corrected to eliminate the effect of soil within the earthworm gut.

Species/Plot	Zn	Cu	Ni	Cd	Cr	Pb
<u>Lumbricus terrestris</u>						
Ref 1 & 2	392	2.1	-	5.4	2.2	-
Ref 3	371	2.3	3.7	13	0.29	4.0
Ref 4 & 5	287	2.0	0.15	8.4	0.45	-
<u>Lumbricus rubellus</u>						
Ref 1 & 2	384	6.6	5.0	10	1.5	1.2
Ref 3	467	4.9	2.3	14	4.0	1.7
Ref 4 & 5	438	2.4	0.35	15	2.1	-
<u>Allolobophora caliginosa</u>						
Ref 1 & 2	514	7.5	2.5	33	2.1	2.1
Ref 3	509	4.3	1.1	37	4.2	0.29
Ref 4 & 5	415	4.6	3.4	33	1.3	5.2
<u>Allolobophora chlorotica</u>						
Ref 1 & 2	304	10	5.6	22	2.4	-
Ref 4 & 5	303	5.3	2.1	14	2.6	2.3
Mean metal concentrations for reference site by earthworm species:						
<u>L. terrestris</u>	350	2.1	1.3	8.8	0.99	4.0
<u>L. rubellus</u>	430	4.6	2.5	13	2.5	1.5
<u>A. caliginosa</u>	479	5.5	2.3	34	2.5	2.5
<u>A. chlorotica</u>	304	7.8	3.9	18	2.5	2.3

Appendix C BLACK ROCK HARBOUR CDF.

TABLE 1 MAY 1986

TABLE 1(a) Record of numbers of soil dwelling fauna sampled in pitfall traps.

PLOT	COL.	ARAN.	OTHERS
1	3	6	3 Hymenoptera/3 Diptera
2	3	4	4 Hymenoptera/3 Diptera/1 Hemiptera
3	-	6	2 Hymenoptera/2 Diptera/1 Hemiptera
4	1	3	1 Diptera
5	2	-	1 Hemiptera
6	-	2	1 Hymenoptera/1 Diptera
7	4	1	1 Diptera
8	1	4	2 Hymenoptera/3 Diptera
9	3	2	1 Hymenoptera/2 Diptera
10	3	-	3 Hymenoptera/1 Diptera
11	2	4	1 Hymenoptera/2 Diptera
12	1	1	2 Diptera/1 Hemiptera
13	3	-	1 Hymenoptera/1 Diptera/1 Hemiptera
14	4	-	2 Diptera
15	2	4	3 Diptera
16	2	3	1 Hymenoptera
17	3	2	3 Hymenoptera/1 Diptera
18	1	1	
19	1	4	1 Hymenoptera/2 Diptera/1 Lepidoptera L.
20	3	3	4 Hymenoptera/1 Diptera
21/22	4	9	3 Hymenoptera/3 Diptera/1 Opiolones
31/32	8	2	4 Hymenoptera

TABLE 1(a) contd...

TRANSECT PLOTS:

PLOT	COL.	ARAN.	OTHERS
23	5	4	4 Hymenoptera/4 Diptera/1 Chilopoda/ 1 Jassidae
24	11	1	5 Hymenoptera/8 Diptera/1 Hemiptera/ 2 Coleoptera L./8 Opiolones/1 Acarina
25	4	3	4 Hymenoptera/2 Jassidae/7 Opiolones
26	9	3	22 Hymenoptera/3 Diptera/1 Hemiptera/1 Isopoda 12 Opiolones/2 Chilopoda/1 Acarina
27	1	2	2 Isopoda

TABLE 1(b) Identification of Coleoptera. MAY 1986

PLOT	SUB-ORDER	FAMILY	NUMBER IN POOLED SAMPLE AT EACH PLOT
1	Geodephaga	Carabidae	2
	Rhynchophora	Curculionidae	1
2	Geodephaga	Carabidae	2
	Heteromera	Anthicidae	1
4	Geodephaga	Carabidae	1
5	Rhynchophora	Curculionidae	2
7	Geodephaga	Carabidae	3
	Rhynchophora	Curculionidae	1
8	Geodephaga	Carabidae	1
9	Geodephaga	Carabidae	2
	Heteromera	Anthicidae	1
10	Geodephaga	Carabidae	3
11	Geodephaga	Carabidae	2
12	Rhynchophora	Curculionidae	1
13	Geodephaga	Carabidae	1
	Heteromera	Anthicidae	1
	Rhynchophora	Curculionidae	1
14	Geodephaga	Cicindelidae	1
	Geodephaga	Carabidae	1
	Rhynchophora	Curculionidae	1
	Clavicornia	Atomaria	1
15	Brachelytra	Staphylinidae	1
	Rhynchophora	Curculionidae	1
16	Rhynchophora	Curculionidae	2
17	Geodephaga	Cicindelidae	1
	Geodephaga	Carabidae	1
	Rhynchophora	Curculionidae	1
18	Geodephaga	Carabidae	1
19	Heteromera	Anthicidae	1

Table 1(b) contd...

PLOT	SUB-ORDER	FAMILY	NUMBER IN POOLED SAMPLE AT EACH PLOT
20	Brachelytra	Staphylinidae	2
	Heteromera	Anthicidae	1
21	Geodephaga	Carabidae	1
	Heteromera	Anthicidae	1
22	Rhyncophora	Curculionidae	2
31	Geodephaga	Carabidae	1
	Rhyncophora	Curculionidae	2
	Heteromera	Anthicidae	3
32	Geodephaga	Carabidae	1
	Heteromera	Anthicidae	1
TRANSECT PLOTS:			
23	Geodephaga	Carabidae	3
	Rhyncophora	Curculionidae	1
	Phytophaga	Chrysomelidae	1
24	Geodephaga	Carabidae	6
	Rhyncophora	Curculionidae	2
	Brachelytra	Staphylinidae	1
	Clavicornia	Atomaria	1
25	Rhyncophora	Curculionidae	1
	Brachelytra	Staphylinidae	2
	Clavicornia	Atomaria	1
26	Geodephaga	Carabidae	3
	Brachelytra	Staphylinidae	1
	Clavicornia	Nitidulidae	1
	Phytophaga	Chrysomelidae	2
27	Clavicornia	Nitidulidae	1

TABLE 1(c) Composition of soil dwelling invertebrate fauna sampled by pitfall trapping over a ten day period at Black Rock. Total dry matter (g) and percentage dry matter contribution (%), three samples per plot. MAY 1986.

PLOT	PRED. COL.	ARAM.	HERB. COL.	OTHERS	TOTAL
1 (g)	0.0135	0.0184	0.004	0.0170	0.0529
(%)	25.5	34.8	7.6	32.1	
2 (g)	0.026	0.0153	0.0018	0.0165	0.0596
(%)	43.6	25.7	3.0	27.7	
3 (g)	-	0.0223	-	0.0085	0.0308
(%)		72.4		27.6	
4 (g)	0.0166	0.0091	-	0.0075	0.0332
(%)	50.0	27.4		22.6	
5 (g)	-	-	0.0076	0.0018	0.0094
(%)			80.9	19.1	
6 (g)	-	0.003	-	0.0037	0.0067
(%)		44.8		55.2	
7 (g)	0.0472	0.0045	0.0163	0.0016	0.0696
(%)	67.8	6.5	23.4	2.3	
8 (g)	0.0148	0.0149	-	0.0072	0.0369
(%)	40.1	40.4		19.5	
9 (g)	0.0283	0.0076	0.0006	0.0053	0.0418
(%)	67.7	18.2	1.4	12.7	
10(g)	0.0289	-	-	0.0152	0.0531
(%)	54.4			28.6	
11(g)	0.0308	0.0077	-	0.0045	0.0430
(%)	71.6	17.9		10.5	
12(g)	-	0.0012	0.0039	0.0035	0.0086
(%)		14.0	45.3	40.7	
13(g)	0.0073	-	0.0069	0.0088	0.0230
(%)	31.7		30.0	38.3	
14(g)	0.0248	-	0.0049	0.0014	0.0311
(%)	79.7		15.8	4.5	
15(g)	0.0010	0.0118	0.0027	0.0034	0.0189
(%)	5.3	62.4	14.3	18.0	

TABLE 1(c) Contd...

PLOT	PRED. COL.	ARAM.	HERB. COL.	OTHERS	TOTAL
16(g) (%)	- 32.4	0.0047 32.4	0.0064 44.1	0.0034 23.4	0.0145
17(g) (%)	0.0371 71.3	0.0043 8.3	0.0031 6.0	0.0075 14.4	0.052
18(g) (%)	0.0167 78.0	0.0047 22.0	-	-	0.0214
19(g) (%)	- 68.8	0.0108 68.8	0.0018 11.5	0.0031 19.7	0.0157
20(g) (%)	0.0019 4.3	0.0096 21.8	0.0010 2.3	0.0316 71.7	0.0451
21(g) (%)	0.0217 55.8	0.0101 26.0	0.0004 1.0	0.0067 17.2	0.0389
22(g) (%)	- 60.6	0.0140 60.6	0.0070 30.3	0.0021 9.1	0.0231
31(g) (%)	0.0197 54.1	0.0042 11.5	0.0074 20.3	0.0051 14.0	0.0364
32(g) (%)	0.0069 37.3	0.0025 13.5	0.0007 3.8	0.0084 45.4	0.0185
TRANSECT PLOTS:					
23(g) (%)	0.0179 34.7	0.0070 13.6	0.0039 7.6	0.0228 44.2	0.0516
24(g) (%)	0.0425 34.5	0.0049 4.0	0.0424 34.4	0.0339 27.5	0.1233
25(g) (%)	0.0020 7.6	0.0035 13.4	0.0040 15.3	0.0167 63.7	0.0262
26(g) (%)	0.0536 42.1	0.0105 8.2	0.0039 3.1	0.0594 46.6	0.1274
27(g) (%)	- 61.3	0.0372 61.3	0.0021 3.5	0.0214 35.3	0.0607

TABLE 1(d) Metal concentrations in major groups of invertebrate fauna, three pooled samples per treatment (ug/g. dry weight). MAY 1986

PLOTS	Zn	Cu	Mn	Cd	Cr	Pb
(1) Predatory COLEOPTERA						
2,10,14,16	67	65	(3.3)	1.5	42	(8.2)
1,9,13,17	72	49	(3.9)	(0.72)	30	(9.0)
5,8,11,19	87	52	(2.4)	(0.80)	19	<6.0
4,7,15,18	73	63	(7.5)	(0.78)	21	(8.1)
21,22,31,32	99	91	(4.7)	(1.7)	52	(15)
Transect	94	31	4.9	(0.38)	8.2	(8.2)
(2) ARANEIDA						
2,10,14,16	271	438	(13)	11	29	(<18)
1,9,13,17	186	344	(8.1)	9.2	21	(11)
5,8,11,19	407	435	(13)	16	18	(<9.3)
4,7,15,18	318	356	(11)	12	20	(<10.6)
3,6,12,20	470	427	(92)	17	256	(10.5)
21,22,31,32	328	500	(13)	15	29	(10.8)
Transect	314	297	13	12	13	(12)
(3) Herbivorous COLEOPTERA						
2,10,14,16	256	70	(10)	(1.5)	39	<29
1,9,13,17	168	98	(14)	(1.4)	55	(26)
5,8,11,19	353	117	(15)	(3.0)	52	<43
4,7,15,18	79	52	<1.6	(0.45)	15	<5.5
21,22,31,32	200	85	<5.9	(1.5)	25	<21
Transect	229	117	(17)	(1.9)	18	<19

TABLE 2 NOVEMBER 1986

Table 2(a) Record of numbers of soil dwelling fauna sampled in pitfall traps, three pooled samples per plot.

PLOT	COL. ¹	ARAN.	OTHERS
1	9	3	3 Hymenoptera/3 Diptera 1 Acarina/1 Neuroptera/1 Homoptera/1 Chilopoda
2	10	2	1 Hymenoptera/1 Acarina/4 Homoptera 2 Orthoptera/2 Coleoptera(adults)
3	2	-	1 Diptera/3 Homoptera/3 Orthoptera 1 Dermaptera/1 Neuroptera/1 Odonata
4	1	1	2 Diptera/1 Isopoda
5	1	-	2 Diptera
6	3	2	1 Hymenoptera/1 Acarina 2 Coleoptera(adult)/1 Homoptera/6 Neuroptera
7	1	4	2 Hymenoptera/1 Hemiptera 1 Acarina/1 Coleoptera(adult)
8	1	2	1 Diptera/1 Hemiptera/1 Orthoptera
9	6	5	5 Hymenoptera/3 Diptera/1 Dermaptera 1 Coleoptera L.
10	18	3	1 Diptera/3 Coleoptera L.
11	47	3	1 Hymenoptera/1 Diptera/1 Hemiptera 1 Odonata/1 Orthoptera/2 Coleoptera(adults)
12	5	5	1 Hymenoptera/3 Diptera/1 Hemiptera
13	20	3	2 Hymenoptera/1 Diptera/2 Hemiptera 1 Coleoptera L./1 Lepidoptera L.
14	10	2	1 Hymenoptera/2 Diptera/3 Hemiptera 1 Orthoptera/1 Coleoptera(adult)
15	10	-	1 Hymenoptera/3 Hemiptera/1 Opiolones
16	-	2	1 Diptera
17	18	3	1 Hymenoptera
18	21	-	1 Hymenoptera/1 Diptera/1 Hemiptera 1 Lepidoptera/1 Coccinellidae L./2 Coleoptera
19	28	6	4 Diptera/1 Isopoda/1 Opiolones 1 Coleoptera(adult)
20	9	2	1 Hymenoptera/3 Diptera/1 Hemiptera
21/22	18	3	3 Hymenoptera/2 Diptera/1 Opiolones 8 Hemiptera/1 Coleoptera(adult)
31/32	7	6	2 Diptera/2 Lepidoptera L.

¹ Coleoptera sampled were all carabid larvae.

TABLE 2(a) contd...

PLOT	COL. ^a	ARAW.	OTHERS
23	76	2	1 Hymenoptera/6 Diptera/1 Chilopoda/2 Hemiptera 1 Isopoda/4 Coleoptera(adults)
24	10	1	4 Hymenoptera/4 Hemiptera/3 Opiolones 3 Coleoptera(adult)/5 Diptera
25	6	3	8 Hymenoptera/18 Diptera/8 Hemiptera 1 Orthoptera/2 Isopoda/6 Coleoptera
26	4	4	23 Diptera/1 Isopoda 7 Coleoptera(adults)
27	-	-	9 Diptera/2 Hemiptera/2 Isopoda

^aAll Carabid larvae.

TABLE 2(b) Metal concentrations in major groups of invertebrate fauna, three pooled samples per treatment (ug/g, dry weight). NOVEMBER 1986

PLOTS	Zn	Cu	Mn	Cd	Cr	Pb
(1) Carabid larvae						
2,10,14,16	103	159	16	2.6	54	21
1,9,13,17	131	310	19	2.2	34	13
5,8,11,19	86	187	7.8	1.3	24	9.1
4,7,15,18	156	208	12	3.7	26	16
3,12,20,6	154	196	19	4.2	15	29
21,22,31,32	97	187	6.0	2.3	37	15
Transect	75	134	9.7	1.4	39	18
(2) ARANEIDA						
2,10,14,16	225	556	11	5.7	55	19
1,9,13,17	265	388	11	8.6	29	5.1
5,8,11,19	337	521	6.1	7.9	35	7.1
4,7,15,18	472	425	11	13	36	20
3,6,12,20	361	507	8.6	9.8	35	10
21,22,31,32	295	259	7.7	7.0	31	11
Transect	352	128	12	4.4	7.7	8.1
(3) Predatory COLEOPTERA(adult)						
whole site	131	80	4.3	1.3	34	6.4
Transect	100	32	7.4	1.3	9.7	11

APPENDIX D OTTAWA MINE SPOIL RECLAMATION SITE

TABLE 1 MAY 1986

TABLE 1(a) Record of numbers of soil dwelling invertebrates collected in pitfall traps.

PLOT	COL.	ARAM.	CHIL.	DIPL.	ISOP.	ORTH.	OTHERS
1	19	23	-	11	-	7	7 Diptera/81 Hymenoptera/ 1 Lepidoptera L.
2a	15	11	3	2	3	7	13 Diptera/1 Hemiptera/ 38 Hymenoptera/8 Lepidoptera L. 1 Coleoptera L.
2cd	23	44	-	2	1	1	7 Diptera/11 Hymenoptera 6 Hemiptera/2 Lepidoptera L.
2e	16	17	-	3	-	2	1 Diptera/1 Hemiptera 26 Hymenoptera/1 Neuroptera
3a	19	5	-	2	6	1	11 Diptera/4 Hemiptera 20 Hymenoptera/1 Acarina 10 Lepidoptera L.
3cd	22	48	-	-	13	5	7 Diptera/9 Hemiptera 11 Hymenoptera/6 Lepidoptera L. 11 Oligochaeta
3e	17	20	-	1	3	5	9 Diptera/12 Hymenoptera 3 Lepidoptera L./3 Oligochaeta
4a	20	15	-	4	3	5	8 Diptera/7 Lepidoptera L. 7 Hymenoptera
4cd	30	26	-	2	15	4	7 Diptera/20 Hymenoptera 1 Hemiptera/3 Lepidoptera L.
4e	24	28	1	-	30	4	2 Diptera/2 Hemiptera 9 Hymenoptera/3 Lepidoptera L. 3 Oligochaeta

TABLE 1(b) Identification of Coleoptera. May 1986

PLOT	SUB-ORDER	FAMILY	NUMBER IN POOLED SAMPLE AT EACH PLOT
1	Geodephaga	Carabidae	2
	Rhynchophora	Curculionidae	1
	Brachelytra	Staphylinidae	1
	Sternoxia	Elaeteridae	4
	Phytophaga	Chrysomelidae	1
2a	Geodephaga	Carabidae	1
	Rhynchophora	Curculionidae	1
	Brachelytra	Staphylinidae	2
	Sternoxia	Elaeteridae	3
	Clavicornia	Atomaria	5
	Lamellicornia	Scarabaeidae	1
2cd	Geodephaga	Carabidae	5
	Brachelytra	Staphylinidae	5
	Sternoxia	Elaeteridae	4
	Clavicornia	Atomaria	8
	Clavicornia	Nitidulidae	1
2e	Geodephaga	Carabidae	3
	Rhynchophora	Curculionidae	1
	Brachelytra	Staphylinidae	1
	Phytophaga	Chrysomelidae	1
	Clavicornia	Atomaria	10
	Clavicornia	Nitidulidae	1
3a	Geodephaga	Carabidae	1
	Rhynchophora	Curculionidae	1
	Brachelytra	Staphylinidae	2
	Clavicornia	Atomaria	10
	Clavicornia	Nitidulidae	1
	Heteromera	Anthicidae	1
	Sternoxia	Elaeteridae	1
	Lamellicornia	Scarabaeidae	1
3cd	Geodephaga	Carabidae	3
	Brachelytra	Staphylinidae	4
	Phytophaga	Chrysomelidae	1
	Clavicornia	Atomaria	10
	Clavicornia	Nitidulidae	2
	Sternoxia	Elaeteridae	1

Table 1(b) contd...

PLOT	SUB-ORDER	FAMILY	NUMBER IN POOLED SAMPLE AT EACH PLOT
3e	Brachelytra	Staphylinidae	1
	Clavicornia	Atomaria	5
	Clavicornia	Nitidulidae	2
	Clavicornia	Phalacridae	2
	Sternoxia	Elateridae	6
4a	Brachelytra	Staphylinidae	4
	Clavicornia	Atomaria	6
	Clavicornia	Nitidulidae	4
	Clavicornia	Phalacridae	4
	Sternoxia	Elateridae	2
4cd	Geodephaga	Carabidae	2
	Clavicornia	Atomaria	11
	Clavicornia	Nitidulidae	4
	Sternoxia	Elateridae	9
	Phytophaga	Chrysomelidae	2
4e	Geodephaga	Carabidae	8
	Rhynchophora	Curculionidae	4
	Brachelytra	Staphylinidae	1
	Clavicornia	Nitidulidae	3
	Heteromera	Anthricidae	1
	Sternoxia	Elateridae	3
	Lamellicornia	Scarabaeidae	1
	Phytophaga	Chrysomelidae	3

TABLE 1 contd...

TABLE 1(c) Composition of soil dwelling invertebrate fauna sampled by pitfall traps over a ten day period at Ottawa. Total dry matter (g) and percentage dry matter contribution (%), four pooled samples per plot.
NOVEMBER 1986.

PLOT	PRED. COL.	ARAN.	OPIO.	CHIL.	HERB. COL.	DIPL.	ISOP.	ORTH.	OTHERS
1	(g) 0.1015 (%) 13.5	0.0784 10.4	0.000 -	0.000 -	0.0319 4.2	0.1066 14.2	0.000 -	0.2728 36.3	0.1608 21.4
2a	(g) 0.1350 (%) 23.9	0.0400 7.1	0.000 -	0.0114 2.0	0.006 1.1	0.0162 2.9	0.0164 2.9	0.0483 8.6	0.2913 51.6
2cd	(g) 0.0847 (%) 20.0	0.2100 49.6	0.000 -	0.000 -	0.0146 3.4	0.0232 5.5	0.0067 1.6	0.0380 9.0	0.0466 11.0
2e	(g) 0.0557 (%) 13.5	0.0554 13.4	0.000 -	0.000 -	0.0056 1.4	0.0618 15.0	0.000 -	0.2051 49.8	0.0283 6.9
3a	(g) 0.0380 (%) 6.5	0.017 2.9	0.000 -	0.000 -	0.0138 2.4	0.012 2.1	0.0291 5.0	0.0746 12.8	0.3975 68.3
3cd	(g) 0.0768 (%) 4.1	0.3071 16.4	0.000 -	0.000 -	0.0158 0.80	0.000 -	0.1000 5.4	0.1454 7.8	1.2225 65.5
3e	(g) 0.0014 (%) 0.20	0.1141 14.0	0.000 -	0.000 -	0.0143 1.8	0.0068 0.80	0.0094 1.2	0.2731 33.4	0.3974 48.8
4a	(g) 0.0016 (%) 0.20	0.0313 3.5	0.003 0.30	0.000 -	0.0115 1.3	0.0513 5.7	0.0512 5.6	0.2483 27.4	0.5083 56.13
4cd	(g) 0.0528 (%) 7.4	0.1681 23.6	0.000 -	0.000 -	0.0209 2.9	0.0267 3.7	0.0711 10.0	0.2864 40.2	0.0861 12.1
4e	(g) 0.0958 (%) 15.9	0.1069 17.8	0.000 -	0.0073 1.2	0.0450 7.5	0.000 -	0.1269 21.1	0.2074 34.5	0.0118 2.0

TABLE 1(d) Metal concentrations in major groups of invertebrate fauna, four pooled samples per plot (ug/g, dry weight). MAY 1986

CARNIVOROUS SPECIES

(1) Predatory COLEOPTERA

PLOT	Zn	Cu	Ni	Cd	Cr	Pb
1	78	12	-	1.6	18	3.7
2a	111	13	-	0.85	8.6	4.5
2cd	83	16	-	-	6.0	6.0
2e			Sample lost			
3a	136	16	-	-	23	15
3cd	94	15	-	-	6.9	8.9
3e			Insufficient sample size			
4a			Insufficient sample size			
4cd	72	13	-	-	4.5	6.3
4e	110	29	-	-	5.0	11

(2) ARANEIDA

PLOT	Zn	Cu	Ni	Cd	Cr	Pb
1	244	164	13	5.2	13	(9.1)
2a	305	52	(6.6)	4.4	7.9	(36)
2cd	284	58	(2.6)	5.1	3.3	(10)
2e	326	73	(4.5)	7.4	3.1	(18)
3a	332	95	(5.5)	(5.0)	(5.7)	(41)
3cd	369	106	(3.8)	7.9	4.7	(13)
3e	428	121	(3.2)	9.0	3.7	(13)
4a	267	59	(17.9)	6.3	5.6	(17)
4cd	299	133	(2.3)	5.8	5.0	(15)
4e	327	122	(3.1)	7.5	5.2	(15)

(3) CHILOPODA

PLOT	Zn	Cu	Ni	Cd	Cr	Pb
2a	608	50	(7.8)	(3.1)	11	(37)

TABLE 1(d) contd....

HERBIVOROUS SPECIES

PLOT	Zn	Cu	Ni	Cd	Cr	Pb
(1) Herbivorous COLEOPTERA						
1	97	38	(14)	(1.2)	(2.7)	(15)
2a			Insufficient sample size			
2cd	132	25	(7.0)	(1.5)	(4.4)	(27)
2e			Insufficient sample size			
3a	117	34	(11)	(0.97)	(7.0)	(37)
3cd	133	27	(6.3)	(1.9)	9.9	(30)
3e	211	34	(19)	(1.5)	(9.3)	(28)
4a	179	40	(19)	(1.3)	(7.7)	(56)
4cd	111	25	(14)	(1.0)	9.0	(20)
4e	133	30	(3.0)	(0.83)	4.9	(10)
(2) ORTHOPTERA						
1	124	25	9.0	(0.57)	4.9	(4.3)
2a	188	30	(2.6)	(1.8)	1.9	(14)
2cd	213	26	(2.0)	(2.5)	<0.51	(11)
2e	102	32	(1.0)	0.71	0.61	(2.9)
3a	251	33	(5.7)	1.8	20	63
3cd	146	49	(1.6)	1.8	1.4	(6.2)
3e	264	84	(2.1)	1.8	2.1	(9.2)
4a	146	29	(0.69)	(0.59)	(0.65)	(3.5)
4cd	190	74	(1.3)	0.77	2.2	(7.9)
4e	151	62	(1.6)	(0.64)	1.9	(9.2)
(3) LEPIDOPTERA LARVAE						
1	80	24	8.3	(0.85)	4.6	(7.2)
2a	209	26	(3.2)	2.4	8.6	(12)
2cd	170	37	(2.9)	(3.3)	9.0	(14)
2e			Insufficient sample size			
3a	200	17	(1.5)	1.2	3.2	(11)
3cd	148	30	(1.4)	1.7	3.0	(7.0)
3e	129	22	(1.3)	2.2	2.0	(4.6)
4a	157	32	(2.9)	1.2	3.5	(12)
4cd	125	20	(1.6)	0.28	1.8	89
4e	132	14	(0.79)	(0.66)	0.83	2.2

TABLE 1(d) contd....

DETRITIVOROUS SPECIES

(1) DIPLOPODA

PLOT	Zn	Cu	Ni	Cd	Cr	Pb
1	288	90	8.4	1.0	6.1	(6.5)
2a	456	99	(12)	(1.9)	4.5	(50)
2cd	453	77	(6.5)	(2.9)	2.8	(16)
2e	323	89	(2.9)	(1.2)	3.3	(12)
3a			Insufficient sample size			
3cd			Insufficient sample size			
3e			Insufficient sample size			
4a	339	125	(3.4)	2.0	5.6	(21)
4cd			Insufficient sample size			
4e			Insufficient sample size			

(2) ISOPODA

PLOT	Zn	Cu	Ni	Cd	Cr	Pb
1			Insufficient sample size			
2a	706	306	(6.6)	7.3	7.4	(35)
2cd			Insufficient sample size			
2e			Insufficient sample size			
3a	907	257	(5.7)	7.1	9.8	(35)
3cd	805	241	11	14	10	30
3e			Insufficient sample size			
4a	505	221	(8.7)	5.9	11	(35)
4cd	311	77	(2.0)	5.8	5.0	(24)
4e	257	209	5.0	7.9	11	36

TABLE 2 NOVEMBER 1986

TABLE 2(a) Record of numbers of soil dwelling invertebrates collected in pitfall traps.

PLOT	COL.	ARAN.	CHIL.	DIPL.	ISOP.	ORTH.	OTHERS
1	10	4	-	-	-	11	5 Diptera/20 Hymenoptera 1 Lepidoptera/1 Hemiptera
2a	4	10	-	2	2	4	11 Diptera/2 Hymenoptera 1 Oligochaeta
2cd	5	14	-	13	2	3	6 Diptera/9 Hemiptera 2 Lepidoptera L. 15 Oligochaeta
2e	2	3	-	11	1	2	8 Diptera/1 Hemiptera 2 Hymenoptera/1 Lepidoptera L. 1 Mollusca/4 Oligochaeta
3a	5	7	-	2	1	7	4 Diptera/11 Hemiptera 20 Hymenoptera
3cd	5	3	-	1	4	-	3 Diptera/4 Hemiptera/5 Mollusca 2 Hymenoptera/1 Lepidoptera 8 Oligochaeta
3e	7	8	-	6	1	6	3 Diptera/3 Hymenoptera/3 Mollusca 4 Hemiptera/1 Oligochaeta
4a	1	9	-	2	1	8	8 Diptera/1 Lepidoptera/2 Mollusca 5 Hymenoptera/13 Hemiptera 12 Oligochaeta
4cd	8	13	-	5	7	3	11 Diptera/8 Mollusca 8 Hemiptera/2 Lepidoptera L. 13 Oligochaeta
4e	4	10	-	5	-	1	10 Diptera/16 Hemiptera 5 Hymenoptera/6 Mollusca 19 Oligochaeta

TABLE 2(b) Metal concentrations in major groups of invertebrate fauna, four pooled samples per plot (ug/g, dry weight). NOVEMBER 1986

CARNIVOROUS SPECIES

(1) Predatory COLEOPTERA

PLOT	Zn	Cu	Ni	Cd	Cr	Pb
1	Insufficient sample size					
2a	236	19	<5.4	4.4	6.0	25
2cd	Insufficient sample size					
2e	113	17	1.9	1.1	1.1	11
3a	Insufficient sample size					
3cd	Insufficient sample size					
3e	Insufficient sample size					
4a	Insufficient sample size					
4cd	113	16	<2.6	0.89	6.0	15
4e	Insufficient sample size					

(2) ARANEIDA

PLOT	Zn	Cu	Ni	Cd	Cr	Pb
1	Insufficient sample size					
2a	261	67	4.2	4.3	7.6	10
2cd	344	103	1.4	9.4	2.7	3.5
2e	217	53	<4.6	5.6	11	<16
3a	217	96	<0.89	5.7	3.0	<3.2
3cd	160	35	<2.6	1.4	11	9.6
3e	238	85	<2.9	5.3	10	15
4a	297	168	2.1	8.0	8.4	19
4cd	422	233	4.0	11	4.6	11
4e	209	168	<0.70	6.6	1.8	<2.5

TABLE 2(b) contd....

HERBIVOROUS SPECIES

(2) ORTHOPTERA

PLOT	Zn	Cu	Mn	Cd	Cr	Pb
1	Insufficient sample size					
2a	257	40	0.86	2.9	3.0	8.5
2cd	140	18	2.9	0.83	2.7	<3.5
2e	Insufficient sample size					
3a	219	55	1.3	2.6	13	9.1
3cd	Insufficient sample size					
3e	181	31	3.3	1.9	9.8	25
4a	276	52	2.5	4.1	5.7	16
4cd	152	43	1.1	0.91	1.0	3.4
4e	Insufficient sample size					

TABLE 2(b) contd...

DETRITIVOROUS SPECIES

(1) DIPLOPODA

PLOT	Zn	Cu	Ni	Cd	Cr	Pb
1	Insufficient sample size					
2a	203	61	<1.5	0.78	4.2	<5.3
2cd	239	110	1.1	0.94	2.3	2.3
2e	236	127	0.89	0.69	2.7	4.3
3a	192	111	<0.88	0.48	3.2	<3.1
3cd	304	81	2.4	2.6	5.5	<7.6
3e	245	95	2.8	1.3	3.8	6.7
4a	Insufficient sample size					
4cd	505	141	7.0	4.4	12	16
4e	460	89	1.7	3.2	3.6	<5.8

(2) ISOPODA

PLOT	Zn	Cu	Ni	Cd	Cr	Pb
1	Insufficient sample size					
2a	382	187	<7.9	4.6	20	<28
2cd	Insufficient sample size					
2e	Insufficient sample size					
3a	Insufficient sample size					
3cd	419	130	<1.6	3.4	7.5	10
3e	Insufficient sample size					
4a	Insufficient sample size					
4cd	409	173	2.0	4.9	9.3	18
4e	552	151	3.5	7.5	7.9	18

TABLE 3 Native earthworms MAY/NOVEMBER 1986

Metal concentrations were not corrected for the presence of soil within the earthworm gut.

Native earthworms collected in the pitfall traps at Ottawa MAY 1986

PLOT	Zn	Cu	Ni	Cd	Cr	Pb
3cd	1,811	122	22	40	49	146
3e	1,710	70	9.3	38	15	50
4e	694	72	16	10	52	173

Native earthworms collected in the pitfall traps at Ottawa NOVEMBER 1986

PLOT	Zn	Cu	Ni	Cd	Cr	Pb
2cd	359	47	5.6	5.5	20	58
2e	466	50	7.1	4.8	23	66
4a	879	54	12	12	44	145
4cd	969	64	14	11	41	131
4e	794	50	14	9.6	50	157

APPENDIX E:

Comparison of Metal Concentrations Within the Same Species and Between Different Genus of the Same Order.

Within an ecosystem some organisms accumulate metals to a greater extent than others and are referred to as target organisms (Martin and Coughtrey, 1982). Target organisms have a potential role for indicating the bioavailability of contaminants in the ecosystem. However, variation in metal concentrations between individuals of the same species and between different genus of the same Order influences their value as bioindicators. In order to assess this variation, two more detailed studies were carried out at Times Beach CDF: the first to assess variation in metal concentrations measured in individuals of the same species (the earthworms Lumbricus rubellus), and the second to compare metal concentrations between different genera of the same taxonomic Order (four genera of woodlice: Order Isopoda).

Intra-specific variation.

Variations in metal concentrations between individual earthworms of the same species were assessed by comparing L. rubellus collected from two different vegetation zones (A and B) as defined by Wilhelm in 1985 (Stafford et al., 1987). Earthworms were collected using the formaldehyde vermifuge and held at 100% humidity for 48 hours for evacuation of soil in the gut before analysis. Ten earthworms were collected from a plot in zone A and six from a plot in zone B. Dried, whole, individual earthworms were weighed and metal concentrations measured (Stafford et al., 1987). Oven dry body weights and heavy metal concentrations of individual earthworms from each sampling plot were recorded (Table 1a). Means and standard deviations of the means for each element are also given.

Increase in concentrations of certain elements in earthworms has been associated with increase in the period of exposure to those elements e.g. Cd (Wade et al. 1982) and Cu, when present at high concentrations (Curry and Cotton, 1980). If increasing age were taken as indicative of increase in the period of exposure; adult, clitellate earthworms may be expected to have higher concentrations compared to immature (non-clitellate) specimens and assuming that body weight increases with age, some correlation between body weight and age may also be expected. Clitellate specimens did not have consistently higher heavy metal concentrations compared to non-clitellate specimens (Table 1a) and in most cases there was a poor correlation between body weight and heavy metal concentration (Table 1b).

Concentrations of the elements Fe, Al and/or Ti have been used in plant and animal studies of metal uptake to indicate whether or not soil is present in the samples (McGrath et al. 1982, Cherney and Robinson 1983, Cherney et al. 1983). High concentrations of these elements are known to be present in soils but not in plant and animal tissues. Results in Table 1a indicate that higher concentrations of these elements were observed in earthworms which also contained higher levels of the elements Cu, Cr, Ni and Pb, while lower levels of Fe, Al and Ti were measured in specimens containing lower levels of Cu, Cr, Ni and Pb. Conversely, Cd, which is known to accumulate within the earthworm tissue to levels exceeding those of the surrounding soil (see review by Beyer 1981) was measured in lowest concentrations in earthworms which had greatest concentrations of Fe, Al and Ti and vice versa (Table 1a). This pattern may be an indication that dredged material was present in the samples as a result of incomplete clearance of the gut by some of the earthworms. Correlation coefficients calculated between

earthworm Fe, Al and Ti concentrations and heavy metal concentrations (Table 1b) indicated a close relationship between these elements and heavy metal concentrations. For all elements except Zn, high correlation coefficients were recorded between worm metal concentrations and concentrations of Ti, Fe and Al. These results suggest that the variation in metal concentrations between individual earthworms of the same species could be attributed to the presence of soil within the earthworm's gut. Correction to eliminate the effect of soil in the gut, using the method of Stafford and McGrath (1986) is likely to reduce this variation between individuals. It would be necessary to have information on the metal concentrations of the substrate/litter ingested by the earthworms to provide further evidence that the variations in metal concentrations measured in earthworms in this study were associated with substrate remaining within the earthworm gut.

Table 1a
Variation in Metal Concentration Between Individual *L. rubellus*.

		Oven dry										
Sample		body wt.	Ca	Ti	Fe	Al	Zn	Cu	Ni	Cd	Cr	Pb
A 1*	121.2	8159	33	7452	2121	1772	31	5.5	18	17	39	
A 2*	112.5	3887	6.7	1295	239	1559	14	0.76	61	4.5	9.8	
A 3*	104.1	3855	7.0	1245	326	1372	18	1.6	75	4.5	12	
A 4	102.3	5527	22	6725	1454	1789	24	5.4	69	19	33	
A 5	96.4	7136	20	5184	1199	1675	24	4.3	76	13	26	
A 6	84.4	4548	8.6	1683	304	1667	17	2.0	60	16	13	
A 7	127.9	5768	17	4347	972	1365	22	3.5	35	11	27	
A 8	69.3	5874	13	2337	397	1727	18	1.5	59	6.1	14	
A 9	96.6	6148	28	7587	1689	1379	25	3.4	26	15	38	
A 10	87.9	6041	28	7469	1209	1392	25	7.8	31	17	30	
Mean	100.3	5694	18	4532	991	1570	22	3.6	51	12	24	
sd	17.3	1354	10	2707	658	177	5.0	2.2	21	5.5	11	
B 1	72.1	5227	11	1446	396	1361	19	1.0	69	7.4	11	
B 2	133.5	4964	30	5439	1339	1499	37	4.2	43	12	20	
B 3	79.6	4916	19	2760	734	1486	21	2.1	80	8.1	18	
B 4	77.5	7637	17	2390	623	2265	21	1.6	102	8.9	23	
B 5	96.0	4582	11	1923	488	2629	21	1.6	159	5.2	18	
B 6	87.9	4089	16	1776	338	1995	17	1.3	75	4.1	11	
Mean	91.1	5236	17	2622	653	1873	23	2.0	88	7.6	17	
sd	22.4	1240	7.0	1456	366	508	7.2	1.2	40	2.8	4.9	

Oven dry body weight measured in mg.

* clitellate earthworms.

All metal concentrations expressed in ug/g, dry weight.

A and B indicate the zones from which earthworms were collected.

sd = standard deviation of the mean.

Table 1b
Correlation Coefficients for the Linear Relationship Between Body Weight
of *L. rubellus* and Heavy Metal Concentration and Between Ti, Fe and Al
Concentrations¹ and Heavy Metal Concentrations in the Earthworms.

Variable	Element					
	Zn	Cu	Ni	Cd	Cr	Pb
Zone A						
Ti	-0.367	0.865	0.941	-0.618	0.760	0.474
Fe	-0.332	0.965	0.995	-0.507	0.830	0.538
Al	-0.356	0.961	0.981	-0.475	0.886	0.597
Oven dry body wt.	-0.064	0.913	0.904	-0.278	0.522	0.331
Zone B						
Ti	0.076	0.947	0.832	-0.717	0.744	0.961
Fe	0.031	0.904	0.865	-0.631	0.790	0.971
Al	0.155	0.961	0.742	-0.632	0.739	0.978
Oven dry body wt.	-0.207	0.290	0.106	-0.307	0.020	0.322

¹ Used as an indication of the presence of soil in the sample.

Inter-generic variation

Variation in metal concentrations between genera of the same taxonomic order was assessed using woodlice (Isopoda) collected in pitfall traps in fall 1985. Four genera were identified: Oniscidae *Oniscus*; Porcellionidae *Porcellio*; Trichoniscidae *Trichoniscus* and Armadillidiidae *Armadillidium*. For each genus the number of individuals was recorded, their oven dry weight (mg) measured and the relative numbers and weight of each genus (expressed as a percentage of the total) calculated (Table 2a).

Table 2a
Numbers and Weights of Isopoda Collected in the Pitfall Traps.

Plot	Genus	Number	(Rel. %)	Weight	(Rel. %)
A1	<u>O. Oniscus</u>	44	(22.45)	0.580	(43.19)
	<u>P. Porcellio</u>	98	(50.00)	0.674	(50.19)
	<u>T. Trichoniscus</u>	48	(24.49)	0.031	(2.31)
	<u>A. Armadillidium</u>	6	(3.06)	0.058	(4.32)
A2	<u>O. Oniscus</u>	17	(14.41)	0.249	(28.52)
	<u>P. Porcellio</u>	72	(61.02)	0.561	(64.26)
	<u>T. Trichoniscus</u>	16	(13.56)	0.026	(2.98)
	<u>A. Armadillidium</u>	13	(11.01)	0.037	(4.24)
A3	<u>O. Oniscus</u>	3	(2.94)	0.092	(13.65)
	<u>P. Porcellio</u>	67	(65.59)	0.453	(67.21)
	<u>T. Trichoniscus</u>	6	(5.88)	0.003	(0.45)
	<u>A. Armadillidium</u>	26	(25.49)	0.126	(18.69)
A4	<u>O. Oniscus</u>	10	(8.21)	0.130	(18.44)
	<u>P. Porcellio</u>	74	(45.96)	0.491	(69.65)
	<u>T. Trichoniscus</u>	65	(40.37)	0.029	(4.11)
	<u>A. Armadillidium</u>	12	(7.45)	0.055	(7.80)

Table 2a(contd.)
Numbers and Weights of Isopoda Collected in the Pitfall Traps.

Plot	Genus	Number	(Rel.%)	Weight	(Rel.%)
B1	<u>O. Oniscus</u>	3	(1.15)	0.077	(17.46)
	<u>P. Porcellio</u>	46	(17.62)	0.276	(62.58)
	<u>T. Trichoniscus</u>	211	(80.84)	0.076	(17.23)
	<u>A. Armadillidium</u>	1	(0.38)	0.012	(2.72)
B2	<u>O. Oniscus</u>	3	(2.48)	0.041	(11.92)
	<u>P. Porcellio</u>	36	(29.75)	0.267	(77.62)
	<u>T. Trichoniscus</u>	81	(66.94)	0.026	(7.56)
	<u>A. Armadillidium</u>	1	(0.83)	0.010	(2.91)
B3	<u>O. Oniscus</u>	1	(0.47)	0.107	(24.04)
	<u>P. Porcellio</u>	40	(18.96)	0.261	(58.65)
	<u>T. Trichoniscus</u>	169	(80.09)	0.067	(15.06)
	<u>A. Armadillidium</u>	1	(0.47)	0.010	(2.25)
B4	<u>O. Oniscus</u>	11	(10.48)	0.147	(40.50)
	<u>P. Porcellio</u>	36	(34.29)	0.198	(54.55)
	<u>T. Trichoniscus</u>	57	(54.29)	0.012	(3.31)
	<u>A. Armadillidium</u>	1	(0.95)	0.006	(1.65)
B5	<u>O. Oniscus</u>	2	(3.70)	0.034	(19.10)
	<u>P. Porcellio</u>	23	(42.59)	0.139	(78.09)
	<u>T. Trichoniscus</u>	29	(53.70)	0.005	(2.81)
	<u>A. Armadillidium</u>	0		0	
C1	<u>O. Oniscus</u>	1	(0.55)	0.033	(6.92)
	<u>P. Porcellio</u>	40	(22.10)	0.348	(72.96)
	<u>T. Trichoniscus</u>	140	(77.35)	0.096	(20.13)
	<u>A. Armadillidium</u>	0		0	
C2	<u>O. Oniscus</u>	15	(6.20)	0.208	(26.94)
	<u>P. Porcellio</u>	80	(33.06)	0.515	(66.71)
	<u>T. Trichoniscus</u>	147	(60.74)	0.049	(6.35)
	<u>A. Armadillidium</u>	0		0	
C3	<u>O. Oniscus</u>	1	(0.33)	0.027	(5.73)
	<u>P. Porcellio</u>	25	(8.31)	0.342	(72.61)
	<u>T. Trichoniscus</u>	274	(91.03)	0.090	(19.11)
	<u>A. Armadillidium</u>	1	(0.33)	0.012	(2.55)
C4	<u>O. Oniscus</u>	0		0	
	<u>P. Porcellio</u>	27	(19.01)	0.264	(79.52)
	<u>T. Trichoniscus</u>	115	(80.99)	0.068	(20.48)
	<u>A. Armadillidium</u>	0		0	

Where sufficient biomass was available, each genus from each plot was analysed (Stafford et al., 1987) and the metal concentrations, in ug/g, dry weight, are given in Table 2b.

Table 2b
Inter-Genetic Differences in Metal Concentrations Between Isopoda
Collected in Pitfall Traps.
Mean concentrations for four traps per plot in ug/g, dry weight.

Plot	Genus	Element					
		Zn	Cu	Ni	Cd	Cr	Pb
A1	<u>Oniscus</u>	133	258	2.4	38	4.9	23
	<u>Porcellio</u>	394	405	2.4	12	7.0	14
	<u>Trichoniscus</u>	258	144	3.5	62	21	22
	<u>Armadillidium</u>	278	307	2.0	4.5	9.4	12
A2	<u>Oniscus</u>	134	252	3.6	46	14	21
	<u>Porcellio</u>	367	331	3.7	11	11	19
	<u>Trichoniscus</u>	126	62	6.6	26	65	12
	<u>Armadillidium</u>	322	431	4.7	6.9	24	20
A3	<u>Oniscus</u>	100	174	1.8	41	9.9	31
	<u>Porcellio</u>	441	300	2.4	11	6.8	12
	<u>Armadillidium</u>	330	316	2.9	5.7	10	15
A4	<u>Oniscus</u>	139	227	1.6	52	10	16
	<u>Porcellio</u>	407	342	2.7	15	8.0	14
	<u>Trichoniscus</u>	371	166	10	79	44	52
	<u>Armadillidium</u>	315	427	2.7	7.2	12	15
B1	<u>Oniscus</u>	154	102	2.3	22	13	11
	<u>Porcellio</u>	395	313	2.8	13	7.5	14
	<u>Trichoniscus</u>	676	107	11	63	45	57
B2	<u>Oniscus</u>	97	143	2.0	28	16	12
	<u>Porcellio</u>	315	212	2.7	13	6.8	12
	<u>Trichoniscus</u>	348	145	12	98	50	60
B3	<u>Oniscus</u>	99	165	2.7	30	6.2	28
	<u>Porcellio</u>	343	242	2.8	12	4.8	12
	<u>Trichoniscus</u>	342	102	7.7	79	29	40
B4	<u>Oniscus</u>	117	211	1.6	45	8.8	12
	<u>Porcellio</u>	422	302	2.4	17	13	12
B5	<u>Oniscus</u>	143	122	14	46	9.9	11
	<u>Porcellio</u>	394	246	2.1	13	5.5	12

Table 2b(contd.)
Inter-Generic Differences in Metal Concentrations Between Isopoda
Collected in Pitfall Traps.

Plot	Genus	Element					
		Zn	Cu	Ni	Cd	Cr	Pb
C1	<u>Oniscus</u>	120	169	<2.8	40	22	<9.6
	<u>Porcellio</u>	303	240	1.9	9.7	4.2	8.5
	<u>Trichoniscus</u>	189	85	3.3	47	11	16
C2	<u>Oniscus</u>	133	169	1.7	33	5.3	11
	<u>Porcellio</u>	397	312	2.5	12	5.9	11
	<u>Trichoniscus</u>	273	120	3.8	62	24	21
C3	<u>Oniscus</u>	158	185	<2.7	37	23	15
	<u>Porcellio</u>	313	249	3.1	9.9	9.2	16
	<u>Trichoniscus</u>	225	92	6.3	59	25	35
C4	<u>Porcellio</u>	285	151	1.4	10	5.3	7.9
	<u>Trichoniscus</u>	229	76	2.4	70	13	13

All concentrations expressed as ug/g, dry weight.

Differences in metal concentrations between genera of Isopoda were clearly evident from Table 2b. Mean metal concentrations for each taxonomic group were compared statistically in Table 2c.

Table 2c
Comparisons Between Metal Concentrations of Isopoda of Different Genera
Mean values expressed as ug/g, dry weight.

Vegetation zone	Species	Element					
		Zn	Cu	Ni	Cd	Cr	Pb
Zone A	<u>Armadillidium</u>	311 ^{b*}	370 ^{a*}	3.1 ^b	6.1 ^{c*}	14 ^b	16 ^{a*}
	<u>Oniscus</u>	127 ^{a*}	228 ^{b*}	2.4 ^b	44 ^{a*}	20 ^b	23 ^{a*}
	<u>Porcellio</u>	402 ^{a*}	345 ^{a*}	2.8 ^b	12 ^{b*}	8.2 ^b	15 ^{a*}
	<u>Trichoniscus</u>	252 ^{b*c*}	124 ^{b*}	6.7 ^a	56 ^{a*}	43 ^a	29 ^{a*}
Zone B	<u>Armadillidium</u>	s	s	s	s	s	s
	<u>Oniscus</u>	122 ^b	149 ^b	4.5 ^b	33 ^b	11 ^b	15 ^b
	<u>Porcellio</u>	374 ^a	263 ^a	2.6 ^b	14 ^c	7.5 ^b	12 ^b
	<u>Trichoniscus</u>	455 ^a	118 ^b	10 ^a	76 ^a	41 ^a	52 ^a
Zone C	<u>Armadillidium</u>	s	s	s	s	s	s
	<u>Oniscus</u>	137 ^a	169 ^b	1.5 ^b	37 ^b	17 ^{a*}	12 ^{a*}
	<u>Porcellio</u>	325 ^a	267 ^a	2.2 ^{a*}	10 ^c	6 ^b	11 ^b
	<u>Trichoniscus</u>	229 ^b	93 ^c	4.0 ^a	60 ^a	18 ^a	21 ^a

a,b,c - means values in a column within each zone followed by the same letter are not significantly different at p < 0.05.

* = Non-parametric statistical comparison of the means was employed.

s = insufficient sample size for analysis.

In terms of absolute metal concentrations, highest concentrations of Cd were present in the Trichoniscus followed by the Oniscus, and both of these groups had higher concentrations compared with the Porcellio and the Armadillidium. Conversely, Cu concentrations were highest in Porcellio and Armadillidium compared with Oniscus and Trichoniscus. The Trichoniscus generally contained higher concentrations of Ni, Cr and Pb compared with the other three genera, and the Oniscus generally contained lower concentrations of Zn compared with the other genera. However, when the contribution of each genus to the total biomass of Isopoda collected in the pitfall trap is also taken into consideration, a different picture emerges (Table 2a). The Trichoniscus, usually the most abundant genus in the traps, had the smallest weight per individual and their contribution to the total biomass was also generally small. Conversely the Oniscus, while present in small numbers, had a greater weight per individual and made up a greater proportion of the total biomass of Isopoda collected in the traps (Table 2a).

Thus, both metal concentration as well as relative biomass are factors which must be taken into consideration when metal concentrations of taxonomic groups are used as target organisms to indicate the nature and degree of contaminant mobility at a contaminated dredged material disposal facility.

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