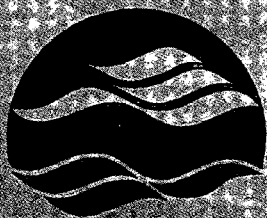




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**APPLICATION OF BEAST SEDIMENT
QUALITY GUIDELINES TO HAMILTON
HARBOUR, AN AREA OF CONCERN**

D. Milani and L.C. Grapentine

NWRI Contribution No. 06-407

**THE APPLICATION OF BEAST SEDIMENT QUALITY GUIDELINES
TO HAMILTON HARBOUR, AN AREA OF CONCERN**

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NWRI Contribution # 06-407

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EXECUTIVE SUMMARY

This report describes sediment quality in Hamilton Harbour (Lake Ontario), identified as an 'Area of Concern' due to water quality issues, aesthetics, trace metal and organic contamination, bacteria, and fish and wildlife stresses. The Benthic Assessment of Sediment (BEAST) methodology was applied to 44 sites in the Harbour in October of 2000. This methodology involves the assessment of sediment quality based on multivariate techniques using data on the physical and chemical attributes of the sediment and overlying water, benthic community structure, and the functional responses of laboratory organisms in toxicity tests. Data from test sites are compared to biological criteria developed for the Laurentian Great Lakes over a three year period. Relationships between toxicity and contaminant concentrations were also evaluated by regression analysis.

The sediment 'Severe Effect Level' is exceeded for several metals including manganese (29 sites), zinc (22 sites), iron (20 sites), copper (17 sites), lead (11 sites), chromium (9 sites), mercury (8 sites), arsenic (4 sites), and nickel (2 sites). Total polycyclic aromatic hydrocarbons (PAHs) in sediments range from 0.5 to 499 $\mu\text{g/g}$, with highest values at sites located in the Randle Reef area. Total polychlorinated biphenyls (PCBs) range from 0.07 to 6.2 $\mu\text{g/g}$, with the highest value observed in the Dofasco boat slip.

There is strong evidence of benthic community impairment at 27 sites and, in general, there is a tendency towards lower taxa diversity, increased abundance of tubificids (and naidiids in some cases), and decreased abundance of chironomids and other taxa. There is strong evidence of toxicity at 21 sites. The mayfly, *Hexagenia* spp., is the most sensitive organism, with low survival and/or growth evident at the majority of sites. Community alteration and toxicity are correlated with elevated levels of metals in sediment (Zn, Hg, Pb, Cu) and increased sediment and overlying water nutrients (total phosphorus and nitrogen, nitrates/nitrites, total organic carbon). Further examination of toxicity-contaminant relationships reveal that toxicity is not clearly related to one contaminant or group of contaminants. Several compounds of PAHs, PCBs (and perhaps Cu) appear jointly related the pattern of toxicity among sampling sites.

The lack of correlation of toxicity with any specific contaminant makes it difficult to set clean up criteria based on a chemical number(s). For the benthic community structure analysis, many test sites did not have a high probability of belonging to any of the Great Lakes reference community groups (reference sites are not a good match), and therefore results for these sites should be interpreted with caution. Most test sites have benthic communities that are *different* or *very different* than reference conditions and therefore offer little discriminatory power for prioritizing sites. It is therefore recommended that future sediment assessment work related to remedial efforts focus on toxicity tests, specifically the *Hexagenia* spp. and *Hyaella azteca* tests, as these two organisms are most strongly correlated to overall toxicity. The sampling coverage in the area of highest sediment contamination (Randle Reef area) is low; therefore, more detailed sampling is needed to adequately define levels of toxicity within the Randle Reef area.

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Abstract

This report describes sediment quality in Hamilton Harbour, identified as an 'Area of Concern' due primarily to organic and trace metal contamination in the sediment and poor water quality. The benthic assessment of sediment (BEAST) methodology was applied to 44 sites in the Harbour. The BEAST method 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 Hamilton Harbour sites were compared to biological criteria developed for the Laurentian Great Lakes. There are elevated levels of several metals and polycyclic aromatic hydrocarbons (PAHs - up to 499 µg/g), specifically in the Randle Reef area. Generally, benthic communities are different than reference at the majority of sites, with a tendency towards lower taxa diversity, increased abundance of oligochaete worms, and a lower abundance of other taxa at most sites. There is strong evidence of toxicity at about half the sites, with low survival and/or growth of the mayfly *Hexagenia* at the majority of these sites. Community alteration and toxicity are correlated with elevated levels of metals in sediment (Zn, Hg, Pb, Cu) and increased levels of overlying water (phosphorus and nitrogen) and sediment (total organic carbon) nutrients. Further examination of toxicity-contaminant relationships by regression analysis reveal that toxicity is not clearly related to one contaminant or group of contaminants. Several compounds of PAHs, PCBs (and perhaps Cu) appear jointly related the pattern of toxicity among sampling sites.

FRENCH VERSION

Milani, D., et L.C. Grapentine. 2006.. « ».

Résumé

Le rapport rend compte de la qualité des sédiments dans le port de Hamilton, identifié comme « secteur préoccupant », principalement à cause de la piètre qualité de l'eau et de la contamination des sédiments par des matières organiques et des métaux traces. Nous avons évalué la qualité des sédiments benthiques dans 44 sites du port en nous servant de la méthode BEAST (*BE*nthic *A*ssessment of *S*edimen*T*). BEAST permet l'évaluation de la qualité des sédiments benthiques d'après : des techniques d'analyses multivariées de données sur la structure de la communauté benthique, les réactions fonctionnelles d'organismes de laboratoire à divers tests de toxicité et les caractéristiques chimiques et physiques des sédiments et de l'eau les recouvrant. Nous avons comparé les données des sites du port de Hamilton aux critères biologiques élaborés pour les Grands Lacs laurentiens. Nous avons constaté des niveaux élevés de plusieurs métaux et d'hydrocarbures aromatiques polycycliques (HAP – jusqu'à 499 µg/g), surtout dans la zone du récif Randle. De façon générale, dans la majorité des sites, les communautés benthiques s'éloignaient des communautés de référence; la tendance observée étant une moins grande diversité des taxons, une plus grande abondance de vers oligochètes et une moins grande abondance des autres taxons. Il existe de fortes indications de toxicité dans près de la moitié des sites, avec un faible taux de survie ou de croissance de l'éphémère *Hexagenia* dans la majorité des sites. Nous avons pu mettre la toxicité et l'altération de la communauté en corrélation avec les niveaux élevés de métaux (Zn, Hg, Pb, Cu) dans les sédiments et les niveaux accrus de nutriments (phosphore et azote) dans les sédiments et l'eau les recouvrant. D'autres examens, par analyse de régression, des rapports entre la toxicité et les contaminants, nous ont appris que la toxicité n'est pas clairement liée à un seul contaminant ou groupe de contaminants. Plusieurs HAP et biphényles polychlorés (BPC) (et peut-être le Cu) semblent conjointement liés au type de toxicité relevé dans les sites d'échantillonnage.

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1 INTRODUCTION

1.1 Background and NWRI Mandate

In the 1970s, 42 locations in the Great Lakes where the aquatic environment was severely degraded were identified as "problem areas" by the International Joint Commission (IJC). Of these, 17 are along Canadian lakeshores or in boundary rivers shared by the US and Canada. The IJC's Great Lakes Water Quality Board recommended in 1985 that a Remedial Action Plan (RAP) be developed and implemented for each problem area. The RAP approach and process is described in the 1987 Protocol to the Great Lakes Water Quality Agreement (GLWQA). The goal is to restore the "beneficial uses" of the aquatic ecosystem in each problem area, which were now called "Areas of Concern" (AOCs). Fourteen possible "impairments of beneficial use", which could be caused by alterations of physical, chemical or biological conditions in the area, are defined in Annex 2 of the GLWQA.

The Canadian government's commitment to the GLWQA was renewed in 2000 with the Great Lakes Basin 2020 (GL2020) Action Plan, under which the efforts of eight federal departments to "restore, conserve, and protect the Great Lakes basin" over the next five years were to be co-ordinated. Environment Canada's contribution included the funding of detailed chemical and biological assessments of sediments in Canadian AOCs. The National Water Research Institute (NWRI) was given the responsibility of conducting and reporting on these assessments.

Under the terms of reference for NWRI's mandate, the Benthic Assessment of Sediment (BEAST) methodology of Reynoldson et al. (1995, 2000) was to be applied to the AOC assessments (see description below). The study described in this document was conducted to supplement existing data to complete an overall assessment of sediments in Hamilton Harbour that are, or have been, exposed to industrial effluents.

1.2 Benthic Assessment of Sediment

The BEAST is a predictive approach for assessing sediment quality in the Great Lakes using multivariate techniques (Reynoldson et al. 1995, 2000; Reynoldson and Day 1998). The approach utilizes data from nearshore reference sites that were sampled from the Laurentian Great Lakes over a three-year period. Information includes benthic community structure (the

type and number of invertebrate taxa present), selected habitat variables, and responses (survival, growth and reproduction) of four benthic invertebrates in laboratory toxicity tests. The reference sites establish normal conditions for selected endpoints, and determine the range of 'normal' biological variability. Expected biological conditions at test sites are predicted by applying relationships developed between biological and habitat conditions.

This assessment method has been used to assess the condition of benthic invertebrate communities and toxicity in a number of AOCs: e.g., Collingwood Harbour, St. Lawrence River (at Cornwall), Bay of Quinte and Peninsula Harbour (Reynoldson et al. 1995; Reynoldson 1998; Reynoldson and Day 1998; Milani and Grapentine 2004, 2005).

1.3 Hamilton Harbour Area of Concern

Hamilton Harbour has been the subject of two major RAP reports – Stage 1: Environmental conditions and problem definition (Hamilton Harbour RAP Team 1992) and Stage 2: Goals, options and recommendations (Hamilton Harbour RAP Team 1992).

Key environmental issues identified for Hamilton Harbour in the RAP reports include:

- Water quality,
- Aesthetics,
- Trace metal and organic contamination,
- Bacteria, and
- Fish and wildlife stresses.

Of the 12 beneficial use impairments identified for Hamilton Harbour, sediment has been associated as the source of the problem or the cause of impairment for the following 5:

- restriction on fish and wildlife consumption,
- degraded fish and wildlife,
- fish tumours,
- degradation of benthos, and
- restrictions on dredging activities.

While there have been improvements made in the Harbour over the years due to remedial efforts, sediment contamination due to elevated levels of ammonia, hydrogen sulphide, trace metals and organics still persists. Toxicity to benthic invertebrates and the presence of pollution tolerant benthic species as the result of urban and historical industrial pollution and eutrophication are an ongoing problem for the harbour (RAP Stage 2).

In October 2000, the National Water Research Institute (NWRI) of Environment Canada sampled Hamilton Harbour to define the general status of sediment contamination. This report presents the results of these investigations and provides a spatial description of the state of the sediments in the harbour and the degree of contamination.

2 METHODS

2.1 Sample Collection and Handling

Forty-five stations were sampled in Hamilton Harbour in October 2000. Station co-ordinates and site depth are provided in Table 1; site locations are shown in Figure 1. One site (7065) was later dropped due to the lack of sediment (site consisted of iron ore pellets). Site co-ordinates were obtained using a differentially corrected global positioning receiver (Magnavox MX300).

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

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

A 40 cm × 40 cm mini-box core (inserted into the sediment) was used to collect the sediment for benthic community and sediment chemistry samples. At each site, five benthic community

samples were subsampled from the box corer using 10 cm × 6.5 cm 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, homogenised in a Pyrex dish, and allocated to containers for chemical and physical analyses of sediment. At five sites (7008, 7021, 7043, 7050, and 70M252), the mini-box core could not be used because the high proportion of sand or sand/clay prevented the box core from sealing. At each of these sites, three sediment samples were collected for benthic community structure analysis and one for chemical and physical analyses using a Ponar grab. Each community structure sample 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. At one site (7060), sediment could not be obtained for toxicity test purposes due to the presence of zebra mussel shells, gravel and rocks, chunks of coal, and wood.

2.2 Taxonomic Identification

Benthic community samples were transferred to 70% ethanol after a minimum of 72 hours in formalin. Invertebrates were sorted for identification to the lowest practical level at the Invertebrate Laboratory at NWRI (Burlington, ON). 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 at the Ecotoxicology Laboratory at NWRI (Burlington, ON). Overlying water used in toxicity tests was 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 - 347 µS/cm; pH 7.5 - 8.5; hardness 120 - 140 mg/L; alkalinity 75 - 100 mg/L; chloride ion 22 - 27 mg/L.

Four sediment toxicity tests were performed: *Chironomus riparius* 10-d survival and growth, *Hyaella 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). For quality control purposes, each test set included control sediment, collected from Long Point Marsh, Lake Erie. All laboratory test organisms thrive in this sediment, which is comprised on average of 70.33% silt, 29.13% clay, 0.54% sand, and 8.1% organic carbon. All tests passed an acceptability criterion based on percent control survival in Long Point sediment before being included in a data set, i.e., $\geq 80\%$ for *H. azteca* and $\geq 70\%$ for *C. riparius* (USEPA 1994; ASTM 1995); $\geq 80\%$ for *Hexagenia* spp., and $\geq 75\%$ for *T. tubifex* (Reynoldson et al. 1998b).

Water chemistry variables (pH, dissolved oxygen (mg/L), conductivity ($\mu\text{S}/\text{cm}$), temperature ($^{\circ}\text{C}$), 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 $23^{\circ}\text{C} \pm 1^{\circ}\text{C}$, 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.

***Hyaella 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 dried at 60°C for 24 hours and dry weights recorded. Initial mayfly wet weights were converted to dry weights using the following

equation from a relationship for nymphs from the Ecotoxicology Lab that was previously determined by regression analysis: Initial dry weight = $[(\text{wet weight} + 1.15) / 7.35]$. Growth was determined by final dry weight minus 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 were counted from the 250- μm sieve. Survival and reproduction were 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 Analyses

Overlying water

Total Kjeldahl Nitrogen (TKN), nitrates/nitrites (NO_3/NO_2), total phosphorus (TP) and alkalinity were analyzed by the National Laboratory for Environmental Testing (NLET) (Burlington, ON) by procedures outlined in Cancilla (1994) and NLET (2000).

Sediment particle size

Particle size analysis (percents sand, silt, clay and gravel) was performed by the Sedimentology Laboratory at NWRI (Burlington, ON) following the procedures of Duncan and LaHaie (1979).

Sediment trace metals and nutrients

Freeze dried sediment was analysed for 29 trace elements (hot aqua regia extracted), major oxides (whole rock), 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.

Organic contaminants

Total polychlorinated biphenyls (PCBs) and polycyclic aromatic hydrocarbons (PAHs) were performed by PSC Analytical Services (Burlington, ON). Analyses of organo-chlorine pesticides (OCPs) and a suite of metals were performed on a subset of sites. Total PCBs methods are those of USEPA SW846 - 8082 modified, PAHs those of USEPA SW846 - 8270C modified, and OCPs those of USEPA SW846 - 8081A modified.

2.5 Data Analysis

2.5.1 BEAST analysis

For the benthic community structure assessment, a BEAST model was used to predict the range of community assemblages that should occur at each test site. Multiple discriminant analysis was used to predict the test sites to one of five reference community groups, based on a previously computed relationship between five environmental variables (latitude, longitude, depth, total organic carbon, and alkalinity) and the community groups (Reynoldson et al. 1995, 2000). For each test site the model assigned a probability it belonging to each of five 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). Test site observed community data were then merged with the reference site community data of the matched (group to which the test site had the highest probability of belonging) reference group, 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, which 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. Probability ellipses were constructed around reference sites only, establishing four categories of difference to reference: equivalent /non-toxic (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) (e.g., Figure 2).

Test data were analyzed in subsets, with the number of test sites analyzed in an ordination numbering $\leq 10\%$ 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).

2.5.2 Sediment toxicity and contaminant relationships

Relationships between sediment toxicity and sediment contamination were assessed graphically and by regression analysis. Initially, to examine general and dominant patterns in the data, comparisons between the toxicity responses and contaminant conditions were made based on integrative, compound variables (from either summation or multivariate ordination of measurement variables). After this, to better detect less dominant (though significant) relationships between two or a few variables, analyses were conducted using the original measurement variables (i.e., toxicity endpoints and concentrations of individual compounds).

Multiple measurements of sediment toxicity were ordinated by HMDS to produce descriptors of sediment toxicity. Euclidean distances were calculated for all pairs of 43 assessment sites based on the 10 toxicity variables (see above), then HMDS was performed on the matrix. To identify and relate the most important of the toxicity endpoints to the two HMDS axes, principal axis correlation was conducted. This procedure produced a vector for each toxicity endpoint along which the projections of sites in ordination space were maximally correlated.

Extractable concentrations of 11 metals (As, Cd, Cr, Cu, Fe, Hg, Mg, Mn, Ni, Pb, Zn) and total concentrations of 3 nutrients (nitrogen, organic carbon, phosphorus) were ordinated by principal components analysis (PCA). Data for all variables were $\ln(x)$ -transformed. The eigenanalysis

was performed on the correlation matrix. The PCB and PAH variables were integrated by summing the concentrations of the individual congeners.

The integrated descriptors of sediment toxicity (axes scores from the HMDS) were plotted against the contaminant descriptors (PCA scores, total PCBs, total PAHs (the latter two of which were $\ln(x)$ -transformed to improve linearity)). To determine whether toxicity was better explained by joint consideration of the contaminant descriptors, a multiple linear regression involving the three contaminant descriptors as predictors was calculated with each toxicity descriptor as the response variable.

Relationships among integrated (HMDS axes scores) and individual measurement (the most significant toxicity endpoints) variables were evaluated by plotting against concentrations of 11 metal, 3 nutrient, 2 PCB and 16 PAH (\ln -transformed) in sediment. The degree to which sediment contaminants account for toxicity was assessed by fitting regression models using best subset procedures (Draper and Smith 1998; Minitab 2000). Available predictors were the above contaminant and nutrient variables, plus mean sediment grain size. Models were fitted for (a) all combinations of metals and nutrients, (b) all combinations of PCBs, PAHs and mean grain size, and then (c) all combinations of the best predictors from the two groups. (This procedure was used to avoid computational difficulties arising from working with 33 predictors simultaneously.) The best models were those having maximum explanatory power, based on R^2_{adjusted} . Regressions and PCA were performed using the software Minitab (Minitab 2000).

2.6 Quality Assurance/Quality Control

Field replication At three randomly selected test sites (7015, 7040, and 7054), triplicate samples of overlying water and sediment were collected for determination of within-site and among-sample variability. Variability in a measured analyte was expressed as the coefficient of variation ($CV = \text{standard deviation} / \text{mean} \times 100$).

Analytical variability Quality control procedures for Caduceon Environmental Laboratory included repeat measurements, and control charting of influences, standards, and blanks. Reference material was used in each analytical run. Calibration standards were run before and after each run.

Run blanks and reference standards were run 1 in 20 samples, while repeats were run 1 in 10 samples. Quality control procedures for PSC analytical included matrix spike and surrogate spike recoveries, and internal standards.

An inter-laboratory comparison (Caduceon and Phillips Laboratories) of trace metals analyses was examined for a subset of sites. Data were compared by regression analysis. The slope of the regression line is a measure of the overall agreement in [metal] determinations, whereas the scatter of points about the line should indicate joint laboratory measurement error.

Benthic community sorting efficiency 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

3.1 Quality Assurance/Quality Control

Variability among site triplicates in a measured analyte has three sources: natural within-site heterogeneity in the distribution of the analyte in sediment or water, differences in handling among samples, and laboratory measurement error. Among-triplicate variability indicates the overall "error" associated with quantifying conditions at a site based on a single sample.

Field replication Variability among field replicated sites (7015, 7040 and 7054), expressed as the coefficient of variation (CV), is shown in Appendix A; Table A1. Excluding organic

contaminants, coefficients of variation range from 0 to 107 % (median 10 %), 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 site 7015, particularly in the particle size fractions of the sediment with CVs of 79, 107, and 104% for sand, silt, and clay, respectively. Metals such as mercury, arsenic and cadmium have the highest CVs (83, 70, and 69%, respectively) for site 7015. For organic contaminants, CVs range from 11 to 84% for PAHs, and from 22 to 81% for total PCBs, with again the highest variability noted for site 7015.

Analytical variability Results are not available for Caduceon laboratory. For PSC Analytical, results of PAH matrix spikes are shown in Appendix A; Table A2. Percent recoveries range from 32% (Benzo(b)fluoranthene) to 93% (Benzo(k)fluoranthene) (mean 68%). Matrix and surrogate spike recoveries for other compounds were not provided; however, the lab provided comments, which are listed in Appendix A. In some cases, spike recoveries were outside of control limits and surrogate recoveries were outside of acceptable limits. Matrix interferences were also noted in a few cases.

Inter-laboratory comparison Inter-laboratory comparisons of copper, lead, zinc, and iron for a subset of Hamilton Harbour sites are shown in Appendix A. These four metals were selected due to the elevated levels compared to other metals. Results show a strong agreement between measurements for copper and iron, a poor agreement for lead (due to 1 value), and a fair agreement for zinc: the slopes of PSC Analytical [metal]_{sed} vs. Caduceon [metal]_{sed} for copper, lead, zinc, and iron are 0.95, 0.49, 0.88, and 0.91, respectively. The percent explained variability (r^2) is 83.7 to 99.9%.

Sorting efficiency The mean percent sorting efficiency for Hamilton Harbour community samples is 3.2%, which is an acceptable level. The sorting efficiency represents the overall average for two sorters over nine months.

3.2 Sediment and Water Physico-Chemical Properties

Overlying water

Conditions of overlying water (0.5 m above the sediment) for Hamilton Harbour sites and the median of the reference sites are provided in Table 3. Test sites have higher levels of nutrients (phosphorus (TP), nitrogen (TKN), and NO_3/NO_2), and lower dissolved oxygen and pH values compared to reference sites. The ranges of dissolved oxygen, pH, conductivity, and alkalinity across sampling sites are 5 mg/L, 0.5 pH units, 223 $\mu\text{S}/\text{cm}$, and 117 mg/L, respectively.

Dissolved oxygen was ≥ 4.9 mg/L at all test sites. Site 70M268 (located at Windermere basin) has the highest levels of alkalinity, conductivity, TKN, and TP, and the lowest levels of oxygen.

Sediment particle size

Percents gravel, sand, silt and clay for Hamilton Harbour sediment are provided in Table 4.

Hamilton Harbour sediment consists mainly of silt (ranging from 0.4 to 85.4%, median 58.6%) and clay (ranging from 0 to 50.3%, median 21.9%), or sand (ranging from 0.4 to 99.0%, median 12.1%) and silt. Generally, test sites are siltier and have less clay than the reference sites (median: 37.9% and 32.0% for reference silt and clay, respectively); sand content is similar for test and reference sites (median 13.7%).

Sediment nutrients

Total phosphorus (TP), total nitrogen (TN), and total organic carbon (TOC) in Hamilton Harbour sediments are shown in Table 5. The provincial Severe Effect Level (SEL, Persaud et al. 1992) is exceeded at 14 sites for TP, at two sites for percent TOC, and at one site for TN. Total nitrogen in sediment ranges from 234 to 9080 $\mu\text{g}/\text{g}$ (median 2410 $\mu\text{g}/\text{g}$), TP ranges from 250 to 7020 $\mu\text{g}/\text{g}$ (median 1555 $\mu\text{g}/\text{g}$), and TOC ranges from 0.2 to 15.2% (median 3.8%). These values are higher than that observed at reference sites (median for TN, TP, and TOC = 1836 $\mu\text{g}/\text{g}$, 538 $\mu\text{g}/\text{g}$, and 2.0%, respectively). The highest TOC is at sites 7014 and 7053, located in the Ottawa Street slip, and the highest TN and TP concentrations is at site 70M268, located at the Windermere basin (see Figure 1).

Trace metals

Trace metal concentrations and the corresponding provincial Lowest Effect Level (LEL) and SEL (where available) are provided in Table 5. Most Hamilton Harbour sites have the 10 metals (that have sediment quality guidelines) greater than the LEL. Metals exceeding the SEL (highlighted in Table 5) include: manganese (Mn - 29 sites), zinc (Zn - 22 sites), iron (Fe - 20 sites), copper (Cu - 17 sites), lead (Pb - 11 sites), chromium (Cr - 9 sites), mercury (Hg - 8 sites), arsenic (As - 4 sites), and nickel (Ni - 2 sites). Cadmium is the only metal that does not exceed the SEL at any site. Manganese levels at test sites range from 283 to 3280 µg/g (median 1390 µg/g), Zn ranges from 31 to 3080 µg/g (median 861 µg/g), Fe ranges from 0.7 to 23.3% (median 3.8%), Cu ranges from 6 to 271 µg/g (median 92 µg/g), Cr ranges from 6.5 to 410 µg/g (median 63 µg/g), Hg ranges from 0.01 to 5.5 µg/g (median 0.3 µg/g), and Pb ranges from 0.5 to 666 µg/g (median 153 µg/g). Many sites are elevated in more than one metal, and metal levels at test sites are higher than those at Great Lakes reference sites. Reference medians (µg/g) for Zn, Cu, Pb and Hg are 105, 25, 38, and 0.05 µg/g, respectively (Table 5).

Organic contaminants

Total PCBS and PAHs are shown in Table 6 and individual congener and Aroclor results are provided in Appendix B; Tables B1 and B2. Total PAHs range from 0.5 to 498.7 µg/g (median 26.6 µg/g); the highest values are at sites in the Randle Reef area. High PAHs (395.6 µg/g) are also found in the Strathearne slip (site 7057). There are no PAH concentrations above the SEL (normalized to TOC) (Table 6). Total PCBs range from 0.07 to 6.17 µg/g (median 0.46 µg/g); highest total PCBs is in the Dofasco boat slip site (7054). No PCB concentrations are above the SEL (normalized to TOC) (Table 6). Organo-chlorine pesticides levels (analysed at a subset of Hamilton Harbour sites located in the Randle Reef area) are low (close to or below detection limits) (Appendix B; Table B3).

3.3 Community Structure

Cluster analysis of benthic invertebrate family abundances in samples previously collected from reference sites in the Laurentian Great Lakes region has established five different community assemblages (Reynoldson and Day 1998; Reynoldson et al. 2000). Based on a multiple discriminant analysis model relating habitat variables (latitude, longitude, depth, alkalinity, and

total organic carbon) to the reference benthic assemblages, 33 Hamilton Harbour sites are matched to reference Group 1, 4 to Group 2, 6 to Group 3, and 1 to Group 4 (Table 7). Many test sites do not have a high probability of reference group membership and some sites show equivocal results. Probabilities of reference group membership range from 35 to 99% (median 55%). There are 28 sites that have a < 60% probability of group membership; 18 of these have a < 50% probability of group membership. Sites that do not have a high probability of membership in any group are not well matched to reference sites based on habitat variables.

Abundances of predominant taxa and taxon richness for Hamilton Harbour sites are shown in Table 8. Complete macroinvertebrate family counts are listed in Appendix C; Table C1. Overall, Hamilton Harbour fauna consist mainly of tubificids, present at all sites mostly at greater abundance than in at reference sites, and to a lesser extent, naidiids (present at 36 sites), sphaeriids (present at 34 sites), and chironomids (present at 20 sites). Taxa characteristic of each reference group are described below, and compared to the macrobenthic fauna observed at matched Hamilton Harbour sites.

Great Lakes reference group 1

The majority of test sites (33) are matched to Group 1; 21/33 sites have a >50% probability of reference group membership (Table 7). Group 1 has a total of 108 sites from Georgian Bay (39), the North Channel (24), Lake Ontario (21), Lake Erie (16), Lake Huron (4), and Lake Michigan (4). This group is characterized mainly by Chironomidae (the midges – 39.9% occurrence), and to a lesser degree Tubificidae (oligochaete worms – 16.7% occurrence) and Sphaeriidae (fingernail clams – 14.7% occurrence). Asellidae (isopods), Naididae (oligochaete worms) and Sabellidae (polychaete worms) are also present (3.6 – 5.5% occurrence). These 6 families make up ~85% of the total families found in this reference group. Table 8a shows the mean abundance of these top 6 families at Hamilton Harbour sites.

Chironomidae are absent or present at lower abundance compared to reference at all test sites. All sites show increased abundance of tubificid worms, with the exception of site 7019, and sphaeriids are absent or lower in abundance at all sites with the exception of sites 7013, 7063, and 70M20. Naidiids are in increased abundance at most sites, and are absent or in decreased

abundance at remaining sites. In general, remaining invertebrate families present in Group 1 are absent or in very low abundance at Hamilton Harbour sites. The number of taxa present at these test sites range from 1 to 9 but most sites have ≤ 5 taxa, below the reference mean (8 taxa). Sites in deeper water (e.g., 7019, 7025, 7045 – depth: 19 – 22 m) are the least diverse (1 or 2 taxa present); site 7060 (located at the Stelco wall near the outfall) is the most diverse.

Great Lakes reference group 2

Four Hamilton Harbour sites are matched to Group 2 (Table 7). Reference Group 2 has a total of 20 sites from Lake Erie (13), Lake Michigan (5), Lake Ontario (1), and Georgian Bay (1). This group is characterized mainly by Tubificidae (70.2% occurrence), and to a lesser extent Sphaeriidae (8.7% occurrence), Chironomidae (7.3% occurrence), Naididae (4.1% occurrence) and Haustoriidae (3.9% occurrence). These 5 families make up ~94% of the total families found in this group. Table 8b shows the mean abundance of the top 5 families at Hamilton Harbour sites.

Test sites consist mainly of tubificids, in decreased abundance at 3 of the 4 sites compared to the reference mean. With the exception of naidiids at sites 7002 and 7058, all other families are either absent or in decreased abundance at test sites. The number of taxa present range from 1 to 5, all below the reference mean (7 taxa). Site 7030, located west of Centennial dock in the west end of the harbour (near the Hamilton yacht clubs) is the least diverse, with only tubificids present in very low abundance.

Great Lakes reference group 3

Six Hamilton Harbour sites are matched to Group 3 (Table 7). Group 3 has a total of nine sites from Lake Erie, and is characterized mainly by Dreissenidae (zebra mussel - 73.8% occurrence), and to a lesser extent Tubificidae (13.5% occurrence), Chironomidae (5.4% occurrence), Valvatidae (snails - 1.5% occurrence) and Naididae (1.2% occurrence). These eight families make up ~95% of the total families found in this group. Table 8c shows the mean abundance of these top families.

Dreissenids are either absent or lower in abundance at all test sites; site 7021, a sandy shallow site located northeast of Willow Point (off Holy Sepulchre Cemetery), has the greatest abundance of zebra mussels (close to the reference mean). Tubificids are in increased abundance at 4 of the 6 sites. Sites 7008 and 7021 have higher abundance for four or more families and are the most diverse sites (12 taxa each). The number of taxa present range from 5 to 12; 4 of the 6 sites are below the reference mean (11 taxa).

Great Lakes reference group 4

One site has the highest probability of belonging to Group 4 (Table 7). Group 4 has a total of 21 sites from Lake Michigan (18), Lake Ontario (1), Georgian Bay (1), and Lake Superior (1), and is characterized mainly by Haustoriidae (65.1% occurrence), and to a lesser extent Lumbriculidae (12.7%), Sphaeriidae (9.6%), Tubificidae (5.7%), Enchytraeidae (3.9%), Chironomidae (1.5%), and Naididae (0.9%). These seven families make up 99% of the total families found in this group. Table 8d shows the mean abundance of the top seven families.

Site 70M268, located at Windermere Basin, has two taxa present; well below the reference mean (6 taxa). Tubificids and naidiids are present in increased abundance (tubificids ~8×, naidiids ~7×); all other families expected to be at 70M268 are absent.

BEAST community structure evaluation

Results of the BEAST evaluation are summarized in Tables 8a to 8d. Ordinations are shown in Appendix D; Figures D1 to D6 (stress ≤ 0.143). Twelve separate ordinations were performed each with a subset of between 1 – 11 Hamilton Harbour sites. The ordinations of the 33 sites that have the highest probability of belonging to reference Group 1 are shown in Figures D1 to D3; the 4 test sites maximally predicted to reference Group 2 are shown in Figure D4; ordinations of sites maximally predicted to Groups 3 and 4 are shown in Figures D5 and D6, respectively.

Families contributing most to the community structure are shown in each ordination. Generally, these include Tubificidae (oligochaete worms), Chironomidae (midges), Sphaeriidae (fingernail clams), Naididae (oligochaete worms), and Dreissenidae (zebra mussels). Significant habitat

variables that are most highly correlated to the ordination axes scores are also shown in each ordination. Generally, metals such as Zn, Cu, Pb, As and Hg, and nutrients such as TOC and phosphorus (sediment) and NO₃/NO₂ and nitrogen (TKN) (overlying water) and are the most highly correlated variables. (Organic contaminants are not included in BEAST analyses; therefore, their contributions are not known.) Invertebrate taxa and environmental variables that are maximally correlated with the site locations (sites in Bands 3 and 4) are shown as vectors in the ordinations.

Hamilton Harbour sites fall into the following bands of similarity to reference conditions:

Band 1 (equivalent to reference):	3 sites
Band 2 (possibly different):	14 sites
Band 3 (different):	8 sites
Band 4 (very different):	19 sites

The majority of Hamilton Harbour sites (61%) are either different or very different from reference. The location of these sites outside of reference is associated with increased abundance of tubificids (and naidiids in some cases), as well as decreased abundance of chironomids (Figures D1 to D3, D6). Examination of the relationship between environmental variables and ordination axes scores reveal significant relationships. For ordinations shown in Figures D1 to D3, several metals and sediment and overlying water nutrients are significantly correlated to ordination axes scores. Some Hamilton Harbour sites are located along an increasing gradient of Zn, Cu, Pb, and Hg (Figures D1 to D3), and nutrients such as NO₃/NO₂, nitrogen, phosphorus and TOC (Figures D1 and D2).

3.4 Sediment Toxicity Tests

Mean species survival, growth, and reproduction in Hamilton Harbour sediments are shown in Table 9. The established criteria for each category (non-toxic, potentially toxic and toxic) for each species are included. Sediment for toxicity test purposes could not be collected at Site 7060 due to presence of coal chunks, rocks and zebra mussel shells. This site is located in the Randle Reef area, close to the Stelco wall (see Figure 1).

The mayfly *Hexagenia* is most sensitive to Hamilton Harbour sediment; low survival and/or negative growth is evident at 27/43 sites (highlighted or italicized – Table 9). There is also acute

toxicity to the midge *Chironomus* at 6 sites (all located in the Randle Reef area) and acute toxicity to the amphipod *Hyaella* and oligochaete worm *Tubifex* at 1 site (7063 – located in Randle Reef area). Site 7063 is the most toxic site, with acute toxicity to all four species.

BEAST toxicity evaluation

The multivariate assessment (ordination) of sites was performed using the ten toxicity test endpoints on three axes (stress = 0.09 – 0.10). The use of multivariate assessment for toxicity test endpoints is advantageous as it reduces the redundancy between endpoints, and also down weights the *Tubifex* endpoints (i.e., *Tubifex* test has four measurable endpoints while the other tests have two) (Reynoldson and Day 1998). Results are summarized in Table 9 and ordinations are provided in Appendix E; Figures E1 to E4. Significant toxicity endpoints ($p \leq 0.05$) are shown in each ordination. The endpoints that contribute most to the ordinations include *Chironomus* survival (r^2 : 0.51 – 0.92), *Hexagenia* survival (r^2 : 0.46 – 0.71), *Hyaella* survival (r^2 : 0.38 – 0.89), and *Tubifex* young production (r^2 : 0.15 – 0.95). Habitat variables (not including organic contaminants) that are most significantly correlated to the ordination axes scores are shown in each ordination. Metals such as Zn, Hg, Pb and total organic carbon are the most highly correlated environmental variables (r^2 : 0.17 – 0.40).

Hamilton Harbour sites fall into the following bands of similarity to reference conditions:

Band 1 (non-toxic):	14 sites
Band 2 (potentially toxic):	8 sites
Band 3 (toxic):	4 sites
Band 4 (severely toxic):	17 sites

Approximately 49% of sites are toxic or severely toxic and these sites are associated with decreased survival or growth of *Hexagenia* (Figures E1 to E4), decreased *Chironomus* survival (Figure E1), and decreased *Tubifex* survival (Figure E4). The departure of site 7063 from reference is most severe (i.e., the site is located the farthest away from the reference centroid; Figure E4). Site 7063 is also far away from reference in a different direction than the rest of the toxic sites. Site 7063 is the only site that shows toxicity to all four species, and the only site that is acutely toxic to *Tubifex*, which explains its location with respect to the other sites in ordination space.

Examination of the relationship between environmental variables and ordination axes scores reveal significant relationships. Several sediment metals such as Zn, Hg, Pb and Cu, and sediment and overlying water nutrients such as TOC, NO₃/NO₂ and phosphorus are the most highly correlated variables. Some sites are located along an increasing gradient of several of these metals (Figures E1 to E4) and nutrients (Figures E2 to E4).

3.5 Sediment Toxicity and Contaminant Concentrations

The relationship between sediment toxicity and contaminant concentrations were also examined in additional multivariate analyses and regression analysis. The BEAST assessment does not incorporate any information on organic contaminants in the sediment because organic contaminant concentrations were not measured in reference sediments. Therefore, these analyses aided in identifying causes of toxicity attributable to organic contaminants, as well as inorganic compounds and sediment grain size.

General contaminant descriptor relationships

Multiple measurements of sediment toxicity, ordinated by HMDS, produced two descriptors (Axis 1 and Axis 2) of sediment toxicity (Appendix F; Figure F1 [top]). The resultant axes represents the original 10-dimensional among-site resemblances very well (stress = 0.086). For Axis 1, all toxicity variables are positively correlated; therefore, the greater the toxicity of a site, the lower its score for Axis 1 (Appendix F; Figure F1 [bottom]). The most important endpoint is *Hexagenia* survival; therefore, sites scoring low values for Axis 1 tend to show greater toxicity to *Hexagenia* survival. For Axis 2, *Chironomus* survival is negatively correlated, whereas *Hexagenia* growth is positively correlated. Thus, sites scoring low values for Axis 2 tend to show greater toxicity to *Hexagenia* growth and sites scoring high values for Axis 2 tend to show greater toxicity to *Chironomus* survival.

The first principal component (PC1) from the PCA of sediment metal and nutrient variables accounts for 67% of the total variation, whereas the remaining components each account for ≤9%. All measurement variables are negatively loaded for PC1 and loadings are of a similar magnitude. Thus, this component – denoted as “metPC1” – is considered a good descriptor of general contamination and nutrient enrichment. Sites elevated in metals and nutrients score low for PC1. For PCBs, 7 of the 9 compounds measured were largely below detection limits. Total

PCB concentration was determined primarily by Aroclor-1254 and Aroclor-1260, which were detected at most sites. Total concentration of 16 PAHs is strongly correlated with the first PC from a PCA of the individual compounds, as well as to the most prevalent compounds.

Therefore, total PAH was used as a descriptor of general PAH contamination.

In terms of the integrated descriptors, sediment toxicity is poorly related to metal and nutrient conditions ("metPC1"), total PCBs ("lnTotPCBs") or total PAHs ("lnTotPAHs") (Appendix F; Figure F2). For the Axis 1 toxicity descriptor, the three contaminant descriptors account for 9.9% of the variability in the multiple linear regression ($P=0.075$ for the regression); total PAHs alone accounts for 12.2% of the variability ($P=0.012$ for the regression). For the Axis 2 descriptor, the contaminant descriptors account for only 14.7% of the variability ($P=0.027$ for the regression) and none of the predictors are significant. Total PCBs alone accounts for 17.3% of the variability ($P=0.003$ for the regression); however, overall lack of fit test is significant at $P = 0.060$.

Individual contaminant relationships

Plots of the 3 toxicity endpoints against 32 contaminant and nutrient variables also show few obvious relationships (Appendix F; Figures F3 to F7). However, regressions of the toxicity descriptors (HMDS Axes 1 and 2) and the measurement contaminant, nutrient, and grain size variables produce some significant relationships. Almost 64% of the variability in the Axis 1 toxicity descriptor is explained by the following predictors:

- lnCd
- lnTOC
- lnAroclor-1260
- lnNaphthalene
- lnAcenaphthene
- lnFluorene
- lnPhenanthrene
- lnFluoranthene
- lnBenzo(k)fluoranthene
- lnDibenzo(ah)anthracene

The regression is significant at $P < 0.001$. However, not all predictors are significant. After dropping terms that are not significant ($P > 0.05$) or have high (> 10) variance inflation factors, the following model explains 52% of the variance in the Axis 1 toxicity descriptor:

$$\text{Axis 1} = -0.102 + 0.728 \ln \text{Acenaphthene} - 0.759 \ln \text{Fluorene}$$

Both predictors are significant at $P < 0.001$ and the regression is significant at $P < 0.001$. Because Axis 1 scores are inversely proportional to toxicity, the predictor with the positive regression coefficient (Acenaphthene) indicates the opposite of a toxicity response to increased sediment concentration. Therefore, toxicity in terms of the Axis 1 descriptor seems related to Fluorene concentrations.

For the Axis 2 toxicity descriptor, a regression ($P = 0.001$) with the following predictors explains 45% of the variability:

- $\ln \text{Cu}$
- $\ln \text{Aroclor-1254}$
- $\ln \text{Naphthalene}$
- $\ln \text{Acenaphthene}$
- $\ln \text{Fluorene}$
- $\ln \text{Benzo(k)fluoranthene}$
- $\ln \text{Benzo(a)pyrene}$
- $\ln \text{Dibenzo(ah)anthracene}$

After dropping non-significant and high variance inflation factor terms, the following model explains 41% of the variance in the Axis 2 toxicity descriptor:

$$\begin{aligned} \text{Axis 2} = & 0.277 - 0.264 \ln \text{Cu} - 0.204 \ln \text{Aroclor1254} + 0.204 \ln \text{Naphthalene} + 0.312 \\ & \ln \text{Acenaphthene} - 0.253 \ln \text{Fluorene} + 0.405 \ln \text{Benzo(k)fluoranthene} - 0.519 \\ & \ln \text{Dibenzo(ah)anthracene} \end{aligned}$$

All predictors are significant at $P < 0.039$, and the regression is significant at $P = 0.001$. Predictors with the positive regression coefficients (Naphthalene, Acenaphthene, Benzo(k)fluoranthene) are potentially toxic to *Chironomus* survival whereas those with negative coefficients (Cu, Aroclor

1254, Fluorene, Dibenzo(ah)anthracene) are possibly toxic to *Hexagenia* (growth) and (to a lesser extent) *Hyalella* survival.

4 CONCLUSIONS

Community structure and toxicity evaluations are summarized in Table 10. Environmental variables exceeding the provincial SEL are included. Spatial maps indicating the level of community alteration and toxicity compared to reference are shown in Figures 3 and 4, respectively.

Sediment contaminants

- Several metals (as well as nutrients) are elevated in the harbour. The following exceed the SEL:
 - Mn (29 sites), Zn (22 sites), Fe (20 sites), Cu (17 sites), Pb (11 sites), Cr (9 sites), Hg (8 sites), As (4 sites), Ni (2 sites), TP (14 sites), TOC (2 sites), TN (1 site)
- Total PAHs are highest in the Randle Reef area (499 µg/g); total PCBs are highest in the Dofasco slip (6.2 µg/g) followed by the Strathearne slip (5.2 µg/g)
- The location in the harbour of the highest contaminant concentrations varies depending on the substance:
 - Randle Reef (site 7059) – highest Mn, Pb, Zn and total PAHs
 - Ottawa St. slip (site 7053) – highest As, Cr, Cu, Fe, Ni and total organic carbon
 - Windermere Basin mouth (site 70M268) – highest phosphorus and nitrogen
 - Central harbour, deep hole (site 70M258) – highest Hg
 - Dofasco slip (site 7054) – highest total PCBs

Benthic community structure and sediment toxicity

- 27/44 sites show strong evidence of degraded communities
- 21/43 sites show strong evidence of toxicity
- Correspondence in the pattern of certain metals (Zn, Hg, Pb, Cu) and sediment and overlying water nutrients (nitrogen, phosphorus, total organic carbon) and the biological conditions of test sites (indicated in the ordination plots as shifts by certain test sites away

from the reference sites in the same direction as these vectors) suggests that these variables may be affecting the benthic environment or toxicity at some sites.

- Toxicity is not clearly related to one contaminant or group of contaminants. Several compounds of PAHs, PCBs (and perhaps Cu) appear jointly related the pattern of toxicity among sampling sites. Contaminant mixtures can exhibit various interactive and confounded effects that are complex and difficult to recognize using a correlation/regression approach with a sample size not much larger than the number of contaminants. Further data and experimental evidence would be needed to test whether the contaminants showing the strongest relationships in these analyses are in fact responsible for the sediment toxicity.

Overall

- 14 sites show concordance between altered communities and laboratory toxicity
- 21 sites show a lack of concordance between toxicity and community impairment (i.e., community impairment and no toxicity or visa versa), suggesting that other stressors may be active, or effects may be chronic and long term or that contaminants are present/bioavailable but there may be community resistance developed.
- The highest probabilities of test sites belonging to any reference community group (based on habitat variables) are low (< 60%) for a large number of the test sites (~64%), and some sites show equivocal results (similar probabilities of group membership). Therefore, the assessment of benthic community impacts for these sites should be interpreted with caution. Unfortunately, finding appropriate reference sites for Hamilton Harbour is difficult because of site-specific natural and anthropogenic conditions of the AOC (a low-energy bay, exposed to seasonal hypoxia at depths below 7 m (Hamilton Harbour RAP Team, 1992) and in some parts subject to physical disturbance from ships). Other harbour and bays in Lake Ontario have also shown effects of human impacts (e.g., Kinney 1972), and thus are not suitable reference areas.

5 RECOMMENDATIONS

- With the remedial measures to be implemented in the Randle Reef area, the sampling coverage in this area is not sufficient to adequately delineate toxic zones/areas within the

reef. A more detailed sediment toxicity evaluation is recommended to further delineate the level of toxicity for this area.

- With the poor matching to reference site groups for many of test sites, and with most sites having *different* or *very different* communities (thereby offering little or no discriminatory power), benthic community structure analysis is not recommended for purposes of making decisions on which specific sites should be remediated.
- Assessment of benthic community recovery and development of delisting criteria should address the complexity of the Hamilton Harbour environment. For areas not influenced by shipping disturbance and seasonal hypoxia, mainly in the littoral zone, degradation/recovery of the benthic community can be indicated by being outside/inside the range of reference conditions defined by either (a) the least contaminated sites in the bay, or (b) predictions from models accounting for effects of habitat attributes and sediment contaminants (to be developed). For areas subject to shipping disturbance and seasonal hypoxia, mainly in the profundal zone, degradation/recovery is best indicated by the presence/absence of a correlation of community conditions with sediment contaminants.
- *Hexagenia* and *Hyalella* endpoints have the highest correlations to overall toxicity. These two toxicity tests are therefore recommended for future work in determining the levels of toxicity.

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

Site	Easting	Northing	Site Depth (m)
7000	598447	4799537	5.0
7002	597715	4792195	8.0
7004	597477	4792537	10.5
7007	596202	4795443	10.0
7008	595223	4795504	1.5
7013	595715	4794176	17.0
7014	597004	4792421	10.0
7015	594717	4795220	8.0
7019	594425	4794625	19.0
7021	592032	4793409	1.0
7022	594245	4792669	14.0
7024	593312	4794361	9.5
7025	593316	4793416	21.0
7030	592138	4792352	11.5
7035	592725	4792426	12.5
7036	590707	4791902	7.0
7038	593416	4792111	9.0
7039	593687	4792021	9.0
7040	594054	4791896	9.0
7043	594919	4792620	9.4
7045	594976	4793235	22.5
7047	596071	4792893	10.5
7049	593004	4793064	8.5
7050	593292	4791819	8.0
7051	593679	4791680	8.0
7052	594027	4791675	8.5
7053	596956	4792419	3.0
7054	597473	4791664	8.0
7055	598256	4791965	9.0
7056	590312	4792475	2.5
7057	598352	4790892	4.5
7058	598430	4791209	4.0
7059	594474	4791775	7.9
7060	594987	4792427	9.1
7061	594213	4792173	8.8
7062	594559	4792407	8.5
7063	594457	4791986	3.1
7064	594641	4792093	4.4
70M20	598072	4791889	7.5
70M252	596545	4795552	5.5
70M258	594382	4793524	20.0
70M268	598843	4791397	3.5
70M270	591491	4792529	12.0
70M4	597353	4793321	18.5

Table 2. Environmental variables measured at each site.

Field	Water	Sediment
Northing	Alkalinity	Trace metals
Easting	Conductivity	Major oxides
Site Depth	Dissolved Oxygen	Total phosphorus, Total Nitrogen
	pH	Total Organic Carbon
	Temperature	Loss on Ignition
	Total Kjeldahl Nitrogen	% Clay, Silt, Sand, & Gravel
	Total Phosphorus	PAHs, PCBs, OCPs
	Nitrates/Nitrites	

Table 3. Measured environmental variables (mg/L) in overlying water.

Site	Alkalinity	Conductivity μS/cm	Dissolved Oxygen	Nitrates/ Nitrites	pH	Total Phosphorus	Total Kjeldahl Nitrogen
Reference Median	82	-	8.7	0.20	8.1	0.01	0.19
7000	106	557	6.2	1.89	7.4	0.07	1.37
7002	107	539	7.9	2.50	7.6	0.07	0.45
7004	99	491	8.3	1.89	7.7	0.05	0.36
7007	99	450	8.5	1.40	7.4	0.05	0.77
7008	102	450	8.0	1.28	7.5	0.04	0.77
7013	100	450	8.0	1.44	7.3	0.03	0.43
7014	101	490	8.2	1.69	7.7	0.05	0.39
7015 ^a	99	450	8.0	1.53	7.5	0.04	0.62
7019	99	420	6.3	1.40	7.3	0.04	0.34
7021	103	460	8.7	1.49	7.4	0.04	0.58
7022	101	486	8.3	1.68	7.8	0.05	0.39
7024	98	450	7.8	1.72	7.5	0.04	0.34
7025	101	450	7.6	1.60	7.5	0.03	0.36
7030	103	450	7.7	1.57	7.5	0.03	0.35
7035	101	450	7.3	1.63	7.4	0.03	0.42
7036	102	450	7.7	1.55	7.3	0.04	0.34
7038	101	487	7.9	1.66	7.7	0.04	0.36
7039	101	487	8.5	1.72	7.7	0.04	0.33
7040 ^a	101	487	7.8	1.80	7.7	0.03	0.35
7043	100	487	7.4	1.85	7.6	0.03	0.36
7045	101	486	8.4	1.63	7.7	0.04	0.39
7047	101	494	9.3	1.94	7.8	0.04	0.36
7049	101	487	8.8	1.77	7.7	0.03	0.34
7050	102	487	9.6	1.72	7.7	0.04	0.36
7051	108	519	8.0	1.81	7.7	0.04	0.35
7052	102	488	9.1	1.79	7.8	0.05	0.39
7053	102	556	7.8	2.24	7.5	0.06	0.42
7054 ^a	111	550	6.2	2.15	7.6	0.08	0.44
7055	114	634	5.0	1.60	7.3	0.18	5.35
7056	104	450	7.6	1.50	7.3	0.04	0.52
7057	105	579	7.3	1.91	7.4	0.11	0.51
7058	123	557	6.7	1.42	7.4	0.09	2.91
7059	100	488	7.5	1.77	7.6	0.04	0.38
7060	101	488	7.5	1.85	7.7	0.04	0.38
7061	102	488	7.4	1.84	7.6	0.36	0.38
7062	99	488	7.8	1.89	7.6	0.04	0.38
7063	102	490	8.0	1.68	7.6	0.04	0.37
7064	101	487	7.8	1.89	7.6	0.04	0.36
70M20	106	564	4.9	2.06	7.4	0.11	0.69
70M252	99	450	8.3	1.75	7.4	0.04	0.18
70M258	101	450	7.4	1.67	7.5	0.04	0.37
70M268	215	643	4.9	0.45	7.3	0.73	17.90
70M270	104	450	7.7	1.51	7.4	0.04	0.46
70M4	99	455	7.8	1.62	7.4	0.04	0.32

^aQA/QC site (value represents the mean of three replicates)

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

Site	% Sand	% Silt	% Clay	% Gravel	Site	% Sand	% Silt	% Clay	% Gravel
Reference Median	13.68	37.89	32.02	0.00	Reference Median	13.68	37.89	32.02	0.00
7000	18.02	61.96	20.02	0.00	7049	7.69	59.72	32.59	0.00
7002	21.83	58.55	19.62	0.00	7050	13.00	58.71	28.29	0.00
7004	4.69	62.99	32.32	0.00	7051	23.05	55.61	21.35	0.00
7007	3.67	67.80	28.53	0.00	7052	35.03	49.77	15.19	0.00
7008	94.68	5.32	0.00	0.00	7053	1.65	85.35	13.00	0.00
7013	2.17	63.33	34.50	0.00	7054 ^a	9.94	68.21	21.85	0.00
7014	0.64	80.29	19.06	0.00	7055	11.51	63.48	25.01	0.00
7015 ^a	66.29	18.83	14.88	0.00	7056	36.28	40.70	23.02	0.00
7019	0.44	60.29	39.26	0.00	7057	5.04	65.13	29.83	0.00
7021	99.63	0.37	0.00	0.00	7058	60.08	27.64	12.28	0.00
7022	0.38	63.37	36.24	0.00	7059	9.32	72.20	18.48	0.00
7024	24.58	45.69	29.73	0.00	7060	65.33	27.87	6.80	0.00
7025	0.39	49.35	50.26	0.00	7061	12.09	67.76	20.15	0.00
7030	17.16	47.90	34.94	0.00	7062	21.86	58.14	20.00	0.00
7035	42.27	35.62	22.11	0.00	7063	31.39	53.35	15.27	0.00
7036	1.01	62.93	36.06	0.00	7064	4.25	72.66	23.09	0.00
7038	43.87	37.03	19.09	0.00	70M20	2.80	71.49	25.71	0.00
7039	38.07	40.47	21.46	0.00	70M252	10.43	65.72	23.85	0.00
7040 ^a	46.93	36.79	16.28	0.00	70M258	0.64	56.57	42.78	0.00
7043	6.85	74.37	18.78	0.00	70M268	22.57	52.83	24.60	0.00
7045	4.73	59.94	35.33	0.00	70M270	61.11	38.10	0.00	0.79
7047	8.97	62.98	28.05	0.00	70M4	2.36	63.54	34.10	0.00

^aQA/QC site (value represents the mean of three replicates)

Table 5. Nutrient and trace metal concentrations in Hamilton Harbour sediment (top 10 cm) (Caduceon laboratory). Values exceeding SELs are highlighted. Values in µg/g dry weight unless otherwise noted.

Site	%Al	As	Cd	Co	Cr	Cu	%Fe	Hg
Reference Median	-	2.5	0.7	10.0	38.0	24.5	-	0.05
7000	1.2	10.1	1.0	9.9	104.6	124.2	4.3	1.72
7002	0.7	27.0	2.0	7.7	112.7	74.3	5.4	0.32
7004	1.1	16.4	0.5	15.9	23.2	114.2	2.6	0.04
7007	1.2	9.5	2.0	10.6	95.0	90.5	4.1	0.28
7008	0.3	2.5	0.5	3.8	8.1	5.9	0.7	0.02
7013	1.7	16.0	2.0	21.0	196.0	151.1	8.2	0.76
7014	1.0	31.0	0.5	14.0	291.0	189.9	16.1	3.48
7015 ^a	0.6	10.0	1.0	7.4	62.3	38.3	2.3	0.12
7019	1.8	36.0	1.0	28.0	176.0	137.5	7.6	3.62
7021	0.2	5.7	0.5	3.9	6.5	7.5	0.7	0.01
7022	1.3	20.4	3.2	9.0	104.3	106.1	5.2	0.39
7024	0.8	14.7	4.0	9.2	89.0	68.4	3.7	0.23
7025	1.5	16.2	3.0	12.0	92.4	103.8	5.0	0.34
7030	1.0	18.2	1.1	8.3	51.6	64.6	2.9	0.16
7035	0.6	14.2	0.5	7.2	27.2	41.8	1.9	0.09
7036	1.3	9.9	2.5	12.4	51.7	78.3	3.3	0.21
7038	0.5	12.8	1.2	6.7	29.2	42.0	1.9	0.42
7039	0.5	14.0	0.5	7.4	27.2	38.8	2.0	0.13
7040 ^a	0.6	16.5	0.5	9.3	49.3	50.4	2.1	1.60
7043	0.4	17.0	0.5	12.4	9.0	13.9	1.0	0.03
7045	1.3	15.3	3.3	12.1	106.8	98.4	5.2	0.36
7047	1.1	9.6	1.5	11.0	39.2	50.3	3.2	0.10
7049	1.2	14.7	2.7	9.8	72.2	103.6	3.6	2.08
7050	1.0	8.7	6.0	9.3	92.5	197.5	2.9	4.42
7051	0.8	15.1	0.9	9.8	47.7	262.5	2.4	0.16
7052	0.8	15.5	1.0	11.5	55.1	113.1	2.4	2.38
7053	0.8	114.4	2.0	5.0	410.0	258.3	23.3	1.48
7054 ^a	0.9	39.2	1.9	17.0	184.0	127.5	11.4	0.77
7055	1.1	8.6	2.8	10.6	106.3	142.4	4.6	0.26
7056	1.0	7.7	0.9	10.6	22.3	46.3	2.1	0.28
7057	1.4	13.4	4.1	8.3	159.1	270.5	5.1	4.16
7058	0.3	5.1	0.9	5.2	63.0	92.9	1.6	0.15
7059	1.1	57.0	0.5	19.0	93.0	129.5	14.7	2.18
7060	0.6	14.4	0.5	8.4	35.2	25.3	2.2	0.11
7061	0.9	13.3	2.4	7.6	56.4	70.0	3.9	0.30
7062	0.8	15.3	1.5	8.9	49.6	51.3	3.3	0.21
7063	0.7	11.3	2.8	5.6	50.2	52.1	5.0	0.39
7064	0.8	9.6	2.2	7.1	54.0	53.9	4.8	0.25
70M20	1.2	18.4	2.8	16.0	165.0	134.7	7.1	0.43
70M252	0.8	16.4	0.8	6.7	44.0	133.4	3.6	0.36
70M258	1.4	17.7	2.8	9.2	89.8	100.3	5.0	5.48
70M268	1.1	8.4	1.2	5.6	75.0	179.0	4.2	0.49
70M270	1.5	14.0	2.4	11.8	64.9	89.0	3.8	0.22
70M4	1.4	22.5	1.7	17.0	138.0	120.4	7.3	0.32
LEL	-	6.0	0.6	-	26	16	2%	0.2
SEL	-	33.0	10	-	110	110	4%	2.0

^aQA/QC site (value represents the mean of three replicates)

Table 5. Continued.

Site	%K	%LOI	%Mg	Mn	%Na	Ni	%P ₂ O ₅	Pb
Reference	-	12.7	-	-	-	29.5	0.17	38.0
Median								
7000	0.14	14.6	0.96	973	0.044	26.7	0.82	158.4
7002	0.07	25.1	0.87	1496	0.035	1.4	0.41	263.2
7004	0.14	25.0	0.82	921	0.036	4.1	0.27	29.9
7007	0.17	28.2	0.93	1509	0.033	32.0	0.73	154.4
7008	0.04	7.7	0.38	283	0.023	6.3	0.19	5.8
7013	0.23	20.8	0.98	2632	0.050	57.1	0.90	344.2
7014	0.10	28.0	0.97	2554	0.052	80.0	0.56	358.8
7015 ^a	0.05	8.2	0.51	851	0.024	27.3	0.41	87.3
7019	0.25	21.0	0.98	2487	0.049	54.4	0.84	318.6
7021	0.01	7.1	0.37	335	0.016	0.9	0.11	0.5
7022	0.13	19.3	0.98	2202	0.036	41.7	0.65	231.2
7024	0.06	15.6	0.89	1609	0.027	33.0	0.56	151.0
7025	0.13	28.7	0.94	2169	0.035	39.8	0.57	203.5
7030	0.09	26.2	0.88	1345	0.024	29.3	0.52	118.3
7035	0.04	11.7	0.76	867	0.024	15.5	0.38	60.9
7036	0.13	17.8	1.26	1278	0.029	33.0	0.53	115.6
7038	0.04	12.6	0.76	805	0.025	13.4	0.31	67.3
7039	0.05	12.9	0.75	992	0.026	13.9	0.29	55.7
7040 ^a	0.06	13.9	0.79	1436	0.026	49.6	0.25	68.0
7043	0.02	25.2	0.71	739	0.022	0.5	0.11	0.5
7045	0.11	21.4	0.94	2550	0.034	38.3	0.65	214.0
7047	0.11	16.7	0.92	1023	0.025	21.7	0.26	53.3
7049	0.12	18.9	1.00	1106	0.040	30.1	0.45	187.0
7050	0.10	21.4	1.93	909	0.035	23.4	0.44	240.7
7051	0.10	21.9	1.00	1225	0.042	39.0	0.36	78.9
7052	0.07	18.3	1.17	2517	0.029	23.0	0.39	146.3
7053	0.04	29.4	1.10	2867	0.029	123.9	0.49	507.0
7054 ^a	0.07	24.2	0.98	2950	0.041	60.0	0.41	530.0
7055	0.10	19.7	0.95	1152	0.035	24.1	0.68	171.6
7056	0.10	15.4	0.93	688	0.031	17.7	0.40	48.6
7057	0.14	21.9	1.66	1286	0.051	38.3	0.87	418.5
7058	0.04	6.0	0.29	324	0.016	49.7	0.21	202.2
7059	0.07	20.7	0.91	3150	0.034	67.0	0.51	666.0
7060	0.04	17.3	0.82	1251	0.031	3.7	0.29	17.3
7061	0.09	16.4	0.91	1506	0.034	21.9	0.43	143.1
7062	0.07	16.3	0.83	1254	0.031	20.0	0.37	98.7
7063	0.08	15.2	0.79	1110	0.037	23.2	0.47	280.2
7064	0.09	18.0	0.86	1460	0.032	18.9	0.39	181.6
70M20	0.14	20.5	0.96	1660	0.038	66.0	0.69	318.0
70M252	0.07	22.1	0.83	806	0.026	22.3	1.45	61.8
70M258	0.13	32.5	0.89	2364	0.037	38.8	0.65	196.1
70M268	0.09	30.7	0.95	679	0.061	27.5	1.41	105.2
70M270	0.15	18.9	1.07	1676	0.035	36.9	0.60	143.8
70M4	0.20	20.5	0.97	2260	0.039	75.0	0.69	283.0
LEL	-	-	-	460	-	16	-	31
SEL	-	-	-	1100	-	75	-	250

^aQA/QC site (value represents the mean of three replicates)

Table 5. Continued

Site	%SiO ₂	Ti	Total N	%Total organic C	Total P	V	Zn
Reference Median	56.5	-	1836	2.0	538	35.5	105
7000	56.0	244	2910	2.9	3020	29.7	899
7002	31.1	191	1740	2.3	1250	24.0	1854
7004	37.1	204	3590	4.0	562	22.9	290
7007	43.6	224	2870	2.8	3030	32.7	1093
7008	67.0	190	234	0.2	484	10.2	61
7013	41.6	263	3860	6.3	2480	54.4	2447
7014	24.1	259	3380	10.7	1160	46.2	1648
7015 ^a	65.3	183	939	1.5	1160	17.4	1041
7019	40.7	264	4320	5.1	2490	55.9	1999
7021	64.4	127	270	0.2	250	12.2	51
7022	44.0	234	3100	4.2	1700	41.9	1435
7024	52.8	211	2220	3.0	2430	28.8	1335
7025	40.6	241	3870	4.2	1520	42.5	1152
7030	45.5	192	1930	2.1	2150	27.2	733
7035	58.8	174	1050	1.3	1090	18.9	343
7036	47.1	237	2310	2.8	1360	31.2	758
7038	57.3	188	1370	3.0	1010	18.1	354
7039	56.0	199	969	3.0	961	18.7	313
7040 ^a	56.5	210	1210	2.7	1280	19.6	352
7043	35.0	130	765	0.7	436	11.8	31
7045	44.3	229	2750	5.9	2350	44.2	1241
7047	50.5	218	1910	2.2	760	26.5	346
7049	45.6	227	3550	4.0	1630	34.1	1013
7050	42.5	262	2570	5.4	679	29.0	821
7051	48.5	237	1620	4.7	556	24.5	411
7052	51.4	293	2510	4.7	1770	27.8	507
7053	15.4	255	3130	15.2	2070	48.5	1668
7054 ^a	32.4	364	2760	7.7	1730	52.0	2970
7055	45.7	229	3280	4.1	3120*	31.0	1053
7056	52.8	215	2070	2.0	1110	22.9	282
7057	41.4	295	3160	7.7	3390	37.1	2507
7058	80.0	117	709	1.6	2220	11.5	431
7059	35.8	347	2210	8.4	1780	61.0	3030
7060	49.3	241	642	2.6	845	17.9	166
7061	50.2	235	1460	3.3	1620	29.5	808
7062	50.6	205	1370	3.9	1220	25.8	621
7063	51.4	233	1340	5.1	1530	25.9	1247
7064	46.6	234	1580	4.7	1210	28.7	854
70M20	41.6	273	2680	4.2	2500	42.0	1650
70M252	47.7	152	3710	2.9	5950	21.4	406
70M258	36.5	224	3040	4.5	1630	41.6	1081
70M268	41.1	178	9080	6.5	7020	24.6	529
70M270	45.4	244	3660	3.2	1970	35.8	867
70M4	42.9	265	3330	4.8	2010	48.0	1420
LEL	-	-	550	1	600	-	120
SEL	-	-	4800	10	2000	-	820

^aQA/QC site (value represents the mean of three replicates)

Table 6. Total PCBs (sum of 9 Aroclors) and total PAHs (sum of 16 compounds) in Hamilton Harbour sediments.

Site	Total PAHs µg/g	Total PAHs/ TOC (1%)	SEL (TOC normalized)	Total PCBs µg/g	Total PCBs/ TOC (1%)	SEL (TOC normalized)
7000	28.51	9.83	290	1.50	0.52	15.37
7002	25.50	11.09	230	3.80	1.65	12.19
7004	0.47	0.12	402	0.07	0.02	21.31
7007	12.32	4.48	275	0.60	0.22	14.56
7008	2.13	9.68	22	< ^a	0.00	1.17
7013	56.91	9.06	628	1.10	0.18	33.28
7014	99.09	9.30	1066	0.87	0.08	56.49
7015 ^a	7.75	3.63	194	0.24	0.11	10.26
7019	49.33	9.63	512	0.97	0.19	27.14
7021	< ^a	0.00	22	< ^a	0.00	1.17
7022	31.17	7.46	418	0.45	0.11	22.15
7024	7.93	2.63	301	0.19	0.06	15.95
7025	27.50	6.55	420	0.55	0.13	22.26
7030	14.23	6.71	212	0.19	0.09	11.24
7035	8.07	6.46	125	0.11	0.09	6.63
7036	8.99	3.22	279	0.12	0.04	14.79
7038	9.00	3.01	299	0.13	0.04	15.85
7039	12.05	3.96	304	0.10	0.03	16.11
7040 ^a	13.32	4.51	300	0.45	0.16	15.88
7043	3.43	4.70	73	<0.14	0.19	3.87
7045	56.22	9.50	592	0.42	0.07	31.38
7047	2.33	1.07	218	0.10	0.05	11.55
7049	21.96	5.56	395	0.37	0.09	20.94
7050	36.84	6.78	543	0.15	0.03	28.78
7051	77.00	16.38	470	0.84	0.18	24.91
7052	10.20	2.18	468	0.39	0.08	24.80
7053	150.40	9.89	1520	0.75	0.05	80.56
7054 ^a	116.23	13.95	849	6.17	0.74	45.01
7055	25.65	6.27	409	1.20	0.29	21.68
7056	3.57	1.77	202	0.08	0.04	10.71
7057	395.60	51.18	773	5.20	0.67	40.97
7058	64.12	40.33	159	1.50	0.94	8.43
7059	498.70	59.09	844	1.70	0.20	44.73
7060	407.60	155.57	262	0.17	0.06	13.89
7061	35.68	10.94	326	0.62	0.19	17.28
7062	155.50	39.47	394	0.28	0.07	20.88
7063	108.69	21.27	511	0.90	0.18	27.08
7064	120.06	25.49	471	0.42	0.09	24.96
70M20	30.22	7.26	416	1.40	0.34	22.05
70M252	4.73	1.61	294	0.30	0.10	15.58
70M258	32.28	7.13	453	0.46	0.10	24.01
70M268	81.46	12.59	647	0.91	0.14	34.29
70M270	11.31	3.51	322	0.60	0.19	17.07
70M4	40.11	8.34	481	1.30	0.27	25.49

^a below detection limit

Table 7. Probabilities (%) of test sites belonging to the Great Lakes reference groups. The highest probability for each site is bolded.

Site	Group 1	Group 2	Group 3	Group 4	Group 5
7000	0.450	0.328	0.215	0.000	0.007
7002	0.351	0.372	0.267	0.000	0.009
7004	0.581	0.294	0.112	0.000	0.013
7007	0.430	0.324	0.235	0.000	0.012
7008	0.140	0.193	0.664	0.000	0.002
7013	0.729	0.227	0.019	0.000	0.025
7014	0.946	0.048	0.001	0.000	0.006
7015	0.326	0.308	0.358	0.000	0.008
7019	0.616	0.307	0.043	0.000	0.033
7021	0.136	0.199	0.663	0.000	0.002
7022	0.554	0.336	0.089	0.000	0.020
7024	0.463	0.315	0.210	0.000	0.011
7025	0.485	0.400	0.073	0.001	0.042
7030	0.315	0.383	0.290	0.000	0.013
7035	0.217	0.349	0.423	0.000	0.011
7036	0.427	0.329	0.235	0.000	0.008
7038	0.449	0.334	0.207	0.000	0.011
7039	0.455	0.333	0.201	0.000	0.011
7040	0.448	0.336	0.205	0.000	0.011
7043	0.174	0.274	0.545	0.000	0.006
7045	0.630	0.301	0.022	0.001	0.046
7047	0.339	0.349	0.301	0.000	0.011
7049	0.573	0.299	0.118	0.000	0.010
7050	0.722	0.226	0.042	0.000	0.009
7051	0.623	0.304	0.062	0.000	0.011
7052	0.649	0.269	0.071	0.000	0.010
7053	0.991	0.008	0.000	0.000	0.001
7054	0.872	0.117	0.003	0.000	0.007
7055	0.523	0.384	0.080	0.000	0.013
7056	0.340	0.297	0.358	0.000	0.005
7057	0.876	0.111	0.007	0.000	0.005
7058	0.245	0.462	0.286	0.000	0.006
7059	0.899	0.090	0.004	0.000	0.006
7060	0.402	0.337	0.251	0.000	0.010
7061	0.483	0.332	0.175	0.000	0.011
7062	0.582	0.285	0.122	0.000	0.010
7063	0.733	0.204	0.058	0.000	0.005
7064	0.691	0.226	0.077	0.000	0.006
70M20	0.588	0.307	0.095	0.000	0.010
70M252	0.484	0.276	0.233	0.000	0.007
70M258	0.531	0.370	0.060	0.001	0.038
70M268	0.001	0.008	0.000	0.991	0.000
70M270	0.442	0.385	0.157	0.000	0.015
70M4	0.595	0.318	0.056	0.000	0.031

Table 8a. Mean abundance of most prominent families (per 33 cm²), taxa diversity, and summary BEAST results for Hamilton Harbour sites maximally predicted to reference Group 1. Families expected to be present that are absent from test sites are highlighted.

Family	Gp. 1 Mean	Gp. 1 Occur. (%)	7000	7004	7007	7013	7014	7019	7022	7024
No. Taxa (± 2 SD)	8 (2 – 14)	-	3	4	6	3	3	1	3	5
Chironomidae	13.4	39.9	0	0	1.0	0	0	0	0	1.8
Tubificidae	5.6	16.7	1033.8	127.4	127.2	144.8	180.4	0.8	150.2	115.6
Sphaeriidae	4.9	14.7	0.4	1.2	2.2	6.6	0.4	0	1.4	0.2
Asellidae	1.8	5.5	0	0	0	0	0	0	0	0
Naididae	1.4	4.3	73.0	6.6	5.6	0.4	47.8	0	1.0	7.4
Sabellidae	1.2	3.6	0	0	0	0	0	0	0	0
BEAST BAND	-	-	4	4	4	4	4	4	4	4

Table 8a. Continued.

Family	Gp. 1 Mean	Gp. 1 Occur. (%)	7025	7036	7038	7039	7040 ^a	7045	7049	7050	7051
No. Taxa (± 2 SD)	8 (2 – 14)	-	2	2	3	3	5	1	5	4	3
Chironomidae	13.4	39.9	0	1.0	0	0	0.4	0	0.2	0	0
Tubificidae	5.6	16.7	120.6	20.6	101.8	104.8	116.3	29.2	41.6	48.5	136.2
Sphaeriidae	4.9	14.7	0.4	0	1.0	0.6	0.9	0	1	0.05	0.6
Asellidae	1.8	5.5	0	0	0	0	0	0	0	0	0
Naididae	1.4	4.3	0	0	0.2	0	2.7	0	1.4	6.3	0.4
Sabellidae	1.2	3.6	0	0	0	0	0	0	0	0	0
BEAST BAND	-	-	4	2	4	4	4	3	2	3	4

^aQA/QC site (value represents mean of three field replicates).

Table 8a. Continued.

Family	Gp. 1 Mean	Gp. 1 Occur. (%)	7052	7053	7054 ^a	7055	7057	7059	7060	7061
No. Taxa (± 2 SD)	8 (2 – 14)	-	2	2	7	3	4	4	9	4
Chironomidae	13.4	39.9	0	0	0	0	0	0	0.3	0.4
Tubificidae	5.6	16.7	91.6	33.0	94.3	2315.4	452.6	185.4	21.8	183.6
Sphaeriidae	4.9	14.7	0	0	2.0	0.6	0.4	1.0	0.5	3.2
Asellidae	1.8	5.5	0	0	0	0	0	0	0.1	0
Naididae	1.4	4.3	1.6	16.4	14.3	36.8	12.6	0.2	1.3	5.6
Sabellidae	1.2	3.6	0	0	0	0	0	0	0	0
BEAST BAND	-	-	4	3	3	4	4	3	2	2

^aQA/QC site (value represents mean of three field replicates).

Table 8a. Continued.

Family	Gp. 1 Mean	Gp. 1 Occur. (%)	7062	7063	7064	70M20	70M252	70M258	70M270	70M4
No. Taxa (± 2 SD)	8 (2 – 14)	-	4	5	5	4	7	2	4	3
Chironomidae	13.4	39.9	0.2	0.8	1.2	0.2	3.6	0	0.4	0
Tubificidae	5.6	16.7	91.4	146.6	233.4	346.2	70.7	111.6	114.6	257.2
Sphaeriidae	4.9	14.7	1.6	7.6	3.4	5.8	0.05	0	0	4.0
Asellidae	1.8	5.5	0	0	0	0	0	0	0	0
Naididae	1.4	4.3	6.2	0	25.0	10.4	3.2	0	5.6	0.4
Sabellidae	1.2	3.6	0	0	0	0	0	0	0	0
BEAST BAND	-	-	1	2	3	4	2	4	3	3

Table 8b. Mean abundance of most prominent families (per 33 cm²), taxa diversity, and summary BEAST results for Hamilton Harbour sites maximally predicted to reference Group 2. Families expected to be present that are absent from test sites are highlighted.

Family	Group 2 Mean	Gp 2 Occur. (%)	7002	7030	7047	7058
No. Taxa (± 2 SD)	7 (3 – 11)	-	4	1	5	4
Tubificidae	86.5	70.2	66.4	2.6	22.8	218.0
Sphaeriidae	10.7	8.7	0.2	0	0.4	0.4
Chironomidae	9.0	7.3	0	0	0	0.2
Naididae	5.1	4.1	12.8	0	2.2	6.8
Haustoriidae	4.8	3.9	0	0	0	0
BEAST BAND	-	-	1	1	2	2

Table 8c. Mean abundance of most prominent families (per 33 cm²), taxa diversity, and summary BEAST results for Hamilton Harbour sites maximally predicted to reference Group 3. Families expected to be present that are absent from test sites are highlighted.

Family	Group 3 Mean	Gp 3 Occur. (%)	7008	7015 ^a	7021	7035	7043	7056
No. Taxa (±2 SD)	11 (7 – 15)	-	12	7	12	5	8	6
Dreissenidae	175.5	73.8	8.3	0.4	155.8	0	0.8	0
Tubificidae	32.2	13.5	88.5	87.7	9.8	192.6	9.9	186.8
Chironomidae	12.8	5.4	67.2	7.9	62.5	0.2	0.5	23.8
Valvatidae	3.6	1.5	0.06	0.3	0	0	0	0
Naididae	2.8	1.2	11.1	1.5	9.8	4.0	0.9	4.2
BEAST BAND	-	-	2	2	2	2	2	2

^aQA/QC site (value represents mean of three field replicates).

Table 8d. Mean abundance of most prominent families (per 33 cm²), taxa diversity, and summary BEAST results for Hamilton Harbour site maximally predicted to reference Group 4. Families expected to be present that are absent from test sites are highlighted.

Family	Group 4 Mean	Gp 4 Occur. (%)	70M268
No. Taxa (±2 SD)	6 (3 – 9)	-	2
Haustoriidae	58.9	65.1	0
Lumbriculidae	11.5	12.7	0
Sphaeriidae	8.7	9.6	0
Tubificidae	5.2	5.7	40.6
Enchytraeidae	3.5	3.9	0
Chironomidae	1.3	1.5	0
Naididae	0.9	0.9	6.0
BEAST BAND	-	-	4

Table 9. Sediment toxicity test results and summary BEAST results. Toxicity is highlighted; potential toxicity is bolded/italicized.

Site	<i>C. riparius</i> Growth	<i>C. riparius</i> survival	<i>H. azteca</i> growth	<i>H. azteca</i> survival	<i>Hexagenia</i> growth	<i>Hexagenia</i> survival	<i>T. tubifex</i> cocoons	<i>T. tubifex</i> hatch	<i>T. tubifex</i> survival	<i>T. tubifex</i> young	BEAST BAND
Ref. Mean	0.35	87.1	0.50	85.6	3.03	96	9.9	57	98	29.0	
7000	0.315	92.00	0.345	89.3	1.065	80.0	11.10	0.47	100.0	15.05	2
7002	0.266	78.67	0.403	88.0	0.500	28.0	6.25	0.80	100.0	7.65	4
7004	0.309	96.00	0.458	73.3	0.581	64.0	6.70	0.76	100.0	10.30	3
7007	0.285	90.67	0.446	94.7	2.949	100.0	8.85	0.74	100.0	5.50	2
7008	0.429	80.00	0.716	89.3	2.623	98.0	9.50	0.69	100.0	17.30	1
7013	0.175	82.67	0.246	76.0	0.581	46.0	7.55	0.79	100.0	21.00	4
7014	0.330	97.33	0.522	82.7	0.068	80.0	10.40	0.41	100.0	22.20	2
7015	0.274	81.33	0.407	94.7	4.823	98.0	11.55	0.53	100.0	30.60	1
7019	0.167	65.33	0.425	81.3	0.739	56.0	7.65	0.82	100.0	31.85	4
7021	0.521	61.33	0.765	96.0	1.052	94.0	10.80	0.68	100.0	30.10	2
7022	0.175	56.00	0.324	74.7	0.481	36.0	8.25	0.66	100.0	20.70	4
7024	0.239	72.00	0.405	98.7	3.630	100.0	8.75	0.62	100.0	18.25	2
7025	0.226	86.67	0.332	78.7	4.196	94.0	7.65	0.75	100.0	18.65	1
7030	0.249	84.00	0.361	100.0	4.474	100.0	9.50	0.72	100.0	14.00	1
7035	0.250	89.33	0.257	74.7	4.216	100.0	9.15	0.70	100.0	19.75	1
7036	0.263	93.33	0.386	93.3	5.722	98.0	9.90	0.81	100.0	14.75	1
7038	0.210	69.33	0.340	85.3	0.803	66.0	9.94	0.82	95.0	5.46	3
7039	0.280	76.00	0.477	89.3	0.434	34.0	7.82	0.79	90.0	7.90	4
7040	0.223	69.33	0.414	78.7	0.281	58.0	5.80	0.64	100.0	6.65	4
7043	0.296	85.33	0.521	96.0	1.007	74.0	4.96	0.82	93.8	7.88	3
7045	0.281	92.00	0.413	93.3	1.035	90.0	8.10	0.71	100.0	23.15	1
7047	0.327	84.00	0.450	84.0	0.999	92.0	6.45	0.84	100.0	14.50	1
7049	0.309	84.00	0.432	92.0	1.435	72.0	7.70	0.69	100.0	11.80	3
7050	0.392	90.67	0.397	90.7	0.410	78.0	8.30	0.80	100.0	10.45	2
7051	0.386	96.00	0.387	88.0	1.690	98.0	9.30	0.66	100.0	14.70	1
7052	0.382	90.67	0.393	96.0	0.682	84.0	9.25	0.48	100.0	15.10	2
7053	0.242	60.00	0.387	72.0	0.080	8.0	9.35	0.54	100.0	17.50	4
7054	0.247	94.67	0.513	90.7	-0.071	86.0	9.50	0.67	100.0	30.00	1
7055	0.291	84.00	0.535	85.3	0.235	56.0	9.45	0.81	100.0	8.15	4
7056	0.372	88.00	0.573	97.3	7.038	100.0	11.25	0.63	100.0	23.55	1
7057	0.264	89.33	0.480	92.0	-0.182	82.0	9.80	0.65	100.0	18.90	1
7058	0.307	86.67	0.302	60.0	0.064	52.0	10.30	0.65	100.0	17.95	4
7059	0.111	50.67	0.311	66.7	0.000	0.0	8.15	0.91	100.0	5.30	4
7061	0.155	40.00	0.359	65.3	-0.013	42.0	9.85	0.89	100.0	18.20	4
7062	0.187	46.67	0.565	96.0	0.441	82.0	10.90	0.88	100.0	17.00	4
7063	0.164	52.00	0.398	9.3	0.000	0.0	0.30	0.20	30.0	0.05	4
7064	0.164	53.33	0.292	78.7	0.029	68.0	7.95	0.84	100.0	10.20	4
70M20	0.312	88.00	0.331	90.7	-0.727	40.0	10.35	0.61	100.0	9.90	4
70M252	0.363	92.00	0.461	94.7	-0.391	96.0	11.20	0.29	100.0	4.85	2
70M258	0.272	92.00	0.467	90.7	-0.505	92.0	10.25	0.66	100.0	24.40	1
70M268	0.673	98.67	0.642	82.7	-0.255	54.0	11.60	0.32	100.0	18.05	4
70M270	0.367	80.00	0.625	97.3	3.362	94.0	9.45	0.81	100.0	29.10	1
70M4	0.176	81.33	0.284	84.0	0.077	26.0	9.25	0.78	100.0	16.45	4
Non-Toxic	0.49 - 0.21	67.7	0.75 - 0.23	67.0	5.0 - 0.9	85.5	12.4 - 7.2	0.78 - 0.38	88.9	46.3 - 9.9	-
Pot. Toxic	0.20 - 0.14	67.6 - 58.8	0.22 - 0.10	66.9 - 57.1	0.8 - 0	85.4 - 80.3	7.1 - 5.9	0.38 - 0.28	88.8 - 84.2	9.8 - 0.8	-
Toxic	< 0.14	< 58.8	< 0.10	< 57.1	neg	< 80.3	< 5.9	< 0.28	< 84.2	< 0.8	-

*Upper limit for non-toxic category is set using 2 X SD of the mean and indicates excessive growth or reproduction.

Table 10. Overall summary of BEAST evaluation of community structure and sediment toxicity. Environmental attributes that exceeded the provincial Severe Effect Level are indicated.

Site	BEAST Assessment Band		Variables >SEL
	Community	Toxicity	
7000	4	2	Cu, Fe, TP(S), Zn
7002	1	4	Cr, Fe, Mn, Pb, Zn
7004	4	3	Cu, Fe
7007	4	2	Fe, Mn TP(S), Zn
7008	2	1	-
7013	4	4	Cr, Cu, Fe, Mn, Pb, TP(S), Zn
7014	4	2	Cr, Cu, Fe, Hg, Mn, Ni, Pb, TOC, Zn
7015	2	1	Zn
7019	4	4	As, Cr, Cu, Fe, Hg, Mn, Pb, TP(S), Zn
7021	2	2	-
7022	4	4	Fe, Mn, Zn
7024	4	2	Mn, TP(s), Zn
7025	4	1	Fe, Mn, Zn
7030	1	1	Mn, TP(S)
7035	2	1	-
7036	2	1	Mn
7038	4	3	-
7039	4	4	-
7040	4	4	Mn
7043	2	3	-
7045	3	1	Fe, Mn, TP(S), Zn
7047	2	1	-
7049	2	3	Hg, Mn, Zn
7050	3	2	Cu, Hg, Zn
7051	4	1	Cu, Mn
7052	4	2	Cu, Hg, Mn
7053	3	4	As, Cr, Cu, Fe, Mn, Ni, Pb, TOC, TP(S), Zn
7054	3	1	As, Cr, Cu, Fe, Mn, Zn
7055	4	4	Cu, Fe, Mn, Zn
7056	2	1	-
7057	4	1	Cr, Cu, Fe, Hg, Mn, Pb, TP(S), Zn
7058	2	4	TP(s)
7059	3	4	As, Cu, Fe, Hg, Mn, Pb, Zn
7060	2	- ^a	Mn
7061	2	4	Mn
7062	1	4	Mn
7063	2	4	Mn, Pb, Zn
7064	3	4	Mn
70M20	4	4	Cr, Cu, Fe, Mn, Pb, TP(s), Zn
70M252	2	2	Cu, TP(s)
70M258	4	1	Fe, Hg, Mn, Zn
70M268	4	4	Cu, Fe, TN(s), TP(s)
70M270	3	1	Mn
70M4	3	4	Cr, Cu, Fe, Mn, Pb, TP(s), Zn

^a sufficient sediment could not be collected for toxicity tests.

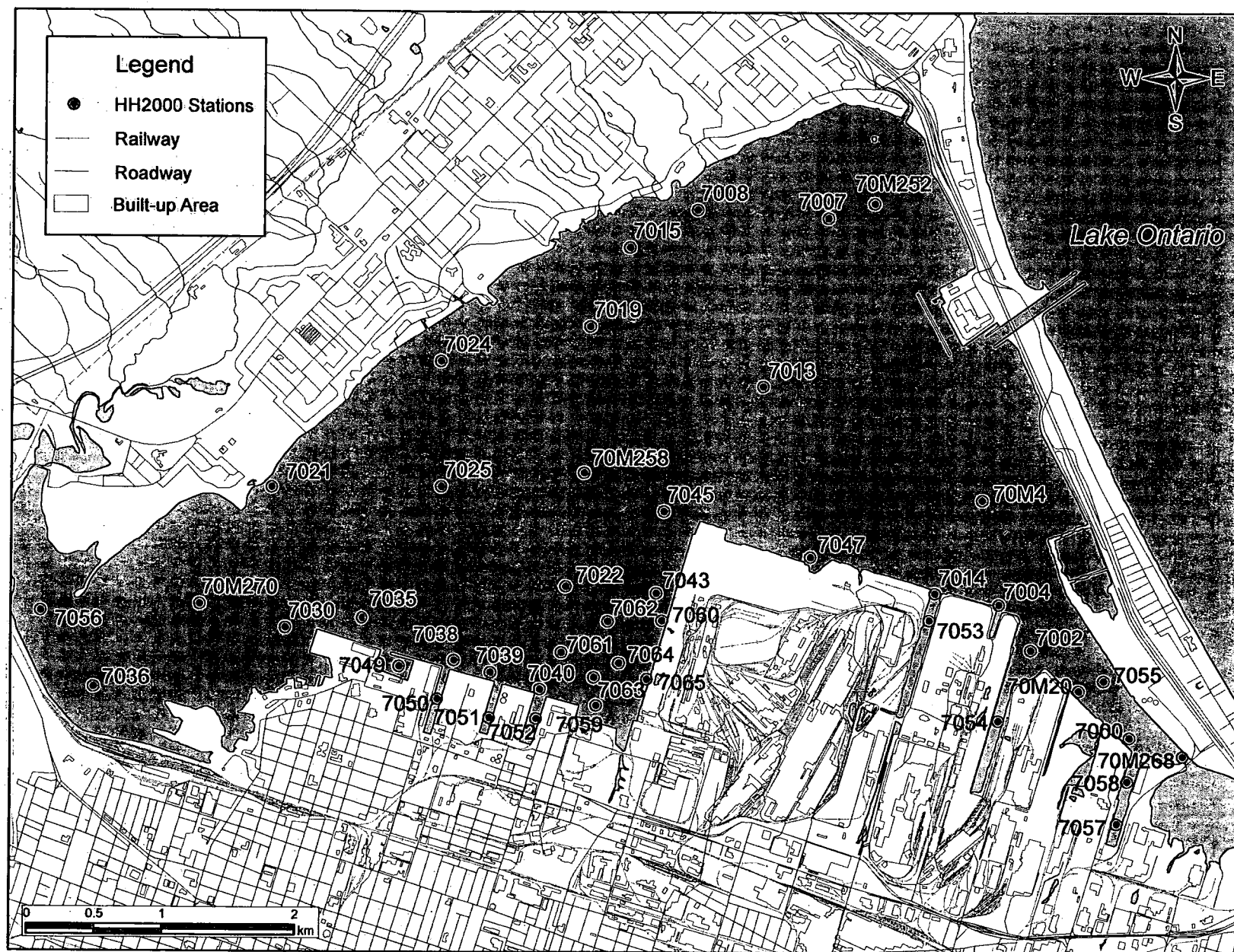


Figure 1. Location of sites in Hamilton Harbour.

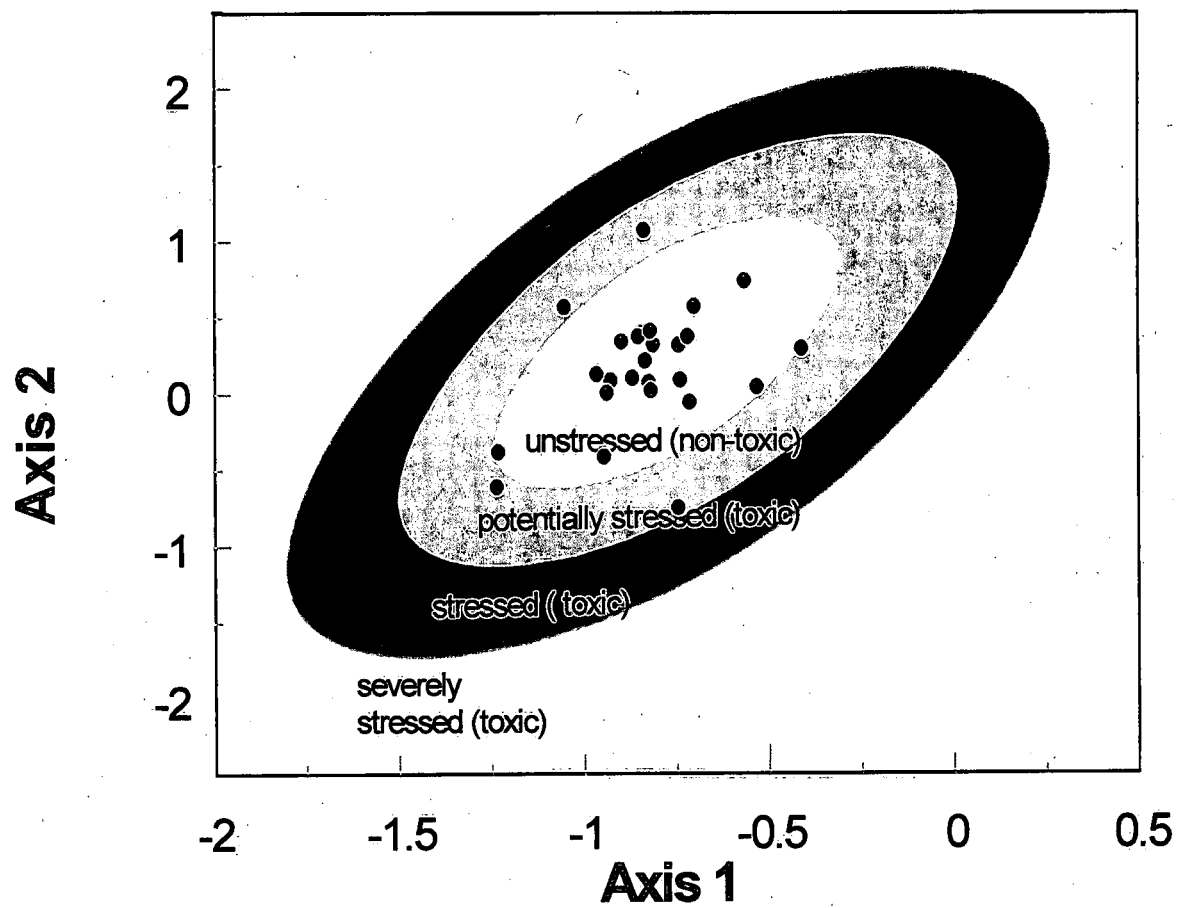


Figure 2. Use of 90, 99, and 99.9% probability bands in determining departure from reference condition.

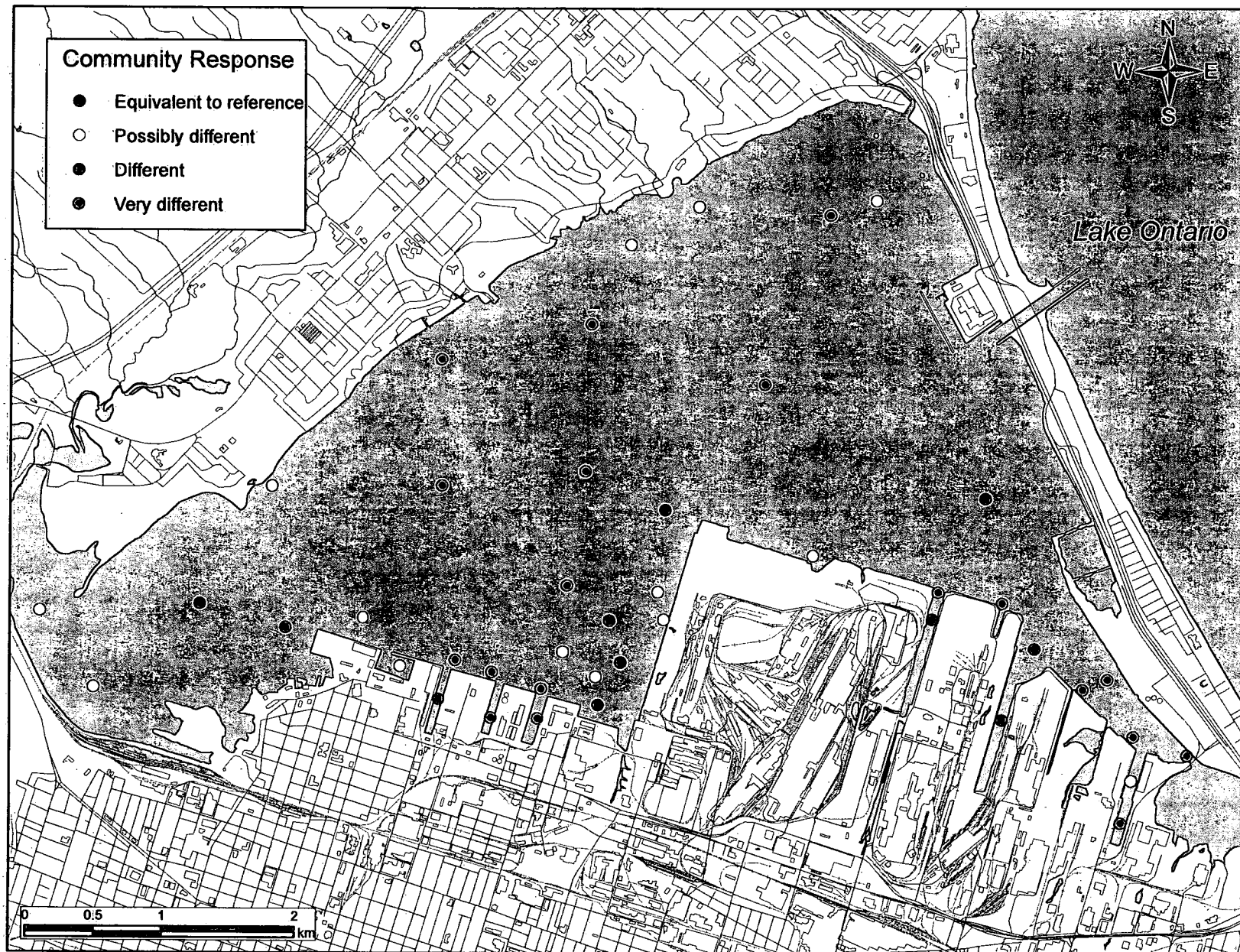


Figure 3. Spatial distribution of sites indicating the level of benthic community alteration compared to reference sites.

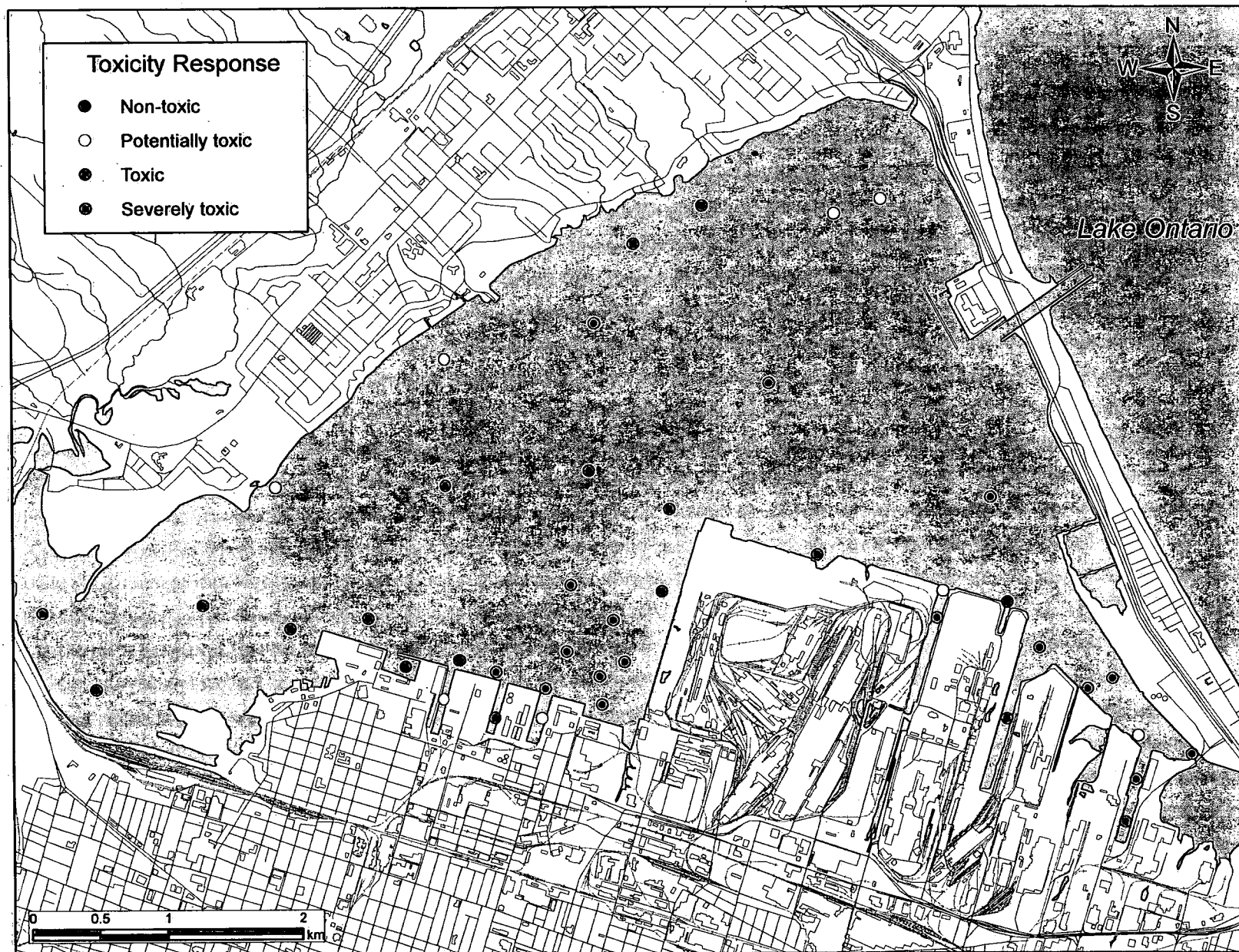


Figure 4. Spatial distribution of sites indicating the level of toxicity compared to reference sites.

APPENDIX A Quality Assurance/Quality Control

Table A1. Coefficients of variation (%) for field-replicated sites.

Parameter	SITE		
	7015	7040	7054
Al ₂ O ₃	6.2	1.5	6.1
Alkalinity	0.4	0.6	0.5
As	70.5	14.4	11.0
CaO	44.2	3.7	6.1
Cd	69.3	0.0	21.4
Clay	103.9	23.7	6.1
Co	3.6	11.8	30.8
Cr	51.8	32.0	2.1
Cu	64.7	15.5	5.5
Fe ₂ O ₃	46.5	3.8	9.4
Hg	82.8	26.9	23.1
K ₂ O	10.3	1.6	8.3
LOI	77.4	10.2	0.8
MgO	32.3	4.0	2.1
MnO	48.3	11.5	11.3
Na ₂ O	40.8	3.6	12.27
Ni	31.9	80.3	1.9
No ₃ /No ₂	5.3	1.8	4.87
P ₂ O ₅	57.6	9.8	3.61
Pb	64.8	6.8	2.67
Sand	78.8	5.5	15.78
Silt	107.3	2.1	4.33
SiO ₂	24.5	2.7	8.27
TiO ₂	30.7	15.7	3.07
TKN (water)	33.7	8.0	0.35
TN (sediment)	70.6	16.1	2.51
TOC	65.7	16.3	17.32
TP(Sediment)	73.4	26.1	6.33
TP(Water)	3.9	16.5	5.59
V	59.5	2.2	3.83
Zn	37.0	3.7	2
Total PAHs	84.0	11.3	12.4
Total PCBs	80.9	22.1	41.7

CLIENT INFORMATION

Attention: Danielle Milani
Client Name: Environment Canada
Project: KW418-01-0100
Project Desc: Randle Reef

Address: Contaminated Site Remediation Section
4905 Dufferin Street
Downsview, ON
M3H 5T4

Fax Number: 416-739-4342

Phone Number: 416-739-5876

LABORATORY INFORMATION

Contact: Nick Boulton, BSc, CChem
Project: AN010766
Date Received: 28-Mar-2002
Date Reported: 30-Apr-2002

Submission No.: 2D0032
Sample No.: 017033-017083

NOTES:

*"-" = not analysed "<" = less than Method Detection Limit (MDL) 'NA' = no data available
LOQ can be determined for all analytes by multiplying the appropriate MDL X 3.33
Blank correction is only performed on oil and grease, BTEX, total purgeable hydrocarbons
and VOC analyses when Canadian methods are utilized.
Solids data is based on dry weight except for biota analyses.
Organic analyses are not corrected for extraction recovery standards except for isotope
dilution methods, (i.e. CARB 429 PAH, all PCDD/F and DBD/DBF analyses)*

Methods used by PSC Analytical Services are based upon those found in 'Standard Methods for the Examination of Water and Wastewater', Nineteenth Edition. Other methods are based on the principles of MISA or EPA methodologies. New York State: ELAP Identification Number 10756.

All work recorded herein has been done in accordance with normal professional standards using accepted testing methodologies, quality assurance and quality control procedures except where otherwise agreed to by the client and testing company in writing. Any and all use of these test results shall be limited to the actual cost of the pertinent analysis done. There is no other warranty expressed or implied. Your samples will be retained at PSC Analytical Services for a period of three weeks from receipt of data or as per contract.

COMMENTS:

- (1) b-BHC blank water matrix spike recovery outside of control limits.
- (2) Surrogate recovery outside acceptance limits.
- (3) Aroclor 1221 Matrix Spike outside of SOP QC limits (21-115%). Matrix Spike possibly double spiked.
- (4) Aroclor 1268 Matrix Spike outside of SOP QC limits (21-142). Matrix Spike possibly double spiked.
- (5) Matrix interference suspected for Aroclor 1262.
- (6) Aldrin and b-BHC Matrix Spike recoveries outside of acceptance limits.
- (7) Aroclor 1262 Matrix Spike outside acceptance limits (39-155%).
- (8) MDL raised for compound marked with '*' due to matrix effect.
- (9) MDL raised 2x due to high moisture content (approx. half of normal dry weight of sample used).
- (10) MDL raised 4x due to high moisture content (approx. half of normal dry weight of sample used).
- (11) Sample concentrations are too high to differentiate Matrix Spike concentrations. It is possible that the sample was not homogenous.
- (12) MDL raised 5x. Sample was diluted 5x prior to injection due to very dark and viscous extract.
- (13) Internal Standards d12-Chrysene, d10-Phenanthrene and d12-perylene were suppressed below acceptable limits due to matrix. Values may be biased low.

Table A2. Percent recovery for matrix spikes (PSC Analytical).

SITE	7059		7045	
Component	28-Mar-2002 Matrix Spike	28-Mar-2002 M.S. % Rec.	28-Mar-2002 Matrix Spike	28-Mar-2002 M.S. % Rec.
Naphthalene	216.39	NA	6.11	49.57
Acenaphthylene	8.30	67.10	5.45	81.96
Acenaphthene	5.76	63.90	5.41	81.75
Fluorene	36.64	NA	5.46	77.65
Phenanthrene	31.74	NA	8.96	62.25
Anthracene	15.11	NA	6.57	81.01
Fluoranthene	32.36	NA	10.81	34.89
Pyrene	28.96	NA	11.04	57.18
Benz(a)anthracene	20.34	NA	8.20	72.08
Chrysene	19.51	NA	8.91	68.60
Benzo(b)fluoranthene	19.15	NA	7.88	32.20
Benzo(k)fluoranthene	11.86	69.40	8.28	92.95
Benzo(a)pyrene	18.80	NA	8.66	58.18
Indeno(1,2,3-cd)pyrene	12.12	58.90	8.60	73.41
Dibenzo(ah)anthracene	6.07	84.70	6.23	91.02
Benzo(ghi)perylene	11.20	68.90	8.18	70.33
Range		58.90 - 84.70		32.20 - 92.95
Mean		68.82		67.81

Inter-Laboratory Comparison of Analyses of Cu, Zn, Pb, and Fe in Sediment from Hamilton Harbour

Analyses for concentrations of total Cu, Zn, Pb, and Fe in sediment were performed by two laboratories: Caduceon Environmental Laboratory, which was selected to measure a suite of trace metals in sediment samples, and PSC Analytical, which conducted trace metal analyses on a subset of sites from the Randle Reef area (8 sites). Each lab received a sediment subsample from the same homogenized sample collected at each site. Those submitted to Caduceon were sent freeze dried, and those submitted to PSC were frozen. Figures A1-A4 show how the site measurements compare graphically.

Overall agreement between labs for the determinations of metal in sediment is indicated by the slope of a regression involving the two variables. As recommended by McArdle (1988) and Draper and Smith (1998), the regression was estimated by the geometric mean (GM, aka reduced major axis) method instead of the ordinary least squares (OLS) method. The OLS method assumes negligible error in the X variable, and can result in biased slope estimates when applied to data in which both X and Y variables are subject to errors of the same magnitude, a situation that clearly applies here. Rather than minimizing the sum of the squares of the deviations of observed Y values from the regression line, as in the OLS method, the GM method minimizes the sum of the areas of the triangles formed by the data point, the point on the line corresponding to the X value, and the point on the line corresponding to the Y value. Geometric Mean slope, b_{GM} , was estimated by

$$b_{GM} = s_y / s_x \quad (\text{Legendre and Legendre 1998})$$

where s_y = standard deviation of Y - values, and s_x = standard deviation of X - values. The b_{GM} estimate is also the geometric mean of the OLS slope of Y on X and the reciprocal of the slope of X on Y . (Note that when the purpose of the analysis is not to estimate functional parameters such as the slope, but only to predict values of Y for given X 's, OLS regression is suitable (Legendre and Legendre 1998).

Copper:

Geometric mean regression slope for $\log[\text{Cu}]_{\text{PSC}}$ vs. $\log[\text{Cu}]_{\text{Caduc}}$:

$$\text{Standard deviation of } \log[\text{Cu}]_{\text{PSC}} = 0.2745 = s_y$$

$$\text{Standard deviation of } \log[\text{Cu}]_{\text{Caduc}} = 0.2885 = s_x$$

$$b_{GM} = s_y / s_x = 0.2745 / 0.2885 = 0.9515$$

$$\text{OLS regression of } Y \text{ vs } X: \log[\text{Cu}]_{\text{PSC}} = 0.1504 + 0.9136$$

$$\log[\text{Cu}]_{\text{Caduc}}$$

$$\text{OLS regression of } X \text{ vs } Y: \log[\text{Cu}]_{\text{Caduc}} = -0.0226 + 1.0098$$

$$\log[\text{Cu}]_{\text{PSC}}$$

For both regressions $P < 0.001$ and $r^2 = 92.3\%$.

As a check, using the alternate slope estimation method:

$$b_{GM} = (0.9136 \times [1 / 1.0098])^{1/2} = 0.952$$

Lead:

Geometric mean regression slope for $\log[\text{Pb}]_{\text{PSC}}$ vs. $\log[\text{Pb}]_{\text{Caduc}}$:

$$\text{Standard deviation of } \log[\text{Pb}]_{\text{Flett}} = 0.4752 = s_y$$

$$\text{Standard deviation of } \log[\text{Pb}]_{\text{Caduc}} = 0.9690 = s_x$$

$$b_{GM} = s_y / s_x = 0.4752 / 0.9690 = 0.4904$$

$$\text{OLS regression of } Y \text{ vs } X: \log[\text{Pb}]_{\text{PSC}} = 1.1726 + 0.4486 \log[\text{Pb}]_{\text{Caduc}}$$

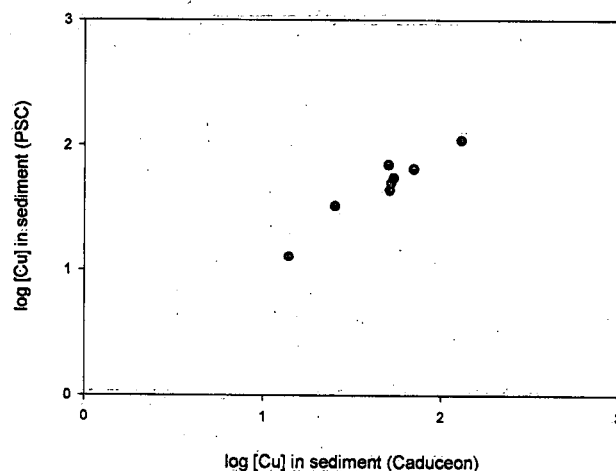


Figure A1. Comparison of Cu measurements between labs.

OLS regression of X vs Y : $\log[\text{Pb}]_{\text{Caduc}} = -1.8928 + 1.8655 \log[\text{Pb}]_{\text{PSC}}$

For both regressions $P=0.0015$ and $r^2 = 83.7\%$.

As a check, using the alternate slope estimation method:

$$b_{\text{GM}} = (0.4486 \times [1 / 1.8655])^{1/2} = 0.4904$$

Zinc:

Geometric mean regression slope for $\log[\text{Zn}]_{\text{PSC}}$ vs $\log[\text{Zn}]_{\text{Caduc}}$:

Standard deviation of $\log[\text{Zn}]_{\text{PSC}} = 0.5376 = s_y$

Standard deviation of $\log[\text{Zn}]_{\text{Caduc}} = 0.6077 = s_x$

$$b_{\text{GM}} = s_y / s_x = 0.5376 / 0.6077 = \mathbf{0.8846}$$

OLS regression of Y vs X : $\log[\text{Zn}]_{\text{PSC}} = 0.3553 + 0.8843 \log[\text{Zn}]_{\text{Caduc}}$

OLS regression of X vs Y : $\log[\text{THg}]_{\text{Caduc}} = -0.3994 + 1.1300 \log[\text{Zn}]_{\text{PSC}}$

For both regressions $P<0.001$ and $r^2 = 99.9\%$.

As a check, using the alternate slope estimation method:

$$b_{\text{GM}} = (0.8843 \times [1 / 1.1300])^{1/2} = 0.8846$$

Iron:

Geometric mean regression slope for $\log(\% \text{Fe})_{\text{PSC}}$ vs $\log(\% \text{Fe})_{\text{Caduc}}$:

Standard deviation of $\log(\% \text{Fe})_{\text{PSC}} = 0.3163 = s_y$

Standard deviation of $\log(\% \text{Fe})_{\text{Caduc}} = 0.3466 = s_x$

$$b_{\text{GM}} = s_y / s_x = 0.3163 / 0.3466 = \mathbf{0.9126}$$

OLS regression of Y vs X : $\log(\% \text{Fe})_{\text{PSC}} = 0.0640 + 0.9119 \log(\% \text{Fe})_{\text{Caduc}}$

OLS regression of X vs Y : $\log(\% \text{Fe})_{\text{Caduc}} = -0.0693 + 1.0950 \log(\% \text{Fe})_{\text{PSC}}$

For both regressions $P<0.001$ and $r^2 = 99.9\%$.

As a check, using the alternate slope estimation method:

$$b_{\text{GM}} = (0.9119 \times [1 / 1.0950])^{1/2} = 0.9126$$

The overall agreement in measurements of Cu and Fe in sediment is good because the slope estimate is close to 1, and is fair for Zn. This suggests that either (a) the analyses of the labs are accurate or (b) analyses are biased in identical ways. The overall agreement for Pb is poor, due primarily to the measurements at site 7043 (18.0/0.5 $\mu\text{g/g}$). The unexplained 7.7, 16.3, and 0.1% of the variation of the regressions should be attributed to laboratory measurement error.

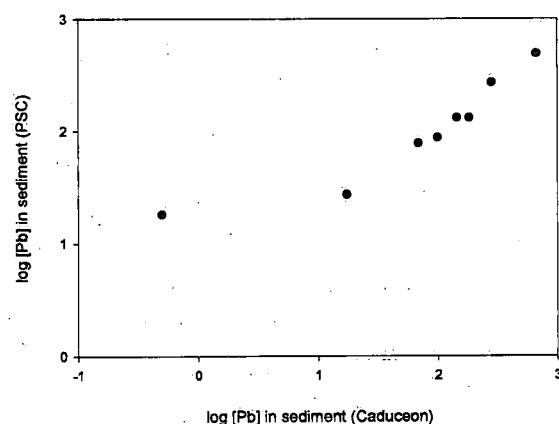


Figure A2. Comparison of Pb measurements between labs.

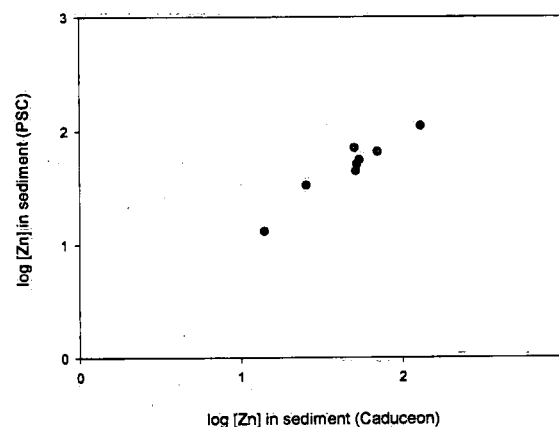


Figure A3. Comparison of Zn measurements between labs.

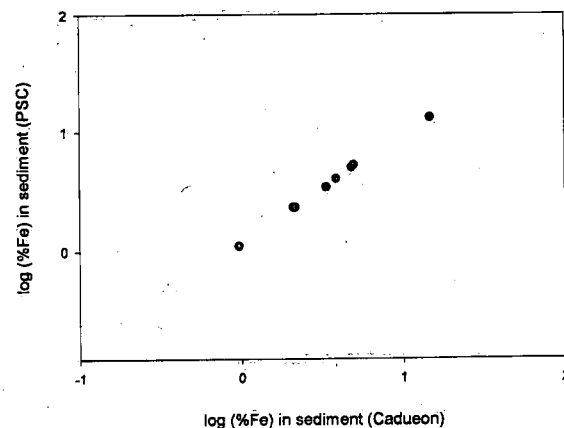


Figure A4. Comparison of Fe measurements between labs.

APPENDIX B Organic/Metal Analyses

Table B1. Polychlorinated Biphenyls in Hamilton Harbour sediment.

SITE			7000	7002	7004	7007	7008	7013	7014	7015-1	7015-2	7015-3	7019	7021	7022
Date Analyzed:			28-Mar-2002	28-Mar-2002	28-Mar-2002	28-Mar-2002	28-Mar-2002	28-Mar-2002	28-Mar-2002	28-Mar-2002	28-Mar-2002	28-Mar-2002	28-Mar-2002	28-Mar-2002	28-Mar-2002
Component	MDL	Units													
Aroclor-1016	0.038	ug/gm	<0.056	<0.058	<0.064	<0.097	<	<0.098	<0.083	<0.048	<0.047	<0.091	<0.11	<	<0.10
Aroclor-1221	0.015	"	<0.022	<0.023	<0.025	<0.038	<	<0.039	<0.033	<0.019	<0.018	<0.036	<0.044	<	<0.041
Aroclor-1232	0.038	"	<0.056	<0.058	<0.064	<0.097	<	<0.098	<0.083	<0.048	<0.047	<0.091	<0.11	<	<0.10
Aroclor-1242	0.038	"	<0.056	<0.058	<0.064	<0.097	<	<0.098	<0.083	<0.048	<0.047	<0.091	0.23	<	<0.10
Aroclor-1248	0.021	"	<0.031	<0.032	<0.035	<0.054	<	<0.054	<0.046	<0.026	<0.026	<0.050	<0.062	<	<0.058
Aroclor-1254	0.059	"	0.52	1.10	<0.099	0.27	<	0.34	0.38	0.07	<0.073	<0.14	<0.17	<	<0.16
Aroclor-1260	0.031	"	0.93	2.70	0.07	0.33	<	0.76	0.50	0.14	0.06	0.44	0.74	<	0.45
Aroclor-1262	0.031	"	<0.046	<0.047	<0.052	<0.079	<	<0.080	<0.068	<0.039	<0.038	<0.074	<0.091	<	<0.085
Aroclor-1268	0.031	"	<0.046	<0.047	<0.052	<0.079	<	<0.080	<0.068	<0.039	<0.038	<0.074	<0.091	<	<0.085
Total PCBs	0.059	"	1.50	3.80	0.07	0.60	<	1.10	0.87	0.21	0.06	0.44	0.97	<	0.45

SITE			7024	7025	7030	7035	7036	7038	7039	7045	7047	7049	7050	7051	7052
Date Analyzed:			28-Mar-2002	28-Mar-2002	28-Mar-2002	28-Mar-2002	28-Mar-2002	28-Mar-2002	28-Mar-2002	28-Mar-2002	28-Mar-2002	28-Mar-2002	28-Mar-2002	28-Mar-2002	28-Mar-2002
Component	MDL	Units													
Aroclor-1016	0.038	ug/gm	<0.088	<0.15	<0.086	<0.069	<0.076	<0.053	<0.067	<0.13	<0.087	<0.089	<0.068	<0.070	<0.057
Aroclor-1221	0.015	"	<0.035	<0.059	<0.034	<0.027	<0.030	<0.021 *	<0.026	<0.050	<0.034	<0.035	<0.027	<0.028	<0.023
Aroclor-1232	0.038	"	<0.088	<0.15	<0.086	<0.069	<0.076	<0.053	<0.067	<0.13	<0.087	<0.089	<0.068	<0.070	<0.057
Aroclor-1242	0.038	"	<0.088	<0.15	<0.086	<0.069	<0.076	<0.053	<0.067	<0.13	<0.087	<0.089	<0.068	<0.070	<0.057
Aroclor-1248	0.021	"	<0.049	<0.082	<0.048	<0.038	<0.042	<0.029	<0.037	<0.070	<0.048	<0.049	<0.038	<0.039	<0.032
Aroclor-1254	0.059	"	<0.14	<0.23	<0.13	<0.11	<0.12	<0.082	<0.10	<0.20	<0.14	<0.14	<0.11	0.53	0.22
Aroclor-1260	0.031	"	0.19	0.55	0.19	0.11	0.12	0.13	0.10	0.42	0.10	0.37	0.15	0.31	0.18
Aroclor-1262	0.031	"	<0.072	<0.12	<0.070	<0.056	<0.062	<0.043	<0.054	<0.10	<0.071	<0.073	<0.056	<0.057	<0.047
Aroclor-1268	0.031	"	<0.072	<0.12	<0.070	<0.056	<0.062	<0.043 *	<0.054	<0.10	<0.071	<0.073	<0.056	<0.057	<0.047
Total PCBs	0.059	"	0.19	0.55	0.19	0.11	0.12	0.13	0.10	0.42	0.10	0.37	0.15	0.84	0.39

SITE			7053	7054-1	7054-2	7054-3	7055	7056	7057	7058	70M4	70M20	70M252	70M258
Date Analyzed:			28-Mar-2002	28-Mar-2002	28-Mar-2002	28-Mar-2002	28-Mar-2002	28-Mar-2002	28-Mar-2002	28-Mar-2002	28-Mar-2002	28-Mar-2002	28-Mar-2002	28-Mar-2002
Component	MDL	Units												
Aroclor-1016	0.038	ug/gm	<0.085	<0.091	<0.085	<0.070	<0.079	<0.057	<0.068	<0.052	<0.083	<0.064	<0.096	<0.12
Aroclor-1221	0.015	"	<0.033	<0.036	<0.034	<0.028	<0.031	<0.022	<0.027	<0.021	<0.033	<0.025	<0.038	<0.046
Aroclor-1232	0.038	"	<0.085	<0.091	<0.085	<0.070	<0.079	<0.057	<0.068	<0.052	<0.083	<0.064	<0.096	<0.12
Aroclor-1242	0.038	"	<0.085	<0.091	<0.085	<0.070	<0.079	<0.057	2.80	<0.052	<0.083	<0.064	<0.096	<0.12
Aroclor-1248	0.021	"	<0.047	<0.050	<0.047	<0.039	<0.044	<0.031	<0.038	<0.029	<0.046	<0.035	<0.053	<0.065
Aroclor-1254	0.059	"	0.43	4.20	1.50	2.30	0.49	<	<0.11	0.86	0.47	0.54	0.19	0.15
Aroclor-1260	0.031	"	0.32	4.70	2.20	3.40	0.68	0.08	2.40	0.61	0.85	0.82	0.11	0.31
Aroclor-1262	0.031	"	<0.069	<0.074	<0.070	<0.057	<0.065	<0.046	<0.055	<0.043	<0.068	<0.052	<0.078	<0.095
Aroclor-1268	0.031	"	<0.069	<0.074	<0.070	<0.057	<0.065	<0.046	<0.055	<0.043	<0.068	<0.052	<0.078	<0.095
Total PCBs	0.059	"	0.75	8.90	3.80	5.80	1.20	0.08	5.20	1.50	1.30	1.40	0.30	0.46

SITE			70M268	70M270	7040-1	7040-2	7040-3	7043	7059	7060	7061	7062	7063	7064
Date Analyzed:			28-Mar-2002	28-Mar-2002	28-Mar-2002	28-Mar-2002	28-Mar-2002	28-Mar-2002	28-Mar-2002	28-Mar-2002	28-Mar-2002	28-Mar-2002	28-Mar-2002	28-Mar-2002
Component	MDL	Units												
Aroclor-1016	0.038	ug/gm	<0.080	<0.15	<0.083	<0.079	<0.071	<0.087	<0.12	<0.062	<0.10	<0.082	<0.069	<0.071
Aroclor-1221	0.015	"	<0.032	<0.059	<0.033	<0.031	<0.028	<0.034	<0.046	<0.025	<0.041	<0.032	<0.027	<0.028
Aroclor-1232	0.038	"	<0.080	<0.15	<0.083	<0.079	<0.071	<0.087	<0.12	<0.062	<0.10	<0.082	<0.069	<0.071
Aroclor-1242	0.038	"	<0.080	<0.15	<0.083	<0.079	<0.071	<0.087	<0.12	<0.062	<0.10	<0.082	<0.069	<0.071
Aroclor-1248	0.021	"	<0.044	<0.082	<0.046	<0.044	<0.039	<0.048	<0.065	<0.034	<0.057	<0.045	<0.038	<0.039
Aroclor-1254	0.059	"	0.47	0.21	0.25	0.28	0.25	<0.14	1.10	0.17	0.44	0.18	0.68	0.30
Aroclor-1260	0.031	"	0.45	0.39	0.22	0.27	0.09	<0.071	0.56	<0.051	0.18	0.09	0.22	0.12
Aroclor-1262	0.031	"	<0.066	<0.12	<0.068	<0.065 *	<0.058	<0.071	<0.096	<0.051	<0.084	<0.067	<0.056	<0.058
Aroclor-1268	0.031	"	<0.066	<0.12	<0.068	<0.065	<0.058	<0.071	<0.096	<0.051	<0.084	<0.067	<0.056	<0.058
Total PCBs	0.059	"	0.91	0.60	0.46	0.55	0.35	<0.14	1.70	0.17	0.62	0.28	0.90	0.42

Table B2. Polycyclic Aromatic Hydrocarbons in Hamilton Harbour sediment.

SITE		7000	7002	7004	7007	7008	7013	7014	7015-1	7015-2	7015-3	7019	7021	7022
Date Analyzed:		28-Mar-2002	28-Mar-2002	28-Mar-2002	28-Mar-2002	28-Mar-2002	28-Mar-2002	28-Mar-2002	28-Mar-2002	28-Mar-2002	28-Mar-2002	28-Mar-2002	28-Mar-2002	28-Mar-2002
Component	MDL Units													
Naphthalene	0.03 mg/kg	1.30	9.00	0.11	0.71	0.05	2.70	9.50	0.31	0.18	0.77	2.30	<	2.30
Acenaphthylene	0.04	0.30	0.23	<0.08	0.14	0.04	0.77	1.50	0.08	<	0.18	0.57	<	0.31
Acenaphthene	0.07	0.17	0.24	<0.14	<0.14	<	0.37	0.59	<	<	<0.14	0.34	<	0.17
Fluorene	0.03	0.20	0.31	<0.06	<0.06	<	0.63	1.30	<	<	<0.06	0.51	<	0.34
Phenanthrene	0.03	1.10	1.60	0.08	0.68	0.14	4.40	6.40	0.30	0.14	0.81	2.90	<	1.80
Anthracene	0.03	0.36	0.58	<0.06	<0.06	0.06	1.40	1.90	0.12	<	0.28	0.83	<	0.65
Fluoranthene	0.02	4.00	2.90	0.15	1.60	0.34	8.60	14.00	0.69	0.31	1.90	6.80	<	4.10
Pyrene	0.03	3.20	2.10	0.13	1.20	0.27	6.30	10.00	0.56	0.28	1.60	5.20	<	3.30
Benzo(a)anthracene	0.02	2.50	1.50	<0.04	0.90	0.18	4.00	8.50	0.42	0.22	0.99	3.40	<	2.20
Chrysene	0.03	2.50	1.50	<0.06	1.00	0.17	4.30	8.20	0.47	0.26	1.30	3.90	<	2.40
Benzo(b)fluoranthene	0.04	3.80	1.50	<0.08	1.70	0.19	6.60	11.00	0.84	0.40	2.20	5.70	<	4.30
Benzo(k)fluoranthene	0.04	1.70	0.62	<0.08	0.79	0.14	3.20	4.20	0.37	0.32	0.87	3.30	<	1.20
Benzo(a)pyrene	0.05	2.90	1.50	<0.10	1.30	0.22	5.20	9.40	0.61	0.32	1.50	5.10	<	3.00
Indeno(1,2,3-cd)pyrene	0.06	2.10	0.98	<0.12	1.20	0.17	4.00	5.80	0.52	<0.32	1.40	4.00	<	2.40
Dibenzo(ah)anthracene	0.04	0.48	<0.27	<0.31	<	0.94	1.30	<	<	<0.08	0.98	<	<	0.50
Benzo(ghi)perylene	0.04	1.90	0.94	<0.08	1.10	0.16	3.50	5.50	0.52	<0.28	1.20	3.50	<	2.20
Total PAHs		28.51	25.50	0.47	12.32	2.13	56.91	99.09	5.81	2.43	15.00	49.33	0.00	31.17
Date Analyzed:		28-Mar-2002	28-Mar-2002	28-Mar-2002	28-Mar-2002	28-Mar-2002	28-Mar-2002	28-Mar-2002	28-Mar-2002	28-Mar-2002	28-Mar-2002	28-Mar-2002	28-Mar-2002	28-Mar-2002
Component	MDL Units													
Naphthalene	0.03 mg/kg	0.58	1.90	0.54	0.73	0.36	1.20	2.20	3.00	0.14	1.40	0.95	2.40	1.80
Acenaphthylene	0.04	<0.08	0.23	0.12	0.06	<0.08	<	0.08	0.50	<0.08	0.13	<0.20	<0.20	0.06
Acenaphthene	0.07	<0.14	<0.28	0.09	<	<0.14	<	0.10	0.47	<0.14	0.15	<0.35	1.40	0.08
Fluorene	0.03	<0.06	0.26	0.16	<	<0.06	<	0.19	0.74	<0.06	0.27	0.39	1.60	0.21
Phenanthrene	0.03	0.43	1.30	1.00	0.59	0.52	0.76	1.10	4.90	0.17	1.50	3.30	14.00	0.82
Anthracene	0.03	0.12	0.36	0.29	0.16	<0.06	0.22	0.28	1.60	0.08	0.46	0.60	2.10	0.26
Fluoranthene	0.02	0.98	3.10	2.10	1.00	1.10	1.20	1.40	8.20	0.39	2.90	5.40	13.00	1.00
Pyrene	0.03	0.78	2.60	1.60	0.84	1.00	0.96	1.00	7.20	0.46	2.70	6.10	11.00	0.94
Benzo(a)anthracene	0.02	0.58	2.00	1.10	0.56	0.71	0.59	0.72	3.70	0.24	1.50	3.00	5.10	0.62
Chrysene	0.03	0.65	2.20	1.20	0.64	0.86	0.71	0.83	4.50	0.30	1.80	3.70	6.00	0.76
Benzo(b)fluoranthene	0.04	1.10	3.50	1.90	0.95	1.40	0.82	1.30	5.60	0.24	2.40	3.80	5.40	0.88
Benzo(k)fluoranthene	0.04	0.52	2.00	0.73	0.55	0.52	0.61	0.37	2.50	0.14	1.20	2.10	3.30	0.45
Benzo(a)pyrene	0.05	0.80	2.90	1.30	0.79	0.92	0.78	0.93	4.90	0.17	1.90	2.90	4.70	0.78
Indeno(1,2,3-cd)pyrene	0.06	0.71	2.40	1.10	0.60	0.81	0.58	0.71	4.00	<0.12	1.70	2.30	3.30	0.68
Dibenzo(ah)anthracene	0.04	<0.08	0.55	<0.08	<	<0.08	<	0.17	0.71	<0.08	0.35	<0.20	0.80	0.16
Benzo(ghi)perylene	0.04	0.68	2.20	1.00	0.60	0.79	0.57	0.67	3.70	<0.08	1.60	2.30	2.90	0.70
Total PAHs		7.93	27.50	14.23	8.07	8.99	9.00	12.05	56.22	2.33	21.96	36.84	77.00	10.20
Date Analyzed:		28-Mar-2002	28-Mar-2002	28-Mar-2002	28-Mar-2002	28-Mar-2002	28-Mar-2002	28-Mar-2002	28-Mar-2002	28-Mar-2002	28-Mar-2002	28-Mar-2002	28-Mar-2002	28-Mar-2002
Component	MDL Units													
Naphthalene	0.03 mg/kg	12.00	31.00	41.00	35.00	1.80	0.11	5.90	1.10	3.30	3.80	0.22	2.30	
Acenaphthylene	0.04	1.80	1.40	1.80	1.50	0.30	<	1.40	0.31	0.54	0.39	<0.08	0.28	
Acenaphthene	0.07	1.00	1.20	1.50	1.40	0.19	<	16.00	2.30	0.21	0.23	<0.14	0.14	
Fluorene	0.03	2.20	1.70	2.30	2.00	0.23	0.04	13.00	1.90	0.43	0.32	<0.06	0.32	
Phenanthrene	0.03	12.00	7.40	9.90	8.80	1.10	0.26	62.00	8.00	2.00	1.40	0.29	1.80	
Anthracene	0.03	4.30	2.40	3.50	3.00	0.33	0.15	15.00	2.00	0.65	0.48	0.11	0.54	
Fluoranthene	0.02	21.00	9.60	12.00	11.00	3.00	0.52	76.00	12.00	4.60	3.30	0.65	3.40	
Pyrene	0.03	18.00	7.50	10.00	9.10	2.90	0.45	63.00	9.70	4.00	2.80	0.59	4.00	
Benzo(a)anthracene	0.02	13.00	5.90	7.10	6.60	2.10	0.28	27.00	4.80	3.30	2.40	0.36	2.60	
Chrysene	0.03	13.00	6.00	7.70	7.00	2.30	0.34	25.00	4.60	3.60	2.50	0.50	2.90	
Benzo(b)fluoranthene	0.04	15.00	7.60	9.40	8.40	3.30	0.39	27.00	5.10	5.20	3.70	0.66	3.50	
Benzo(k)fluoranthene	0.04	5.80	3.20	3.80	3.50	1.40	0.21	11.00	2.00	1.80	1.30	0.20	2.10	
Benzo(a)pyrene	0.05	12.00	6.00	7.50	6.60	2.50	0.29	21.00	4.20	3.80	2.90	0.40	3.10	
Indeno(1,2,3-cd)pyrene	0.06	9.00	5.00	6.00	5.50	2.00	0.25	15.00	2.80	3.10	2.10	0.37	2.80	
Dibenzo(ah)anthracene	0.04	2.10	1.30	1.50	1.30	0.40	<	3.50	0.61	0.68	0.50	<0.08	<0.40	
Benzo(ghi)perylene	0.04	8.20	4.70	5.80	5.30	1.80	0.28	14.00	2.70	2.90	2.10	0.38	2.50	
Total PAHs		150.40	101.90	130.80	116.00	25.65	3.37	395.60	64.12	40.11	30.22	4.73	32.28	
Date Analyzed:		28-Mar-2002	28-Mar-2002	28-Mar-2002	28-Mar-2002	28-Mar-2002	28-Mar-2002	28-Mar-2002	28-Mar-2002	28-Mar-2002	28-Mar-2002	28-Mar-2002	28-Mar-2002	28-Mar-2002
Component	MDL Units													
Naphthalene	0.03 mg/kg	0.61	0.65	2.50	2.10	1.90	0.56	230.00	17.00	4.70	3.40	19.00	12.00	
Acenaphthylene	0.04	0.38	<0.08	0.10	<	0.09	<0.08	5.10	8.90	0.34	1.20	0.89	0.96	
Acenaphthene	0.07	0.40	<0.14	0.12	<	0.12	<0.14	2.70	3.80	0.19	1.80	0.70	1.10	
Fluorene	0.03	0.40	0.10	0.21	0.13	0.13	<0.06	38.00	11.00	0.61	2.30	21.00	1.70	
Phenanthrene	0.03	2.60	0.65	1.40	1.00	1.20	0.46	38.00	76.00	2.30	18.00	5.90	9.20	
Anthracene	0.03	0.67	0.14	0.36	0.25	0.39	0.18	13.00	22.00	0.84	6.90	2.30	3.30	
Fluoranthene	0.02	10.00	1.40	2.00	1.40	1.90	0.55	40.00	70.00	4.20	25.00	10.00	15.00	
Pyrene	0.03	9.60	1.40	1.40	1.30	1.50	0.44	31.00	59.00	3.90	23.00	8.90	16.00	
Benzo(a)anthracene	0.02	8.00	0.81	0.94	0.81	0.86	0.24	20.00	21.00	2.30	11.00	6.20	8.00	
Chrysene	0.03	8.00	1.10	1.10	0.87	1.00	0.23	18.00	23.00	2.80	12.00	6.00	9.50	
Benzo(b)fluoranthene	0.04	11.00	1.20	1.30	1.30	1.30	0.30	18.00	24.00	3.40	12.00	6.40	11.00	
Benzo(k)fluoranthene	0.04	5.20	0.81	0.59	0.33	0.56	0.17	8.60	11.00	1.60	6.20	4.60	5.80	
Benzo(a)pyrene	0.05	10.00	1.10	1.00	0.96	1.10	0.30	17.00	23.00	3.00	12.00	6.40	9.90	
Indeno(1,2,3-cd)pyrene	0.06	7.00	0.95	0.76	0.65	0.70	<0.12	9.30	18.00	2.50	9.50	4.90	7.60	
Dibenzo(ah)anthracene	0.04	1.40	<0.08	0.21	<	<	<0.08	2.10	2.90	0.50	1.60	1.10	1.60	
Benzo(ghi)perylene	0.04	6.20	1.00	0.73	0.63	0.76	<0.08	7.90	17.00	2.50	9.60	4.40	7.40	
Total PAHs		81.46	11.31	14.72	11.73	13.51	3.43	498.70	407.60	35.68	155.50	108.69	120.06	

Table B3. Organo-chlorine pesticides for a subset of Hamilton Harbour sites (Randle Reef area sites).

SITE			7040-1	7043	7059	7060	7061	7062	7063	7064
<i>Date Analyzed:</i>			28-Mar-2002	28-Mar-2002	28-Mar-2002	28-Mar-2002	28-Mar-2002	28-Mar-2002	28-Mar-2002	28-Mar-2002
Component	MDL	Units								
Aldrin	0.002	ug/gm	<0.004	<0.005	<0.006	<0.003	0.01	0.01	<0.004	0.02
a-BHC	0.002	"	<0.004	<0.005	<0.006	<0.003	<0.005	<0.004	<0.004	<0.004
b-BHC	0.003	"	<0.007	<0.007	<0.009	<0.005	<0.008	<0.006	<0.005	<0.006
g-BHC (Lindane)	0.002	"	<0.004	<0.005	<0.006	<0.003	<0.005	<0.004	<0.004	<0.004
d-BHC	0.004	"	<0.009	<0.009	<0.012	<0.007	<0.011	<0.009	<0.007	<0.007
a-Chlordane	0.004	"	<0.009	<0.009	0.05	<0.007	<0.011	<0.009	<0.007	<0.007
g-Chlordane	0.006	"	<0.013	<0.014	<0.019	<0.010	<0.016	<0.013	<0.011	<0.011
Isodrin	0.004	"	<0.009	<0.009	<0.012	<0.007	<0.011	<0.009	<0.007	<0.007
p,p'-DDD	0.003	"	<0.007	<0.007	<0.009	<0.005	<0.008	<0.006	<0.005	<0.006
p,p'-DDE	0.004	"	<0.009	<0.009	<0.012	<0.007	<0.011	<0.009	<0.007	<0.007
p,p'-DDT	0.004	"	<0.009	<0.009	<0.012	<0.007	<0.011	<0.009	<0.007	<0.007
Dieldrin	0.006	"	<0.013	<0.014	<0.019	<0.010	<0.016	<0.013	<0.011	<0.011
a-Endosulfan	0.003	"	<0.007	<0.007	<0.009	<0.005	<0.008	<0.006	<0.005	<0.006
b-Endosulfan	0.002	"	<0.004	<0.005	<0.006	<0.003	<0.005	<0.004	<0.004	<0.004
Endosulfan Sulfate	0.004	"	<0.009	<0.009	<0.012	<0.007	<0.011	<0.009	<0.007	<0.007
Endrin	0.003	"	<0.007	<0.007	<0.009	<0.005	<0.008	<0.006	<0.005	<0.006
Endrin Ketone	0.003	"	<0.007	<0.007	<0.009	<0.005	<0.008	<0.006	<0.005	<0.006
Endrin Aldehyde	0.004	"	<0.009	<0.009	<0.012	<0.007	<0.011	<0.009	<0.007	<0.007
Heptachlor	0.003	"	<0.007	<0.007	<0.009	<0.005	<0.008	<0.006	<0.005	<0.006
Heptachlor Epoxide	0.003	"	<0.007	<0.007	<0.009	<0.005	<0.008	<0.006	<0.005	<0.006
Methoxychlor	0.018	"	<0.039	<0.041	<0.056	<0.030	<0.049	<0.039	<0.033	<0.034
Mirex	0.006	"	<0.013	<0.014	<0.019	<0.010	<0.016	<0.013	<0.011	<0.011
Toxaphene	0.064	"	<	<	<	<	<	<	<	<

Table B4. Metal concentrations for a subset of Hamilton Harbour sites.

SITE			7040-1	7043	7059	7060	7061	7062	7063	7064
Date Analyzed:			28-Mar-2002	28-Mar-2002	28-Mar-2002	28-Mar-2002	28-Mar-2002	28-Mar-2002	28-Mar-2002	28-Mar-2002
Component	MDL	Units								
Aluminum	30	mg/kg	5400.00	3500.00	9400.00	5200.00	7600.00	6500.00	6000.00	6800.00
Barium	0.2	"	71.00	110.00	120.00	72.00	80.00	67.00	58.00	76.00
Beryllium	0.1	"	0.30	0.20	1.00	0.40	0.50	0.40	0.50	0.50
Boron	2.5	"	5.20	2.70	13.00	5.20	5.60	4.70	5.40	5.80
Cadmium	0.2	"	1.90	<	5.60	1.00	2.10	2.00	2.30	2.00
Calcium	20	"	73000.00	170000.00	53000.00	94000.00	60000.00	69000.00	48000.00	68000.00
Chromium	5	"	33.00	16.00	68.00	36.00	52.00	47.00	46.00	50.00
Cobalt	5	"	7.00	<	11.00	6.00	8.00	7.00	8.00	7.00
Copper	5	"	70.00	13.00	110.00	33.00	65.00	44.00	50.00	55.00
Iron	5	"	23000.00	11000.00	130000.00	23000.00	40000.00	34000.00	52000.00	50000.00
Lead	10	"	77.00	18.00	490.00	27.00	130.00	87.00	270.00	130.00
Magnesium	40	"	7300.00	6600.00	8800.00	7100.00	8500.00	7600.00	7300.00	7900.00
Manganese	5	"	1500.00	760.00	2700.00	1300.00	1400.00	1200.00	1100.00	1400.00
Molybdenum	1	"	2.00	<	5.00	<	2.00	2.00	2.00	2.00
Nickel	5	"	20.00	7.00	36.00	15.00	26.00	23.00	24.00	22.00
Phosphorus	50	"	1200.00	490.00	2000.00	750.00	1800.00	1500.00	2100.00	1600.00
Potassium	100	"	680.00	540.00	1100.00	560.00	990.00	870.00	810.00	930.00
Silicon	10	"	470.00	900.00	1700.00	740.00	420.00	420.00	750.00	470.00
Silver	0.5	"	1.00	<	<	<	<	<	<	<
Sodium	50	"	150.00	170.00	450.00	150.00	170.00	150.00	170.00	160.00
Strontium	0.1	"	130.00	280.00	110.00	180.00	110.00	120.00	90.00	130.00
Sulphur	10	"	1700.00	2300.00	3500.00	1200.00	1800.00	1700.00	2500.00	1600.00
Thallium	20	"	<	<	<	<	<	<	<	<
Tin	5	"	11.00	<	47.00	<	31.00	30.00	27.00	26.00
Titanium	5	"	170.00	100.00	260.00	160.00	180.00	150.00	160.00	180.00
Vanadium	10	"	20.00	11.00	53.00	20.00	27.00	26.00	26.00	27.00
Zinc	5	"	420.00	47.00	2700.00	210.00	820.00	630.00	1300.00	890.00
Zirconium	5	"	<	<	6.00	<	<	<	6.00	<

APPENDIX C

Invertebrate Family Counts

Table C1. Family level identification of macroinvertebrates in Hamilton Harbour sediment.

Site	7000	7002	7004	7007	7008	7013	7014	7015-1	7015-2	7015-3	7019	7021	7022
Asellidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Caenidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00
Ceratopogonidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Chaoboridae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Chironomidae	0.00	0.00	0.00	1.00	67.24	0.00	0.00	7.20	12.40	4.00	0.00	62.47	0.00
Dreissenidae	0.00	0.00	0.00	0.00	8.26	0.00	0.00	0.20	0.00	1.00	0.00	155.82	0.00
Empididae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.00	0.00	0.00
Enchytraeidae	0.00	0.00	0.00	0.00	0.11	0.00	0.00	0.00	0.00	0.00	0.00	1.68	0.00
Gammaridae	0.00	0.00	0.20	0.20	0.12	0.00	0.00	0.00	0.00	0.00	0.00	1.34	0.00
Hydriidae	0.00	0.20	0.00	0.00	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.71	0.00
Hydrobiidae	0.00	0.00	0.00	0.00	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hydroptilidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.11	0.00
Leptoceridae	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00
Macrobiotidae	0.00	0.00	0.00	0.00	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Naididae	73.00	12.80	6.60	5.60	11.11	0.40	47.80	0.20	1.80	2.60	0.00	9.84	1.00
Physidae	0.00	0.00	0.00	0.00	0.00	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	0.00	0.00	0.00	0.15	0.00
Pylalidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00
Sphaeriidae	0.40	0.20	1.20	2.20	0.90	6.60	0.40	1.00	0.60	1.40	0.00	0.00	1.40
Tubificidae	1033.80	66.40	127.40	127.20	88.51	144.80	180.40	68.00	98.40	97.40	0.80	9.84	150.20
Valvatidae	0.00	0.00	0.00	0.40	0.06	0.00	0.00	0.40	0.00	0.40	0.00	0.00	0.00

Site	7024	7025	7030	7035	7036	7038	7039	7040-1	7040-2	7040-3	7043	7045	7047
Asellidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.12	0.00	0.00
Caenidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	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	0.00	0.00	0.00	0.00
Chaoboridae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Chironomidae	1.80	0.00	0.00	0.20	1.00	0.00	0.00	0.20	0.20	0.80	0.51	0.00	0.00
Dreissenidae	0.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.83	0.00	2.40
Empididae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Enchytraeidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Gammaridae	0.00	0.00	0.00	0.20	0.00	0.00	0.40	0.00	0.00	0.00	0.15	0.00	0.60
Hydriidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.03	0.00	0.00
Hydrobiidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hydroptilidae	0.00	0.00	0.00	0.00	0.00	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	0.00	0.00	0.00	0.00	0.00
Macrobiotidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Naididae	7.40	0.00	0.00	4.00	0.00	0.20	0.00	3.00	3.20	1.80	0.86	0.00	2.20
Physidae	0.00	0.00	0.00	0.00	0.00	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	0.00	0.00	0.00	0.00	0.00
Pylalidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sphaeriidae	0.20	0.40	0.00	2.00	0.00	1.00	0.60	1.80	0.60	0.40	0.44	0.00	0.40
Tubificidae	115.60	120.60	2.60	192.60	20.60	101.80	104.80	145.00	96.40	107.40	9.88	29.20	22.80
Valvatidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table C1. Continued.

Site	7049	7050	7051	7052	7053	7054-1	7054-2	7054-3	7055	7056	7057	7058
Asellidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Caenidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	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	0.60	0.00	0.00
Chaoboridae	0.00	0.00	0.00	0.00	0.00	0.20	0.00	0.00	0.00	0.00	0.00	0.00
Chironomidae	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	23.80	0.00	0.20
Dreissenidae	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.20	0.00	0.00	0.00	0.00
Empididae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Enchytraeidae	0.00	0.00	0.00	0.00	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	0.20	0.60	0.00	0.80	0.00	0.00
Hydridae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hydrobiidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hydroptilidae	0.00	0.00	0.00	0.00	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	0.00	0.00	0.00	0.00
Macrobiotidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Naididae	1.40	6.26	0.40	1.60	16.40	10.80	23.80	8.20	36.80	4.20	12.60	6.80
Physidae	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Planorbidae	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pylalidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sphaeriidae	1.00	0.05	0.60	0.00	0.00	2.00	0.40	3.60	0.60	0.20	0.40	0.40
Tubificidae	41.60	48.51	136.20	91.60	33.00	58.80	83.80	140.20	2315.40	186.80	452.60	218.00
Valvatidae	0.00	0.00	0.00	0.00	0.00	0.00	0.20	1.20	0.00	0.00	0.40	0.00

Site	7059	7060	7061	7062	7063	7064	70M20	70M252	70M258	70M268	70M270	70M4
Asellidae	0.00	0.12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Caenidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	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	0.00	0.00	0.00
Chaoboridae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Chironomidae	0.00	0.32	0.40	0.20	0.80	1.20	0.20	3.63	0.00	0.00	0.40	0.00
Dreissenidae	0.00	0.21	0.00	0.00	0.40	0.00	0.00	0.12	0.00	0.00	0.00	0.00
Empididae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Enchytraeidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Gammaridae	0.00	0.15	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.20	0.00
Hydridae	0.20	3.92	0.00	0.00	0.00	0.60	0.00	0.00	0.00	0.00	0.00	0.00
Hydrobiidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hydroptilidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.00	0.00	0.00
Leptoceridae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Macrobiotidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Naididae	0.20	1.30	5.60	6.20	0.00	25.00	10.40	3.24	0.00	6.00	5.60	0.40
Physidae	0.00	0.00	0.00	0.00	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	0.00	0.00	0.00	0.00
Pylalidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sphaeriidae	1.00	0.46	3.20	1.60	7.60	3.40	5.80	0.05	0.00	0.00	0.00	4.00
Tubificidae	185.40	21.85	183.60	91.40	146.60	233.40	346.20	70.73	111.60	40.60	114.60	257.20
Valvatidae	0.00	0.03	0.00	0.00	0.40	0.00	0.00	0.03	0.00	0.00	0.00	0.00

APPENDIX D BEAST Community Structure Ordinations

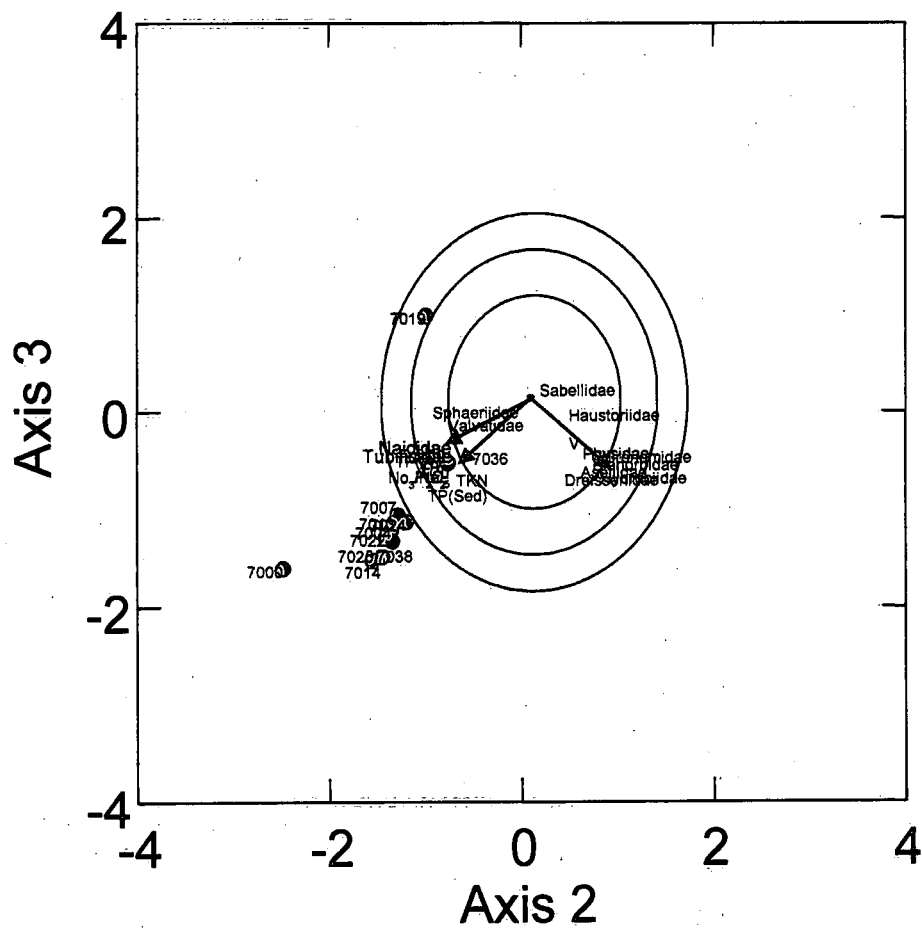


Figure D1. Ordination of subset of test sites using benthic community structure data (family level) summarized on Axes 2 & 3, showing 90%, 99%, and 99.9% probability ellipses around reference sites. (Reference sites themselves are not shown.) Significant families and environmental variables are shown. Note: Site 7019 is in Band 4 on Axes 1 & 2. Stress = 0.137.

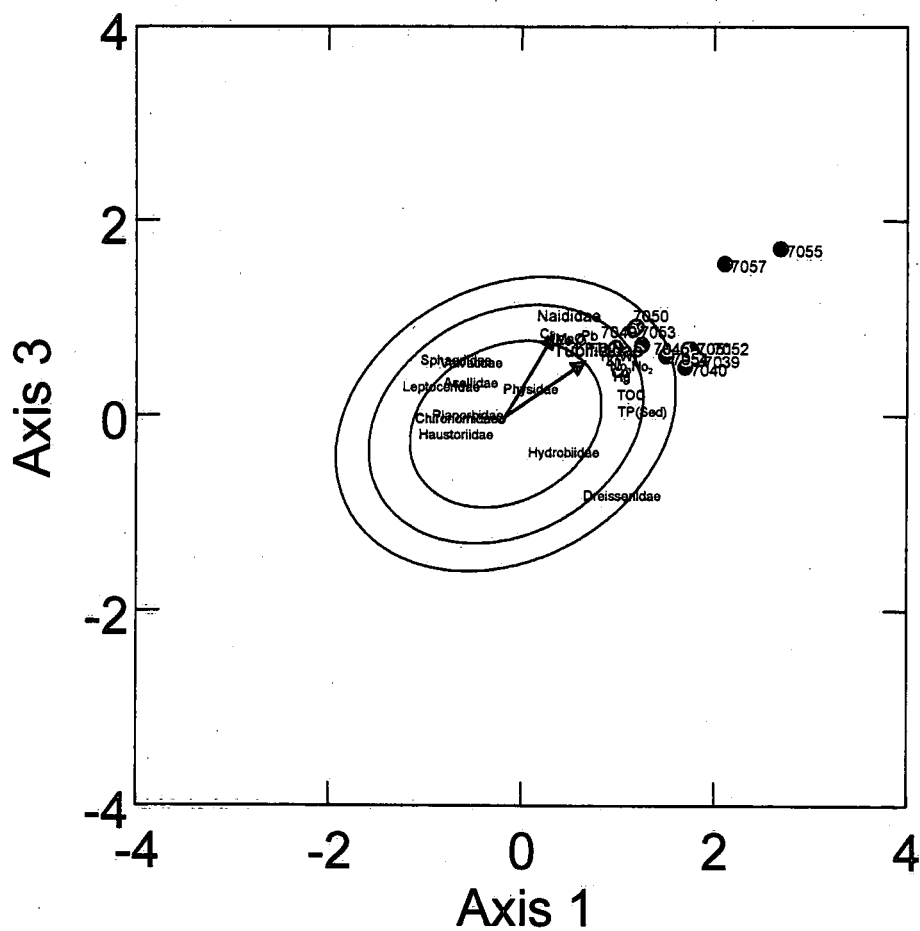


Figure D2. Ordination of subset of test sites using benthic community structure data (family level) summarized on Axes 1 & 3, showing 90%, 99%, and 99.9% probability ellipses around reference sites. (Reference sites themselves are not shown.) Significant families and environmental variables are shown. Stress = 0.143.

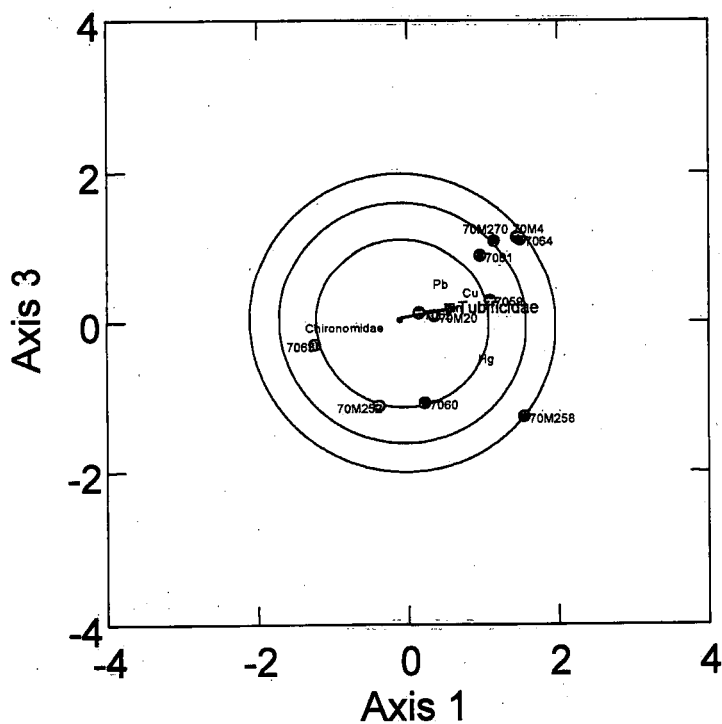
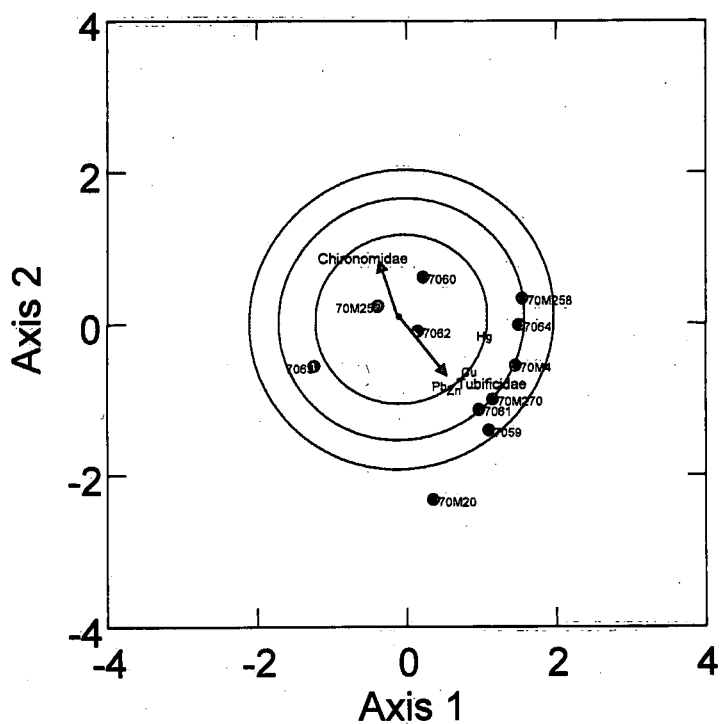


Figure D3. Ordination of subset of test sites using benthic community structure data (family level) on Axes 1 & 2 [top] and Axes 1 & 3 [bottom], showing 90%, 99%, and 99.9% probability ellipses around reference sites. (Reference sites themselves are not shown.) Significant families and environmental variables are shown. Stress = 0.138.

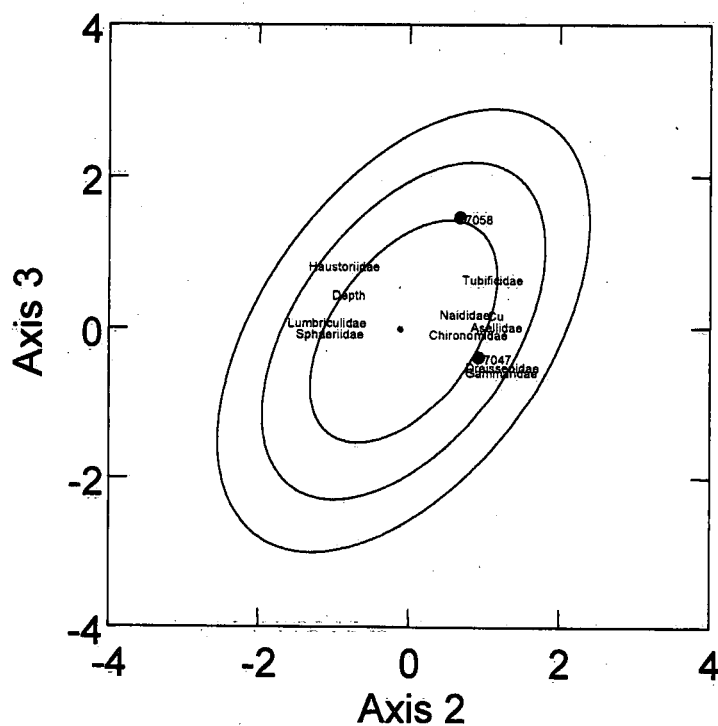
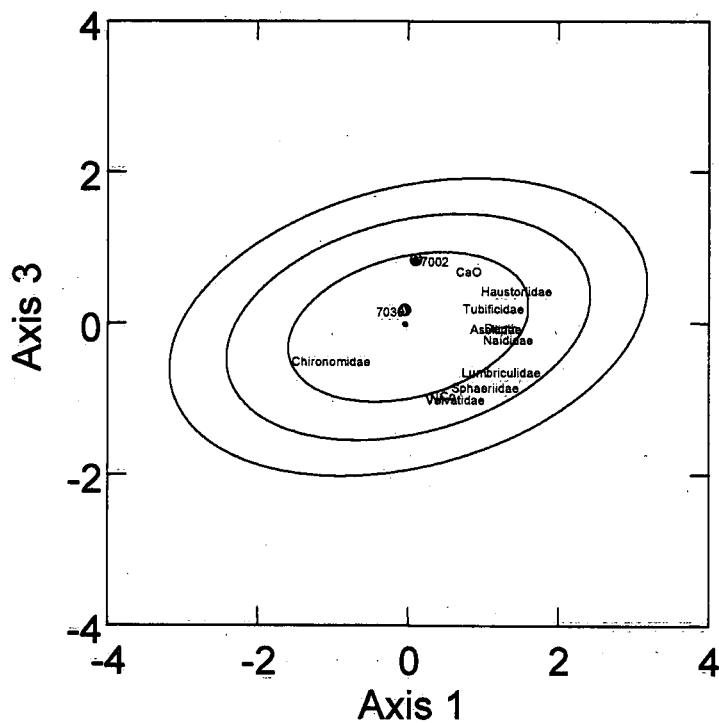


Figure D4. Ordination of subset of test sites using benthic community structure data (family level) summarized on Axes 1 & 3 [top] and Axes 2 & 3 [bottom], showing 90%, 99%, and 99.9% probability ellipses around reference sites. (Reference sites themselves are not shown.) Significant families and environmental variables for each ordination are shown. Stress = 0.115 – 0.122.

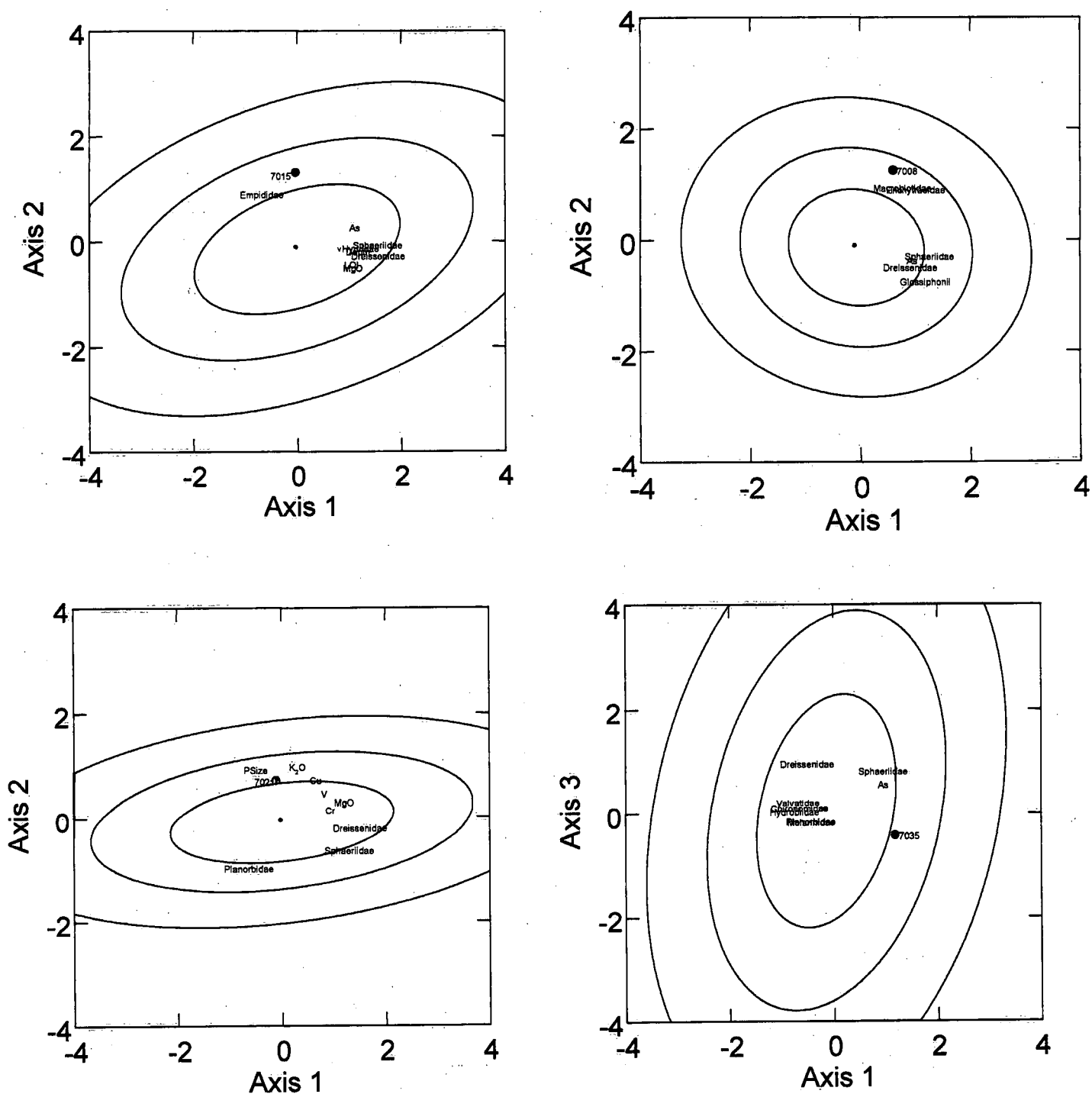


Figure D5. Ordination of subset of test sites using benthic community structure data (family level) summarized on Axes 1 & 2 or Axes 1 & 3 [bottom right], showing 90%, 99%, and 99.9% probability ellipses around reference sites. (Reference sites themselves are not shown.) Significant families and environmental variables for each ordination are shown. Stress = 0.062 – 0.132.

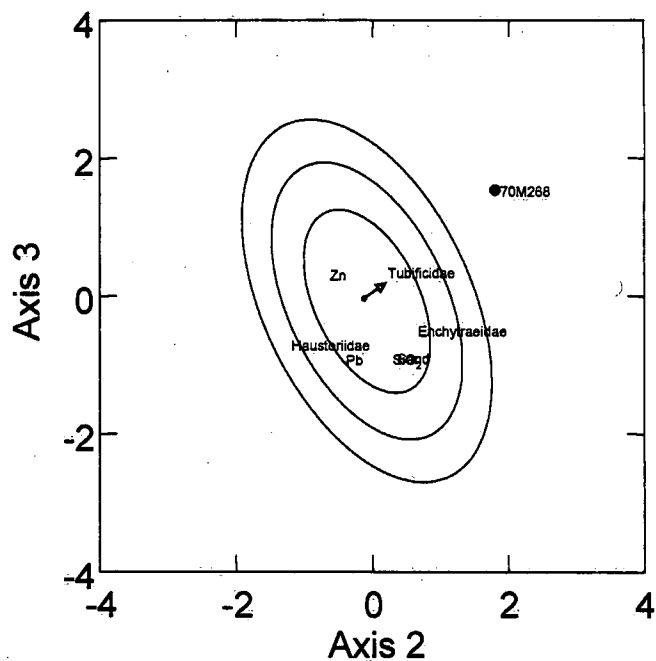
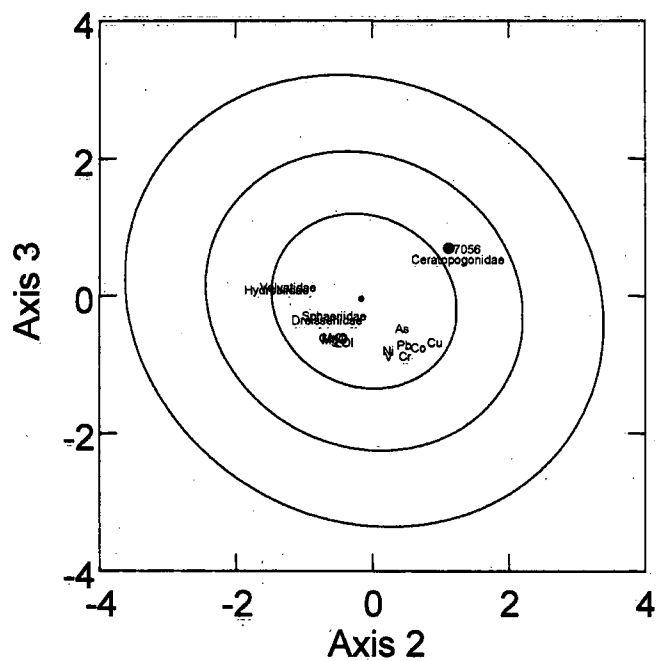
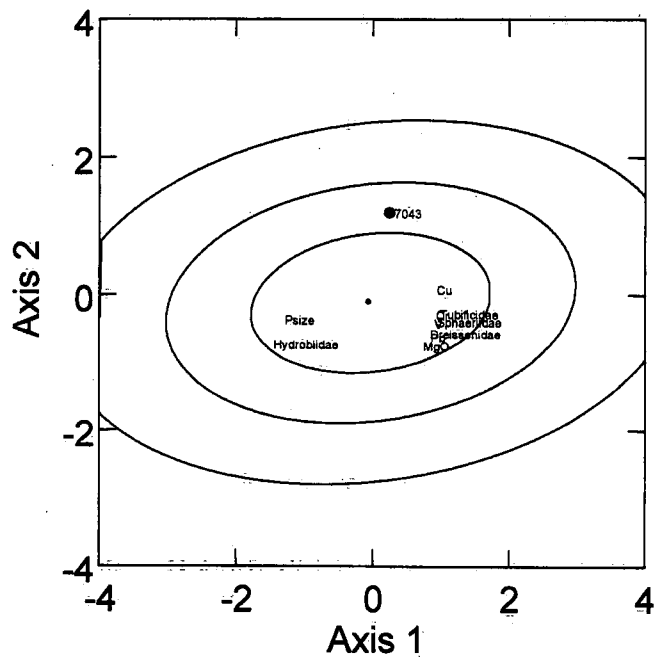


Figure D6. Ordination of subset of test sites using benthic community structure data (family level) summarized on Axes 2 & 3 [top] or Axes 1 & 2 [bottom], showing 90%, 99%, and 99.9% probability ellipses around reference sites. (Reference sites themselves are not shown.) Significant families and environmental variables for each ordination are shown. Stress = 0.121 – 0.139.



APPENDIX E BEAST Toxicity Ordinations

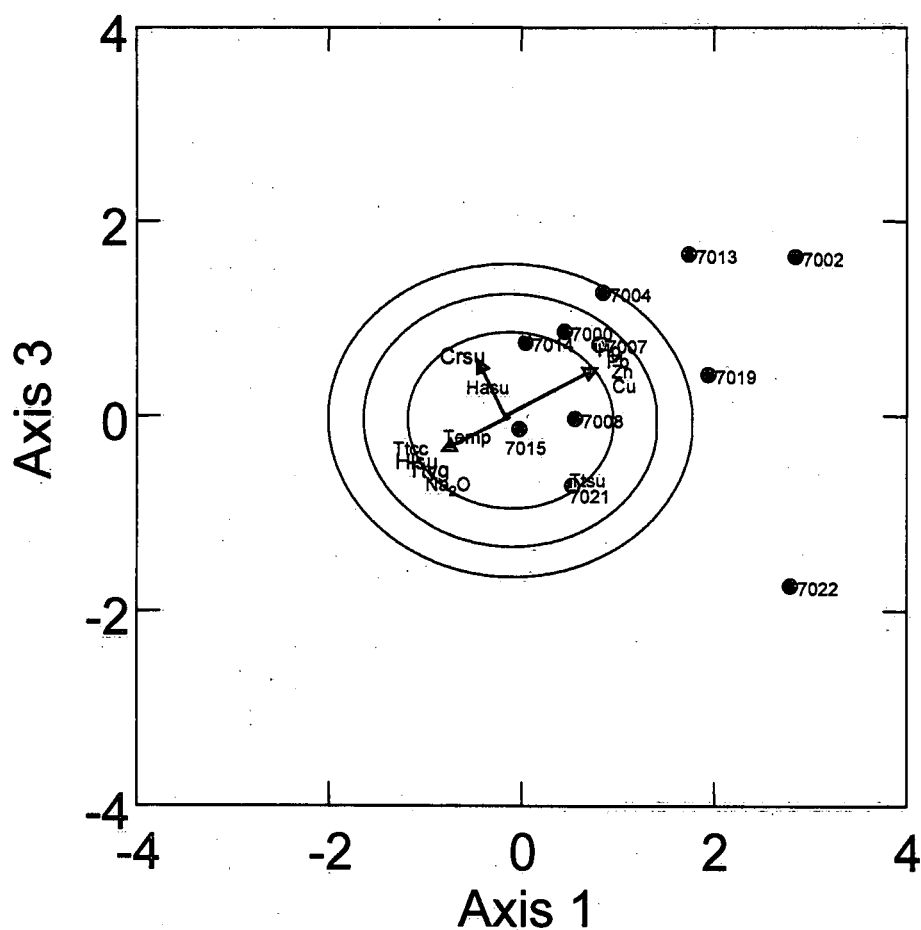


Figure E1. Assessment of subset of test sites using 10 toxicity test endpoints, showing 90%, 99%, and 99.9% probability ellipses around reference sites (reference sites themselves are not shown). Significant endpoints are shown [*Chironomus* survival (Crsu), *Hexagenia* survival (Hlsu), *Hyaella* survival (Hasu), *Tubifex* survival (Ttsu), cocoon production (Ttcc), and young production (Ttyg)]. Note: Sites 7014 and 7021 are in Band 2 on Axes 2 & 3 (not shown). Stress level = 0.099.

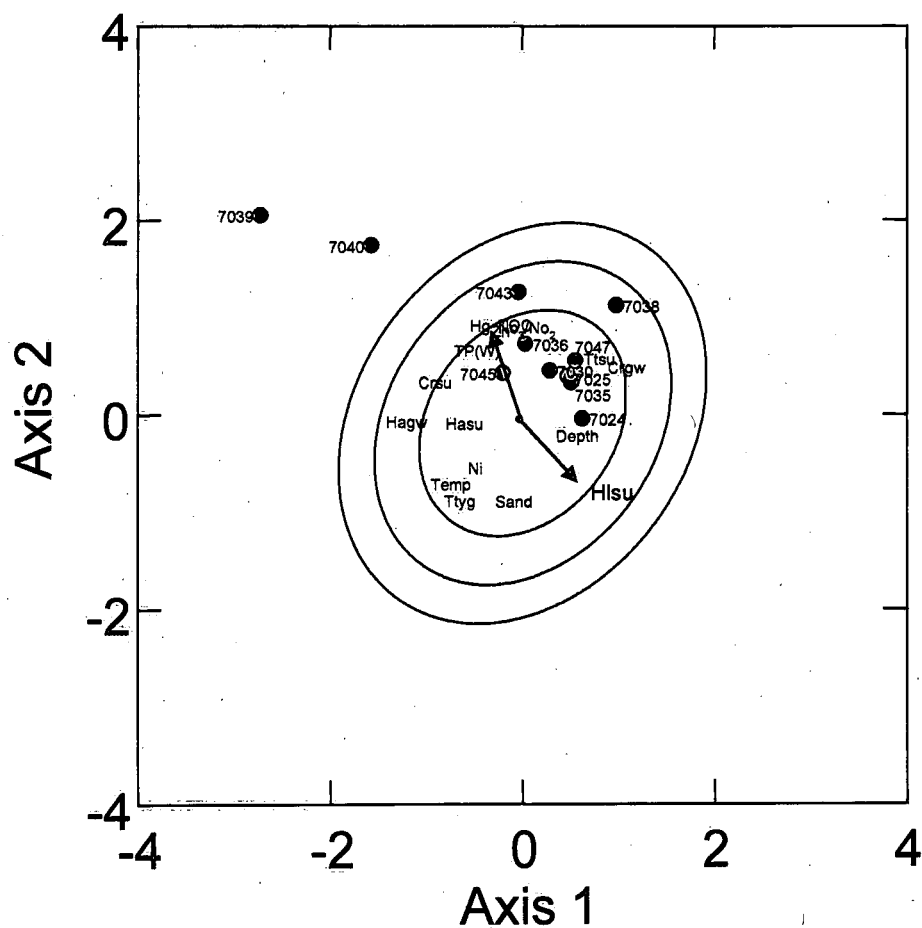


Figure E2. Assessment of subset of test sites using 10 toxicity test endpoints, showing 90%, 99%, and 99.9% probability ellipses around reference sites (reference sites themselves are not shown). [*Chironomus* survival (Crsu) and growth (Crgw), *Hexagenia* survival (Hlsu), *Hyaella* survival (Hasu) and growth (Hagw), *Tubifex* survival (Ttsu) and young production (Ttyg)]. Stress level = 0.094.

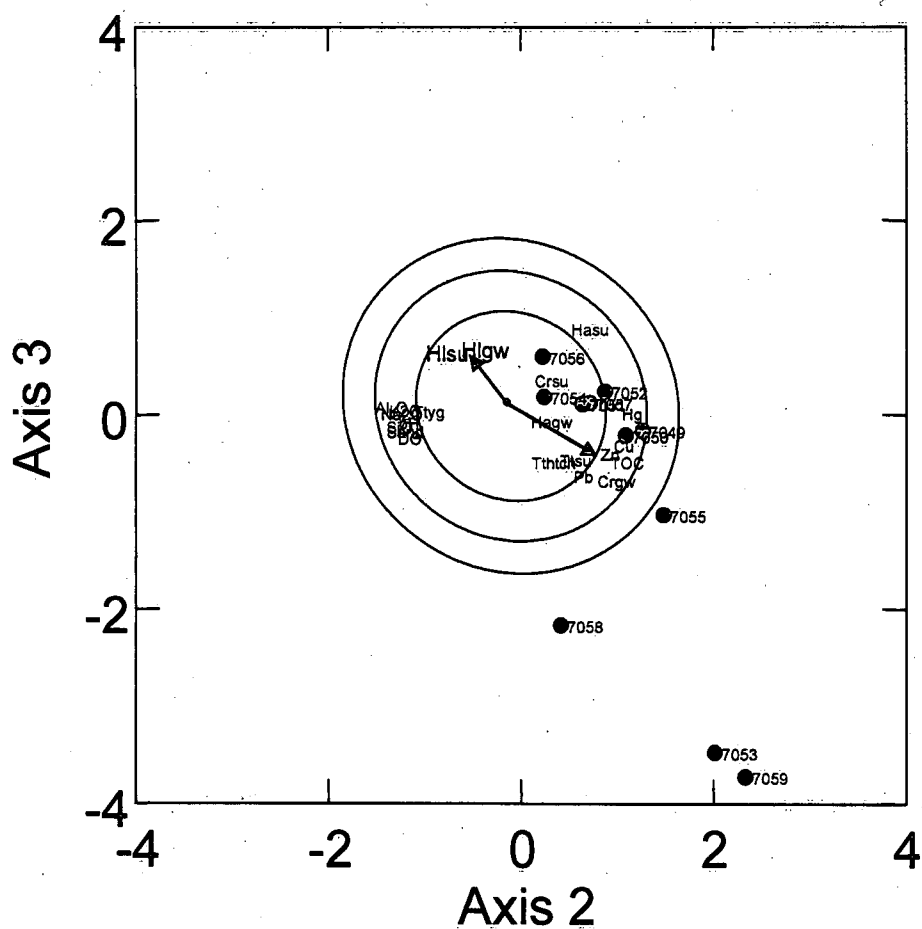


Figure E3. Assessment of subset of test sites using 10 toxicity test endpoints, showing 90%, 99%, and 99.9% probability ellipses around reference sites (reference sites themselves are not shown). [*Chironomus* survival (Crsu) and growth (Crgw), *Hexagenia* survival (Hlsu) and growth (Hlgw), *Hyaella* survival (Hasu) and growth (Hagsw), *Tubifex* survival (Ttsu), percent cocoon hatch (Ttch) and young production (Ttyg)]. Stress level = 0.096.

APPENDIX F

Sediment Toxicity –Contaminant Relationships

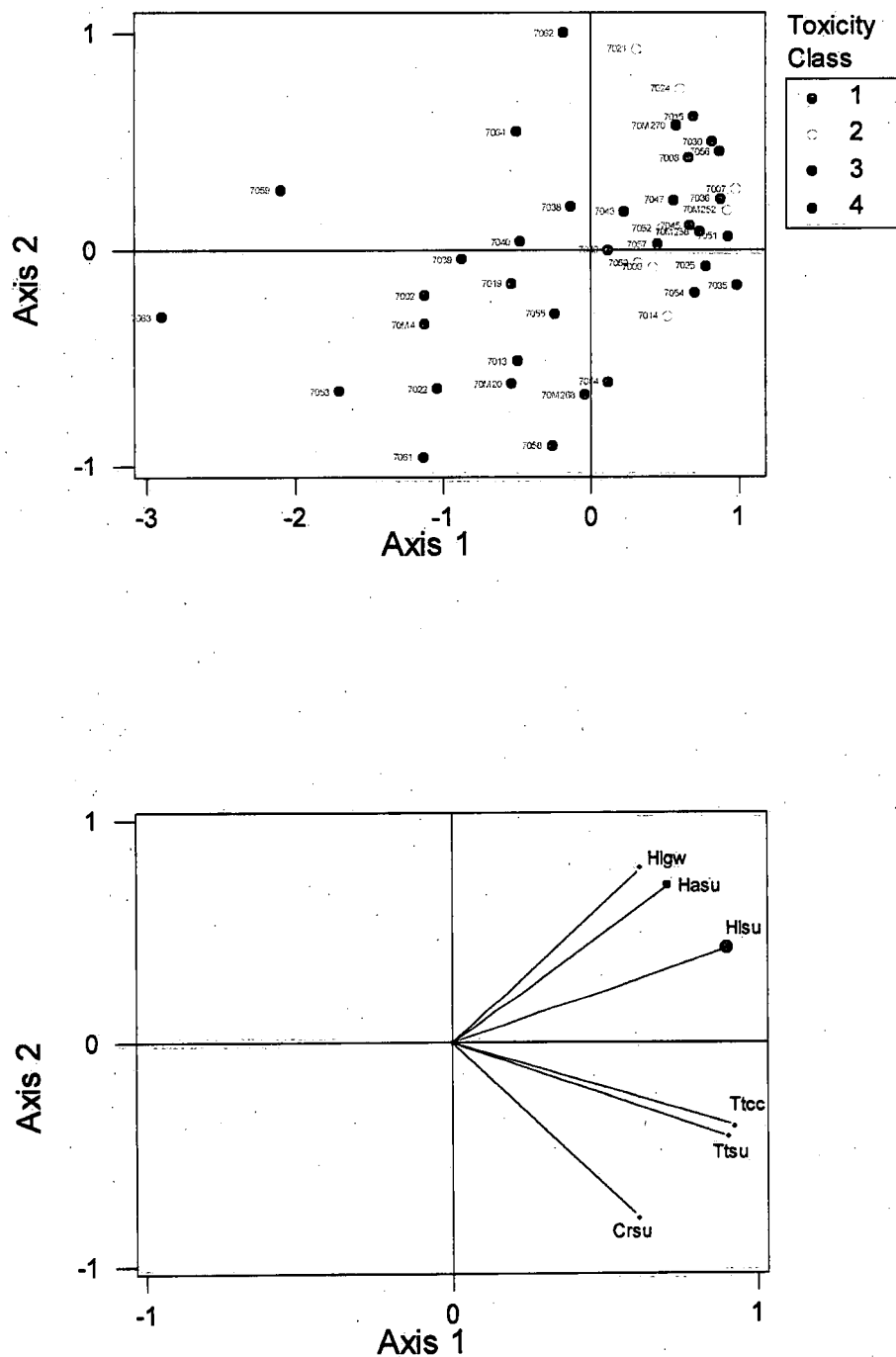


Figure F1. Toxicity of sediment from Hamilton Harbour sites (2000) represented by 2-dimensional hybrid multidimensional scaling. Upper figure shows coordinates of sites, colour-coded by toxicity class as determined by the BEAST assessment with reference sites. The lower figure shows directions of maximum correlations of toxicity endpoints with sites in HMDS dimensions. The size of the point at the end of each vector is proportional to the strength of the overall correlation of the toxicity endpoint to the axes as determined by principal axis correlation. (*Hyaella* and *Chironomus* growth and *Tubifex* percent hatch and number of young are not significant endpoints and therefore are not shown).

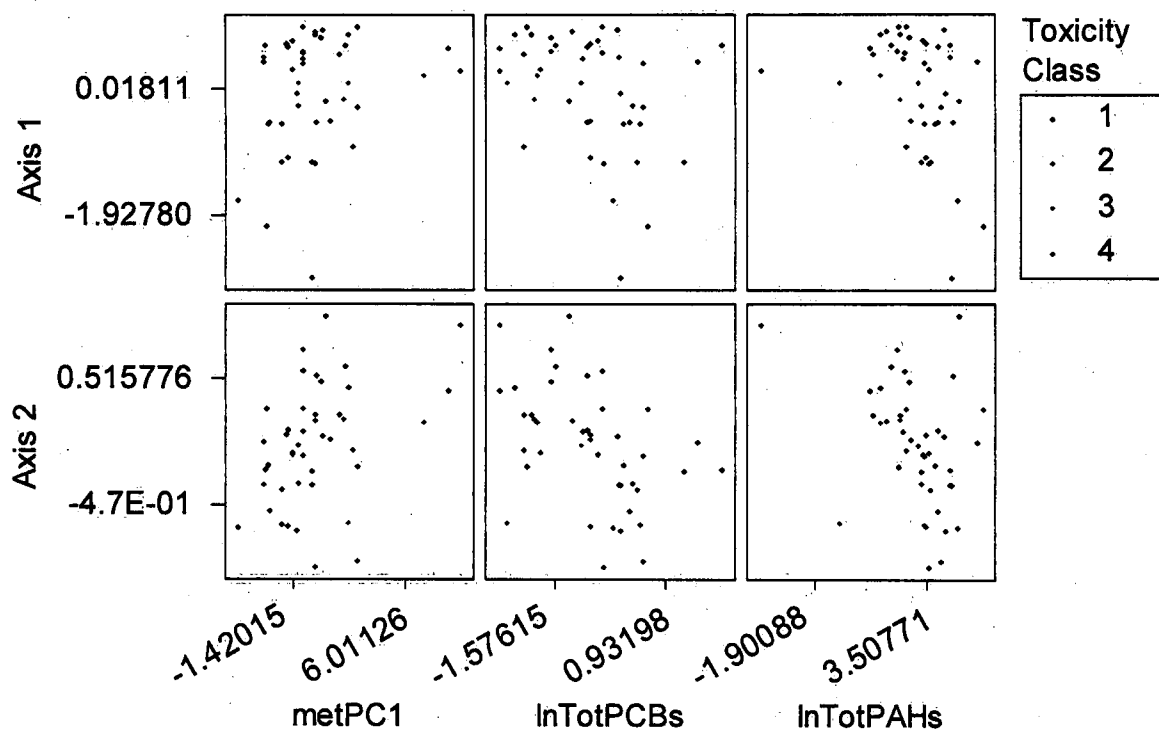


Figure F2. Hamilton Harbour sediment toxicity relationships to contaminant concentrations based on integrated descriptors. Low values for Axis 1 correspond to sites with high relative toxicity to *Hexagenia*. Low values for Axis 2 correspond to high relative toxicity to *Hexagenia* and *Hyaella* and high values for Axis 2 correspond to high relative toxicity to *Chironomus*. (See text for derivation of variables.)

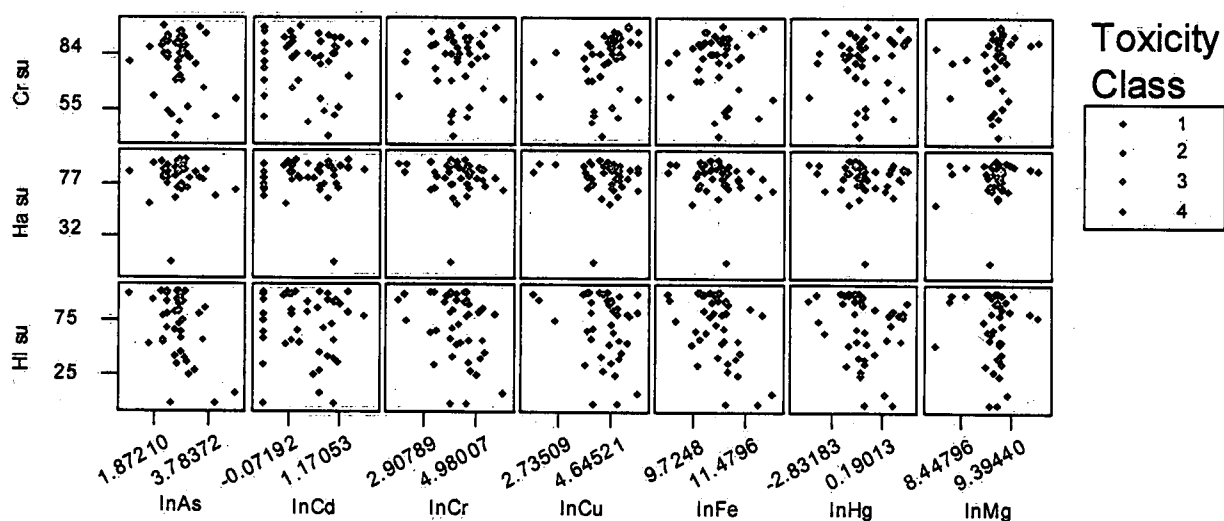


Figure F3. Hamilton Harbour sediment toxicity relationships to ln(x)-transformed metal concentrations. "Cr su", "Ha su" and "Hl su" = survival of *Chironomus*, *Hyaella* and *Hexagenia*, respectively. Sites are colour-coded by toxicity class as determined by the BEAST assessment with reference sites (see above).

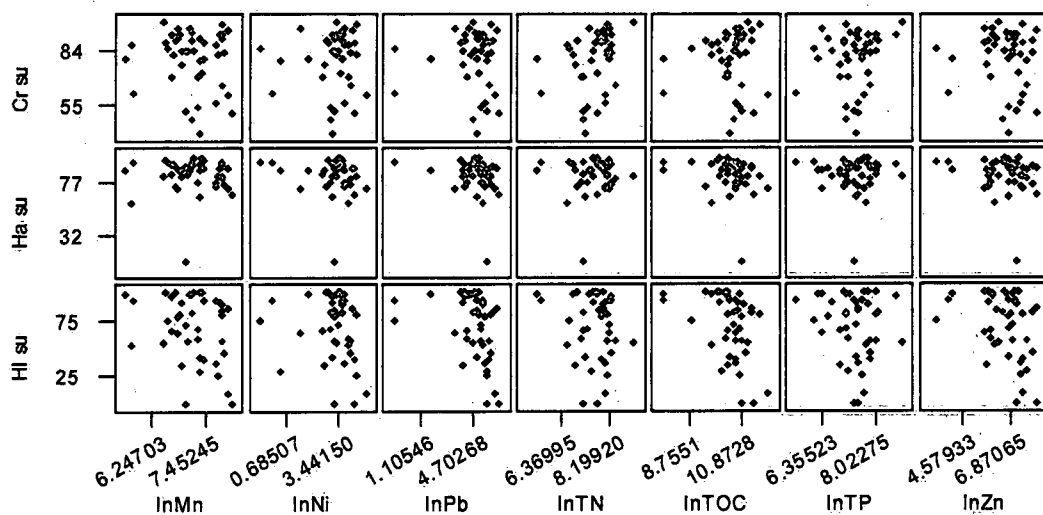


Figure F4. Hamilton Harbour sediment toxicity relationships to metal and nutrient concentrations. Sites are colour-coded by toxicity class as in Figure F3.

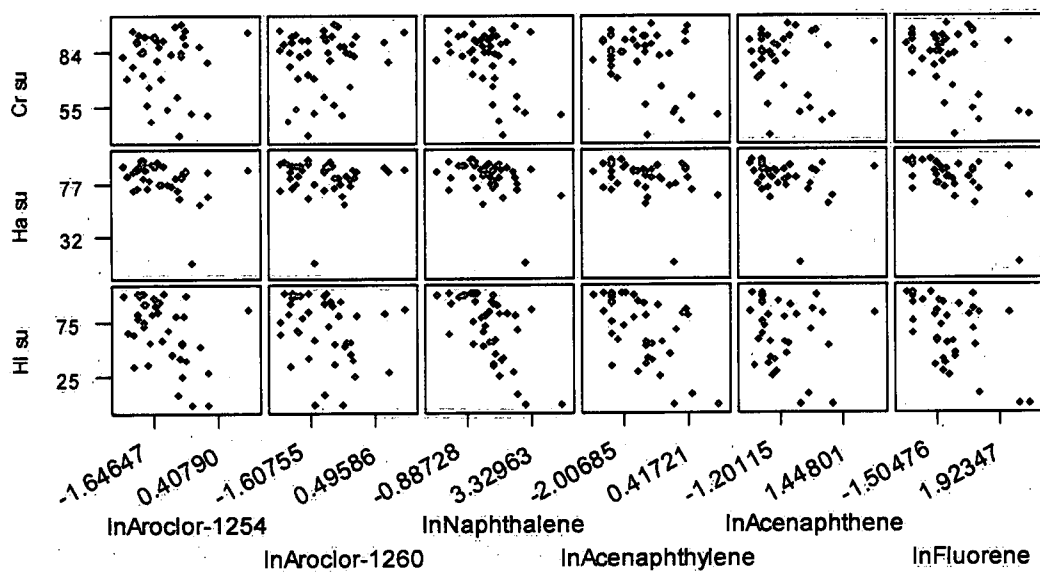


Figure F5. Hamilton Harbour sediment toxicity relationships to PCB and PAH concentrations. Sites are colour-coded by toxicity class as in Figure F3.

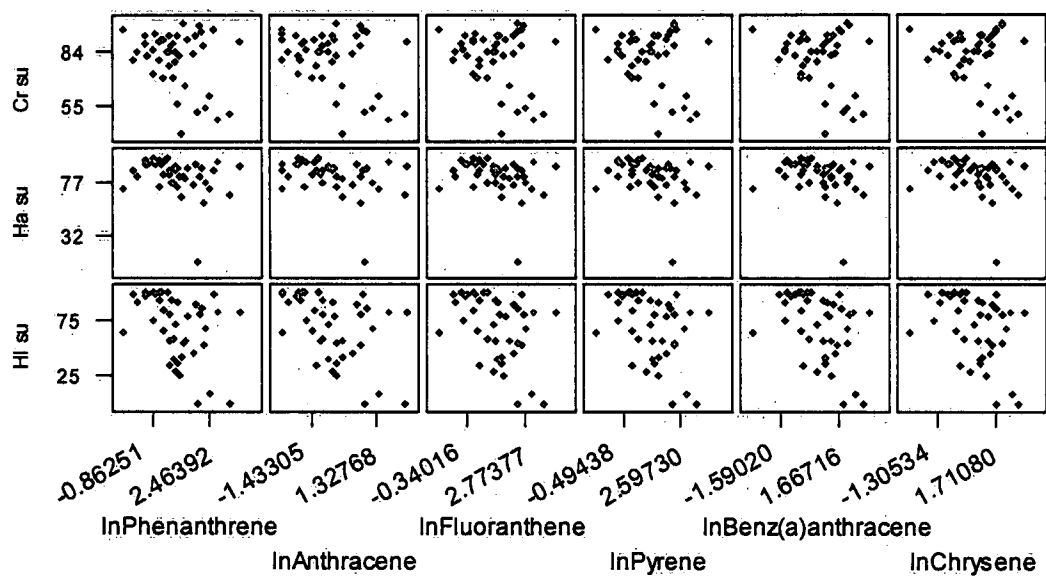


Figure F6. Hamilton Harbour sediment toxicity relationships to PAH concentrations I. Sites are colour-coded by toxicity class as in Figure F3.

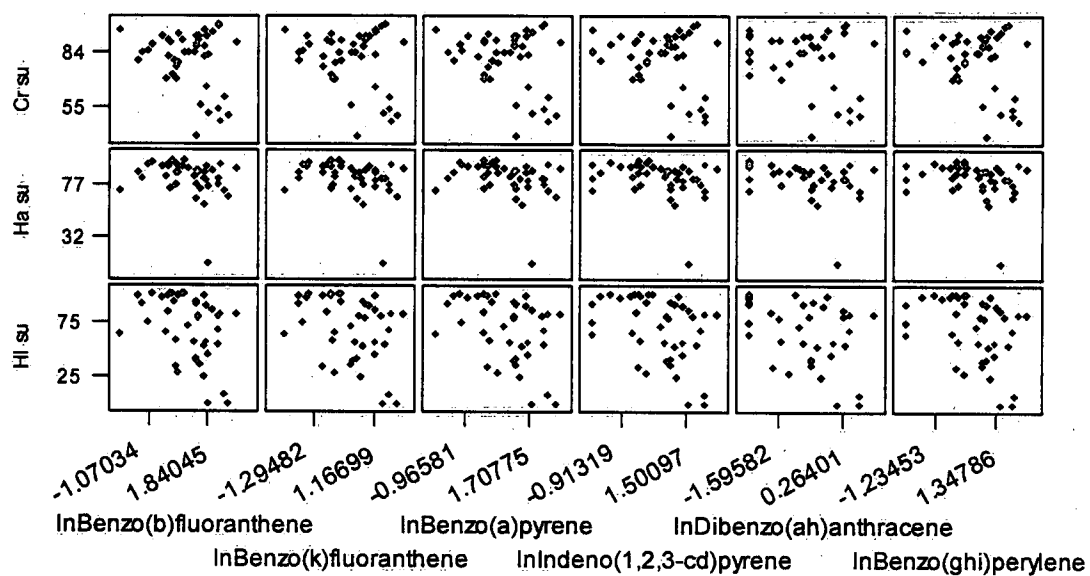


Figure F7. Hamilton Harbour sediment toxicity relationships to PAH concentrations II. Sites are colour-coded by toxicity class as in Figure F3.

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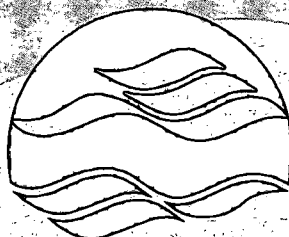
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