05-320

Environment Canada / Environnement Canada

Canada

The Application of Beast Sediment Quality Guiddlines To Peninsula Harbour, Lake Superior, an area of Concern

BY:
D. Milani and L.C. Grapentine

NWRI Contribution No: 05-320

ONAL WATER
RCH INSTITUTE
UT NATIONAL DE
CHE SUR LES EAUX

THE APPLICATION OF BEAST SEDIMENT QUALITY GUIDLEINES TO PENINSULA HARBOUR, LAKE SUPERIOR, AN AREA OF CONCERN

D. Milani and L.C. Grapentine

NWRI Cont. # 05-320

Environment Canada
National Water Research Institute
867 Lakeshore Road, P.O. Box 5050
Burlington, Ontario L7R 4A6

SUMMARY

This report describes sediment quality in Peninsula Harbour, located on the northeastern shore of Lake Superior, and identified as an Area of Concern (AOC) due primarily to sediment mercury contamination. The benthic assessment of sediment (BEAST) methodology was applied to 33 sites in the Harbour, with emphasis placed on Jellicoe Cove (21 sites), an area containing the highest concentrations of mercury due to past discharges into the Cove.

The BEAST methodology involves the assessment of sediment quality based on multivariate techniques using data on benthic community structure, the functional responses of laboratory organisms in toxicity tests, and the physical and chemical attributes of the sediment and overlying water. Data from test sites were compared to biological criteria developed for the Laurentian Great Lakes.

The highest sediment mercury concentrations are found in Jellicoe Cove, with 13 of the 21 sites exceeding the provincial sediment Severe Effect Level. Total mercury concentrations in the surficial sediment range from 0.04 to 19.50 µg/g, and methyl mercury concentrations (measured in Jellicoe Cove sediments only) range from 0 to 22.6 ng/g. Generally, benthic communities in Jellicoe Cove are different than reference with enrichment evident, likely due to the high organic matter present in the Cove. Benthic communities in the remaining parts of the harbour are more similar to reference. Severe toxicity, mainly to the amphipod *Hyalella azteca*, is evident at four sites; however, toxicity does not appear related to sediment mercury.

A study examining mercury bioaccumulation in resident biota and the potential risk of adverse effects to higher trophic level organisms due to biomagnification is recommended, specifically in Jellicoe Cove, the area of highest sediment mercury contamination.

Résumé

Le présent rapport décrit la qualité des sédiments dans le havre Peninsula (lac Supérieur), qui est un « secteur préoccupant » en raison principalement de la contamination des sédiments par le

mercure. La méthode d'évaluation des sédiments benthiques (BEAST) a été appliquée à 33 sites, et plus spécifiquement à l'anse Jellicoe (21 sites); il s'agit d'un secteur où ont été enregistrés les taux de mercure les plus élevés en raison des rejets industriels qui se faisaient directement dans l'anse. La méthode BEAST comprend l'évaluation de la qualité des sédiments fondée sur une technique multidimensionnelle faisant appel à des données sur la structure de la communauté benthique, aux réponses fonctionnelles des organismes de laboratoire, aux tests de toxicité, et aux attributs physiques et chimiques des sédiments et de la couche d'eau susjacente. Les données provenant des sites à l'étude ont été comparées aux critères biologiques élaborés pour les Grands Lacs laurentiens.

Les concentrations les plus élevées de mercure dans les sédiments sont relevées dans l'anse Jellicoe où, dans 13 des 21 sites, la concentration dépasse les lignes directrices provinciales sur le seuil d'effet grave dans les sédiments. Les concentrations de mercure total dans les sédiments de surface varient de 0,04 à 19,50 µg/g; les concentrations de méthylmercure (mesurées dans l'anse Jellicoe uniquement) varient de 0 à 22,6 ng/g. En général, les communautés benthiques de l'anse Jellicoe sont différentes des communautés de référence avec évidence d'enrichissement, probablement dû à la grande quantité de matière organique présente dans l'anse. Les communautés benthiques présentes dans les autres parties du havre ressemblent davantage aux communautés de référence. Une toxicité grave, surtout pour l'amphipode *Hyalella azteca*, est évidente à quatre sites; toutefois, les concentrations de mercure à ces sites sont assez faibles (plage : 0,04 à 0,37 µg/g), ce qui porte à croire que le mercure n'est pas l'agent responsable.

Comme les sédiments de l'anse Jellicoe contiennent des taux élevés de mercure, un toxique bioamplifiable rémanent, il est recommandé d'établir la bioaccumulation chez le benthos résident dans l'anse et le risque potentiel de contamination des organismes des niveaux supérieurs de la chaîne trophique (c'est-à-dire les consommateurs d'invertébrés benthiques et leurs prédateurs) par bioamplification.

ACKNOWLEDGEMENTS

The authors wish to thank R. Santiago for design input and assistance in site selection, and A. Mudroch for survey design and assistance in the field. We also wish to acknowledge the technical support of C. Logan, S. Thompson, P. Mudroch, J. Dow, J. Webber, E. James, R. Baldwin, and T. Pascoe.

Funding for this project was provided by the Great Lakes Basin 2020 Action Plan. Funds for methyl mercury analysis were provided by the Environmental Protection Branch, Environment Canada – Ontario Region.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

APPENDICES

1 INTRODUCTION

1.1 Objectives for GL2020 Sediment Assessment Study

The GL2020 Sediment Assessment Study was a five-year programme that commenced in 2000. The primary objective of the programme was to provide an overall assessment of sediment contamination in Canadian Areas of Concern (AOC), based on biological sediment guidelines according to BEAST methodology (Reynoldson et al. 1995, 2000). The assessment process utilizes organisms present in the sediment (benthic invertebrates) as these animals are the most exposed and potentially most sensitive to contaminants associated with sediment. Decision on the spatial extent and severity of contamination is based on the type and number of species present, and the response (survival, growth and reproduction) of invertebrates in standard laboratory tests. As a result, study maps are generated for the AOC that define the areas where biological effects are observed and relates any observed responses to specific contaminants.

1.2 Peninsula Harbour Area of Concern

Peninsula Harbour was identified as an Area of Concern (AOC) by the International Joint Commission in 1985, due primarily to the elevated levels of mercury present in the sediments. Mercury contamination was caused by the historical use of mercury in the production of chlorine and caustic soda by a former chlor-alkali plant (closed 1977). The Peninsula AOC has been the subject of two major RAP reports – Stage 1: Environmental Conditions and Problem Definition (Peninsula Harbour RAP Team 1991) and Stage 2: Remedial Strategies for Ecosystem Restoration (Peninsula Harbour RAP Team 1998). The environmental issues of concern identified for Peninsula Harbour in these reports are:

- Mercury contamination,
- PCB contamination,
- Presence of other contaminants (trace metals, oil and grease),
- Bacterial contamination,
- Aesthetic impairment,
- Habitat destruction and degradation (due to accumulation of wood fibres and bark),
- Exotic species (sea lamprey), and

- Fish health problems related to contaminants.

Of the known "beneficial use impairments" associated with the AOC, all are associated with sediment contamination, and include: degradation of benthos, restrictions on fish consumption, degradation of fish populations, restrictions on dredging activities, and loss of fish habitat (Peninsula Harbour RAP Team 1991, 1998). The loss of fish habitat resulted from the accumulation of wood fibre and bark from the paper mill operations.

In October 2000, the National Water Research Institute (NWRI) of Environment Canada undertook a sampling program in Peninsula Harbour to define the general status of contamination in the Harbour as well as to delineate the extent of contamination in Jellicoe Cove, which is adjacent to the bleached kraft pulp mill (Marathon Pulp Inc.), and the former chlor-alkali plant. Thirty-three stations were sampled with emphasis (21 sites) placed on Jellicoe Cove. This report presents the results of these investigations and provides a spatial description of the state of the sediments in Peninsula Harbour along with the degree of contamination.

2 METHODS

2.1 Sample Collection

Sediment was collected from 33 sites in Peninsula Harbour October 1 – 2, 2000. Site co-ordinates are provided in Table 1 and site locations are shown in Figure 1. Of the 33 sites, 21 were located in Jellicoe Cove. Nineteen of the 21 Jellicoe Cove sites were taken from a sampling grid superimposed on the area by BEAK International Inc. in their 2000 survey (Burt and Fitchko 2001). (The initial grid consisted of 64 stations, located 80 m apart.) The remaining two stations were previously sampled by Environment Canada in the fall of 1990 and 1999. Site location was established in the field using a Magnavox MX300 differential Global Positioning System.

Table 1. Station co-ordinates (UTM Nad 83) and site depth.

Site	Depth	Northing	Easting
Jellicoe Cove			
A1	12.7	5397329.6	544420.5
A2	18.9	5397248.4	544352.7
A5	25.1	5397101.8	544178.6
B5	20.3	5396989.5	544243.0
C3	15.8	5397077.7	544438.2
C6	13.3	5396864.6	544239.5
D1	13.3	5397125.5	544636.2
D4	13.9	5396936.6	544417.0
D5	15.0	5396935.4	544366.0
E3	12.5	5396951.8	544556.3
E5	12.3	5396827.8	544436.5
F2	8.8	5396945.3	544668.7
F4	10.0	5396813.7	544533.2
G3	9.1	5396824.5	544677.5
G5	6.7	5396685.3	544552.4
G6	5.1	5396639.2	544487.9
H3	6.5	5396762.3	544734.2
H5	4.5	5396639.2	544607.6
I5	2.3	5396575.6	544688.2
57	1.3	5396507.5	544744.2
58	17.0	5396936.5	544310.5
Outside Jellicoe Cove			
59	70.5	5396137.6	542399.9
60	26.0	5397852.0	542605.2
61	83.6	5399336.8	540173.2
62	43.1	5397343.1	543357.8
64	77.2	5395565.6	542280.7
65	95.2	5394937.0	541307.7
66	72.7	5395830.3	541450.4
67	61.6	5396554.8	542720.7
68	38.6	5397392.2	542672.0
70	33.0	5397104.6	543874.2
71	4.0	5399460.7	543891.4
289	21.5	5399162.2	542806.6

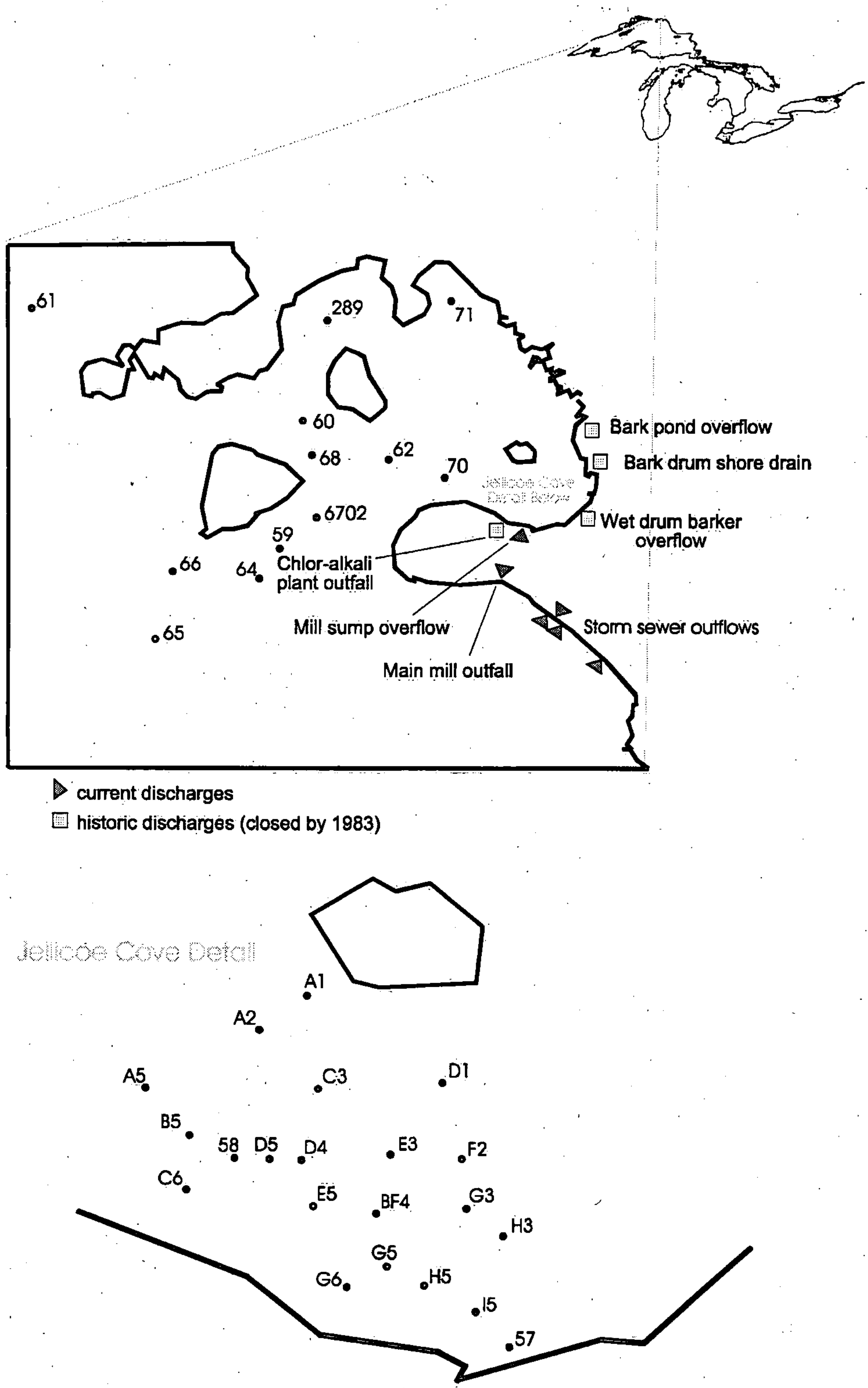

Figure 1. Location of sites in Peninsula Harbour study area.

At each site, samples were collected for chemical and physical analysis of sediment and overlying water, benthic community structure, and laboratory sediment toxicity tests. Environmental variables measured are shown in Table 2. Sampling techniques and methods for sample collection are described in Reynoldson et al. (1995, 1998a).

Table 2. Environmental variables measured at each site.

Field	Water	Sediment
Northing	Alkalinity	Trace metals and major oxides
Easting	Conductivity (on site)	Total Mercury
Site Depth	Dissolved Oxygen (on site)	Methyl Mercury (Jellicoe Cove sites only)
	pH (on site)	Total phosphorus, Total Nitrogen
	Temperature (on site)	Total Organic Carbon, Loss on Ignition
	Total Kjeldahl Nitrogen	Percents Clay, Silt, Sand and Gravel
	Total Phosphorus	
	Nitrates/Nitrites	

Prior to sediment collections, overlying water samples were obtained using a van Dorn sampler, from 0.5 meter from the bottom. Temperature, conductivity, pH and dissolved oxygen were measured using Hydrolab apparatus. Samples for alkalinity, total phosphorus, total nitrogen, and nitrates/nitrites were dispensed to appropriate containers and stored at 4°C for later analysis.

Where possible, a mini-box corer (40 cm × 40 cm) was used to obtain sediment for the benthic community and sediment chemistry analyses. At each site, five benthic community samples were extracted from the box corer using 10 cm (6.5 cm diameter) Plexiglas tubes. Samples were sieved through a 250-μm mesh screen and the residue preserved with 5% formalin for later identification. The remaining top 10-cm of sediment from each box core was removed, homogenized in a Pyrex dish, and allocated to containers for chemical and physical analyses of sediment. At 14 sites, a mini box core could not be used because of the high proportion of sand or compact clay, which prevented the mini-box core from sealing. At these sites, three Ponars were collected for benthic community structure, and one Ponar for chemical and physical properties of the sediment. Each community structure Ponar was sieved in its entirety and the residue preserved as described above.

A mini-Ponar sampler was used to obtain the sediment for toxicity tests (five replicates/grabs per site). Each sediment grab was placed in a plastic bag, sealed and stored in buckets at 4°C.

2.2 Taxonomic Identification

Benthic community samples were transferred to 70% ethanol after a minimum of 72 hours in formalin. Invertebrates were sorted and identified to the lowest practical level. Slide mounts were made for Chironomidae and Oligochaeta and identified to Genus/Species using high power microscopy.

2.3 Sediment Toxicity Tests

Toxicity tests were performed in the Ecotoxicology Laboratory at NWRI (Burlington, ON). Water used in toxicity tests was the City of Burlington tap water (Lake Ontario), which was charcoal filtered and aerated for a minimum of three days prior to use. Water characteristics included: conductivity 273 – 347μS/cm; pH 7.5 - 8.5; hardness 120 - 140 mg/L; alkalinity 75 - 100 mg/L; and chloride ion 22 - 27 mg/L.

Four sediment toxicity tests were performed: *Chironomus riparius* 10-d survival and growth, *Hyalella azteca* 28-d survival and growth, *Hexagenia* spp. 21-d survival and growth, and *Tubifex tubifex* 28-d survival and reproduction. Sediment handling procedures and toxicity test methods are described elsewhere (Borgmann and Munawar 1989; Borgmann et al. 1989; Krantzberg 1990; Reynoldson et al. 1991; Bedard et al. 1992; Day et al. 1994; Reynoldson et al. 1998b). Each test included a control sediment for quality control purposes. This control sediment was collected from Long Point Marsh, Lake Erie, and was composed on average of 70.33% silt, 29.13% clay, 0.54% sand, and 8.1% organic carbon. All tests passed an acceptability criteria based on percent control survival in Long Point sediment before being included in a data set, i.e., ≥ 80% for *H. azteca* and ≥70% for *C. riparius* (USEPA 1994; ASTM 1995); ≥80% for *Hexagenia* spp., and ≥75% for *T. tubifex* (Reynoldson et al. 1998b).

Water chemistry variables (pH, dissolved oxygen (mg/L), conductivity (μS/cm), temperature (° C), and total ammonia (mg/L)) were measured in each replicate test beaker on day 0 (start of test) and at the completion of the test. Tests were run under static conditions in environmental chambers at 23°C ±1 °C, under a photoperiod of 16L: 8D and an illumination of 500 - 1000 lux, with the exception of *T. tubifex* test which was run in the dark.

***Hyalella azteca* 28-Day Survival and Growth Test**

The test was conducted for 28 days using 2 -10 day old organisms. On day 28, the contents of each beaker were rinsed through a 250-μm screen and the surviving amphipods counted. Amphipods were then dried at 60 °C for 24 hours and dry weights recorded. (Initial weights were considered negligible.)

***Chironomus riparius* 10-Day Survival and Growth Test**

The test was conducted for 10 days using first instar organisms. On day 10, the contents of each beaker were wet sieved through a 250-μm screen and the surviving chironomids counted. Chironomids were then dried at 60 °C for 24 hours and dry weights recorded. (Initial weights were considered negligible.)

***Hexagenia* spp. 21-Day Survival and Growth Test**

The test was conducted for 21 days using pre-weighed nymphs (between 5 - 8 mg wet weight/nymph). On day 21, the contents of each jar were wet sieved through a 500-μm screen and surviving mayfly nymphs counted. Nymphs were then dried at 60 °C for 24 hours and dry weights recorded. Initial mayfly wet weights were converted to dry weights (the relationship of mayfly wet weight to dry weight was previously determined by regression analysis) using the following equation: Initial dry weight = [(wet weight + 1.15)/ 7.35]. Growth was determined by final dry weight – initial dry weight.

***Tubifex tubifex* 28-Day Survival and Reproduction Test**

The test was conducted for 28 days using sexually mature worms (gonads visible). On day 28, the contents of each beaker were rinsed through a 500-μm and 250-μm sieve sequentially. The number of surviving adults, full cocoons, empty cocoons, and large immature worms were counted from the 500-μm sieve and the number of small immature worms counted from the 250-μm sieve. Reproduction was assessed using four endpoints: Number of surviving adults, total number of cocoons produced per adult, the percent of cocoons hatched, and total number of young produced per adult.

2.4 Sediment and Water Physico-chemical Analysis

Overlying Water

Overlying water samples were analyzed for total Kjeldahl Nitrogen (TKN), nitrates/nitrites (NO_3/NO_2), total phosphorus (TP) and alkalinity by the National Laboratory for Environmental Testing (NLET) (Burlington, ON) by procedures outlined in NLET (2000).

Sediment Particle Size

Particle size analysis was performed by the Sedimentology Laboratory at NWRI (Burlington, ON) following the procedure of Duncan and LaHaie (1979).

Sediment Trace Metals and Nutrients

Freeze dried sediment was analysed for total mercury, 29 trace elements, major oxides, loss on ignition (LOI), total organic carbon (TOC), total phosphorus (TP), and total nitrogen (TN) by Caduceon Laboratory (Ottawa, ON) using in house procedures or USEPA/CE (1981) standard methodologies. For sediment total mercury, 0.5g of freeze dried sediment was digested with HNO_3:HCl for two hours. $SnCl_2$ was added to reduce Hg to volatile metallic form. If there was high organic material, $KMnO_4$ was added to the digestion solution to destroy organo-mercury bonds. Hydroxyl amine hydrochloride was then added to neutralize $KMnO_4$ excess so $SnCl_2$ could react with Hg in solution. Digestion was followed by measurement using a cold vapour atomic absorption spectrometer. The detection limit was 5 ng/g dw.

Analysis of methyl mercury in Jellicoe Cove sediment was performed by Flett Research Ltd. (Winnipeg, MB), based on procedures of Bloom and Crecelius (1983), Horvat et al. (1993) and Liang et al. (1994). Sediment was prepared for analysis by distilling 200-300 mg of homogenized sample (or spikes or blanks) in ~45 mL of low-mercury deionized water.

Approximately 40 mL of distillate was collected and acidified with KCl/H_2SO_4. (Note: Since methyl mercury results were ≤0.1% of the total mercury results, a methylene chloride extraction was carried out on some of the highest total mercury samples. No significant difference in methyl mercury concentrations was observed between results obtained by either method. Therefore, it was assumed that insignificant methyl mercury production was occurring in the distillation process and thus all samples were processed by distillation.) An aliquot of the prepared sample (1-2 mL, depending on observed interferences from the matrix) was ethylated in solution (final volume ~ 40 mL) using sodium tetraethyl borate. The solution was buffered to pH 5.5. The resulting ethylmethyl mercury was purged onto a Tenax trap with mercury-free nitrogen. The trap was heated, purged with UHP argon onto a GC column (for separation of the ethylmethyl mercury from Hg° and diethyl mercury), run through a pyrolizer (to reduce all mercury to Hg°), and then sent to a cold vapour atomic fluorescence analyser for detection. (GC oven: Perkin Elmer 8410 GC; column: chromasorb WAW-DMSC 60/80 mesh with 15% OV-3; detector: Brooks-Rand CVAFS model-2). The detection limit was 0.25 ng/g dw.

2.5 Data Analysis

The BEAST is a predictive approach for assessing sediment quality in the Great Lakes (Reynoldson et al. 1995, 2000; Reynoldson and Day 1998). It consists of a database containing information on benthic community structure, selected habitat variables, and responses of four benthic invertebrates in laboratory toxicity tests. The database currently consists of nearshore reference sites that were sampled from the Laurentian Great Lakes over a three-year period. The reference sites establish normal conditions for selected endpoints, and determine the range of 'normal' biological variability. As a result, expected biological conditions at Peninsula Harbour sites were predicted by examining the relationships between variability and habitat conditions.

For the benthic community structure assessment, the BEAST model predicted the community assemblage that should occur at a test site. Using multiple discriminant analysis, environmental variables (identified as predictors - i.e., latitude, longitude, depth, alkalinity, and total organic carbon; Reynoldson et al. 1995, 2000) for the test and reference sites were merged and the model assigned a probability of the test site belonging to each of the reference faunal groups.

Community structure assessments were conducted at the family level, as this taxonomic detail is shown to be sensitive for the determination of stress (Reynoldson et al. 2000). Because the samples were collected either with core tubes (mini-box corer) or with the Ponar, a set of conversion factors was used to make the data comparable prior to site assessments. To adjust for the efficiency of the Ponar relative to the box core, benthic counts were divided by 0.69, with the exception of the chironomids, hirudines, nematodes, oligochaetes and sphaeriids, where 0.52, 0.71, 0.64, 0.55 and 0.75 were used, respectively. Counts were then adjusted for area. Test site data were then merged with the reference site data of the matched (group to which the test site has the highest probability of belonging) reference group only and ordinated using hybrid multidimensional scaling (HMDS, Belbin 1993), applied to a Bray-Curtis distance matrix.

For the toxicity assessment, toxicological responses were ordinated using HMDS applied to a Euclidean distance matrix (standardized data). Toxicity endpoints for the test sites were compared to those for one group of reference sites (there are no separate distinct groups as with the community structure assessment).

Principal axis correlation (Belbin 1993) was used to identify relationships between habitat variables and community or toxicity data. This did not include organic contaminant data as these compounds were not measured in the reference sediments. Significant invertebrate families or toxicity endpoints, and environmental variables were identified using Monte-Carlo permutation tests (Manly 1991). Test sites were compared to confidence bands derived from matched reference sites. By using probability ellipses constructed around reference sites only, four categories of similarity-difference to reference were established: the same (within the 90% probability ellipse), possibly different/potentially toxic (between the 90 and 99% ellipses), different/toxic (between the 99 and 99.9% ellipses), and very different/severely toxic (outside the 99.9% ellipse) (see Figure 2).

Test data were analyzed in subsets, with the number of test sites analyzed in an ordination numbering ≤10% reference sites (i.e., if there are 100 reference sites, then a subset of ≤ 10 test sites would be ordinated at one time). Multiple discriminant analysis and probability ellipses were performed using the software SYSTAT (Systat Software Inc. 2002), and HMDS was performed using PATN (Blatant Fabrications Pty Ltd. 2001).

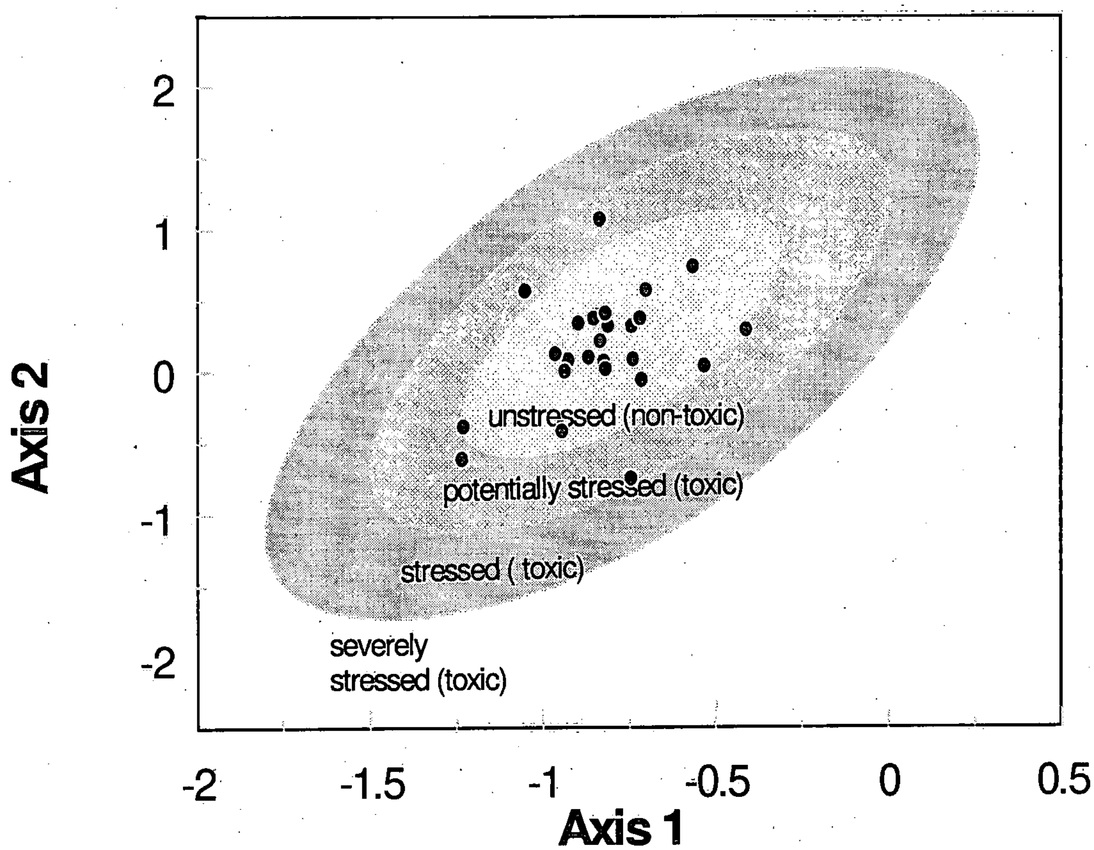

Figure 2. The use of 90, 99, and 99.9% probability ellipses around reference sites to determine the level of departure from reference condition.

2.6 Quality Assurance/Quality Control

Field Replication

At four randomly selected sites (B5, 64, 67, and 71), triplicate overlying water, sediment and benthic invertebrate samples were collected for determination of within-site and among-sample variability. Variability in a measured analyte was expressed as the coefficient of variation (CV = standard deviation / mean × 100).

Analytical

Flett Research Ltd. conducted determinations of methyl mercury in Jellicoe Cove sediment. Quality control evaluation for this procedure included analyses of sample blanks, duplicates, and matrix spikes, as well as the evaluation of sample recoveries. Sample duplicates were analyzed at least once every seven samples, and matrix spikes were performed on every four samples to determine methyl mercury recoveries.

Benthic Community Sorting

To evaluate control measures for benthic invertebrate enumeration (on a monthly basis), a previously sorted sample was randomly selected, re-sorted, and the number of new organisms found counted. The percent of organisms missed (%OM) was calculated using the equation:

$$\%OM = \# \text{ organisms missed} / \text{total organisms found} \times 100$$

A desired sorting efficiency is < 5%. If the %OM was > 5%, two more replicate samples were randomly selected and the %OM calculated. The average %OM was calculated based on the three samples re-sorted, and represents the standard sorting efficiency for that month. The average %OM is based on only one replicate sample if %OM is ≤ 5%).

3 RESULTS AND DISCUSSION

3.1 Sediment and Water Physico-Chemical Properties

Overlying Water

Conditions of overlying water (0.5 m above the sediment) are similar for the most part at Peninsula Harbour sites for the variables measured (Table 3). The ranges of variables for all sites are: alkalinity 31 mg/L, conductivity 19 µS/cm, dissolved oxygen 2.6 mg/L, NO_3/NO_2 0.05 mg/L, pH 0.8, temperature 7.1 °C, TKN 0.07 mg/L, and TP 0.007 mg/L, suggesting homogeneity in water mass across sampling sites.

Sediment Particle Size

Particle size data for Peninsula Harbour sediment are shown in Table 4. In general, sediments consist of sand (ranging from 2 to 97%; median 32%) and/or silt (ranging from 2 to 80%; median 54%), with the exception of sites A1 & 60, which consist mainly of clay (82 and 72%, respectively). In general, clay is a minor component of the sediment (ranging from 0 to 82%; median 10%), and there is no or very little gravel (0 to 3%). The median percentage of sand in Jellicoe Cove is higher (40%) compared to sites located outside the Cove (23%), whereas median percentage of silt is higher at sites outside the Cove (64%) compared to Jellicoe Cove sites (49%).

Table 3. Measured environmental variables in Peninsula Harbour overlying water.

Site	Alkalinity (mg/L)	Conduct-ivity (µS/cm)	D.O. (mg/L)	NO_3/NO_2 (mg/L)	pH	Temp (°C)	Total Kjeldahl N	Total P
Reference Group 5 mean	64.9	-	10.5	0.28	8.0	10.0	0.11	0.009
A1	40.4	89.5	11.1	0.33	7.8	11.8	0.12	0.006
A2	40.4	89.5	11.1	0.32	7.7	11.8	0.12	0.007
A5	40.8	90.4	10.9	0.33	7.7	11.6	0.16	0.008
B5	40.8	90.0	11.0	0.32	7.9	12.0	0.11	0.006
C3	40.8	90.4	10.9	0.32	7.8	11.9	0.12	0.006
C6	40.5	90.1	11.0	0.32	7.8	12.1	0.13	0.008
D1	40.9	90.9	11.0	0.32	7.7	11.6	0.12	0.005
D4	40.7	89.9	11.2	0.33	7.8	11.8	0.11	0.007
D5	40.3	96.9	12.9	0.35	7.7	12.1	0.12	0.005
E3	40.3	89.6	11.1	0.33	7.8	11.7	0.15	0.006
E5	41.0	90.8	11.0	0.33	7.8	12.1	0.13	0.006
F2	40.8	89.8	10.9	0.32	7.8	12.2	0.12	0.007
F4	40.6	89.9	11.0	0.33	7.8	12.1	0.12	0.005
G3	40.9	90.4	11.1	0.32	7.8	12.2	0.13	0.006
G5	40.5	90.1	11.0	0.32	7.8	12.3	0.13	0.002
G6	40.9	94.6	11.0	0.32	7.8	12.2	0.12	0.003
H3	40.6	91.0	11.1	0.31	7.8	12.3	0.12	0.002
H5	40.7	89.4	11.4	0.32	7.9	11.8	0.12	0.003
I5	40.3	89.5	11.5	0.30	7.9	11.8	0.11	0.003
57	41.5	89.8	11.5	0.34	8.0	12.1	0.11	0.005
58	40.6	90.5	10.9	0.32	7.8	12.1	0.11	0.005
59	40.7	86.0	10.6	0.31	7.7	11.8	0.10	0.007
60	40.6	84.0	10.8	0.32	7.9	11.7	0.11	0.005
61	40.8	87.0	10.3	0.32	7.2	11.3	0.09	0.005
62	40.1	85.0	10.8	0.31	7.9	11.8	0.12	0.006
64	40.3	78.0	10.6	0.32	7.3	11.6	0.10	0.005
65	40.5	85.0	12.1	0.35	7.3	5.2	0.09	0.005
66	40.8	87.0	10.6	0.32	7.3	11.9	0.12	0.006
67	40.3	86.0	10.5	0.32	7.2	12.0	0.13	0.005
68	40.8	82.0	11.0	0.30	7.7	11.7	0.12	0.004
70	40.8	86.2	10.6	0.32	7.3	11.8	0.13	0.006
71	41.5	92.6	10.8	0.33	7.9	12.2	0.12	0.006
289	70.9	85.0	10.3	0.33	7.6	12.1	0.12	0.003

Table 4. Physical characteristics of Peninsula Harbour sediment (top 10 cm).

Site	% Sand	% Silt	% Clay	% Gravel
Reference Group 5 Mean	37.82	26.36	34.96	0.86
Jellicoe Cove				
A1	2.07	16.39	81.54	0.00
A2	97.20	2.46	0.00	0.34
A5	21.21	70.27	8.52	0.00
B5	52.59	39.72	7.69	0.00
C3	22.97	69.03	8.00	0.00
C6	86.93	9.23	3.64	0.19
D1	40.30	51.65	8.05	0.00
D4	39.40	54.00	6.60	0.00
D5	24.10	66.99	8.91	0.00
E3	38.46	52.76	8.78	0.00
E5	35.10	55.06	9.84	0.00
F2	53.07	36.17	10.76	0.00
F4	22.88	67.53	9.58	0.00
G3	8.45	80.11	11.44	0.00
G5	41.79	48.54	9.67	0.00
G6	86.27	10.72	0.00	3.01
H3	18.39	68.52	13.09	0.00
H5	40.28	48.83	10.89	0.00
I5	90.57	9.43	0.00	0.00
57	83.34	15.98	0.00	0.68
58	41.18	47.81	11.01	0.00
Outside Jellicoe Cove				
59	25.26	63.10	11.64	0.00
60	11.59	16.12	71.63	0.67
61	2.41	76.44	21.16	0.00
62	21.48	67.27	11.25	0.00
64	10.01	77.93	12.06	0.00
65	18.00	65.75	16.25	0.00
66	32.44	56.47	11.09	0.00
67	24.26	66.50	9.24	0.00
68	6.65	76.25	17.10	0.00
70	39.71	51.39	8.90	0.00
71	81.66	17.90	0.00	0.44
289	25.06	61.10	13.84	0.00

Sediment Trace Metals and Nutrients

Total and methyl mercury concentrations in Peninsula Harbour sediment are shown in Figure 3 and Table 5. Jellicoe Cove sediments have the highest concentrations of total Hg, ranging from 0.04 to 19.50 μg/g dry weight (median 3.46 μg/g) (Figure 3a); sediments outside the cove have total Hg concentrations ranging from 0.04 to 2.32 μg/g (median 0.99 μg/g) (Figure 3b, Table 5). Total mercury at all test sites are higher than the Great Lakes reference mean (0.07 μg/g), with the exception of A1 (0.04 μg/g), and Carden Cove site 71 (0.04 μg/g). Most test sites (30 of 33) exceed the provincial Lowest Effect Level (LEL, Persaud 1992) for Hg (0.2 μg/g), and 16 of 33 sites exceed the Severe Effect Level (SEL, Persaud 1992) for Hg (2.0 μg/g); 13 of the 16 sites that exceed the SEL are in Jellicoe cove.

Methyl mercury (measured in Jellicoe cove sediments only) range from 0 to 22.6 ng/g (Figure 3a, Table 5). The highest methyl mercury concentration occurs at site H5, which also has the highest total Hg concentration. The fraction of methyl mercury is site specific (e.g. see sites E3 and E5 – methyl mercury is higher in E3 yet total Hg is much lower in E3 than E5); methyl mercury ranges between 0 to 1.5% of the total mercury (mean 0.48%). Regression analysis on log transformed data reveals is a significant relationship between total and methyl mercury in Jellicoe Cove sediment ($r^2 = 0.52$, $p = <0.001$).

Remaining trace metals, total organic carbon (TOC), loss on ignition (LOI), total phosphorus (TP), and total nitrogen (TN) are shown in Table 5. Environmental variables exceeding the provincial LEL at the majority of sites including Cr, Cu, Ni, TOC and TN; variables exceeding the LEL at certain sites include Cd (1 site), Zn (1 site), Fe (3 sites), Mn (6 sites) and TP (4 sites). Most metal concentrations are similar or lower than the mean of the Great Lakes reference site group. No trace metals exceed the SEL. Total organic carbon ranges from 0.2 to 11.0% (median 2.3%) and exceeds the SEL at one Jellicoe Cove site (F2). Total organic carbon is higher in Jellicoe Cove compared to outside the Cove, with medians of 3.7% and 1.7%, respectively. Total N ranges from 60 to 1660 μg/g (median 673 μg/g) and TP ranges from 291 to 1060 μg/g (median 481 μg/g), and in general, concentrations are similar across test sites.

Site Depth

Jellicoe Cove sites and the Carden Cove site (71) are shallow (range 1 – 25 m) compared to the mean depth for the Great Lakes reference sites (37 m) and sites located outside the cove (range 22 – 95 m) (Table 1). The median depth for sites in Jellicoe Cove and outside the cove is 12.5 m and 52.4 m, respectively.

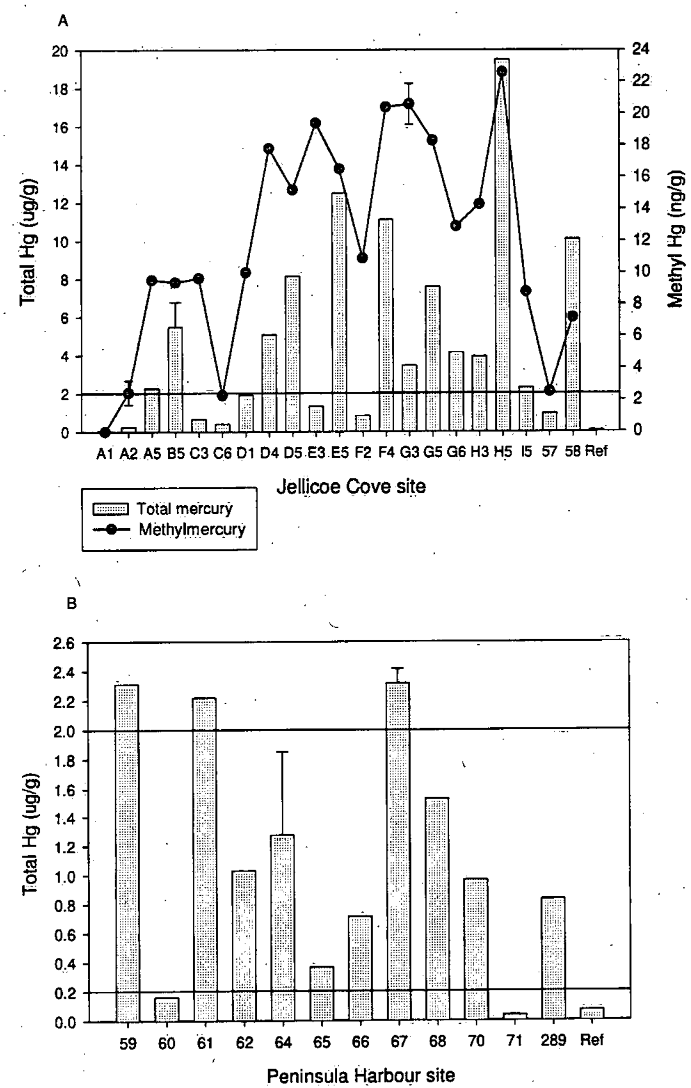

Figure 3. Total mercury (μg/g) and methyl mercury (ng/g) concentrations in Peninsula Harbour sediment: A) Jellicoe Cove sites; B) Sites located outside Jellicoe Cove. The horizontal line represents the provincial SEL (A & B) (2.0 μg/g) and the LEL (B) (0.2 μg/g).

Table 5. Metal and nutrient concentrations in Peninsula Harbour sediment. Values exceeding the provincial SEL are highlighted. Values in µg/g dry weight unless otherwise noted.

Site	%Al_2O_3	As	%CaO	Cd	Co	Cr	Cu	%Fe
Reference Gp 5 mean	11.4	11.4	3.7	1.1	15.3	49.9	34.6	-
A1	11.2	< 5	13.2	< 1	12.4	43.6	27.0	2.4
A2	10.6	< 5	3.0	< 1	4.3	25.2	5.0	1.2
A5	10.1	< 5	4.5	< 1	5.3	32.3	20.4	1.4
B5	11.0	< 5	4.4	< 1	6.1	37.9	18.1	1.5
C3	10.8	< 5	3.8	< 1	4.2	24.5	10.8	1.1
C6	12.4	< 5	2.9	< 1	5.1	29.2	7.3	1.2
D1	9.8	< 5	5.2	< 1	4.7	27.7	14.0	1.1
D4	11.0	< 5	4.4	< 1	5.2	29.3	14.4	1.3
D5	10.4	< 5	4.5	< 1	5.9	33.2	19.9	1.4
E3	9.6	< 5	3.0	< 1	6.0	28.9	14.1	1.2
E5	10.7	< 5	4.4	< 1	5.0	38.0	21.4	1.5
F2	10.0	< 5	3.1	< 1	3.8	24.2	7.6	1.1
F4	10.0	< 5	5.1	< 1	5.2	32.6	17.2	1.3
G3	9.4	< 5	5.0	< 1	5.6	32.6	20.7	1.3
G5	10.4	< 5	3.6	< 1	6.2	31.1	18.9	1.5
G6	11.1	< 5	3.2	< 1	5.9	28.2	9.0	1.5
H3	9.2	< 5	6.1	< 1	4.7	37.0	17.9	1.3
H5	10.0	< 5	5.1	< 1	5.3	27.7	14.2	1.4
I5	10.8	< 5	4.0	< 1	4.7	26.0	7.0	1.3
57	12.0	< 5	3.8	< 1	5.6	38.0	11.4	1.8
58	10.9	< 5	4.3	< 1	5.1	29.3	21.4	1.4
59	10.7	< 5	5.5	< 1	5.9	33.7	26.2	1.4
60	12.2	< 5	8.4	< 1	11.9	51.1	25.9	2.7
61	11.8	< 5	4.0	< 1	9.6	39.0	57.0	2.2
62	10.4	< 5	5.9	< 1	6.0	33.4	23.7	1.5
64	10.7	< 5	5.4	< 1	7.6	36.9	35.8	1.6
65	12.3	< 5	3.4	< 1	8.1	42.4	22.7	1.9
66	11.2	< 5	4.5	< 1	7.5	37.6	22.7	1.6
67	10.6	< 5	5.7	< 1	6.4	31.7	23.7	1.3
68	10.8	5.0	5.5	1.2	8.2	36.3	35.1	1.8
70	11.0	< 5	4.5	< 1	6.8	35.0	16.5	1.5
71	11.7	< 5	3.3	< 1	2.4	19.8	5.6	1.0
289	10.4	< 5	5.0	< 1	7.5	34.1	30.5	1.7
LEL	-	6.0	-	0.6	-	26	16	2%
SEL	-	33.0	-	10	-	110	110	4%

Table 5. Continued.

Site	Total Hg	Methyl Hg (ng/g)	$\%K_2O$	%LOI	%MgO	Mn	$\%Na_2O$	Ni
Reference Gp 5 mean	0.07	-	2.6	8.5	2.6	-	1.8	56.5
A1	0.04	0.00	2.4	20.5	4.4	547	1.3	28.7
A2	0.24	2.45	2.2	1.9	1.4	167	3.1	13.2
A5	**2.26**	9.53	1.8	10.3	3.0	184	2.4	18.7
B5	**5.46**	9.38	2.0	7.6	2.7	188	2.8	20.7
C3	0.65	9.64	2.0	10.0	2.1	119	2.7	11.1
C6	0.40	2.28	1.9	2.4	1.6	164	3.3	13.6
D1	1.90	10.00	1.8	11.3	2.9	137	2.4	13.9
D4	**5.06**	17.80	2.0	8.8	2.6	137	2.8	14.5
D5	**8.13**	15.20	1.9	9.9	2.9	187	2.5	18.1
E3	1.33	19.40	1.8	17.5	1.6	138	2.6	14.1
E5	**12.50**	16.50	1.9	9.8	2.7	168	2.6	18.2
F2	0.83	10.90	1.7	13.8	1.5	116	2.5	10.9
F4	**11.10**	20.40	1.9	10.6	3.0	148	2.5	16.7
G3	**3.46**	20.50	1.8	15.9	2.9	181	2.3	18.2
G5	**7.59**	18.30	1.8	11.0	2.3	171	2.5	18.5
G6	**4.13**	12.90	1.8	7.7	1.7	161	2.9	15.5
H3	**3.93**	14.30	1.7	18.2	2.2	148	2.4	20.7
H5	**19.50**	22.60	1.8	13.2	2.1	139	2.5	16.9
I5	**2.30**	8.76	1.7	1.8	1.4	102	2.9	10.7
57	0.94	2.50	2.0	1.2	1.8	156	3.4	14.7
58	**10.10**	7.16	2.1	9.1	2.5	168	2.9	16.5
59	**2.31**	-	2.2	8.3	3.6	272	2.7	20.5
60	0.16	-	2.5	13.4	3.6	473	2.2	30.6
61	**2.22**	-	2.6	8.1	2.8	**1198**	2.5	25.9
62	1.03	-	2.1	9.5	3.7	275	2.7	19.6
64	1.28	-	2.2	8.9	3.6	435	2.5	23.5
65	0.37	-	2.5	4.5	2.3	1057	2.8	23.1
66	0.72	-	2.2	5.7	2.9	615	2.7	22.3
67	**2.32**	-	2.0	10.4	3.7	242	2.5	19.1
68	1.53	-	2.2	9.5	3.8	467	2.4	23.1
70	0.97	-	2.0	6.7	2.9	244	2.8	19.1
71	0.04	-	1.7	0.5	1.2	94	3.2	10.9
289	0.83	-	2.1	9.8	3.3	359	2.4	21.9
LEL	0.2	-	-	-	-	460	-	16
SEL	2.0	-	-	-	-	1100	-	75

Table 5. Continued.

Site	$\%P_2O_5$	Pb	$\%SiO_2$	$\%TiO_2$	Total N	%Total organic C	Total P	V	Zn
Reference Gp 5 mean	0.18	40.2	62.7	0.56	1830	1.7	824	58.9	112.6
A1	0.28	3.4	41.2	0.35	478	0.7	416	40.0	57.1
A2	0.22	0.5	73.9	0.30	234	0.3	293	18.1	21.6
A5	0.26	1.2	62.9	0.23	775	3.5	446	25.9	65.4
B5	0.29	0.5	66.4	0.23	465	2.2	433	25.1	64.0
C3	0.28	0.5	66.8	0.21	478	3.8	433	20.9	45.0
C6	0.24	0.5	70.9	0.17	242	0.7	291	19.0	33.9
D1	0.25	0.5	63.3	0.19	518	3.9	473	19.6	50.2
D4	0.27	0.6	65.9	0.24	561	3.4	515	22.7	54.0
D5	0.26	2.2	64.7	0.22	783	3.5	481	24.6	80.9
E3	0.27	0.5	60.3	0.32	765	6.8	401	22.8	56.7
E5	0.26	0.5	64.1	0.22	962	3.7	464	26.0	84.0
F2	0.27	0.5	64.0	0.19	673	**11.0**	503	20.2	57.9
F4	0.29	2.9	63.0	0.22	914	4.3	503	24.1	88.8
G3	0.25	6.8	59.4	0.19	1660	6.7	409	26.7	113.4
G5	0.25	2.2	64.6	0.22	983	6.7	428	27.8	93.6
G6	0.27	0.5	68.9	0.18	523	5.5	386	23.3	69.8
H3	0.26	3.0	57.5	0.30	1600	8.3	406	25.5	118.0
H5	0.27	0.5	61.3	0.31	1430	6.8	409	24.1	111.8
I5	0.30	2.2	72.2	0.28	138	0.4	564	22.7	38.6
57	0.46	1.1	69.9	0.69	165	0.4	1060	32.1	149.3
58	0.28	1.4	64.8	0.23	550	2.9	542	23.4	61.2
59	0.29	6.7	63.9	0.27	600	1.5	543	25.0	55.3
60	0.31	0.5	53.1	0.38	409	0.3	568	44.1	63.3
61	0.38	17.7	63.1	0.39	1380	2.0	764	35.3	95.1
62	0.30	0.5	61.8	0.25	681	1.9	545	26.6	55.6
64	0.30	9.4	63.1	0.29	763	1.5	585	27.5	62.9
65	0.36	0.5	69.0	0.34	710	0.9	820	31.3	46.4
66	0.31	3.6	65.9	0.27	435	0.9	553	26.5	43.8
67	0.29	4.6	62.4	0.24	738	2.1	431	23.4	53.5
68	0.32	5.6	61.7	0.31	983	1.8	511	29.6	70.3
70	0.27	0.5	65.5	0.22	454	2.3	444	25.6	53.6
71	0.36	3.4	73.9	0.48	60	0.2	650	20.5	14.6
289	0.30	2.8	61.9	0.29	1130	2.9	550	31.0	70.4
LEL	-	31	-	-	550	1%	600	-	120
SEL	-	250	-	-	4800	10%	2000	-	820

3.2 Community Structure

All thirty-three test sites are predicted to the same Great Lakes faunal group (Reference Group 5) based on four habitat attributes (alkalinity, sample depth, latitude, & longitude) (Table 6). The probability of the test sites belonging to Group 5 ranges from to 59.2 to 99.9% (mean 87.0%, median 89.0%). Reference Group 5 consists of 75 sites from Lake Superior (30), Georgian Bay (19), the North Channel (12), Lake Michigan (7), Lake Ontario (5) and Lake Huron (2).

Table 6. Probabilities of test sites belonging to Great Lakes reference community groups.

	Probability of Membership				
Site	Gp 1	Gp 2	Gp 3	Gp 4	**Gp 5**
A1	0.138	0.002	0.001	0.000	**0.859**
A2	0.068	0.001	0.001	0.000	**0.930**
A5	0.032	0.001	0.000	0.000	**0.967**
B5	0.057	0.001	0.000	0.000	**0.941**
C3	0.097	0.002	0.001	0.000	**0.901**
C6	0.129	0.002	0.001	0.000	**0.868**
D1	0.129	0.002	0.001	0.000	**0.869**
D4	0.121	0.002	0.001	0.000	**0.877**
D5	0.107	0.002	0.001	0.000	**0.890**
E3	0.142	0.002	0.001	0.000	**0.855**
E5	0.143	0.002	0.001	0.000	**0.853**
F2	0.207	0.002	0.002	0.000	**0.788**
F4	0.184	0.002	0.002	0.000	**0.812**
G3	0.201	0.002	0.002	0.000	**0.795**
G5	0.256	0.003	0.002	0.000	**0.739**
G6	0.295	0.003	0.003	0.000	**0.700**
H3	0.260	0.003	0.002	0.000	**0.735**
H5	0.312	0.003	0.003	0.000	**0.683**
I5	0.376	0.003	0.003	0.000	**0.618**
57	0.401	0.003	0.003	0.000	**0.592**
58	0.085	0.001	0.001	0.000	**0.913**
59	0.000	0.000	0.000	0.002	**0.998**
60	0.028	0.001	0.000	0.000	**0.971**
61	0.000	0.000	0.000	0.010	**0.989**
62	0.003	0.000	0.000	0.000	**0.996**
64	0.000	0.000	0.000	0.005	**0.995**
65	0.000	0.000	0.000	0.038	**0.962**
66	0.000	0.000	0.000	0.003	**0.997**
67	0.000	0.000	0.000	0.001	**0.999**
68	0.006	0.000	0.000	0.000	**0.994**
70	0.012	0.000	0.000	0.000	**0.988**
71	0.317	0.003	0.003	0.000	**0.678**
289	0.029	0.001	0.000	0.000	**0.969**

Reference Group 5 is characterized mainly by Haustoriidae, with a 44.3% occurrence at reference sites (Table 7), consisting almost entirely of the amphipod *Pontoporeia hoyi*. Also part of reference Group 5 are Tubificidae (oligochaete worm – 16.6% occurrence), Sphaeriidae (the fingernail clams – 11.5% occurrence), Chironomidae (the midges – 9.9% occurrence), and Lumbriculidae and Enchytraeidae (oligochaete worms –5.3 and 6.8% occurrence, respectively). These six most dominant families make up ~94% of the total families found at Group 5 reference sites. To a lesser degree, Naididae (oligochaete worm), Asellidae (isopod), Valvatidae (snail), and Gammaridae (amphipod) are also present (0.6 – 1.9% occurrence). Table 7 shows the mean abundance of these invertebrate families at Peninsula Harbour sites. Complete invertebrate family counts are provided in Appendix A; Table A1.

Jellicoe Cove sites are diverse, ranging from 7 to 14 taxa per site (mean: 10 taxa), compared to the Group 5 reference mean (6 taxa) (Table 7). The number of taxa in 12 of the 21 Jellicoe Cove sites is greater than two standard deviations above the reference mean. Diversity at sites outside of Jellicoe Cove is lower, ranging from 3 to 7 taxa; most sites are close to the Group 5 reference mean.

Jellicoe Cove sites are dominated primarily by chironomids, tubificids and sphaeriids, which are present all sites in the cove (Table 7). Haustoriidae, the predominant reference group amphipod family, is in low abundance or absent, but overall, there is a trend towards greater abundance and diversity of taxa in Jellicoe Cove compared to reference. The low abundance or absence of Haustoriidae may be depth related (median site depth in the cove is 12.5 m, while median depth for reference group sites is 28.0 m) as there is an increased abundance of the Gammarid amphipods (normally found at shallower depths than haustoriids) at the three sites where the haustoriids are absent. Chironomids are highly abundant in the cove, and tubificids are abundant at > 70% of sites in the cove. All families with a ≥ 9.9% occurrence in the reference group are present (with the exception of the Haustoriidae at three sites as mentioned). Other families such as Naididae, Valvatidae, and Asellidae are also present in increased abundance at the majority of sites in the cove.

Sites located outside Jellicoe Cove consist primarily of Haustoriidae (present at all sites), Chironomidae (absent from 1 site), Sphaeriidae (absent from 2 sites) and Tubificidae (absent from 4 sites). Abundances of major taxa are lower at the sites located outside of Jellicoe Cove, and are closer to reference means overall. The number of top 10 reference taxa expected to be at test sites that are absent range from 0 to 3 for Jellicoe Cove sites and from 2 to 7 for sites outside the Cove (highlighted – Table 7).

Table 7. Mean abundance of macroinvertebrate families (per 33 cm^2), taxa richness and BEAST summary results. Invertebrate families predicted to be at Peninsula Harbour sites that are absent are highlighted. Group 5 reference means and percent occurrences are provided.

Family	Group 5 Mean	Occurrence in Gp 5 (%)	A1	A2	A5	B5	C3	C6	D1	D4
No. Taxa (±2 SD)	6 (2 – 9)	-	9	11	8	8	11	10	11	9
Haustoriidae	12.1	44.3	0.80	1.66	5.40	3.60	0.81	3.51	1.30	1.00
Tubificidae	4.5	16.6	4.10	4.14	24.20	15.00	17.40	5.63	11.96	16.20
Sphaeriidae	3.1	11.5	0.27	1.61	15.20	10.20	7.97	5.93	9.80	3.60
Chironomidae	2.7	9.9	17.39	11.20	9.00	28.80	10.43	54.26	14.94	16.60
Lumbriculidae	1.8	6.8	1.04	4.21	0.20	5.20	0.59	1.53	0.66	0.80
Enchytraeidae	1.4	5.3	0.15	1.64	0.00	2.00	0.00	0.07	0.08	0.00
Naididae	0.5	1.9	2.13	11.11	0.20	19.60	1.91	4.62	0.37	9.80
Asellidae	0.4	1.5	0.03	0.00	12.20	0.00	10.62	3.09	17.34	3.40
Valvatidae	0.2	0.7	1.81	0.42	0.40	2.00	0.32	2.88	0.42	1.20
Gammaridae	0.2	0.6	0.00	0.00	0.00	0.00	1.56	0.00	7.15	0.00
BEAST BAND	-	-	4	3	2	4	3	4	3	3

Table 7. Continued.

Family	Group 5 Mean	Occurrence in Gp 5 (%)	D5	E3	E5	F2	F4	G3	G5	G6
No. Taxa (±2 SD)	6 (2 – 9)	-	7	11	9	9	9	9	11	12
Haustoriidae	12.1	44.3	1.40	0.00	2.40	0.18	1.60	2.00	0.00	0.30
Tubificidae	4.5	16.6	32.20	17.40	30.80	9.97	13.80	15.20	18.80	6.69
Sphaeriidae	3.1	11.5	5.60	20.00	20.40	6.21	9.40	19.60	9.31	2.74
Chironomidae	2.7	9.9	38.00	8.80	55.40	3.65	30.60	27.20	16.03	37.03
Lumbriculidae	1.8	6.8	0.00	0.80	0.00	3.18	0.00	0.00	0.19	1.95
Enchytraeidae	1.4	5.3	0.00	0.00	0.20	0.00	0.00	0.00	0.00	0.04
Naididae	0.5	1.9	10.60	13.80	24.40	3.12	13.80	6.80	1.00	6.70
Asellidae	0.4	1.5	2.60	25.60	12.20	6.52	3.60	46.40	9.86	2.58
Valvatidae	0.2	0.7	2.40	0.20	6.80	0.15	12.40	6.60	4.04	1.52
Gammaridae	0.2	0.6	0.00	5.60	0.00	2.42	0.00	4.00	5.26	3.07
BEAST BAND	-	-	3	3	4	3	3	4	3	3

Table 7. Continued.

Family	Group 5 Mean	Occurrence in Gp 5 (%)	H3	H5	I5	57	58	59	60	61	62
No. Taxa (±2 SD)	6 (2 – 9)	-	11	14	11	10	10	4	8	3	7
Haustoriidae	12.1	44.3	1.80	0.00	1.31	0.09	5.40	4.20	3.71	6.20	7.20
Tubificidae	4.5	16.6	4.20	15.81	2.27	2.46	18.80	0.00	0.39	8.20	23.20
Sphaeriidae	3.1	11.5	4.00	16.38	5.14	4.10	16.60	4.40	1.16	0.00	1.40
Chironomidae	2.7	9.9	24.20	33.80	29.38	21.85	23.00	2.00	8.34	0.00	2.40
Lumbriculidae	1.8	6.8	0.00	0.15	2.35	1.57	1.60	4.00	1.73	0.20	2.80
Enchytraeidae	1.4	5.3	0.00	0.04	0.00	0.37	1.00	0.00	0.55	0.00	0.20
Naididae	0.5	1.9	2.80	1.60	5.97	8.58	23.40	0.00	0.08	0.00	0.60
Asellidae	0.4	1.5	9.40	11.77	0.36	0.03	0.40	0.00	0.00	0.00	0.00
Valvatidae	0.2	0.7	2.20	12.51	2.59	0.18	2.60	0.00	0.82	0.00	0.00
Gammaridae	0.2	0.6	0.00	6.63	0.00	0.06	0.00	0.00	0.00	0.00	0.00
BEAST BAND	-	-	3	3	3	4	2	1	2	1	1

Table 7. Continued.

Family	Group 5 Mean	Occurrence in Gp 5 (%)	64	65	66	67	68	70	71	289
No. Taxa (±2 SD)	6 (2 – 9)	-	4	6	5	5	6	6	6	7
Haustoriidae	12.1	44.3	6.20	2.80	3.40	5.11	6.00	6.20	1.22	4.40
Tubificidae	4.5	16.6	0.00	0.00	0.00	5.03	9.60	22.20	0.11	9.00
Sphaeriidae	3.1	11.5	0.20	0.20	0.40	0.41	4.40	4.40	0.00	14.40
Chironomidae	2.7	9.9	0.40	0.40	0.40	1.34	4.40	17.80	1.30	11.20
Lumbriculidae	1.8	6.8	5.40	1.60	4.20	2.13	0.60	3.80	0.00	0.00
Enchytraeidae	1.4	5.3	0.00	2.20	2.40	0.00	0.00	0.00	3.00	0.00
Naididae	0.5	1.9	0.00	0.20	0.00	0.00	0.20	1.00	0.67	0.20
Asellidae	0.4	1.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.80
Valvatidae	0.2	0.7	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.60
Gammaridae	0.2	0.6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
BEAST BAND	-	-	1	2	2	1	1	2	2	2

BEAST (Benthic Community) Evaluation

Results of the BEAST evaluation are summarized in Table 7. Ordinations are shown in Appendix B; Figures B1 – B4 (stress ≤ 0.165). Four separate ordinations were performed each with a subset of 8 – 9 Peninsula Harbour sites. Macroinvertebrate families that are most highly correlated to the ordination axes scores are Tubificidae and Haustoriidae (r^2 range: 0.49 – 0.72), followed by Chironomidae and Sphaeriidae (r^2 range: 0.40 – 0.61). For Jellicoe Cove sites, examination of the relationship between environmental variables and ordination axes scores reveals that the most highly correlated variables overall are Hg (r^2: 0.24 – 0.44) and TOC (r^2:

0.22 – 0.37) (Appendix B; Figures B1 – B3). For sites outside of Jellicoe Cove, depth is the most highly correlated environmental variable ($r^2 = 0.26$) (Appendix B; Figure B4).

Peninsula Harbour sites fall into the following bands:

Band 1 (equivalent to reference): 6 sites

Six sites are located in Band 1 (inside the 90% probability ellipse) (Appendix B; Figures B3 and B4). All sites are located outside of Jellicoe Cove.

Band 2 (possibly different): 8 sites

Eight sites fall in Band 2 (between the 90% and 99% ellipses) and therefore are "possibly different" than reference (Appendix B; Figures B1, B3 and B4). They include the remaining six sites located outside of Jellicoe Cove and two sites in the cove (58 and A5). The movement of sites outside of reference is associated with decreased abundance of Chironomidae for some sites (65, 66, 71; Figure B4) (increased depth as well), while increased abundance of Chironomidae for others (70, 289; Figure B4) (sites are oriented along the same family vector line in the opposite or same direction, respectively).

Band 3 and Band 4 (different/very different): 19 sites

Thirteen sites fall in Band 3 (between the 99% and 99.9% ellipses), and six sites fall in Band 4 (outside the 99.9% ellipse) (Appendix B; Figures B1 – B3). All sites are in Jellicoe Cove and most are associated with increased abundance of several families, and are oriented along a gradient of increasing TOC and Hg (shown as vectors in Figures B1 – B3).

While benthic communities at Jellicoe Cove sites are different or very different than at reference, data show a general trend towards greater diversity and abundance of taxa in the Cove. Enrichment is likely due to the high organic matter present in the sediment, also noted by Smith (1992). While there are high levels of mercury at some sites, the high percentage of total organic carbon may be affecting mercury availability to the benthos. The low occurrence of insects (with the exception of Chironomidae) in Peninsula Harbour sediment is consistent with other reports (Smith 1992; Sibley et al. 1991), and the reference group (Group 5) used in the assessment is also characterized by the low occurrence of insect taxa. The absence or low abundance of Haustoriidae (the most predominant taxa at the reference sites) at the majority of sites in Jellicoe Cove may be related to depth/temperature as Haustoriidae tend to be present in deeper water/colder waters. (Gammarid amphipods, usually present in the shallower areas, are present at the sites where the haustoriids are absent.) Benthic communities at sites outside of Jellicoe Cove are more similar to reference sites (test sites are either equivalent to or possibly different than reference); however, some sites (e.g., 61, 59 and 64), have low taxa diversity compared to reference.

3.3 Sediment Toxicity Tests

Mean species survival, growth, and reproduction in Peninsula Harbour sediment is shown in Table 8. The established numerical criteria for each category (non-toxic, potentially toxic and toxic) for each species are included. Toxicity is highlighted and potential toxicity is italicized.

Toxicity is evident at four sites: one site in Jellicoe Cove (A1) and three sites located outside of the cove (60, 65 and 71) (Table 8). *H. azteca* is the most sensitive organism, with low survival evident at these sites. Site A1, which is also acutely toxic to *C. riparius*, has low contaminants present (Figure 3, Table 5), but consists of hard compact clay (81.5%) (Table 4), which may be a confounding factor in toxicity. Site 71 (located in Carden Cove) is acutely toxic to *Tubifex* and is potentially toxic to both *Hyalella* and *Hexagenia*. Site 71 also has low contaminant concentrations (Figure 3, Table 5), but consists of hard compact sand (81.7 %) (Table 4); therefore, the physical nature of the sediment may be a confounding factor at this site. (The mini-box could not penetrate further than a few centimetres during sampling.) Over the course of the toxicity test, *Hexagenia* were frequently observed swimming in the water column attempting to burrow in the sediment and *Tubifex* were visible on the surface of the sediment, indicating that sediment at site 71 is not suitable for burrowing for these species. Sites showing potential toxicity include E3 (*Tubifex* cocoon production), and 66 (*Hyalella* survival).

Table 8. Sediment toxicity test results and BEAST summary results. Toxicity is highlighted, potential toxicity italicized.

Site	*C. riparius* Survival	*C. riparius* Growth	*H. azteca* Survival	*H. azteca* growth	*Hexagenia* survival	*Hexagenia* growth	*T. tubifex* Survival	*T. tubifex* Cocoon/ad	*T. tubifex* % hatch	*T. tubifex* Young/ad	**BEAST BAND**
Reference Mean	87.1	0.35	85.6	0.50	96.2	3.03	97.9	9.9	57.0	29.0	-
A1	**45.3**	0.29	**14.7**	***0.18***	100	1.62	100	7.3	90.6	10.3	**4**
A2	92.0	0.42	80.0	0.46	98.0	2.02	100	12.4	58.0	32.0	1
A5	85.3	0.31	90.7	0.27	100	4.21	100	9.8	61.7	27.1	1
B5	92.0	0.30	90.7	0.45	98.0	3.41	100	9.8	60.0	30.4	1
C3	88.0	0.31	86.7	0.47	94.0	4.55	100	11.0	57.9	24.5	1
C6	94.7	0.31	86.7	0.59	100	3.28	100	11.9	71.9	31.3	1
D1	85.8	0.31	93.3	0.49	98.0	4.63	100	11.3	57.5	30.8	1
D4	88.0	0.30	97.3	0.30	100	3.88	100	10.4	55.5	22.9	1
D5	93.3	0.31	96.0	0.38	98.0	4.35	100	11.3	63.4	18.8	1
E3	88.3	0.27	88.3	0.37	100	2.08	100	***7.0***	50.0	17.8	1
E5	84.0	0.32	84.0	0.27	98.0	3.99	100	12.1	61.2	22.2	1
F2	85.0	0.34	76.0	0.23	98.0	2.66	100	10.3	59.2	17.4	1
F4	86.7	0.30	90.7	0.34	96.0	3.90	100	9.9	60.4	22.2	1
G3	94.7	0.30	90.7	0.35	100	4.48	100	10.6	59.7	20.3	1
G5	96.0	0.32	77.3	0.33	100	5.88	100	10.8	57.1	23.8	1
G6	97.3	0.29	88.0	0.35	98.0	4.01	100	9.9	57.5	20.1	1
H3	98.7	0.35	86.7	0.42	100	4.68	100	10.4	51.7	21.6	1
H5	88.7	0.35	85.3	0.32	98.0	5.05	95.0	9.3	55.1	28.2	1
I5	93.3	0.43	68.3	0.42	100	2.75	100	10.6	64.1	29.8	1
57	86.7	0.40	89.3	0.25	98.0	2.23	100	11.5	60.9	32.6	1
58	90.0	0.33	89.3	0.39	92.0	3.70	100	11.8	64.9	31.7	1
59	97.3	0.30	96.0	***0.19***	98.0	3.96	100	10.8	68.6	23.0	1
60	73.3	0.39	**13.3**	0.32	96.0	2.56	95.0	8.7	97.9	11.8	**4**
61	89.7	0.32	80.0	0.29	100	2.43	100	10.0	77.1	22.0	1
62	97.3	0.36	81.3	0.41	94.0	3.57	100	10.9	60.3	26.0	1
64	96.0	0.35	86.7	0.41	94.0	2.79	100	10.2	73.5	20.9	1
65	96.7	0.31	**54.7**	0.54	92.0	2.30	100	9.3	89.9	16.8	**4**
66	97.7	0.32	***60.0***	0.38	96.0	2.45	100	8.9	78.3	15.5	**3**
67	85.3	0.42	90.7	0.31	100	3.46	100	8.4	67.5	19.6	1
68	81.3	0.43	93.3	0.37	100	3.55	100	***7.1***	68.9	18.3	1
70	75.0	0.41	90.7	0.36	100	3.81	100	9.0	54.7	23.3	1
71	84.0	0.42	***60.0***	0.32	***82.0***	***0.07***	**65.0**	9.8	95.4	11.4	**4**
289	84.0	0.40	98.33	0.42	100	4.03	100	9.3	56.5	19.0	1
Non-Toxic	≥67.7	0.49 – 0.21	≥67.0	0.75 – 0.23	≥85.5	5.0 – 0.9	≥88.9	12.4 – 7.2	78.1 – 38.1	46.3 – 9.9	-
Potentially toxic	67.6 – 58.8	0.20 – 0.14	66.9 – 57.1	0.22 – 0.10	85.4 – 80.3	0.8 – 0	88.8 – 84.2	7.1 – 5.9	38.0 – 28.1	9.8 – 0.8	-
Toxic	**< 58.8**	**< 0.14**	**< 57.1**	**< 0.10**	**< 80.3**	-	**< 84.2**	**< 5.9**	**< 28.1**	**< 0.8**	-

Note: The upper limit for non-toxic category is set using 2 × SD of the mean and indicates excessive growth or reproduction.

BEAST (Toxicity) Evaluation

Results of the BEAST toxicity evaluation are summarized in Table 8. Ordinations are shown in Appendix C; Figures C1 – C3 (stress ≤ 0.11). Each figure represents a separate ordination with a subset of 10 – 12 Peninsula Harbour sites. Toxicity endpoints that are most highly correlated to axes scores are *Hyalella* survival ($r^2 \geq 0.87$) and *Chironomus* survival ($r^2 \geq 0.80$). Monte-carlo random permutations reveal that these endpoints are significant in the ordination space (it is not just a random artifact of the data). No measured environmental variable is highly correlated ($r^2 \leq 0.27$) to the axes scores in any ordination. Toxicity endpoints and environmental variables contributing most to the ordination are shown as vectors in each figure. Total mercury is not a significant variable in any ordination and therefore is not shown in the figures.

Peninsula Harbour sites fall into the following bands:

Band 1 (non-toxic): **28 sites**

The majority of sites are located in Band 1 (Appendix C; Figures C1 – C3). All Jellicoe Cove sites with the exception of site A1 are non-toxic.

Band 2 (potentially toxic): **0 sites**

Band 3 (toxic): **1 site**

Site 66, located outside of Jellicoe Cove, is associated with low amphipod survival; the site is located along the same vector line as *Hyalella* survival (Hasu) in the opposite direction (Appendix C; Figure C1).

Band 4 (severely toxic): **4 sites**

One site is in Jellicoe Cove (A1), and three are outside of Jellicoe Cove (60, 65 and 71) (Appendix C; Figures C1 and C2). Site A1 is associated with low amphipod and midge survival; the *Hyalella* survival (Hasu) and *Chironomus* survival (Crsu) vectors are orientated along similar vector line but in opposite direction to site A1 (Figure D2). Increased clay (shown as a vector in Figure C1) is correlated to the location of site A1 outside the reference group. Sites 60, 65 and 71 are associated with low amphipod survival; the *Hyalella* survival (Hasu) vector is located along the same vector line as sites in the opposite direction (Figure C1). Sediment total nitrogen is the most highly correlated environmental variable ($r^2 = 0.24$), and the sites are located along a gradient of decreasing total nitrogen (shown as vector). Increased Fe (as Fe_2O_3), P (as P_2O_5), Na (as Na_2O) and sediment total phosphorus are associated with these sites although correlations are not high (r^2 range: 0.12 – 0.16).

3.4 Quality Assurance/Quality Control

Field Replication

Variability among field replicated sites (B5, 64, 67, and 71), expressed as the coefficient of variation (CV), is shown in Appendix D; Table D1. Coefficients of variation range from 0.14 to 93 % (median 5.2 %), not uncommon for field-replicated samples (samples were taken from three separate box core drops). Differences in variability are seen among sites and among the parameter from the same site. The highest variability is noted for lead measurement, with CV's ranging from 30 to 93%, and for copper and total mercury, with CVs ranging from 6 to 76% and from 4 to 45% respectively.

Analytical

Data for Flett Research laboratory duplicates and matrix spike recoveries are shown in Appendix D; Table D2. Recoveries for samples are good, ranging from 78.4 to 92.1% (mean 84.4%). The relative percent difference for duplicate analyses range from 0 to 27% (mean 10.9%), and recoveries for matrix spikes range from 68.1 to 104.6% (mean 84.4%).

Benthic Sorting Efficiency

The mean percent sorting efficiency for Peninsula Harbour community samples is 2.6 %, which is an acceptable level (≤ 5%). The value (2.6%) represents the overall average for four sorters over a six month period.

4 CONCLUSIONS

The assessments of community and toxicity are summarized in Table 9. Trace metals and nutrients exceeding provincial LELs and SELs are included. Spatial maps indicating levels of toxicity and community alteration compared to reference are shown in Figures 4 and 5.

Chemistry

Mercury levels are elevated in Peninsula Harbour, especially in Jellicoe Cove. The Severe Effect Level for total mercury (2.0 µg/g) is exceeded at 13 of the 21 sites in Jellicoe Cove and at 3 of the 12 sites outside of the cove. The highest total mercury in Jellicoe Cove (site H5) exceeds the highest observed outside of the cove (site 67) by ~8×. Evidence suggests a local source of mercury to Jellicoe Cove. Other trace metal concentrations in the harbour are low generally. Total organic carbon is elevated in Jellicoe Cove compared to other areas in the Harbour and to the Great Lakes reference mean.

Benthic Community Structure

Generally, benthic invertebrate communities in Jellicoe Cove are "different" than reference (Figure 4) and data show a trend towards greater diversity and abundance of taxa in the cove, indicative of enrichment. Enrichment is likely due to the high organic matter present in the sediment. Benthic communities at sites located outside Jellicoe Cove are more similar to reference sites (Figure 4).

Toxicity

There is strong evidence of toxicity at five sites (A1, 60, 65, 66 and 71) (Figure 5). Total mercury concentrations at these sites are fairly low (site 66 has the highest concentration at 0.72 µg/g dw), and methyl mercury concentrations are either 0 (site A1) or were not measured (sites 60, 65, 66 and 71). Toxicity, observed mainly for *Hyalella*, may be substrate related in some cases (sites A1 and 60 consist of a high proportion of compact clay, and site 71 of sand), or perhaps an unmeasured stressor(s) (organic contaminants were not analyzed). Toxicity does not appear to be related to sediment mercury concentrations.

5 RECOMMENDATIONS

While there is no conclusive evidence of mercury toxicity as measured by laboratory toxicity tests or impairment of resident benthic communities due to mercury, mercury levels are nonetheless elevated, most notably in Jellicoe Cove. Mercury is likely accumulating in the tissues of resident benthic invertebrates, but to what level is not known. The potential risk to higher trophic organisms (consumers of benthic invertebrates and their predators) through biomagnification is ultimately of major concern in areas where persistent biomagnifiable substances such as mercury are present.

A study examining mercury bioaccumulation in resident biota and the evaluation of the potential risk of adverse effects to higher trophic level organisms due to biomagnification is recommended, specifically in Jellicoe Cove, the area of highest sediment mercury contamination (the area of historic mercury discharges). This additional component of information along with the three components already assessed in the current study is required to make a decision on sediment quality and the need to remediate, a rule-based weight of evidence approach developed by Environment Canada and Ontario Ministry of Environment scientists (Grapentine et al. 2002). The study should include body burden measurements in several distinct resident taxa, as accumulation can vary depending on the taxon.

Table 9. Summary of BEAST evaluation of community structure and sediment toxicity. Environmental variables exceeding the Lowest Effect Level (LEL) and Severe Effect Level (SEL) are indicated.

Site	BEAST Assessment Band		>LEL	>SEL
	Community	Toxicity		
A1	4	4	Cr, Cu, Fe, Mn, Ni	-
A2	3	1	-	-
A5	2	1	Cr, Cu, Hg, Ni, TN, TOC	Hg
B5	4	1	Cr, Cu, Hg, Ni, TOC	Hg
C3	3	1	TOC	-
C6	4	1	Cr	-
D1	3	1	Cr, TOC	-
D4	3	1	Cr, Hg, TN, TOC	Hg
D5	3	1	Cr, Cu, Ni, Hg, TN, TOC	Hg
E3	3	1	Cr, TN, TOC	-
E5	4	1	Cr, Cu, Hg, Ni, TN, TOC	Hg
F2	3	1	TN, TOC	TOC
F4	3	1	Cr, Cu, Hg, Ni, TN, TOC	Hg
G3	4	1	Cr, Cu, Hg, Ni, TN, TOC	Hg
G5	3	1	Cr, Cu, Hg, Ni, TN, TOC	Hg
G6	3	1	Cr, Hg, TOC	Hg
H3	3	1	Cr, Cu, Hg, Ni, TN, TOC	Hg
H5	3	1	Cr, Hg, Ni, TN, TOC	Hg
I5	3	1	Hg	Hg
57	4	1	Cr, TP, Zn	-
58	2	1	Cr, Cu, Hg, Ni, TOC	Hg
59	1	1	Cr, Cu, Hg, Ni, TN, TOC	Hg
60	2	4	Cr, Cu, Fe, Mn, Ni	-
61	1	1	Cr, Cu, Fe, Hg, Mn, Ni, TN, TOC, TP	Hg, Mn
62	1	1	Cr, Cu, Ni, TN, TOC	-
64	1	1	Cr, Cu, Ni, TN, TOC	-
65	2	4	Cr, Cu, Mn, Ni, TN, TP	-
66	2	3	Cr, Cu, Mn, Ni	-
67	1	1	Cr, Cu, Hg, Ni, TN, TOC	Hg
68	1	1	Cd, Cr, Cu, Mn, Ni, TN, TOC	-
70	2	1	Cr, Cu, Ni, TOC	-
71	2	4	TP	-
289	2	1	Cr, Cu, Ni, TN, TOC	-

BEAST Bands: 1 =unstressed/non-toxic; 2 =possibly different/potentially toxic; 3= different/toxic; 4 =very different/severely toxic

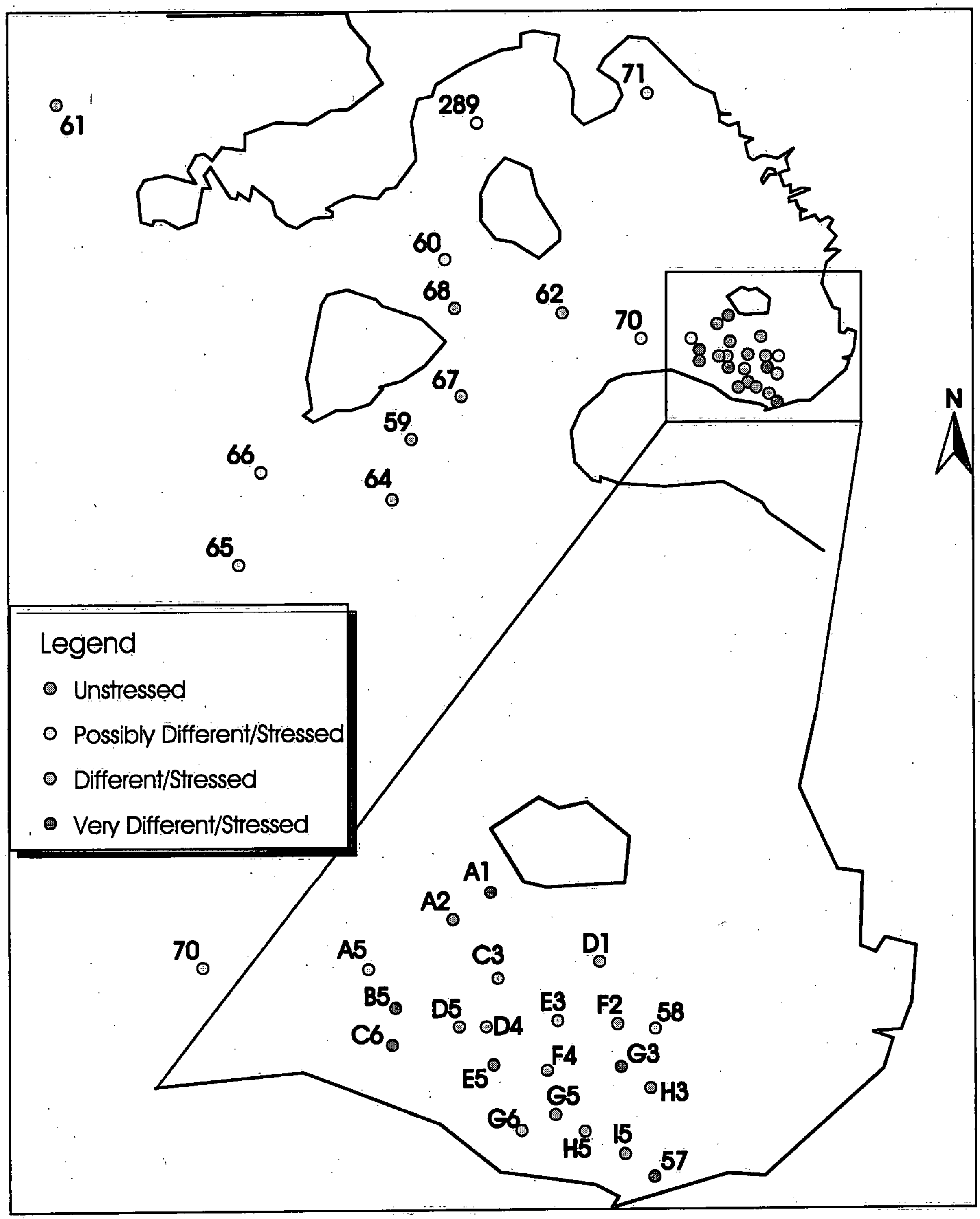

Figure 4. Spatial distribution of test sites indicating the level of benthic community alteration compared to Great Lakes reference sites.

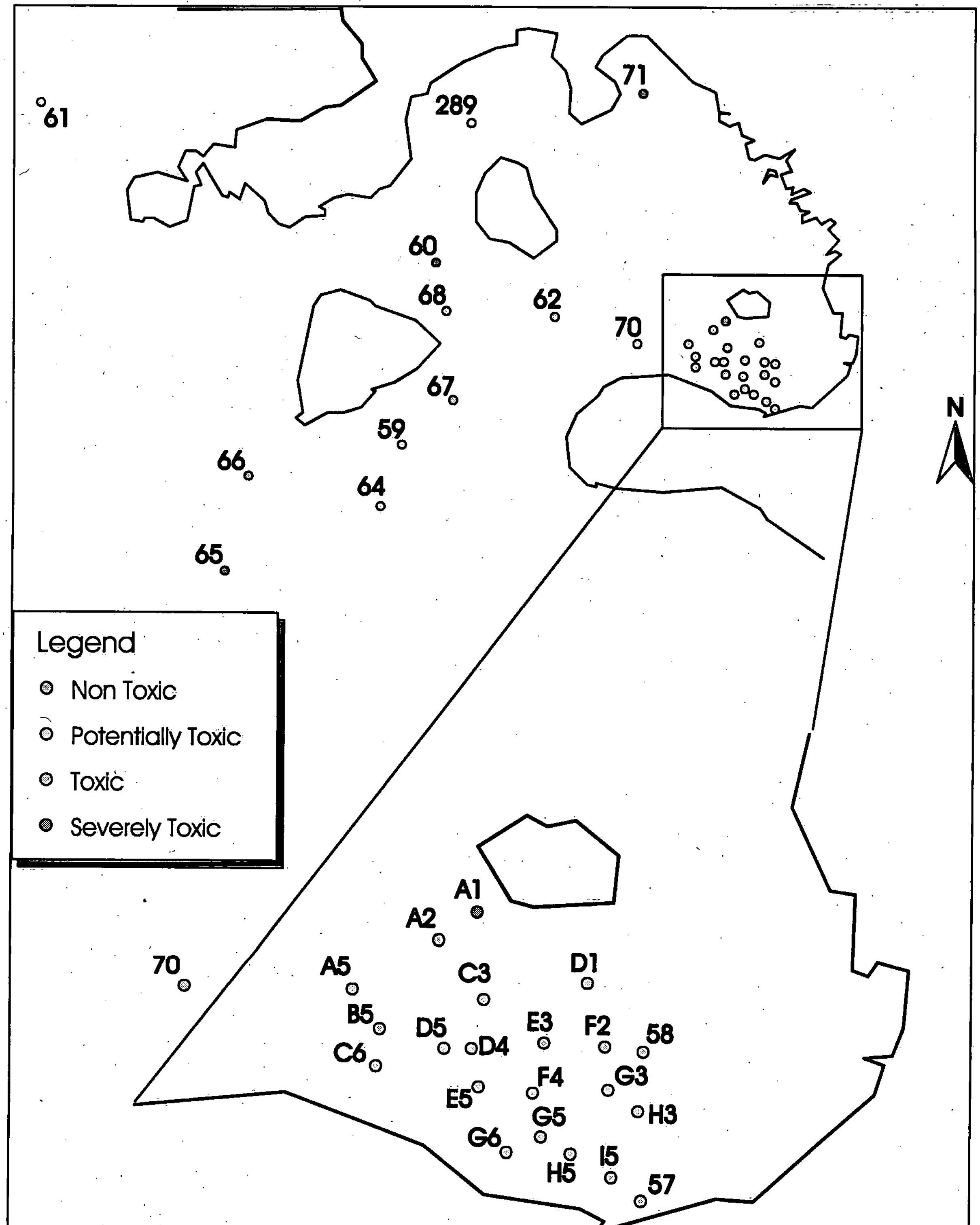

Figure 5. Spatial distribution of test sites indicating the level of toxicity compared to Great Lakes reference sites.

6 REFERENCES

ASTM (American Society for Testing & Materials) 1995. Standard test methods for measuring the toxicity of sediment-associated contaminants with freshwater invertebrates. In: Annual Book of ASTM Standards, Vol. 11.05, Philadelphia, PA, pp. 1204-1285.

Bedard, D., A. Hayton and D. Persaud. 1992. Ontario Ministry of the Environment laboratory sediment biological testing protocol. Water Resources Branch, Ontario Ministry of the Environment, Toronto, Ontario, Canada.

Belbin, L. 1993. PATN, pattern analysis package. Division of Wildlife and Ecology, CSIRO, Canberra, Australia.

Blatant Fabrications Pty Ltd. 2001. PATN Version 3.03. December 2, 2004.

Bloom, N.S., and E.A. Crecelius. 1983. Determination of mercury in seawater at sub-nanogram per liter levels. Marine Chemistry, 14: 49-59.

Borgmann, U., and M. Munawar. 1989. A new standardised sediment bioassay protocol using the amphipod *Hyalella azteca* (Saussure). Hydrobiol.188/189: 425-431.

Borgmann, U., K.M. Ralph, and W.P. Norwood. 1989. Toxicity Test Procedures *for Hyalella azteca*, and Chronic Toxicity of Cadmium and Pentachlorophenol to *H. azteca*, *Gammarus fasciatus*, and *Daphnia magna*. Arch. Environ. Contam. Toxicol. 18: 756-764.

Burt, A. and J. Fitchko. 2001. Jellicoe Cove and Carden Cove Sediment Quality Investigation, 18 p. In: J. Fitchko [Ed.] Peninsula Harbour Feasibility Study Phase II Comprehensive Site Investigation. Interim Report No. 2. Beak International Incorporated Report to the Town of Marathon.

Day, K.E., R.S. Kirby, and T.B. Reynoldson. 1994. Sexual dimorphism in *Chironomus riparius* (Meigan): Impact on interpretation of growth in whole sediment toxicity tests. Eviron. Toxicol. Chem. 13: 35-39.

Duncan, G.A., and G.G. LaHaie. 1979. Size analysis procedures in the sedimentology laboratory. National Water Research Institute Manual. Environment Canada, Burlington, Ontario.

Grapentine, L.C., J. Anderson, D. Boyd, G.A.Burton, C. DeBarros, G. Johnson, C. Marvin, D. Milani, S. Painter, T. Pascoe, T. Reynoldson, L. Richman, K. Solomon, and P.M Chapman. 2002. A decision making framework for sediment assessment developed for the Great Lakes. Hum. Ecol. Risk Assess. 8: 1641 – 1655.

Horvat M., L. Liang, and N. Bloom. 1993. Comparison of distillation with other current isolation methods for the determination of methyl mercury compounds in low level environmental samples. Part II. Water. Anal. Chim. Acta, 282: 153 - 168.

Krantzberg, G. 1990. Sediment bioassay research and development. PDF03. Ontario Ministry of the Environment Research Advisory Committee, Toronto, Ontario, Canada.

Liang, L., N.S. Bloom, and M. Horvat. 1994. Simultaneous determination of mercury speciation in biological materials by GC/CVAFS after ethylation and room temperature precollection. Clin. Chem. 40: 602.

Manly, B.F.J. 1991. Randomization and Monte Carlo methods in biology. Chapman & Hall, London. 281 p. In: Belbin, L. 1993. PATN, pattern analysis package. Division of Wildlife and Ecology, CSIRO, Canberra, Australia.

NLET (National Laboratory for Environmental Testing) 2000. Schedule of services 2000-01. Environment Canada. National Water Research Institute, Burlington, Ontario.

Peninsula Harbour RAP Team. 1991. Stage 1:Environmental conditions and problem definition. ISBN: 0-7729-9035-2.

Peninsula Harbour RAP Team. 1998. Stage 2: Remedial strategies for ecosystem restoration (draft). 54 pp. + Appendices.

Persaud, D., R. Jaagumagi, and A. Hayton. 1992. Guidelines for the protection and management of aquatic sediment quality in Ontario. ISBN 0-7729-9248-7. Ontario Ministry of the Environment, Water Resources Branch, Toronto.

Reynoldson, T.B., S.P. Thompson, and J.L. Bamsey. 1991. A sediment bioassay using the tubificid oligochaete worm *Tubifex tubifex*. Environ. Toxicol. Chem. 10: 1061-1072.

Reynoldson T. B., R.C. Bailey, K.E. Day and R.H. Norris. 1995. Biological guidelines for freshwater sediment based on benthic assessment of sediment (the BEAST) using a multivariate approach for predicting biological state. Aust. J. Ecol. 20: 198-219.

Reynoldson, T.B., C. Logan, T. Pascoe and S.P. Thompson. 1998a. Methods Manual II: Lake Invertebrate sampling for reference-condition databases. National Water Research Institute, Burlington, Ontario, Canada.

Reynoldson, T.B., C. Logan, D. Milani, T. Pascoe, and S.P. Thompson. 1998b. Methods Manual IV: Sediment toxicity testing, field and laboratory methods and data management. NWRI Report No. 99-212.

Reynoldson, T.B., C. Logan, D. Milani, T. Pascoe, and S.P. Thompson. 1998c. Methods Manual III: Laboratory procedures for sample management. National Water Research Institute, Burlington , Ontario, Canada.

Reynoldson, T.B. and K.E. Day. 1998. Biological guidelines for the assessment of sediment quality in the Laurentian Great Lakes. National Water Research Institute, Burlington, Ontario, Canada. NWRI Report No. 98-232.

Reynoldson, T.B., K.E. Day, and T. Pascoe. 2000. The development of the BEAST: a predictive approach for assessing sediment quality in the North American Great Lakes. In: Assessing the biological quality of fresh waters. RIVPACS and other techniques. J.F. Wright, D.W. Sutcliffe, and M.T. Furse (Eds). Freshwater Biological Association, UK. pp. 165 – 180.

Sibley, P.K., D.R. Barton, and D.G. Dixon. 1991. A review of benthic invertebrate surveys in Peninsula Harbour and adjacent nearshore waters of Lake Superior, 1969 –1989. Technical Report No.10. Prepared for the North Shore of Lake Superior RAP. 170 pp.

Smith, I.R. 1992. 1991 Peninsula Harbour sediment study. Great Lakes section, Ontario Ministry of Environment and Energy, Toronto, Ontario. 40 pp.

SYSTAT Software Inc. 2002. SYSTAT Version 10.2.

USEPA/CE (United States Environmental Protection Agency/Corps of Engineers). 1981. Procedures for handling and chemical analysis of sediment and water samples. Environmental laboratory, US Army Engineer Waterways Experiment Station, Vicksburg, Mississippi, pp 3-118. EPA/CE-81-1.

USEPA (U.S. Environmental Protection Agency). 1994. Methods for measuring the toxicity and bioaccumulation of sediment associated contaminants with freshwater invertebrates. Office of Research and Development, Report EPA/600/R-94/024.

APPENDIX A Invertebrate Family Level Identification

Table A1. Macroinvertebrate family level identification in Peninsula Harbour samples.

Family	A1	A2	A5	B5	C3	C6	D1	D4
Asellidae	0.03	0.00	12.20	0.00	10.62	3.09	17.34	3.40
Ceratopogonidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Chironomidae	17.39	11.20	9.00	28.80	10.43	54.26	14.94	16.60
Dreissenidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Enchytraeidae	0.15	1.64	0.00	2.00	0.00	0.07	0.08	0.00
Erpobdellidae	0.00	0.00	0.00	0.00	0.00	0.00	0.11	0.00
Gammaridae	0.00	0.00	0.00	0.00	1.56	0.00	7.15	0.00
Glossiphoniidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Haustoriidae	0.80	1.66	5.40	3.60	0.81	3.51	1.30	1.00
Hydrobiidae	0.00	0.03	0.00	0.00	0.00	0.12	0.00	0.20
Leptoceridae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Lumbriculidae	1.04	4.21	0.20	5.20	0.59	1.53	0.66	0.80
Lymnaeidae	0.00	0.03	0.00	0.00	0.10	0.00	0.00	0.00
Naididae	2.13	11.11	0.20	19.60	1.91	4.62	0.37	9.80
Piscicolidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Planorbidae	0.00	0.09	0.00	0.00	0.29	0.00	0.00	0.00
Sphaeriidae	0.27	1.61	15.20	10.20	7.97	5.93	9.80	3.60
Tubificidae	4.10	4.14	24.20	15.00	17.40	5.63	11.96	16.20
Valvatidae	1.81	0.42	0.40	2.00	0.32	2.88	0.42	1.20

Family	D5	E3	E5	F2	F4	G3	G5	G6
Asellidae	2.60	25.60	12.20	6.52	3.60	46.40	9.86	2.58
Ceratopogonidae	0.00	0.20	0.00	0.00	0.00	0.00	0.00	0.00
Chironomidae	38.00	8.80	55.40	3.65	30.60	27.20	16.03	37.03
Dreissenidae	0.00	0.20	0.00	0.00	0.00	0.00	0.00	0.00
Enchytraeidae	0.00	0.00	0.20	0.00	0.00	0.00	0.00	0.04
Erpobdellidae	0.00	0.20	0.60	0.00	0.00	0.00	0.00	0.00
Gammaridae	0.00	5.60	0.00	2.42	0.00	4.00	5.26	3.07
Glossiphoniidae	0.00	0.00	0.00	0.00	0.00	0.00	0.36	0.03
Haustoriidae	1.40	0.00	2.40	0.18	1.60	2.00	0.00	0.30
Hydrobiidae	0.00	0.00	0.00	0.00	0.40	0.00	0.16	0.00
Leptoceridae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Lumbriculidae	0.00	0.80	0.00	3.18	0.00	0.00	0.19	1.95
Lymnaeidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Naididae	10.60	13.80	24.40	3.12	13.80	6.80	1.00	6.70
Piscicolidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Planorbidae	0.00	0.00	0.00	0.00	0.40	0.60	7.24	0.97
Sphaeriidae	5.60	20.00	20.40	6.21	9.40	19.60	9.31	2.74
Tubificidae	32.20	17.40	30.80	9.97	13.80	15.20	18.80	6.69
Valvatidae	2.40	0.20	6.80	0.15	12.40	6.60	4.04	1.52

Table A1. Continued.

Family	H3	H5	I5	57	58	59	60	61	62
Asellidae	9.40	11.77	0.36	0.03	0.40	0.00	0.00	0.00	0.00
Ceratopogonidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Chironomidae	24.20	33.80	29.38	21.85	23.00	2.00	8.34	0.00	2.40
Dreissenidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Enchytraeidae	0.00	0.04	0.00	0.37	1.00	0.00	0.55	0.00	0.20
Erpobdellidae	0.40	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Gammaridae	0.00	6.63	0.00	0.06	0.00	0.00	0.00	0.00	0.00
Glossiphoniidae	0.20	0.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Haustoriidae	1.80	0.00	1.31	0.09	5.40	4.20	3.71	6.20	7.20
Hydrobiidae	0.20	0.53	0.21	0.00	0.40	0.00	0.00	0.00	0.00
Leptoceridae	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00
Lumbriculidae	0.00	0.15	2.35	1.57	1.60	4.00	1.73	0.20	2.80
Lymnaeidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Naididae	2.80	1.60	5.97	8.58	23.40	0.00	0.08	0.00	0.60
Piscicolidae	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Planorbidae	2.40	3.36	0.12	0.00	0.00	0.00	0.00	0.00	0.00
Sphaeriidae	4.00	16.38	5.14	4.10	16.60	4.40	1.16	0.00	1.40
Tubificidae	4.20	15.81	2.27	2.46	18.80	0.00	0.39	8.20	23.20
Valvatidae	2.20	12.51	2.59	0.18	2.60	0.00	0.82	0.00	0.00

Family	64	65	66	67	68	70	71	289
Asellidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.80
Ceratopogonidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Chironomidae	0.40	0.40	0.40	1.34	4.40	17.80	1.30	11.20
Dreissenidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Enchytraeidae	0.00	2.20	2.40	0.00	0.00	0.00	3.00	0.00
Erpobdellidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Gammaridae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Glossiphoniidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Haustoriidae	6.20	2.80	3.40	5.11	6.00	6.20	1.22	4.40
Hydrobiidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Leptoceridae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Lumbriculidae	5.40	1.60	4.20	2.13	0.60	3.80	0.00	0.00
Lymnaeidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Naididae	0.00	0.20	0.00	0.00	0.20	1.00	0.67	0.20
Piscicolidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Planorbidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sphaeriidae	0.20	0.20	0.40	0.41	4.40	4.40	0.00	14.40
Tubificidae	0.00	0.00	0.00	5.03	9.60	22.20	0.11	9.00
Valvatidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.60

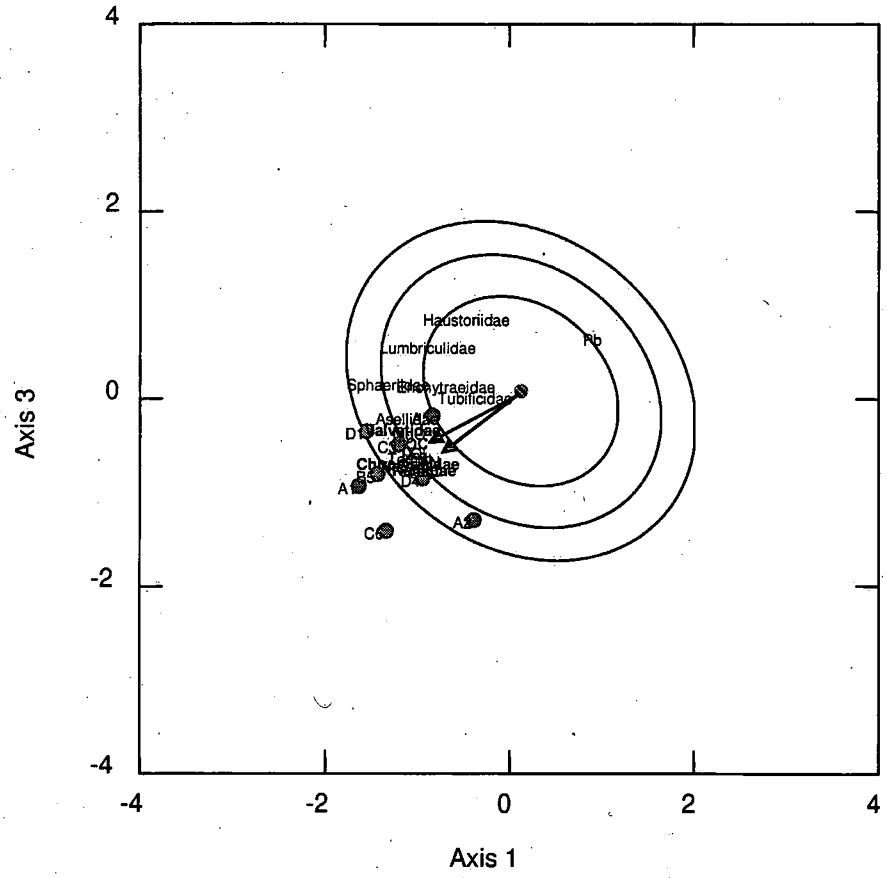

Figure B1. Ordination of a subset of test sites using benthic community structure data (family level) summarized on Axis 1 & 3 showing 90% (smallest ellipse), 99% (middle ellipse), and 99.9% (largest ellipse) probability ellipses around reference sites (not shown). Significant families and environmental variables are shown. The contribution of most significant families and environmental variables are shown as vectors. Stress = 0.165.

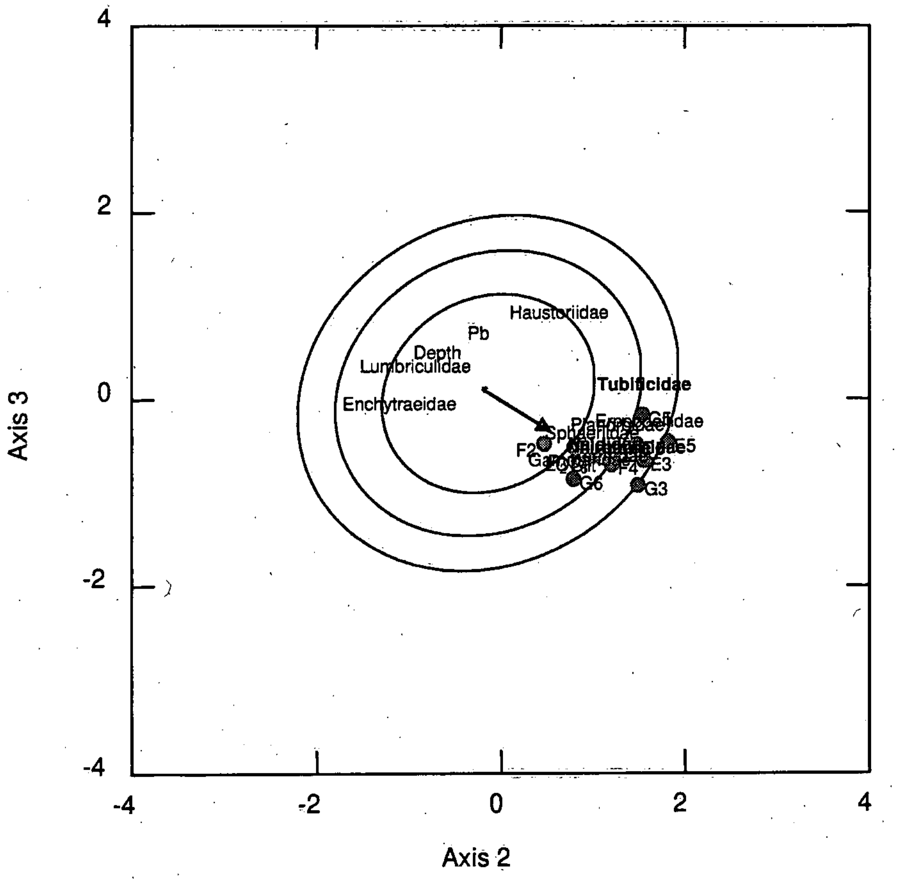

Figure B2. Ordination of a subset of test sites using benthic community structure data (family level) summarized on Axis 2 & 3 showing 90% (smallest ellipse), 99% (middle ellipse), and 99.9% (largest ellipse) probability ellipses around reference sites (not shown). Significant families and environmental variables are shown. Stress = 0.147.

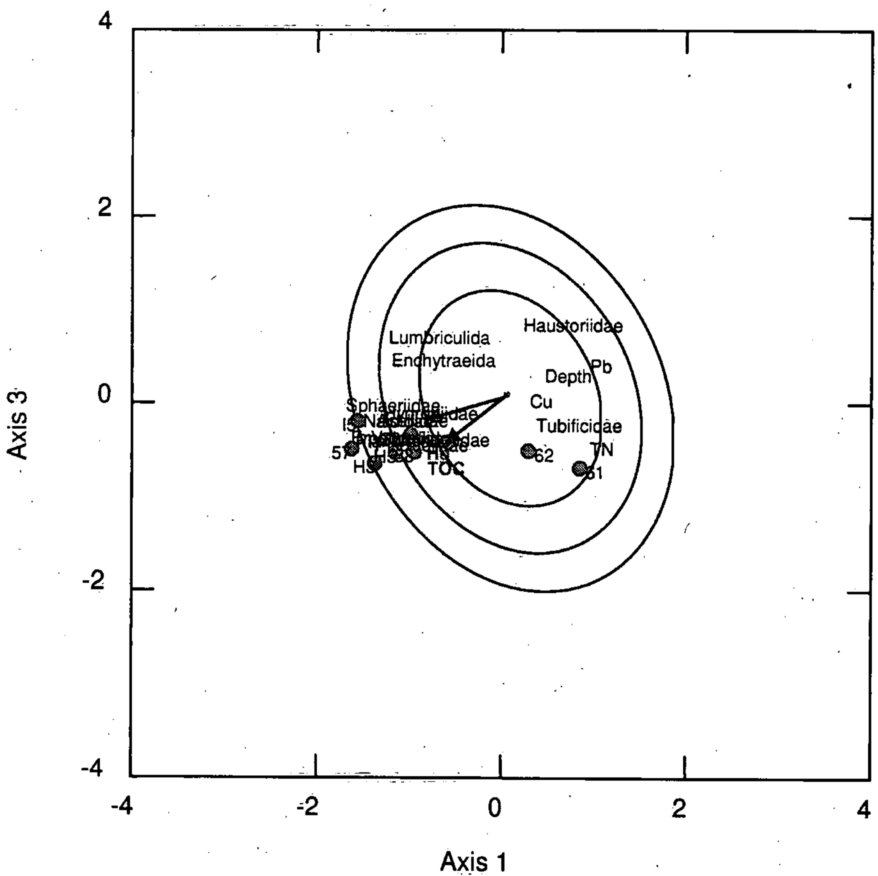

Figure B3. Ordination of a subset of test sites using benthic community structure data (family level) summarized on Axis 1 & 3 showing 90% (smallest ellipse), 99% (middle ellipse), and 99.9% (largest ellipse) probability ellipses around reference sites (not shown). Significant families and environmental variables are shown. The contribution of most significant families and environmental variables are shown as vectors. Stress = 0.161.

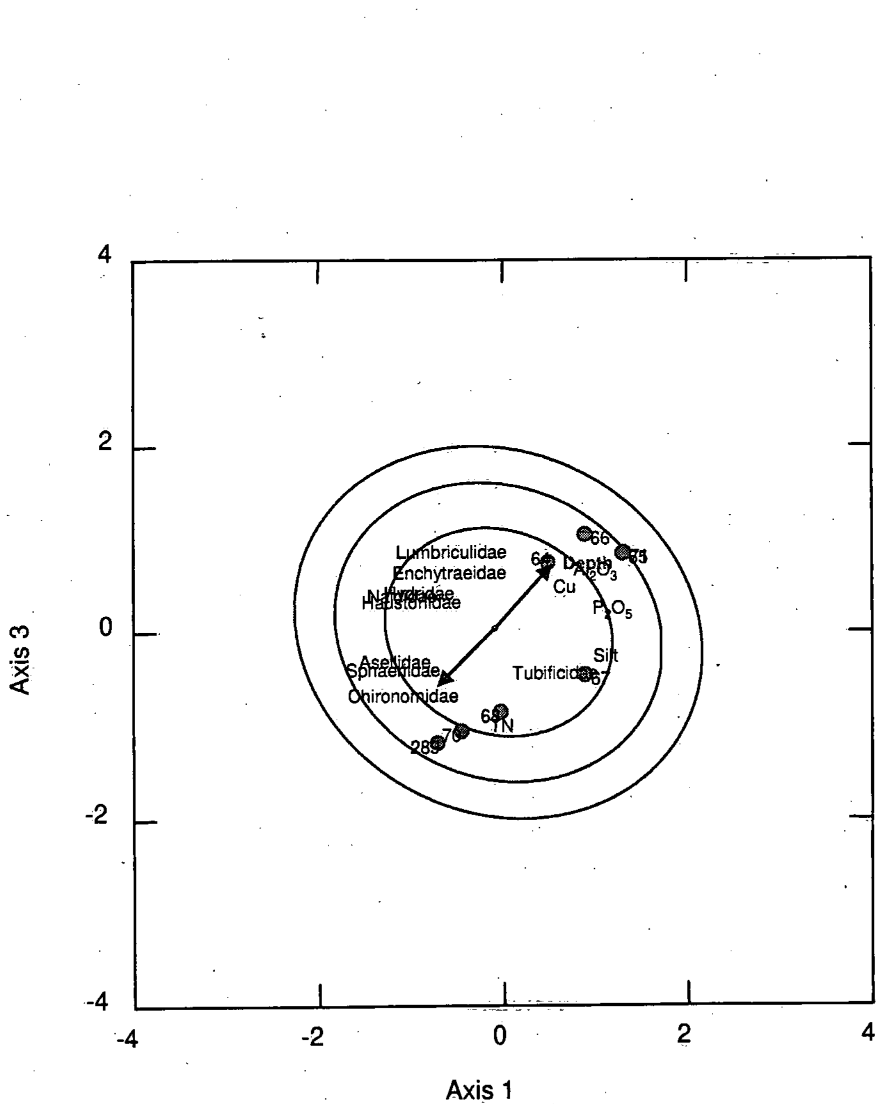

Figure B4. Ordination of a subset of test sites using benthic community structure data (family level) summarized on Axis 1 & 3 showing 90% (smallest ellipse), 99% (middle ellipse), and 99.9% (largest ellipse) probability ellipses around reference sites (not shown). Significant families and environmental variables are shown. The contribution of most significant families and environmental variables are shown as vectors. Stress = 0.164.

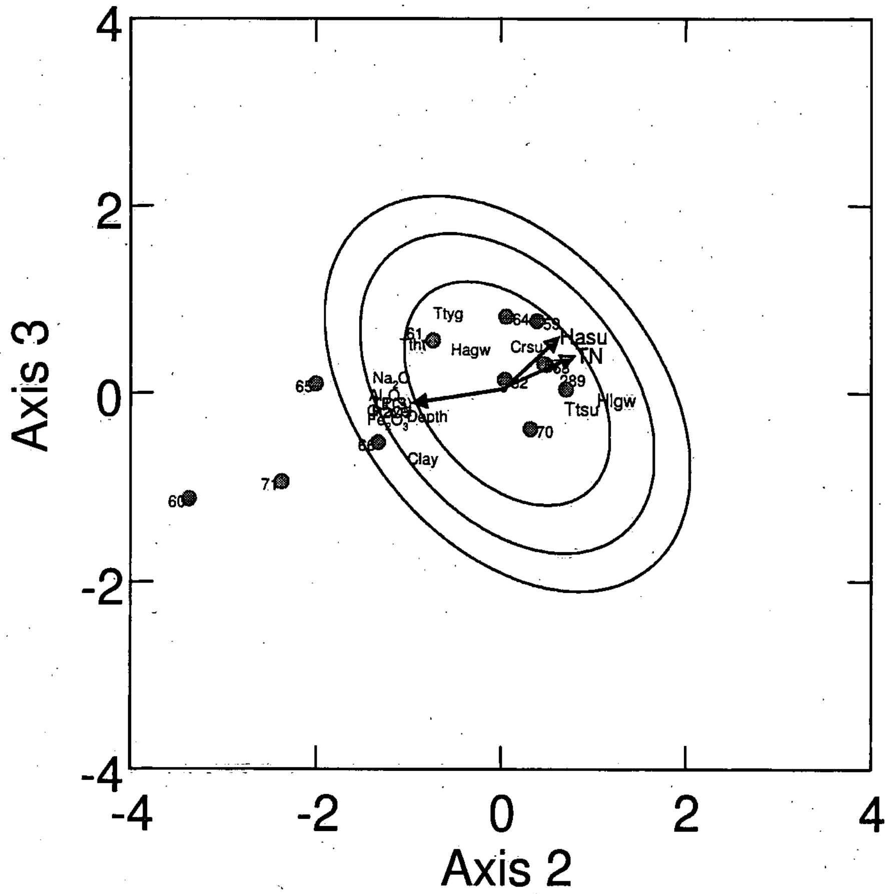

Figure C1. Assessment of a subset of test sites using ten toxicity test endpoints, showing 90%, 99%, and 99.9% probability ellipses around reference sites (not shown). The contributions of most significant toxicity endpoints and environmental variable(s) are shown with arrows. [*Tubifex* hatch (Ttht), *Hyalella* growth (Hagw), *Hyalella* survival (Hasu), *Tubifex* young production (Ttyg), *Chironomus* survival (Crsu), *Chironomus* growth (Crgw), *Hexagenia* growth (Hlgw)]. Stress level = 0.107.

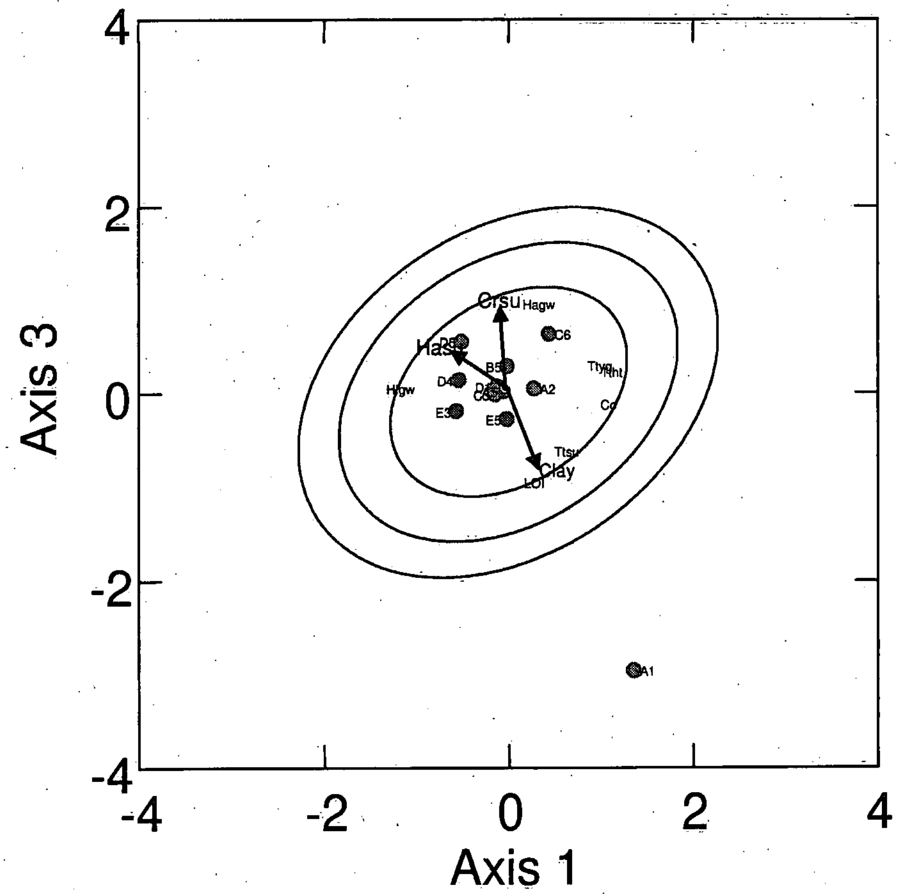

Figure C2. Assessment of a subset of test sites using 10 toxicity test endpoints, showing 90%, 99%, and 99.9% probability ellipses around reference sites (not shown). The contributions of most significant toxicity endpoints and environmental variable(s) are shown with arrows. [*Tubifex* hatch (Ttht), *Hyalella* growth (Hagw), *Hyalella* survival (Hasu), *Tubifex* young production (Ttyg), *Chironomus* survival (Crsu), *Chironomus* growth (Crgw), *Hexagenia* growth (Hlgw)]. Stress level = 0.102.

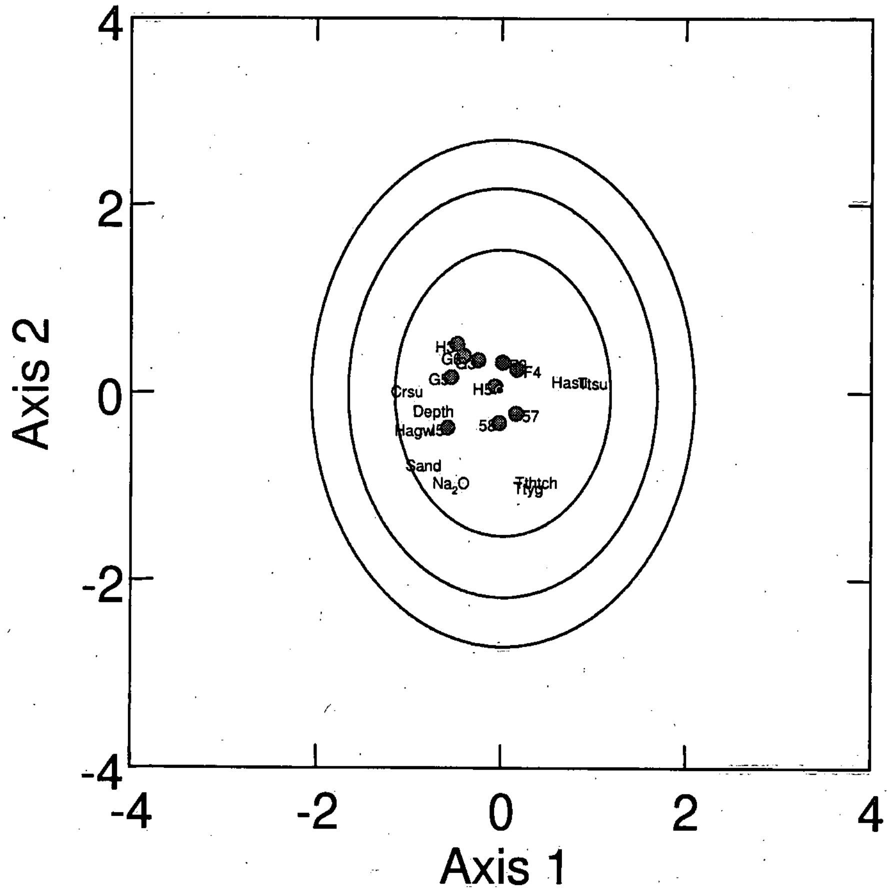

Figure C3. Assessment of a subset of test sites using ten toxicity test endpoints, showing 90%, 99%, and 99.9% probability ellipses around reference sites (not shown). The contributions of most significant toxicity endpoints and environmental variable(s) are shown with arrows. [*Tubifex* hatch (Ttht), *Hyalella* growth (Hagw), *Hyalella* survival (Hasu), *Tubifex* young production (Ttyg), *Chironomus* survival (Crsu), *Chironomus* growth (Crgw), *Hexagenia* growth (Hlgw)]. Stress level = 0.107.

Table D1. Variability in field replicated Peninsula Harbour sites.

Site	Al_2O_3	Alkalinity	CaO	Clay	Co	Cr	Cu	Fe_2O_3	Hg
64-1	10.688	40.300	5.450	12.060	7.551	36.890	35.850	3.306	1.530
64-2	10.658	40.300	5.516	11.810	7.552	36.524	32.840	3.495	1.680
64-3	11.380	40.800	4.450	13.790	7.199	35.017	20.615	3.471	0.616
Mean	10.909	40.467	5.139	12.553	7.434	36.143	29.768	3.424	1.275
SD	0.408	0.289	0.597	1.078	0.204	0.993	8.069	0.103	0.576
CV	**3.744**	**0.713**	**11.624**	**8.589**	**2.742**	**2.747**	**27.104**	**2.996**	**45.157**
67-1	10.461	40.400	5.637	8.610	6.801	38.280	26.663	3.115	2.330
67-2	10.190	40.400	6.000	10.900	6.650	32.864	25.131	3.120	2.410
67-3	10.558	40.300	5.672	9.240	6.385	31.709	23.673	3.202	2.210
Mean	10.403	40.367	5.770	9.583	6.612	34.284	25.155	3.145	2.317
SD	0.191	0.058	0.200	1.183	0.211	3.508	1.495	0.049	0.101
CV	**1.835**	**0.143**	**3.470**	**12.344**	**3.187**	**10.233**	**5.944**	**1.546**	**4.345**
71-1	11.686	41.500	3.340	0.000	2.402	19.811	5.564	3.967	0.038
71-2	12.141	41.700	2.996	0.000	2.125	17.177	1.814	2.766	0.033
71-3	11.571	41.600	3.113	0.000	2.272	16.664	1.545	3.596	0.035
Mean	11.799	41.600	3.150	0.000	2.266	17.884	2.974	3.443	0.035
SD	0.301	0.100	0.175	0.000	0.139	1.688	2.247	0.615	0.003
CV	**2.554**	**0.240**	**5.548**	**-**	**6.114**	**9.440**	**75.530**	**17.871**	**7.122**
B5-1	10.975	40.800	4.433	7.690	6.082	37.865	18.125	3.391	6.930
B5-2	11.209	40.400	4.126	8.130	5.921	31.542	14.618	3.471	4.400
B5-3	10.780	40.800	4.208	7.810	5.498	30.664	14.528	3.455	5.060
Mean	10.988	40.667	4.256	7.877	5.834	33.357	15.757	3.439	5.463
SD	0.215	0.231	0.159	0.227	0.302	3.929	2.052	0.042	1.312
CV	**1.954**	**0.568**	**3.739**	**2.888**	**5.174**	**11.778**	**13.020**	**1.231**	**24.021**

Table D1. Continued.

Site	K_2O	LOI	MgO	MnO	Na_2O	Ni	$NO3/NO_2$	P_2O_5	Pb	Sand
64-1	2.220	8.920	3.630	0.067	2.480	23.454	0.317	0.297	9.365	10.010
64-2	2.200	9.130	3.713	0.072	2.470	22.612	0.319	0.307	6.917	10.990
64-3	2.370	5.880	2.973	0.098	2.720	21.119	0.317	0.327	1.447	18.940
Mean	2.263	7.977	3.439	0.079	2.557	22.395	0.318	0.310	5.909	13.313
SD	0.093	1.819	0.406	0.017	0.142	1.182	0.001	0.015	4.054	4.897
CV	**4.105**	**22.802**	**11.793**	**21.356**	**5.536**	**5.280**	**0.363**	**4.973**	**68.598**	**36.786**
67-1	2.060	9.460	3.628	0.045	2.580	20.997	0.323	0.299	6.869	18.570
67-2	2.110	11.320	3.920	0.049	2.520	19.792	0.310	0.303	3.495	22.790
67-3	2.020	10.410	3.667	0.048	2.540	19.101	0.316	0.293	4.636	24.260
Mean	2.063	10.397	3.738	0.048	2.547	19.963	0.316	0.298	5.000	21.873
SD	0.045	0.930	0.159	0.002	0.031	0.959	0.007	0.005	1.716	2.954
CV	**2.185**	**8.946**	**4.243**	**3.910**	**1.200**	**4.806**	**2.057**	**1.652**	**34.326**	**13.504**
71-1	1.710	0.500	1.203	0.065	3.160	10.880	0.328	0.364	3.385	81.660
71-2	1.910	0.480	1.030	0.046	3.400	6.255	0.336	0.324	2.553	98.160
71-3	1.820	0.480	1.169	0.058	3.250	6.167	0.332	0.330	4.624	91.890
Mean	1.813	0.487	1.134	0.056	3.270	7.767	0.332	0.339	3.520	90.570
SD	0.100	0.012	0.092	0.010	0.121	2.696	0.004	0.022	1.042	8.329
CV	**5.524**	**2.373**	**8.107**	**17.635**	**3.708**	**34.712**	**1.205**	**6.419**	**29.599**	**9.196**
B5-1	1.990	7.560	2.662	0.041	2.830	20.717	0.319	0.290	0.500	52.590
B5-2	2.000	6.620	2.461	0.042	2.880	16.388	0.307	0.286	0.500	47.030
B5-3	1.870	6.930	2.574	0.041	2.750	15.998	0.330	0.278	2.243	50.890
Mean	1.953	7.037	2.565	0.041	2.820	17.701	0.319	0.285	1.081	50.170
SD	0.072	0.479	0.101	0.001	0.066	2.619	0.012	0.006	1.006	2.849
CV	**3.704**	**6.807**	**3.933**	**2.155**	**2.325**	**14.796**	**3.610**	**2.024**	**93.094**	**5.679**

Table D1.	Continued.

Site	Silt	SiO_2	TiO_2	TKN	TN	TOC	TP(Sed)	TP(Wat)	V	Zn
64-1	77.930	63.090	0.286	0.100	763.000	1.450	585.000	0.005	27.472	62.861
64-2	77.210	62.610	0.287	0.125	933.000	1.870	591.000	0.006	28.264	65.082
64-3	67.270	66.640	0.297	0.110	534.000	0.850	611.000	0.007	26.149	41.666
Mean	74.137	64.113	0.290	0.112	743.333	1.390	595.667	0.006	27.295	56.537
SD	5.958	2.201	0.006	0.013	200.226	0.513	13.614	0.001	1.069	12.926
CV	**8.036**	**3.433**	**2.016**	**11.268**	**26.936**	**36.881**	**2.285**	**12.354**	**3.916**	**22.862**
67-1	72.820	61.500	0.247	0.134	652.000	2.010	431.000	0.006	26.393	56.710
67-2	66.310	59.910	0.251	0.109	772.000	2.780	445.000	0.005	24.786	55.279
67-3	66.500	62.430	0.245	0.133	738.000	2.100	431.000	0.005	23.413	53.453
Mean	68.543	61.280	0.247	0.125	720.667	2.297	435.667	0.005	24.864	55.147
SD	3.705	1.274	0.003	0.014	61.849	0.421	8.083	0.000	1.492	1.633
CV	**5.405**	**2.080**	**1.194**	**11.293**	**8.582**	**18.331**	**1.855**	**9.800**	**6.000**	**2.960**
71-1	17.900	73.870	0.483	0.116	59.500	0.160	650.000	0.006	20.517	14.602
71-2	1.770	76.030	0.312	0.113	60.900	0.130	596.000	0.005	20.296	14.971
71-3	8.020	73.470	0.444	0.129	62.900	0.230	654.000	0.005	17.670	13.441
Mean	9.230	74.457	0.413	0.119	61.100	0.173	633.333	0.005	19.495	14.338
SD	8.133	1.377	0.090	0.009	1.709	0.051	32.393	0.000	1.584	0.799
CV	**88.113**	**1.850**	**21.684**	**7.127**	**2.797**	**29.605**	**5.115**	**6.797**	**8.124**	**5.570**
B5-1	39.720	66.420	0.228	0.107	465.000	2.220	433.000	0.006	25.104	63.964
B5-2	44.840	65.330	0.244	0.129	518.000	-	489.000	0.005	23.771	50.523
B5-3	41.290	66.910	0.231	0.127	516.000	1.960	508.000	0.007	23.314	52.415
Mean	41.950	66.220	0.234	0.121	499.667	2.090	476.667	0.006	24.063	55.634
SD	2.623	0.809	0.009	0.012	30.039	0.184	38.991	0.001	0.930	7.276
CV	**6.253**	**1.221**	**3.638**	**10.054**	**6.012**	**8.797**	**8.180**	**14.439**	**3.867**	**13.078**

Table D2. Laboratory QA/QC data for methyl mercury (Flett Research laboratory).

Samples		Duplicates				Matrix Spikes	
Site	Recovery (%)	Site	A2	G3	A1	Site	Recovery (%)
D4	78.4	Sample	1.42	9.51	0	D4	88.7
I5	78.4	Duplicate	2.21	10.37	0	I5	68.1
E5	78.4	RPD[1] (%)	27.1	5.7	0	B5	104.6
E3	78.4					F2	79.7
H5	78.4					G6	75.7
A5	78.4					G5	89.4
A2	78.4						
B5	92.1					**mean**	**84.4**
C3	92.1						
C6	92.1						
F2	92.1						
57	92.1						
58	92.1						
G3	92.1						
G5	82.6						
G6	82.6						
D1	82.6						
D5	82.6						
H3	82.6						
F4	82.6						
A1	82.6						
mean	**84.4**						

[1] RPD = Relative percent difference = $(x_1 - x_2)/ (x_1 + (x_2/2)) \times 100$

PRINTED IN CANADA ON RECYCLED PAPER
IMPRIMÉ AU CANADA SUR DU PAPIER RECYCLÉ

National Water Research Institute
Environment Canada
Canada Centre for Inland Waters
P.O. Box 5050
867 Lakeshore Road
Burlington, Ontario
L7R 4A6 Canada

National Hydrology Research Centre
11 Innovation Boulevard
Saskatoon, Saskatchewan
S7N 3H5 Canada

NATIONAL WATER RESEARCH INSTITUTE
INSTITUT NATIONAL DE RECHERCHE SUR LES EAUX

Institut national de recherche sur les eaux
Environnement Canada
Centre canadien des eaux intérieures
Case postale 5050
867, chemin Lakeshore
Burlington, Ontario
L7R 4A6 Canada

Centre national de recherche en hydrologie
11, boul. Innovation
Saskatoon, Saskatchewan
S7N 3H5 Canada

Environment Canada Environnement Canada

Canada