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THE APPLICATION OF BEAST SEDIMENT QUALITY GUIDELINES TO THE NIPIGON BAY AREA OF CONCERN

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WSTD Contribution No. 06-458

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SUMMARY

This report describes sediment quality in Nipigon Bay, identified as an Area of Concern due to water quality impairments, significant declines of fish populations, and changes in the benthos close to industrial discharges. As part of the Great Lakes 2020 Action Plan, the benthic assessment of sediment (BEAST) methodology was applied to 15 sites in September 2003. The BEAST methodology involves the assessment of sediment quality based on multivariate techniques using data on benthic community structure, the functional responses of laboratory organisms in toxicity tests, and the physical and chemical attributes of the sediment and overlying water. Data from test sites are compared to biological criteria developed for the Laurentian Great Lakes.

Contamination of sediment by metals in the Nipigon Bay sites is generally low. Although 1 to 8 metals are elevated above the provincial Sediment Quality Guideline Lowest Effect Level at all sites, exceedences of the Severe Effect Level are limited to a few sites for manganese and iron. Benthic communities at the majority of sites, especially in the western part of the bay near the industrial discharge and in the channel south of the outfall, are different from those at reference sites. These communities are characterized by the absence or low abundance of a dominant reference group amphipod (haustoriids) and enrichment of pollution tolerant taxa (tubificids, chironomids). Despite the absence or low abundance of haustoriids, some sites have diverse benthic communities which include other pollution intolerant species; therefore, these communities are not judged to be degraded. Sediments from four sites are severely toxic with acute toxicity to the amphipod *Hyalella azteca*. The cause of this toxicity is not clear. The contribution of organic contaminants is unknown as they were not measured. Industrial discharges are not likely responsible because toxicity occurs in the eastern portion of the bay but is low or absent in the western area closer to outfall.

According to the decision-making framework for sediment contamination, developed under the Canada-Ontario Agreement respecting the Great Lakes Basin Ecosystem, management actions are not indicated for any site. The reason for benthos alteration and sediment toxicity needs to be determined for 9 and 4 sites, respectively. No further actions are needed for two sites.

RÉSUMÉ

Ce rapport décrit la qualité des sédiments dans la baie Nipigon, qui a été définie comme un secteur préoccupant en raison de la dégradation de la qualité de l'eau, de la baisse marquée des populations de poissons et des changements observés dans le benthos à proximité des rejets industriels. Dans le cadre du plan d'action Grands Lacs 2020, la méthode d'évaluation des sédiments benthiques (BEAST) a été appliquée à 15 sites en septembre 2003. Cette méthode consiste à évaluer la qualité des sédiments à l'aide de techniques d'analyse à plusieurs variables qui utilisent les données sur la structure des communautés benthiques, les réponses fonctionnelles des organismes expérimentaux durant les essais de toxicité, ainsi que les propriétés physiques et chimiques des sédiments et des eaux sus-jacentes. Les données provenant des sites d'essais sont ensuite comparées aux critères biologiques établis pour la région laurentienne des Grands Lacs.

Dans l'ensemble, la contamination des sédiments par les métaux est faible dans la baie Nipigon. Ainsi, bien que la concentration minimale avec effet — prévue dans les lignes directrices provinciales sur la qualité des sédiments — ait été dépassée pour un à huit métaux dans tous les sites, seuls quelques sites ont présenté des concentrations de manganèse et de fer supérieures à la concentration entraînant des effets graves. Dans la majorité des sites, et plus particulièrement dans la portion ouest de la baie située près des rejets industriels et dans le chenal au sud des points de rejet, les communautés benthiques diffèrent de celles observées dans les sites de référence, étant caractérisées par l'absence ou une faible abondance d'un amphipode dominant du groupe de référence (haustoridés) et par un enrichissement en taxons tolérants à la pollution (tubificidés, chironomidés). Cependant, malgré l'absence ou la faible abondance d'haustoridés, certains sites présentent des communautés benthiques diversifiées qui comptent d'autres espèces intolérantes à la pollution; on ne considère donc pas qu'il y a eu dégradation de ces communautés. Les sédiments de quatre sites se sont révélés hautement toxiques, présentant une toxicité aiguë pour l'amphipode *Hyalella azteca*, mais la cause de cette toxicité reste à préciser. Enfin, les effets de la contamination organique n'ont pu être évalués, car celle-ci n'a pas été mesurée. Cependant, il ne semble pas que les rejets industriels soient la cause de cette toxicité, car celle-ci est présente dans la portion est de la baie alors qu'elle est faible, voire absente, dans la portion ouest, pourtant plus près des points de rejet.

Selon le cadre décisionnel défini dans l'Accord Canada-Ontario concernant l'écosystème du bassin des Grands Lacs pour gérer la contamination des sédiments, aucun site ne requiert l'adoption de mesures de gestion. Cependant, les causes de l'altération du benthos et de la toxicité des sédiments devront être étudiées respectivement dans neuf et quatre sites. Enfin, aucune mesure additionnelle n'est jugée nécessaire à deux endroits.

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1 INTRODUCTION

1.1 Objectives for GL2020 Sediment Assessment Study

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

1.2 Nipigon Bay Area of Concern

Nipigon Bay, located on the most northerly shore of Lake Superior, was identified as an AOC by the International Joint Commission due to water quality impairments, significant declines of fish populations and changes in the benthos close to industrial discharges. The Nipigon Bay AOC has been the subject of two major Remedial Action Plan (RAP) reports – Stage 1: Environmental Conditions and Problem Definition (Nipigon Bay RAP Team 1991) and Stage 2: Remedial Strategies for Ecosystem Restoration (Nipigon Bay RAP Team 1995). Environmental issues of concern listed in the RAP Stage 1 report are:

- Metal and organic (oil and grease) contamination in sediment,
- Undesirable algae,
- Native fish population declines,
- Degraded water quality including high levels of metals, organics and nutrients, taste/odour problems and effluent plumes, and
- Presence of pollution tolerant benthic communities.

Point sources of contaminants include the Norampac linerboard mill in Red Rock and the Red Rock Water Pollution Control Plant (WPCP), which discharge into Nipigon Bay, and the

Nipigon WPCP, which discharges into the Nipigon River (Nipigon Bay RAP Team 1991). Upgrades to industrial and municipal plants have resulted in improvements to the AOC, and some of the 8 “beneficial use impairments” identified in the 1991 Stage 1 report have been completely or partially restored. However, there are impairments related to substrate conditions that still remain and sediments continue to be one of several non-point sources of contaminants to the bay. Impairments include degraded benthic communities in the vicinity of the Norampac mill discharge and Nipigon WPCP outfall, the loss of habitat due to wood fibre and contaminant accumulation, and degraded fish populations (Nipigon Bay RAP Team 1995).

In September 2003, Environment Canada undertook a sampling program in Nipigon Bay to define the general status of contamination in the bay. This report presents the results of these investigations and provides a spatial description of the state of the sediments in the bay along with the degree of contamination.

2 METHODS

2.1 Sample Collection

Fifteen sites were sampled in Nipigon Bay September 17-19, 2003. Site positions and depths are provided in Table 1 and site locations are shown in Figure 1. Site positions were established in the field using a Magnavox MX300 Differential Global Positioning System receiver. Differential corrections were received from Coast Guard beacons signals. Fine-grained sediment was targeted for collection. However, this was not always possible, especially in the Nipigon River.

At each test site, samples were collected for chemical and physical analysis of sediment and overlying water, benthic community structure and sediment toxicity tests. Environmental variables measured or analyzed are shown in Table 2. Details on sampling techniques and methods for sample collection are described in Reynoldson et al. (1998a,b). Prior to sediment collections, water samples were obtained using a van Dorn sampler, taken 0.5 meters from the bottom. Temperature, conductivity, pH, and dissolved oxygen were measured on site with Hydrolab water quality instruments. Samples for alkalinity, total phosphorus, total Kjeldahl nitrogen, nitrates/nitrites, and total ammonia were dispensed to appropriate containers and stored (4°C) for later analysis.

A 40 cm × 40 cm mini-box corer was used to obtain the benthic community and sediment chemistry samples. Benthic community samples were subsampled from the mini-box core using 10-cm (6.5-cm diameter) acrylic tubes. Samples were sieved through a 250-μm mesh screen and the residue preserved with 5% formalin for later identification. The remaining top 10 cm of sediment from each box core was removed, homogenized in a Pyrex dish and allocated to containers for chemical and physical analyses of the sediment. At one site (6974), where a mini-box corer could not be used, three ponar grabs were collected for benthic community structure analysis and one ponar grab was collected for chemical and physical properties of the sediment. Each community structure ponar sample was sieved in its entirety and the residue preserved as described above. Sediment samples were stored at 4°C.

Five mini-Ponars were collected per site for the laboratory toxicity tests (approximately 2 L sediment per replicate). Each of the five sediment grabs was placed in separate plastic bag, sealed, and stored in a 10 L bucket at 4°C.

2.2 Sediment and Water Physico-Chemical Analyses

Overlying water

Analyses of alkalinity, total phosphorus, nitrates/nitrites, total ammonia and total Kjeldahl nitrogen were performed by the Environment Canada's National Laboratory for Environmental Testing (NLET) (Burlington, ON) by procedures outlined in Cancilla (1994) and NLET (2003).

Particle size

Percents gravel, sand, silt, and clay were determined by the Sedimentology Laboratory at Environment Canada (Burlington, ON) following the procedure of Duncan and LaHaie (1979).

Sediment trace metals and nutrients

Freeze dried sediment was analyzed for trace elements (hot aqua regia extracted), major oxides (whole rock), loss on ignition, total organic carbon, total phosphorus, and total Kjeldahl nitrogen by Caduceon Laboratory (Ottawa, ON), using USEPA/CE (1981) standard methodologies or in house procedures.

2.3 Taxonomic Identification

Benthic community samples were transferred to 70% ethanol after a minimum of 72 hours in formalin. Invertebrates in the benthic community samples were sorted, identified to the family level, and counted at the Invertebrate Laboratory at Environment Canada (Burlington, ON). Slide mounts were made for Oligochaetae and Chironomidae and identified to family using high power microscopy.

2.4 Sediment Toxicity Tests

Four sediment toxicity tests were performed: *Chironomus riparius* 10-day survival and growth test, *Hyalella azteca* 28-day survival and growth test, *Hexagenia* spp. 21-day survival and growth test, and *Tubifex tubifex* 28-day adult survival and reproduction test. Sediment handling procedures and toxicity test methods are described elsewhere (Borgmann and Munawar 1989; Borgmann et al. 1989; Krantzberg 1990; Reynoldson et al. 1991, 1998b). All tests passed acceptability criteria for their data to be used in the site assessments. The criteria are based on percent control survival in a reference sediment (Long Point Marsh, Lake Erie): i.e., ≥80% for *H. azteca* and ≥70% for *C. riparius* (USEPA 1994; ASTM 1995); ≥80% for *Hexagenia* spp., and ≥ 75% for *T. tubifex* (Reynoldson et al. 1998b). Toxicity tests were performed at the Ecotoxicology Laboratory at Environment Canada (Burlington, ON).

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

Hyalella azteca 28-day survival and growth test

The *H. azteca* 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 were counted. Amphipods were dried at 60 °C for 24 hours and dry weights recorded. Initial weights were considered zero.

Chironomus riparius 10-day survival and growth test

The *C. riparius* 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 were counted. Chironomids were dried at 60 °C for 24 hours and dry weights recorded. Initial weights were considered zero.

Hexagenia spp. 21-day survival and growth test

The *Hexagenia* spp. test was conducted for 21 days using preweighed nymphs (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 were 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 = [(wet weight + 1.15)/ 7.35]. Growth was determined by final dry weight minus initial dry weight.

Tubifex tubifex 28-day reproduction and survival test

The *T. tubifex* 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 numbers of small immature worms were counted from the 250-µm sieve. Survival and reproduction was assessed with four endpoints: number of surviving adults, total number of cocoons produced per adult, percent of cocoons hatched, and total number of young produced per adult.

2.5 Data Analysis

BEAST analysis

Test sites were assessed using BEAST methodology (Reynoldson and Day 1998; Reynoldson et al. 2000). The BEAST model predicts the invertebrate community group that should occur at a test site based on natural environmental conditions. Multiple discriminant analysis was used to predict the test sites to one of five reference community groups using 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 of 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). All community data were adjusted to be equivalent to sampling by box corer. To adjust for the efficiency of the Ponar grab relative to the box core, benthic abundances for site 6974 were divided by 0.69, with the exception of the chironomids, oligochaetes, sphaeriids, nematodes and hirudinea, where 0.52, 0.55, 0.75, 0.64, and 0.71 were used, respectively. All counts were then adjusted to the area of the subsampling core tube (33.14 cm^2). Community data for the test sites were merged with the reference site invertebrate data of the matched (group to which the test site has the highest probability of belonging) reference group only and ordinated using hybrid multidimensional scaling (HMDS; Belbin 1993), with Bray-Curtis distance site × site association matrices calculated from raw data. Toxicity data were analyzed using HMDS, with Euclidean distance site × site association matrices calculated from standardized data. Toxicity endpoints for the test sites were compared to those for all reference sites. (There are no distinct groups as with the community structure assessment.) Principal axis correlation (Belbin 1993) was used to identify relationships between habitat attributes and community or toxicity responses. This did not include organic contaminant data, which were not measured in the reference sediments. Significant endpoints and environmental attributes were identified using Monte-Carlo permutation tests (Manly 1991). Test sites were assessed by comparison to confidence bands of appropriate reference sites. Probability ellipses were constructed around reference sites, establishing four categories of difference from 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) (Figure 2). Test site toxicological responses were compared to numerical criteria previously established for each category (non-toxic, potentially toxic and toxic) and species from reference site data (Reynoldson and Day 1998).

Test data were analyzed in subsets to maintain the ratio of test: reference sites ≤0.10. Multiple discriminant analysis was performed and probability ellipses (Figure 2) were produced using the software SYSTAT (Systat Software Inc. 2002). HMDS, principal axis correlation, and Monte-Carlo tests were performed using the software PATN (Blatant Fabrications Pty Ltd. 2001).

Sediment toxicity and contaminant concentrations

Relationships between sediment toxicity and sediment contamination for Nipigon Bay sites 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 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).

The sediment toxicity data for Nipigon Bay sites were ordinated again by HMDS, as a single group and without the reference site data. To identify and relate the most important of the toxicity endpoints to the HMDS axes, principal axis correlation was conducted. Concentrations in sediment of 9 metals (As, Cd, Cr, Cu, Fe, Mn, Ni, Pb, Zn) were ordinated by principal components analysis (PCA). The eigenanalysis was performed on the correlation matrix. Data for all variables were log(x)-transformed.

The integrated descriptors of sediment toxicity (axes scores from the HMDS) and the most important individual toxicity endpoint (survival of *Hyalella*) were plotted against the integrated contaminant descriptors (from PCA) as well as individual log(x)-transformed sediment contaminants, nutrients and grain size. To determine whether toxicity was better explained by joint consideration of the contaminant descriptors, multiple linear regression involving the contaminant descriptors as predictors was calculated with each toxicity descriptor as the response variable. The degree to which individual sediment variables account for individual toxicity response was assessed by fitting regression models using "best subset" procedures (Draper and Smith 1998; Minitab 2000). Models were fitted for (a) metals, (b) sediment nutrients and grain size, (c) overlying water nutrients, and then (d) all combinations of the best predictors from the four groups. (This procedure was used to avoid computational difficulties arising from working with multiple predictors simultaneously.) The best models were those having maximum explanatory power (based on $R^2_{adjusted}$), minimum number of nonsignificant predictors, and minimum amount of predictor multicollinearity.

2.6 Quality Assurance/Quality Control

Field variability

At two randomly selected sites (R4 and E8), triplicate overlying water, sediment and benthic invertebrate samples were collected for determination of within-site and among-sample variability. Variability in a measured analyte was expressed as the coefficient of variation (CV = standard deviation / mean × 100). Variability in community composition between the site replicates was examined by their location in ordination space. The proximity of the site replicates in ordination space was an indication of their similarity/dissimilarity.

Laboratory

Quality control procedures for Caduceon Environmental Laboratory involved 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 duplicates were run 1 in 10 samples. Sample duplicate measurements of sediment metals, major oxides and nutrients were expressed as the relative percent difference ($=(x_1 - x_2)/(x_1 + x_2)/2 \times 100$).

Community structure sorting

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

%OM = # Organisms missed / Total organisms found × 100

The desired sorting efficiency (as %OM) is ≤ 5% (or >95% recovery). If the %OM was > 5%, two more replicate samples were randomly selected and the %OM calculated. The average %OM was calculated based on the three samples re-sorted, and represents the standard sorting efficiency for that month. The average %OM is based on only one replicate sample if %OM is < 5%.

3 RESULTS AND DISCUSSION

3.1 Sediment and Water Physico-Chemical Properties

Overlying water

The variables measured in the overlying water (0.5 m above the sediment) are similar for most sites, suggesting some homogeneity in water mass across most sampling sites (Table 3). The ranges for the variables are 28.8 mg/L for alkalinity, 65.2 µS/cm for conductivity, 12.61 mg/L for dissolved oxygen, 0.34mg/L for nitrates/nitrites (NO_3/NO_2), 0.044mg/L for total ammonia (NH_3), 0.73 for pH, 3.86 °C for temperature, 0.096 mg/L for total Kjeldahl nitrogen (TKN), and 0.0927mg/L for total phosphorus (TP). Site 6974, located at the mouth of the Nipigon River, is most dissimilar to the rest of the sites, with the highest alkalinity, TKN, and the lowest NO_3/NO_2. Sites in the eastern portion of the bay (R7, R8, R9, R10) have the lowest alkalinity, conductivity, and the highest NO_3/NO_2. The MOE collected water samples from 6 sites in Nipigon Bay in 1999; TP was typically between 4 to 8 µg/L, except for 2 sites downstream of the mill and the Red Rock WPCP, where they were 24 to 40 µg/L (Richman 2004). This is similar to the current study, where TP is in the range of ~6 to 17 µg/L, except for 2 sites downstream of the mill and Red Rock WPCP outfalls (E6 and E8), where concentrations are 35 and 58 µg/L (Table 3), greater than the Interim Provincial Water Quality Objective of 20 µg/L (to avoid nuisance concentrations of algae in lakes).

Sediment particle size

Percents sand, silt, clay, and gravel are shown in Table 4. Overall, sediments are dominated by clay (4.1 to 63.8%, median 51.8%), and silt (10.3 to 72.1%, median 43.4%). Percent sand (0.3 to 85.6%, median 1.1%) is low overall; most sites have <7%. Three sites have an appreciable amount of sand: the site at the mouth of the Nipigon River (6974; 59%); 1 site ~600 m south of 5-mile Point (E6; 86%) and 1 site near Kama Pt (R7; 20%). A small amount of gravel (0.3%) is present at Site R7. Substrate types are important as they can affect contaminant bioavailability, benthic community types, and toxicity test results.

Sediment nutrients and trace metals

Sediment nutrient and trace metal concentrations are shown in Table 5. Ranges for the selected nutrients are: total organic carbon (TOC), 0.6 to 5.5% (median 1.2%); total Kjeldahl nitrogen, 473 to 2300 μg/g (median 1180 μg/g); and total phosphorus, 458 to 981 μg/g (median 709 μg/g). The highest TOC concentrations are at the sites closest to the mill outfall (3.4% and 5.5%, sites E4 and E5). Visual observations at the time of sampling noted approximately 10 cm of woody debris overlying sandy sediment at site E4, and submerged vegetation at site E6. The highest total Kjeldahl nitrogen concentrations are found at E5 followed by sites R8 and R9 (eastern portion of the bay). All sediment nutrient concentrations at test sites are within the range observed at Lake Superior reference sites ($n = 31$; Reynoldson and Day 1998), with the exception of total organic carbon at E4 and E5 (Table 5). The range in TOC for Lake Superior reference sites is 0.17 to 2.9% (Table 5). In the Environmental Effects Monitoring (EEM) Cycle 3 survey (also performed in September of 2003), the highest sediment TOC (3.1 to 8.6%) was found at sites in a far-field area, located approximately 750 to 800m from the mill outfall (Stantec 2004). Sites E4 and E5 are located approximately 900 to 1300m from the mill outfall.

There are exceedences of the provincial Lowest Effect Level (LEL; Persaud et al. 1992) at all sites for 1 to 8 metals. Sites R8, R9 and R10 sites have the greatest number of LEL exceedences (6 to 8 metals), while a site south of Red Rock has only 1 LEL exceedence (nickel). (This site has a very high sand content - 86%.) The Severe Effect Level (SEL) for manganese (Mn, 1100 μg/g) is exceeded by ~2 to 3× at 3 sites (R8, R9, R10); Mn concentrations range from 185 to 2940 μg/g (median 697 μg/g; Table 5). The SEL for iron (Fe, 4%) is just slightly exceeded at 2 sites (R9, R10). The MOE collected sediment samples (top 3 cm) from 6 sites in Nipigon Bay in 1999 (Richman 2004). There were exceedences of the LEL for several metals and no exceedences of SELs, similar to what is found in the current study. Richman (2004) attributes the metal concentrations as typical in some cases for Lake Superior because comparison of test site concentrations to background values for the Great Lakes basin and Lake Superior (pre-colonial sediment horizons) showed test sites to be below or similar to background. In the current study, observed concentrations also fall within the range of the background values reported in Richman (2004) with the exception of cadmium and zinc at sites R8 to R10, where they are just slightly above. (Reported ranges: cadmium, 0.4 to 0.7μg/g; zinc, 53 to 137.1μg/g.)

All trace metal concentrations for Nipigon Bay sites are within the range observed for Lake Superior reference sites (n = 31; Reynoldson and Day 1998) (Table 5). The RAP Stage 1 report (Nipigon Bay RAP Team 1991) states that contaminants in the eastern part of the bay are thought to be deposited in this area as a result of transport from the lake rather than from the mill (due to distance from industrial discharge, predominant currents in the bay, and the nature of contaminants).

Organic contaminants

Organic contaminants were not analyzed in the sediment samples. However, a MOE study conducted in 1999 showed that organic contaminants such as dioxin-like PCBs and octachlorodioxin (n = 1) and total PAHs (n = 3 or 4) were elevated in sediment south of the mill outfall compared to other stations in Nipigon Bay (Richman 2004). The dioxin-like PCBs were reported to make up more than half of the toxic equivalency value (TEQ) near the local mill outfall, while in other Lake Superior AOCs (Jackfish Bay, Thunder Bay, Peninsula Harbour) and the Spanish Harbour AOC, dioxin-like PCBs represented a small fraction of the TEQ.

3.2 Community Structure

All 15 Nipigon Bay sites are maximally predicted to Great Lakes Reference Group 5 (Table 6). The probabilities are very high, ranging from 74.7% to 99.6% (mean 92%). Sites E4, E6 and E8, located near Red Rock, are fairly shallow compared to the other sites in the bay (Table 1) which may explain the slightly lower probabilities of reference group membership for these sites. (The mean depth for Group 5 reference sites is 36.6 m.)

Reference Group 5 has a total of 75 sites mainly from Lake Superior (30), as well as Georgian Bay (19), the North Channel (12), Lake Michigan (7), Lake Ontario (5) and Lake Huron (2). This group is characterized by the Haustoriidae (44.3% occurrence in Group 5 - consisting almost entirely of the amphipod *Diporeia hoyi*), as well as the Tubificidae (16.6% occurrence), Sphaeriidae (11.5% occurrence) and Chironomidae (9.9% occurrence). To a lesser degree, Group 5 also consists of Lumbriculidae, Enchytraeidae, and Naididae (oligochaete worms - 1.9 to 6.8% occurrence). These 7 families make up 96% of the total families found in Reference Group 5.

Table 7 shows the mean abundances (per 33 cm^2 – the area of the subsampling core tube) of each of these 7 reference group families for Nipigon Bay sites. Complete invertebrate family counts are provided in Appendix A; Table A1, and species (or lowest identified taxon level) abundances are provided in Appendix A; Table A2. In total, 42 benthic families (Table A1) and a total of 135 taxa (Table A2) were identified in Nipigon Bay samples.

Nipigon Bay sites are dominated primarily by two families which are present at all sites: Tubificidae, represented by 15 taxa, and Chironomidae, represented by 45 taxa. Sphaeriidae are present at all sites except one (E5, at Five Mile Point, below the Norampac/WPCP outfall), and Naididae are present at all sites except 2 (R9, R10, far eastern part of the bay). There are increased abundances of tubificids (from ~2 to 50× reference mean) at 12 of the 15 sites, and generally, the tubificid worms consist mainly of the unidentifiable immatures (with and without chaetal hairs), followed by *Aulodrilus* (4 species), *Potamothrix* (3 species) and *Limnodrilus* (2 species) (Appendix A; Table A2). There are increased abundances of chironomids (from ~1.5 to 27×) at 11 of the 15 sites. Chironomids consist primarily of *Procladius* sp. (present at all sites except R10; Table A2). Sphaeriid abundances are close to or slightly lower than the reference mean at the most sites; sites 6974 and E6 have the highest abundances (3.4 and 5.9× greater than the reference mean). The greatest densities of tubificids, chironomids, sphaeriids as well as naidids are in the western bay. Haustoriidae, the most predominant reference Group 5 taxa, are absent at 6974 (mouth of Nipigon River), R1 (upstream of the mill/Red Rock WPCP outfall), E4 and E5 (just below the outfall); they are in low abundance at remaining sites. Sites R8, R9 and R10 (far eastern portion of the bay) have the highest abundances of haustoriids (2.8, 9.2 and 7.6 amphipods per 33cm^2, respectively). (Sites R8, R9 and R10 generally have the lowest abundance of chironomids and tubificids.)

Macroinvertebrate family diversity at Nipigon sites ranges from 4 to 19 taxa (Table 7). The number of taxa is below the reference mean (6 families) at 3 sites, equal to the reference mean at 3 sites and between 1.2 to 3× greater than the reference mean at 9 sites. Site E5 (below Norampac/WPCP outfall) has the lowest diversity while sites 6974 (mouth of Nipigon River) and E6 (south of E5) have the highest diversity (19 taxa each).

Relative Taxon Abundances

The mean relative abundance of the predominant macroinvertebrate taxa found in Nipigon Bay (tubificids, chironomids, sphaeriids, amphipods, and mayflies) are shown in Figure 3. Tubificids dominate in the area southeast of the mill/WPCP outfall and in the western part of the bay, comprising 50 to 86% of the macroinvertebrate community, followed by chironomids (6 to 19%). Mayflies are present at most sites closest to the outfall (except E5), but are absent in the deeper southwestern bay. Stantec (2004) found that oligochaetes (mostly tubificids) comprised 50% of the entire community in a near-field area of Nipigon Bay (close to mill outfall) and in a far-field area (~800m from mill outfall), oligochaetes (again most of which were tubificids) dominated (70%) the communities. In this study, communities at sites upstream of the mill outfall are dominated by chironomids (41%), followed closely by tubificids (39%). Remaining taxa comprise between 0 to 8% of the community and amphipods are absent at these upstream sites. Sites in the eastern part of the bay are most similar to reference sites. The Great Lakes reference (Group 5) community consists of 44% amphipods (almost entirely haustoriids), followed by 17% tubificids while 28% of organisms at the eastern Nipigon sites are amphipods, and ~18% are tubificids (Reynoldson and Day 1998). In the Cycle 3 EEM survey (Stantec 2004), similar taxonomic differences were observed between reference and mill effluent-exposed sites: oligochaetes (mainly tubificids) were less dominant, and amphipods were more dominant in the reference area than in exposed sites.

BEAST assessment of benthic community

Results of the BEAST community structure evaluation are summarized in Table 7. A spatial map indicating the level of benthic community alteration is provided in Figure 4. Ordinations are shown in Appendix B; Figures B1 and B2 (stress ≤ 0.15). Two separate ordinations were performed each with a subset of 7 and 8 Nipigon Bay sites.

Nipigon Bay sites fall into the following bands of similarity to reference conditions: (Table 7, Figure 4):

Band 1 (equivalent to reference):	2 sites	(R9, R10)
Band 2 (possibly different):	4 sites	(R1, R4, R7, R8)
Band 3 (different):	4 sites	(E4, E6, E8, E12)

Band 4 (very different): 5 sites (6974, E5, E14, E15, E16)

The macroinvertebrate families most highly correlated with the ordination axes are (in descending order): Haustoriidae (r^2=0.68, 0.59), Tubificidae (r^2=0.57, 0.47), Chironomidae (r^2=0.51, 0.30), Sphaeriidae (r^2=0.44, 0.32) and Lumbriculidae (r^2=0.37). The sites that are outside the 90% ellipse have increased abundances of Tubificidae, Chironomidae, and several other macroinvertebrate families (Sites are oriented along the vector line in the same direction.) (Appendix B; Figures B1 and B2). The sites in Band 4 are most different from reference due to their greatest distance from the reference centroid in ordination space. The relationship between the community response and habitat variables was examined by correlation of the ordination of the community data and the habitat information. There are no high correlations ($r^2 \leq 0.18$). The difference of sites in the western part of the bay (near point source outfalls and in the deep south channel that runs to Nipigon Straight) from reference sites is associated with elevated overlying water total phosphorus (TP(W)), total Kjeldahl nitrogen (TKN), and temperature (Temp), and sediment magnesium oxide (MgO), total organic carbon (TOC) and Hg (Figure B1).

3.3 Sediment Toxicity Tests

Mean species survival, growth and reproduction in Nipigon Bay sediment is provided in Table 8. The established numerical criteria for each category (non-toxic, potentially toxic and toxic) for each species are included. Water quality parameters (dissolved oxygen, pH, temperature, ammonia and conductivity) measured at the start and end of the tests is provided in Appendix C; Table C1. There are no unusual recordings and water quality was consistent throughout the tests.

Acute toxicity to *Hyalella is* evident at 4 sites: R7, R8, R9 and R10 (survival: 8 to 48%); potential toxicity due to reduced *Hyalella* survival is also evident at Site E8 (60% survival). Sites E4 and R1 have low *Tubifex* cocoon production (6.5 to 7.1 cocoons per adult) and therefore fall in the potentially toxic category based on the numerical guidelines. There is no toxicity to the midge *Chironomus* or the mayfly *Hexagenia*.

BEAST assessment of toxicity

Results of the BEAST toxicity evaluation are summarized in Table 8. A spatial map showing the level of toxicity is provided in Figure 5. Ordinations are shown in Appendix D; Figures D1 and D2 (stress ≤ 0.10). Each of the two figures represents a separate ordination on a subset of 7 or 8 Nipigon Bay sites.

Nipigon Bay sites fall into the following bands of toxicity relative to reference conditions: (Table 8, Figure 5):

Band 1 (non-toxic):	8 sites (6974, E4, E5, E6, E12, E14, E15, R4)
Band 2 (potentially toxic):	3 sites (E8, E16 and R1)
Band 3 (toxic):	0 sites
Band 4 (severely toxic):	4 sites (R7, R8, R9 and R10)

Six of the 10 toxicity endpoints are significant in each ordination (r^2: 0.09 to 0.97). Sites in Band 4 are associated with decreased *Hyalella* survival (i.e., are located along the same vector line as *Hyalella* in the opposite direction) (Appendix D; Figure D2). The relationship between the toxicological response and habitat variables was examined by correlation of the ordination of the toxicity data and the habitat information. There are no high correlations ($r^2 \leq 0.18$). Those variables oriented with the site positions in ordination space include gravel (r^2=0.09; Figure D1), and copper (Cu, r^2=0.08; Figure D2), although correlations are very weak. (Copper concentrations are fairly low at sites R7, R8, R9 and R10, ranging from 32 to 59 µg/g; Table 5.) Strong sediment toxicity occurs at sites east of Vert Island, in the eastern part of the bay while sites located closest to the mill outfall are non-toxic.

3.4 Toxicity-Contaminant Relationships

Examination of relationships between sediment toxicity and sediment contaminants both graphically and by regression analysis may aid in identifying possible causes of toxicity attributable to inorganic compounds, sediment nutrients and sediment grain size. (Organic contaminants were not measured.) The ordination of the multiple measurements of sediment toxicity by HMDS for Nipigon Bay sites without reference site data produced two descriptors of sediment toxicity (Appendix E; Figure E1). The most highly correlated endpoint (r^2 = 1.0) is

Hyalella survival (Hasu), shown as a vector in Figure E1. *Hyalella* survival is negatively correlated with Axes 1 and 2; therefore, the greater the toxicity, the higher its score for Axes 1 and 2. The most highly correlated environmental variables include arsenic (As; $r^2 = 0.66$), cadmium (Cd; $r^2 = 0.62$), lead (Pb; $r^2 = 0.58$) and total organic carbon (TOC; $r^2 = 0.52$). Toxic sites (located in upper right quadrant of ordination) are associated with elevated metals (Cd and Pb), which are shown as vectors in the ordination.

Integrated toxicity descriptors – contaminant relationships

Nine metals (As, Cd, Cr, Cu, Fe, Mn, Ni, Pb, Zn) were ordinated by principal components analysis (PCA). The first 3 principal components account for 88.2, 5.7% and 3.1% of the total variation, respectively. All measurement variables were negatively loaded for PC1, and loadings are of a similar magnitude. The first principal component – denoted as "metPC1" – was used as a general descriptor of metal contamination.

The integrated descriptors of sediment toxicity (Axis 1 and 2 scores "*ToxAxis1*" and "*ToxAxis2*" from the HMDS) were plotted against the integrated metal toxicity descriptor (metPC1) (Appendix E; Figure E2). In a regression with *ToxAxis 1*, metPC1 (negative coefficient) explains ~32% of the variability:

$$\text{ToxAxis1} = -\ 0.000 - 0.201\ \text{metPC1};\ p = 0.017,\ r^2_{adj} = 31.6\%$$

Predictors with negative coefficients are potentially toxic to *Hyalella* survival. No significant relationship was found for *ToxAxis 2*.

Individual toxicity descriptors - contaminant relationships

The relationships among individual toxicological response variables were evaluated by plotting the most significant endpoint, *Hyalella* survival, against concentrations of individual physical and chemical variables (Appendix E; Figures E3 and E4). The most significant relationship is provided below. Predictor coefficients that are negative (Pb) indicate that decreased *Hyalella* survival is related to increased concentrations.

Hyalella survival = - 1.42 + 2.40 log Ni - 1.59 log Pb ; $p=0.001$, $r^2_{adj}=66.1\%$

Potential causes of toxicity

Up to 66% of the variability in toxicity of Nipigon Bay sediments is explained by metals. Regression of the individual toxicity response (survival of *Hyalella*) and individual contaminant concentrations produces the strongest relationship.

Predictors with coefficients indicating decrease in toxicity with increase in contaminant concentration do not suggest causal relationships. After excluding predictors not indicative of toxicity relationships, toxicity to *Hyalella* is most strongly associated with Pb. However, Pb concentrations in Nipigon Bay are not high (range: <5 to 29 µg/g, below the LEL), and are within the range observed for Lake Superior reference sites (1 to 55µg/g). It is therefore not clear what is causing toxicity to *Hyalella*. Industrial discharges from the Red Rock area are not likely responsible because toxicity occurs in the eastern portion of the bay but is low or absent in the western area closer to outfall.

3.5 Quality Assurance/Quality Control

Variability among field-replicated sites, expressed as the coefficient of variation (CV), is shown in Appendix F; Table F1. The CVs range from 0 to 66.7 % (median 3.7 %), not uncommon for field-replicated samples (taken from three separate box core drops). Differences in variability are seen among sites and among parameter for the same site. The highest variability is noted for total phosphorus in overlying water for site E8 followed by the percent clay in the sediment for E8 (16.9%). Quality control results from Caduceon laboratory (i.e., reference standards, sample duplicate measurements) are not available.

Community variability

Variability in community composition (examined by location of site replicates in ordination space) is shown in Figure F1. The replicate sites of E8 and R4 are in close proximity to each other in ordination space, indicating good agreement between the field replicates (Appendix F; Figure F1). All three replicates of R4 are in Band 2. For E8, two replicates (1 and 2) are in Band 2 and one is in Band 3, but site replicates are close. These results indicate that the community structure is well represented by one box core sample.

Sorting efficiency

Sorting efficiency was determined by re-sorting 10 samples. The mean percent sorting efficiency for the community samples is 3.5%, which represents the average sorting efficiency of three sorters over a three month period. This is an acceptable low level, indicating that there was a good recovery (>95%) of organisms from the samples.

3.6 Decision–Making Framework for Sediment Contamination

A risk-based, decision-making framework for the management of sediment contamination was recently developed by the Canada-Ontario Agreement Sediment Task Group using four lines of evidence (sediment chemistry, toxicity, benthic community structure and biomagnification potential). This decision framework was developed from the Sediment Triad and BEAST frameworks, and is described in Grapentine et al. (2002) and Chapman and Anderson (2005). The overall assessment of a test site is achieved by integrating the information obtained both within and among the four lines of evidence. Interpretation of the overall assessment for management implications also considers the degree of degradation for each line of evidence. This framework was applied to the current study using three lines of evidence (chemistry, toxicity, benthic community structure). The decision matrix for the weight of evidence categorization of Nipigon Bay sites is provided in Table 9. For the sediment chemistry column, sites with exceedences of a sediment quality guideline (SQG) – low are indicated by "⭘"; sites with SQG-high exceedences by "●". Substances exceeding the provincial Lowest Effect Level (LEL) and Severe Effect Level (SEL) are listed. For the toxicity and benthos alteration columns, sites determined from BEAST analyses as toxic/severely toxic or different/very different from reference, respectively, are indicated by "●"; sites determined as potentially toxic or possibly different from reference by "⭘". Sites with no SQG exceedences, no sediment toxicity, or benthic communities equivalent to reference conditions are indicated by "○". Some sites show potential toxicity or possible benthos alteration but are not recommended for further action. For these sites, most or all individual toxicity endpoints are in the non-toxic categories according to the numerical guidelines or the benthos alteration is not judged to be detrimental (decreased taxon richness, reduced average abundance).

Overall Nipigon Bay site assessments are as follows:

Management actions

This is not indicated for any site. From 1 to 8 metals are elevated above LELs, but there is no strong concurrence of high metal concentration with sediment toxicity or altered benthic communities at any site.

Determine reason for benthos alteration

This is indicated for 9 sites: 6974 (mouth of Nipigon River)
E4, E5, E6, E8 (south of Norampac/Red Rock WPCP outfall)
E12, E14, E15, E16 (deep channel flowing to Nipigon Straight).

From 1 to 5 metals are above LELs at each site. Benthic communities are different or very different from reference conditions. There is no strong evidence of toxicity. Note: sites R1, R4, R7 and R8 have benthic communities that are possibly different from reference conditions. Diversity at these sites is high (8 to 19 taxa) and some pollution intolerant taxa are present (i.e., amphipods, mayflies, trichopterans; Appendix A, Tables A1 and A2); therefore, degradation is not a concern.

Determine reason for sediment toxicity

This is indicated for 4 sites: R7, R8 (near Kama Pt)
R9, R10 (7-10 km southeast of Vert Island).

From 5 to 8 metals are above LELs at these sites. Toxicity is severe due to low amphipod survival and it is not clear what is causing toxicity. Benthic communities are equivalent to reference or benthos alteration is not judged to be detrimental. Communities may have acclimated/adapted or there is insufficient stress to cause population-level responses.

No further actions needed

This is indicated for 2 sites: R1 (upstream of Norampac, downstream of Nipigon WPCP)
R4 (~3 km east of Norampac/Red Rock WPCP outfall)

Five metals exceed LELs at each site; however, benthos alteration is not judged to be detrimental and there is no strong evidence of toxicity.

4 CONCLUSIONS

Sediment Contaminants

- Several metals are above Sediment Quality Guidelines in Nipigon Bay. From 1 to 8 metals are above provincial Lowest Effect Levels; sites located in the eastern portion of the bay have the most exceedences – between 6 to 8 metals. Exceedences of the Severe Effect Level are limited to manganese at 3 sites in the eastern bay. Iron just exceeds the SEL at 2 sites.
- Organic contaminants were not measured in the sediments.

Benthic Community Structure

- Sites in western Nipigon Bay have communities different from reference sites, due to the absence or low abundance of haustoriids (a key reference amphipod taxon), and enrichment of tubificid worms as well as chironomids (midges), naidid worms and sphaeriids (fingernail clams) in some cases. These sites are located at the mouth of the Nipigon River, in the vicinity of Norampac, and in the channel running south of Red Rock to Nipigon Straight.
- Elevated levels of total organic carbon, total Kjeldahl nitrogen (overlying water), and total phosphorus (overlying water) are associated with the difference of some of the sites from reference conditions.
- Generally, benthic communities at sites in the eastern portion of the bay are more similar than the other Nipigon Bay sites to reference sites communities.
- Benthic communities are not impaired at the four severely toxic sites (R7, R8, R9, R10). Communities may have acclimated/adapted at these sites or there is insufficient stress to cause population-level responses.

Sediment Toxicity

- There is severe toxicity at sites in eastern Nipigon Bay due to low amphipod (*Hyalella azteca)* survival.

- It is not clear what is causing toxicity to *Hyalella*. From the BEAST analysis, toxicity is not highly correlated to any measured environmental variable. Regressions indicate that metal toxicity explains up to 66% of the variability; however, individual metal concentrations are not high or the predictor has a coefficient indicating decrease in toxicity with increase in contaminant concentration, which does not suggest a causal relationship.
- Industrial discharges are not likely responsible because toxicity occurs in the eastern portion of the bay but is low or absent in the western area closer to outfall.

Decision-making framework for sediment contamination

- Management actions are not indicated for any site. While several metals are elevated above Sediment Quality Guidelines (Lowest Effect Level) at most sites, there is no strong concurrence of benthos alteration and sediment toxicity.
- The reason for benthos alteration and for sediment toxicity needs to be determined for 9 sites and 4 sites, respectively.
- No further actions are indicated for 2 sites.

5 RECOMMENDATIONS

- Benthic communities at the toxic sites should be monitored for change in status.

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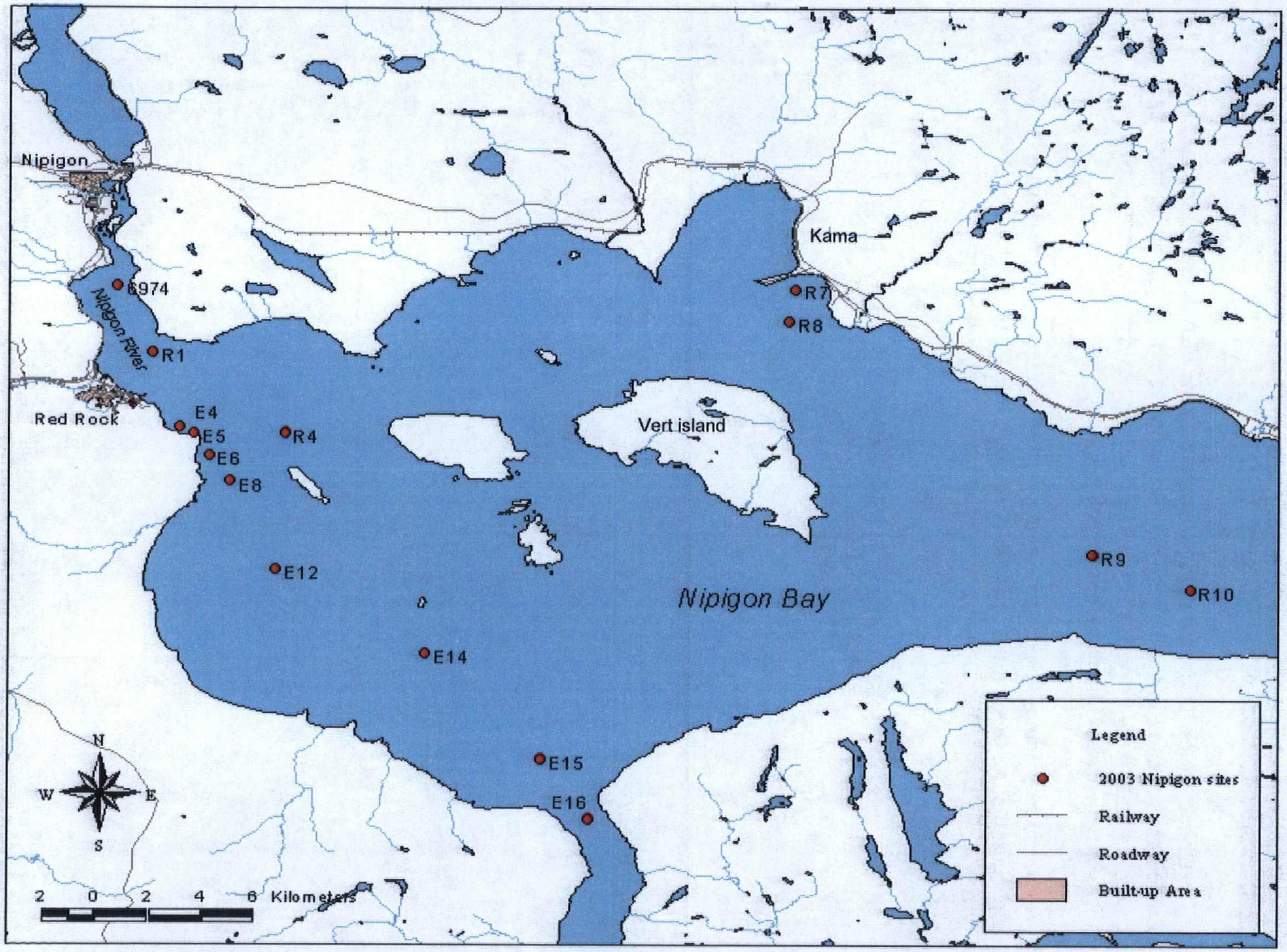

Figure 1. Location of sites in Nipigon Bay.

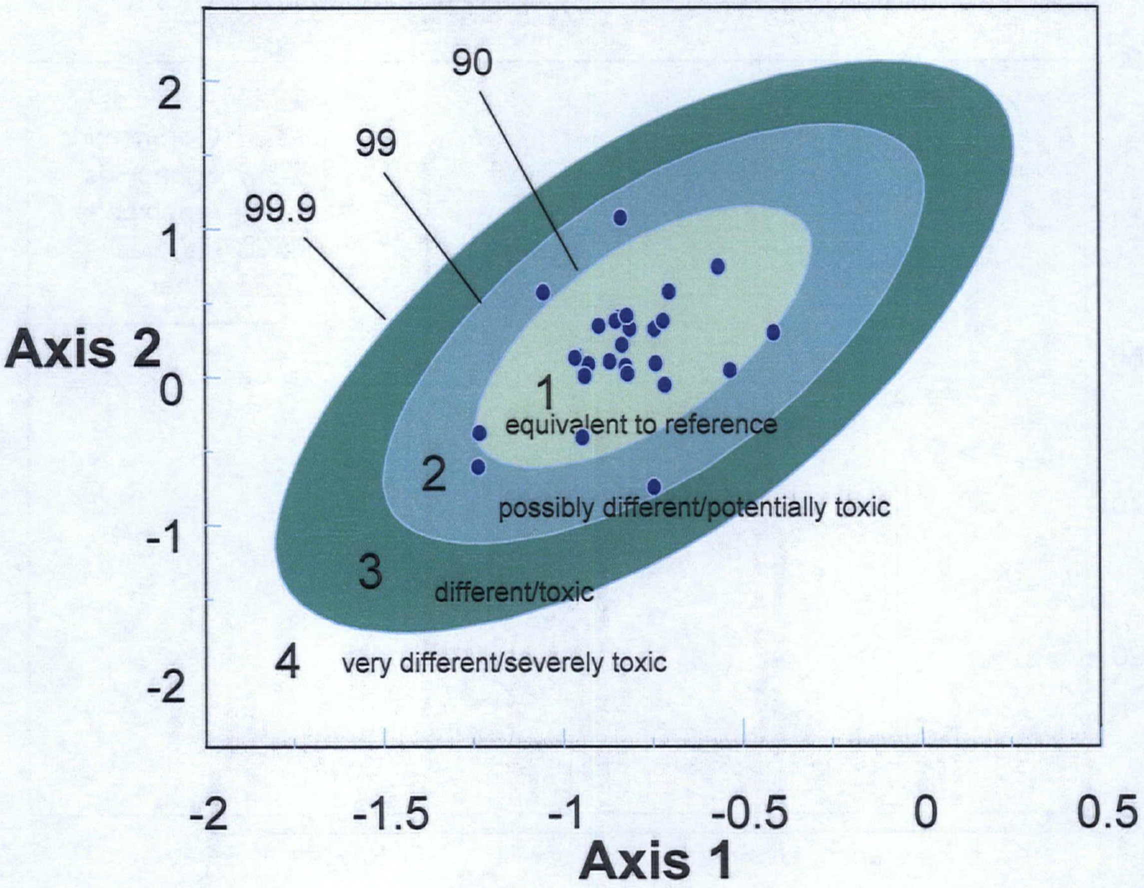

Figure 2. Four reference bands in ordination space showing the 90, 99, and 99.9% probability ellipses around reference sites.

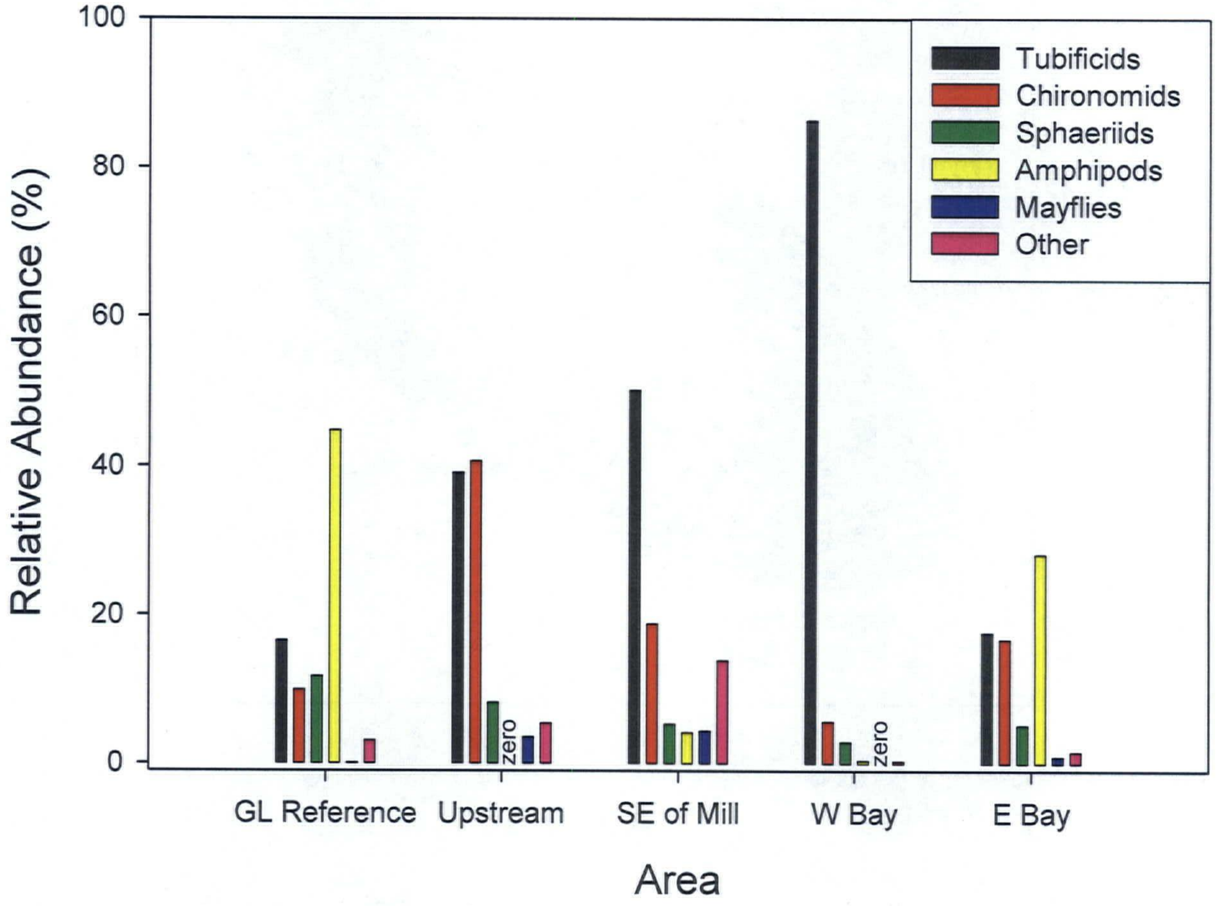

Figure 3. Mean relative abundance of dominant benthic macroinvertebrate groups collected in Nipigon Bay.

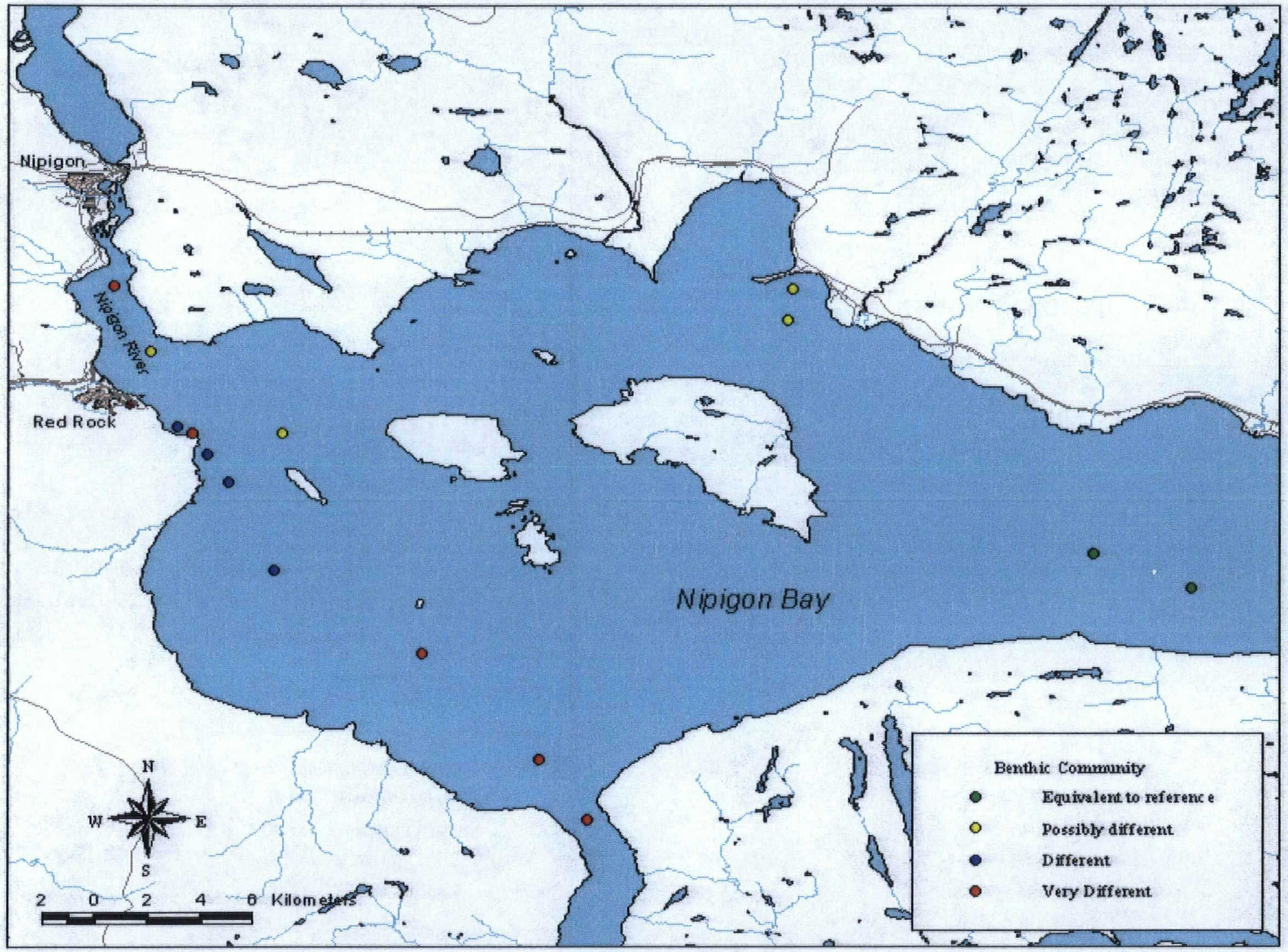

Figure 4. Spatial distribution of sites indicating the level of benthic community alteration compared to Great Lakes reference sites.

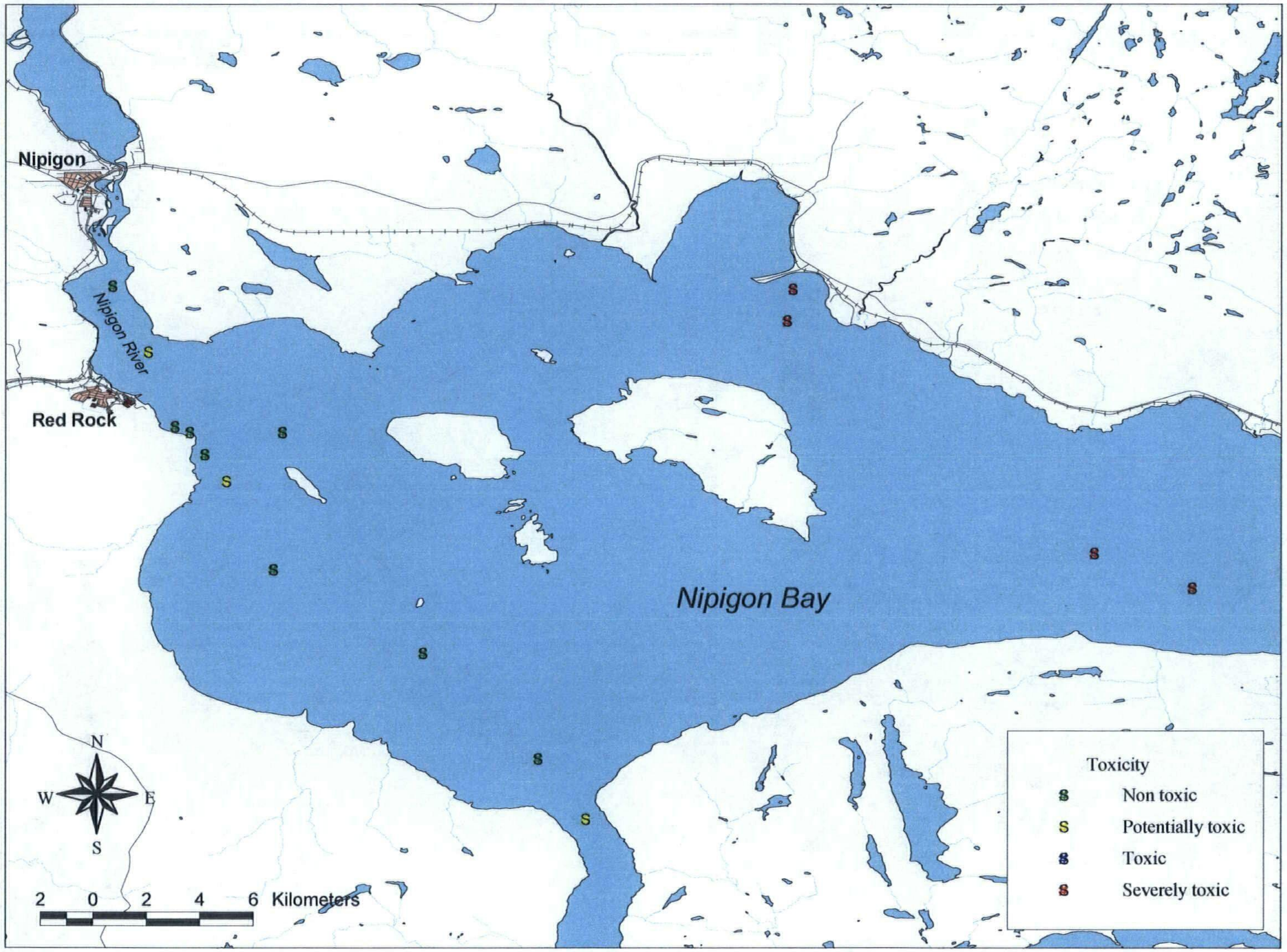

Figure 5. Spatial distribution of sites indicating the level of toxicity compared to Great Lakes reference sites.

Table 1. Nipigon Bay site positions (UTM NAD83) and site depth.

Site	Site Depth (m)	Northing	Easting
6974	8.7	5425917	408211
R1	15.9	5423366	409045
E4	3.9	5420504	409663
E5	17.0	5420275	410027
E6	0.9	5419419	410382
E8	4.7	5418389	410902
E12	32.9	5414993	412007
E14	49.0	5411739	415713
E15	49.3	5407651	418569
E16	60.8	5405334	419721
R4	14.6	5420241	412301
R7	10.1	5425544	425109
R8	20.6	5424324	424958
R9	36.4	5415343	432422
R10	39.5	5413982	434842

Table 2. Environmental variables measured at each site.

Field	Overlying Water	Sediment (top 10 cm)
Northing	Alkalinity	Trace Metals
Easting	Conductivity	Major Oxides
Site Depth	Dissolved Oxygen	Total Phosphorus
	pH	Total Kjeldahl Nitrogen
	Temperature	Total Organic Carbon, Loss on Ignition
	Total Kjeldahl Nitrogen	% Clay, Silt, Sand and Gravel
	Nitrates/Nitrites	
	Total Ammonia	
	Total Phosphorus	

Table 3. Physico-chemical conditions of overlying water in Nipigon Bay.

Site	Alkalinity m/L	Conductivity µS/cm	Dissolved O_2	NH_3 m/L	NO_3/NO_2 m/L	pH	Temp °C	Total Kjeldahl N m/L	Total P µg/L
6974	73.3	147	16.0	0.011	0.011	7.98	16.79	0.209	11.3
R1	52.8	123	10.3	0.020	0.235	7.98	16.64	0.134	13.9
E4	55.9	126	-[a]	0.026	0.223	8.06	16.55	0.160	16.6
E5	59.3	119	13.8	0.026	0.176	8.08	16.59	0.159	12.3
E6	58.5	124	-[a]	0.030	0.188	8.12	16.44	0.161	35.2[b]
E8	60.0	126	22.8	0.026	0.170	8.10	16.66	0.171	58.1[b]
E12	55.3	171	10.0	0.020	0.204	8.08	16.54	0.150	15.9
E14	59.2	151	8.8	0.019	0.277	7.54	9.37	0.150	10.9
E15	59.3	144	8.7	0.018	0.282	7.52	9.19	0.123	10.9
E16	59.8	142	9.5	0.021	0.290	7.59	9.33	0.138	15.4
R4	61.4	131	10.2	0.023	0.192	7.99	16.78	0.171	14.0
R7	48.3	106	16.4	0.012	0.290	8.00	15.97	0.138	8.3
R8	48.9	117	10.8	0.011	0.296	8.20	16.25	0.117	5.5
R9	44.5	108	12.8	0.009	0.351	7.80	13.43	0.113	8.6
R10	46.1	108	12.3	0.053	0.342	7.47	13.06	0.161	10.9
Lake Superior Reference[c]	39-53		10.3-15.0		0.24-0.36	7.5-7.9	5-20	0.031-0.226	3.6-28

[a] data not available

[b] exceeds the interim Provincial Water Quality Objective of 20µg/L

[c] Reynoldson and Day 1998, n = 31

Table 4. Physical characteristics of Nipigon Bay sediment (top 10 cm).

Site	% Sand	% Silt	% Clay	% Gravel
6974	58.5	30.0	11.5	0
R1	1.1	56.0	42.9	0
E4	6.9	67.2	25.9	0
E5	3.2	65.6	31.2	0
E6	85.6	10.3	4.1	0
E8	2.9	72.1	24.9	0
E12	0.8	46.5	52.7	0
E14	0.5	37.6	61.9	0
E15	0.5	35.8	63.8	0
E16	1.9	46.3	51.8	0
R4	0.7	43.1	56.2	0
R7	19.6	33.9	46.3	0.3
R8	1.1	39.7	59.2	0
R9	0.7	37.6	61.8	0
R10	0.3	42.4	57.3	0

Table 5. Trace metal and nutrient concentrations in Nipigon Bay sediment. Substances exceeding Provincial Severe Effect Levels are highlighted.

Parameter	Units	M.D.L.	Reference Method	Superior Reference[a]	6974	R1	E4	E5	E6	E8-01	E8-02	E8-03	E12	E14	E15	E16	R4-01	R4-02	R4-03	R7	R8	R9	R10
Aluminum (Al)	µg/g	300	SM 3120		10400	18600	13500	16000	9180	13700	11100	12300	17700	19400	21700	16600	18400	19700	20800	18400	23600	25300	26300
Aluminum (Al)	pct				1.04	1.86	1.35	1.6	0.918	1.37	1.11	1.23	1.77	1.94	2.17	1.66	1.84	1.97	2.08	1.84	2.36	2.53	2.63
Antimony (Sb)	µg/g	0.2	SM 3114		< 0.2	0.2	0.4	0.4	0.2	0.2	< 0.2	< 0.2	0.2	0.5	0.4	0.2	0.2	0.4	0.4	0.4	0.5	0.5	0.5
Arsenic (As)	µg/g	1	SM 3114	< - 25	< 1	3	2	3	1	2	2	2	3	3	3	3	4	4	4	6	10	11	9
Barium (Ba)	µg/g	1	SM 3120		32	86	54	69	26	52	47	53	86	101	103	79	98	97	101	100	180	199	177
Beryllium (Be)	µg/g	0.2	SM 3120		< 0.2	0.3	< 0.2	0.3	< 0.2	< 0.2	< 0.2	< 0.2	0.3	0.4	0.4	0.3	0.4	0.4	0.4	0.5	0.7	0.7	0.7
Bismuth (Bi)	µg/g	5	SM 3120		< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5
Cadmium (Cd)	µg/g	0.5	SM 3120	0.1-4.3	< 0.5	< 0.5	< 0.5	0.7	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	0.5	< 0.5	0.8	1.5	1.7	1.3
Calcium (Ca)	µg/g	100	SM 3120		27200	39700	30800	27100	10400	47500	47600	50100	34900	33100	34400	37500	28900	29700	30400	6580	8550	10400	10700
Calcium (Ca)	pct				2.72	3.97	3.08	2.71	1.04	4.75	4.76	5.01	3.49	3.31	3.44	3.75	2.89	2.97	3.04	0.658	0.855	1.04	1.07
Chromium (Cr)	µg/g	1	SM 3120	8-78	33	47	33	43	19	29	26	30	44	49	52	40	47	48	51	57	66	69	68
Cobalt (Co)	µg/g	1	SM 3120	1-30	10	15	11	13	9	11	10	11	15	17	17	14	16	16	17	15	21	22	21
Copper (Cu)	µg/g	1	SM 3120	3-80	20	33	31	39	7	27	26	28	34	37	35	33	36	35	36	32	52	59	55
Iron (Fe)	µg/g	300	SM 3120		18000	28200	20400	23200	19400	20200	18500	19900	27700	30100	31100	26400	29600	29900	30500	29100	38900	42000	40600
Iron (Fe)	pct				1.8	2.82	2.04	2.32	1.94	2.02	1.85	1.99	2.77	3.01	3.11	2.64	2.96	2.99	3.05	2.91	3.89	4.2	4.06
Lead (Pb)	µg/g	5	SM 3120	1-55	< 5	9	5	8	< 5	5	< 5	6	8	9	9	5	12	11	12	16	26	29	27
Magnesium (Mg)	µg/g	100	SM 3120		13600	27000	19300	19900	5630	22800	22400	23600	24900	25700	26000	24200	23200	23200	24000	10900	15000	15900	16200
Magnesium (Mg)	pct				1.36	2.7	1.93	1.99	0.563	2.28	2.24	2.36	2.49	2.57	2.6	2.42	2.32	2.32	2.4	1.09	1.5	1.59	1.62
Manganese (Mn)	µg/g	1	SM 3120		269	969	319	358	185	431	414	460	616	955	713	640	900	873	861	697	2410	2940	2320
Molybdenum (Mo)	µg/g	1	SM 3120		< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
Nickel (Ni)	µg/g	1	SM 3120	5-107	21	35	23	28	17	22	21	22	32	42	37	31	34	34	36	34	48	52	48
Potassium (K)	µg/g	300	SM 3120		854	2600	1540	2120	567	1460	1230	1420	2660	3080	3580	2390	2790	2980	3110	2770	4100	4460	4640
Potassium (K)	pct				0.0854	0.26	0.154	0.212	0.0567	0.146	0.123	0.142	0.266	0.308	0.358	0.239	0.279	0.298	0.311	0.277	0.41	0.446	0.464
Sodium (Na)	µg/g	200	SM 3120		845	865	988	792	1190	1140	854	944	811	800	993	881	794	879	935	543	647	666	747
Sodium (Na)	pct				0.0845	0.0865	0.0988	0.0792	0.119	0.114	0.0854	0.0944	0.0811	0.08	0.0993	0.0881	0.0794	0.0879	0.0935	0.0543	0.0647	0.0666	0.0747
Silver (Ag)	µg/g	0.5	SM 3120		< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5
Selenium (Se)	µg/g	0.1	SM 3114		0.1	0.2	0.2	0.3	< 0.1	0.1	0.1	0.2	0.2	0.3	0.2	0.2	0.3	0.2	0.2	0.3	0.6	0.5	0.4
Strontium (Sr)	µg/g	1	SM 3120		24	34	27	27	17	35	31	34	29	29	35	30	27	30	32	20	26	29	31
Titanium (Ti)	µg/g	1	SM 3120		1020	1470	1120	1160	1460	1220	923	1040	1260	1340	1740	1270	1330	1490	1630	1400	1560	1720	1900
Thallium (Tl)	µg/g	0.02	EPA 6020		< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	0.2	0.3	0.4
Tin (Sn)	µg/g	10	SM 3120		< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
Tungsten (W)	µg/g	200	SM 3120		< 200	< 200	< 200	< 200	< 200	< 200	< 200	< 200	< 200	< 200	< 200	< 200	< 200	< 200	< 200	< 200	< 200	< 200	< 200
Vanadium (V)	µg/g	1	SM 3120		56	55	59	50	127	58	53	55	53	55	61	57	56	59	62	53	66	69	71
Yttrium (Y)	µg/g	0.5	SM 3120		5.3	11.2	8.6	9.7	5.2	8.6	7.6	8.2	9.9	10.5	11.4	9.3	10.9	11.3	11.8	12	14.2	14.8	14.6
Zinc (Zn)	µg/g	1	SM 3120	20-172	41	69	54	79	35	46	41	43	72	80	79	63	78	78	80	95	139	150	141
Mercury (Hg)	µg/g	0.005	SM 3112	0.008-0.26	0.019	0.046	0.052	0.081	0.015	0.028	0.022	0.022	0.039	0.037	0.054	0.029	0.05	0.06	0.061	0.056	0.072	0.076	0.081
Aluminum (Al_2O_3)	%	0.01	IN-HOUSE		11.57	11.83	11.61	11.4	13.6	11.32	11.08	11.14	12.99	12.86	13.05	12.32	12.86	12.63	13.11	13.31	14.32	14.68	14.29
Barium (BaO)	%	0.001	IN-HOUSE		0.038	0.05	0.043	0.049	0.033	0.043	0.043	0.043	0.053	0.057	0.055	0.05	0.055	0.055	0.054	0.056	0.068	0.069	0.067
Calcium (CaO)	%	0.01	IN-HOUSE		6.71	6.78	7.43	6	7.58	9.67	9.86	9.69	6.8	6.43	6.48	7.7	6.18	6.34	6.19	2.21	2.6	2.68	2.81
Chromium (Cr_2O_3)	%	0.01	IN-HOUSE		< 0.01	< 0.01	0.01	0.01	0.01	< 0.01	< 0.01	< 0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Iron (Fe_2O_3)	%	0.05	IN-HOUSE		4.51	4.91	5.1	4.93	7.43	4.93	4.92	5.04	5.62	6.08	5.91	5.77	6.05	6.06	5.95	5.03	7.34	7.72	7.51
Potasium (K_20)	%	0.01	IN-HOUSE		1.56	2.25	1.8	2.17	1.22	1.77	1.77	1.81	2.4	2.51	2.49	2.21	2.44	2.47	2.37	2.58	2.94	2.96	2.99
Magnesium (MgO)	%	0.01	IN-HOUSE		3.62	5.37	5.02	4.65	3.93	5.73	5.8	5.88	5.75	5.8	5.61	5.85	5.4	5.49	5.36	2.38	3.43	3.65	3.74
Manganese (MnO)	%	0.01	IN-HOUSE		0.07	0.11	0.08	0.07	0.1	0.09	0.09	0.09	0.1	0.14	0.11	0.11	0.14	0.14	0.13	0.1	0.31	0.37	0.31
Sodium (NaO)	%	0.01	IN-HOUSE		2.65	2.13	2.34	2.17	2.95	2.36	2.4	2.35	2.2	2.16	2.09	2.26	2.22	2.23	2.27	2.46	2.14	2.03	2.08
Phosphorus (P_2O_5)	%	0.03	IN-HOUSE		0.09	0.14	0.15	0.17	0.09	0.12	0.12	0.12	0.13	0.15	0.15	0.13	0.15	0.15	0.15	0.16	0.2	0.21	0.2
Silica (SiO_2)	%	0.01	IN-HOUSE		61.76	55.01	52.8	51.77	60.1	53.37	53	53.3	54.66	52.8	54.07	53.58	54.71	54.15	56.06	67.12	58.2	56.64	55.46
Titanium (TiO_2)	%	0.01	IN-HOUSE		0.5	0.54	0.64	0.57	1.16	0.62	0.62	0.63	0.6	0.61	0.6	0.63	0.65	0.65	0.64	0.51	0.7	0.74	0.74
Loss on Ignition	%	0.05	IN-HOUSE		5.98	10.76	12.18	16.46	1.95	9.73	9.96	10.2	10.23	10.14	10.06	9.77	9.18	9.39	9.05	4.97	7.66	7.95	9.8
Whole Rock Total	%		IN-HOUSE		99.1	99.9	99.2	100.4	100.1	99.8	99.7	100.3	101.6	99.7	100.7	100.4	100	99.8	101.3	100.9	99.9	99.7	100
Total Nitrogen	µg/g	0.05	EPA 351.2	354-2422	837	1510	1790	2300	473	764	634	731	1150	1150	1410	1160	1150	1180	1340	1430	1980	1900	1610
Phosphorus-Total	ug/g	0.01	EPA 365.4	165-1125	614	784	584	794	458	654	549	611	692	616	734	746	709	664	794	748	870	981	840
Total Organic Carbon	%	0.1	EPA 415.1	0.17-2.93	0.9	1.3	3.4	5.5	0.6	0.9	0.8	0.7	1.2	1.1	1.1	0.7	1.1	1.2	1.2	1.3	1.7	2.1	1.4

[a] Reynoldson and Day 1998, n = 31

Table 6. Probabilities of test sites belonging to 1 of 5 Great Lakes faunal groups. The highest probability for each site is bolded.

Site	Probability of Membership				
	Group 1	Group 2	Group 3	Group 4	Group 5
6974	0.070	0.005	0.000	0.001	**0.924**
R1	0.048	0.002	0.000	0.000	**0.950**
E4	0.249	0.004	0.000	0.000	**0.747**
E5	0.082	0.001	0.000	0.000	**0.916**
E6	0.211	0.008	0.001	0.000	**0.779**
E8-1	0.147	0.006	0.001	0.000	**0.846**
E8-2	0.145	0.007	0.001	0.000	**0.848**
E8-3	0.143	0.007	0.001	0.000	**0.850**
E12	0.006	0.001	0.000	0.001	**0.992**
E14	0.001	0.000	0.000	0.012	**0.987**
E15	0.001	0.000	0.000	0.012	**0.987**
E16	0.000	0.000	0.000	0.046	**0.954**
R4-1	0.042	0.003	0.000	0.001	**0.954**
R4-2	0.051	0.003	0.000	0.000	**0.945**
R4-3	0.051	0.003	0.000	0.000	**0.946**
R7	0.104	0.003	0.000	0.000	**0.893**
R8	0.032	0.001	0.000	0.000	**0.967**
R9	0.006	0.000	0.000	0.000	**0.994**
R10	0.003	0.000	0.000	0.001	**0.996**

Table 7. Mean abundance of dominant macroinvertebrate families (per 33.14 cm^2 – area of core tube), family diversity, and BEAST difference-from-reference band. Families expected to be at test sites that are absent are highlighted.

Family	Group 5 Mean	Occurrence in Gp 5 (%)	6974	R1	E4	E5	E6	E8[a]	E12	E14	E15	E16	R4[a]	R7	R8	R9	R10
No. Taxa (± 2 SD)	6 (2-9)	-	19	9	11	4	19	11	6	6	6	5	11	10	8	7	5
Haustoriidae	12.1	44.3	0	0	0	0	0.4	0.1	0.6	0.4	0.6	0.2	1.4	0.6	2.8	9.2	7.6
Tubificidae	4.5	16.6	54.4	20.0	33.4	225.8	62.4	8.4	66.8	120.4	214.2	138.8	7.7	15.0	2.4	3.8	1.2
Sphaeriidae	3.1	11.5	10.6	4.4	0.6	0	18.2	2.1	3.0	6.2	3.6	2.4	2.1	2.6	2.0	0.2	0.4
Chironomidae	2.7	9.9	72.2	16.4	9.2	6.4	17.6	14.1	4.0	4.4	33.0	2.0	6.1	18.4	2.8	1.0	0.8
Lumbriculidae	1.8	6.8	4.0	0	0	0	0.2	0	0	0	0	0	0	0	1.2	3.2	0
Enchytraeidae	1.4	5.3	2.31	0	0	0	0	0	0	0	0	0	0	0	0.2	9.8	2.2
Naididae	0.5	1.9	2.2	0.4	0.2	25.8	0.2	1.3	1.6	0.2	8.8	20.4	0.7	3.2	7.4	0	0
BEAST BAND	-	-	**4**	2	**3**	**4**	**3**	**3**	**3**	**4**	**4**	**4**	2	2	2	1	1

[a] QA/QC site; values represent the average of three field replicates

Table 8. Mean percent survival, growth (mg dry wt) and reproduction in sediment toxicity tests and BEAST difference-from-reference band. Toxicity is highlighted red and potential toxicity is bolded/italicized.

Site	*C. riparius* %survival	*C. riparius* growth	*H. azteca* %survival	*H. azteca* growth	*Hexagenia* %survival	*Hexagenia* growth	*T. tubifex* %survival	*T. tubifex* No. cocoons/adult	*T. tubifex* %hatch	*T. tubifex* No. young/adult	**BEAST BAND**
Great Lakes Reference Mean	87.1	0.35	85.6	0.50	96.2	3.03	97.9	9.9	57.0	29.0	-
6974	86.67	0.498	91.99	0.591	96	3.922	100	10.5	58.7	19.9	1
R1	94.67	0.383	98.67	0.642	100	3.322	100	***6.5***	80.1	24.4	2
E4	97.33	0.346	81.34	0.319	100	2.996	100	***7.1***	39.9	31.6	1
E5	85.33	0.386	85.33	0.418	100	3.862	100	11.0	55.0	30.6	1
E6	90.67	0.538	93.33	0.271	100	3.838	100	11.1	53.2	25.9	1
E8	89.33	0.495	***60.00***	0.329	100	2.368	100	10.4	73.8	28.3	2
E12	93.33	0.381	92.00	0.516	100	3.098	100	8.8	60.7	24.9	1
E14	80.00	0.420	95.99	0.628	100	3.152	100	9.5	62.5	23.6	1
E15	89.33	0.368	82.67	0.456	100	2.644	100	8.8	69.3	20.7	1
E16	92.00	0.371	91.99	0.507	100	2.840	100	9.6	88.4	21.0	2
R4	96.00	0.389	71.99	0.296	100	3.532	100	11.3	59.8	25.1	1
R7	82.67	0.426	**13.33**	0.581	98	2.664	100	9.3	62.9	19.5	**4**
R8	86.67	0.388	**8.00**	***0.203***	100	2.842	100	9.7	60.6	17.3	**4**
R9	83.99	0.387	**30.67**	0.400	98	2.984	100	9.8	59.5	21.4	**4**
R10	84.00	0.439	**48.00**	0.433	100	3.328	100	10.3	60.1	21.7	**4**
Non-toxic[a]	≥67.7	0.49 – 0.21	≥67.0	0.75 – 0.23	≥85.5	5.0 – 0.9	≥88.9	12.4 – 7.2	78.1 – 38.1	46.3 – 9.9	-
Potentially toxic	67.6 – 58.8	0.20 – 0.14	66.9 – 57.1	0.22 – 0.10	85.4 – 80.3	0.8 – 0	88.8 – 84.2	7.1 – 5.9	38.0 – 28.1	9.8 – 0.8	-
Toxic	**< 58.8**	**< 0.14**	**< 57.1**	**< 0.10**	**< 80.3**	-	**< 84.2**	**< 5.9**	**< 28.1**	**< 0.8**	-

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

Table 9: Decision matrix for weight-of-evidence categorization of Nipigon Bay sites based on three lines of evidence. For the sediment chemistry column, sites with exceedences of the Severe Effect Level (SEL) for metals are indicated by "●", and sites with exceedences of the Lowest Effect Level (LEL) by "⭘". Substances exceeding LELs and SELs are listed. For the toxicity and benthos alteration columns, sites determined from BEAST analyses as toxic/severely toxic or different/very different from reference, respectively, are indicated by "●"; and sites determined as potentially toxic or possibly different from reference by "⭘". Sites with no SQG exceedences, no sediment toxicity, or benthic communities equivalent to reference conditions are indicated by "○". Some sites that show possible benthos alteration or potential toxicity are not recommended for further action; in these cases, the benthos alteration is not judged to be detrimental (decreased taxon richness, reduced average abundance) and overall toxicity is judged to be minimal (limited to one endpoint).

Site	Sediment Chemistry	Toxicity	Benthos Alteration	Metal(s) exceeding LEL	Metal(s) exceeding SEL	Assessment
6974	⭘	○	●	Cr, Cu, Ni	-	Determine reasons for benthos alteration[a]
R1	⭘	⭘[b]	⭘[c]	Cr, Cu, Fe, Mn, Ni	-	No further actions needed
E4	⭘	○	●	Cr, Cu, Ni	-	Determine reasons for benthos alteration[a]
E5	⭘	○	●	Cd, Cr, Cu, Fe, Ni	-	Determine reasons for benthos alteration[a]
E6	⭘	○	●	Ni	-	Determine reasons for benthos alteration[a]
E8	⭘	⭘[b]	●	Cr, Cu, Ni	-	Determine reasons for benthos alteration[a]
E12	⭘	○	●	Cr, Cu, Fe, Mn, Ni	-	Determine reasons for benthos alteration[a]
E14	⭘	○	●	Cr, Cu, Fe, Mn, Ni	-	Determine reasons for benthos alteration[a]
E15	⭘	○	●	Cr, Cu, Fe, Mn, Ni	-	Determine reasons for benthos alteration[a]
E16	⭘	⭘[b]	●	Cr, Cu, Fe, Mn, Ni	-	Determine reasons for benthos alteration[a]
R4	⭘	○	⭘[c]	Cr, Cu, Fe, Mn, Ni	-	No further actions needed
R7	⭘	●	⭘[c]	Cd, Cr, Cu, Fe, Mn, Ni	-	Determine reasons for sediment toxicity
R8	●	●	⭘[c]	As, Cd, Cr, Cu, Fe, Mn, Ni, Zn	Mn	Determine reasons for sediment toxicity
R9	●	●	○	As, Cd, Cr, Cu, Fe, Mn, Ni, Zn	Fe, Mn	Determine reasons for sediment toxicity
R10	●	●	○	As, Cd, Cr, Cu, Fe, Mn, Ni, Zn	Fe, Mn	Determine reasons for sediment toxicity

[a] Benthos alteration may be the result of other factors, either natural (e.g., competition/predation, habitat differences) or human-related (e.g., water column contamination) (Chapman and Anderson 2005)

[b] According to the numerical guidelines, no endpoints or only one individual toxicity endpoint is in the potentially toxic category; therefore, overall toxicity is not judged to be detrimental.

[c] Benthos alteration is not judged to be detrimental.

APPENDIX A: Invertebrate Counts

Table A1. Abundance of invertebrate families (per 33 cm^2 – area of core tube).

Family	6974	R1	E4	E5	E6	E8-1	E8-2	E8-3	E12	E14	E15	E16	R4-1	R4-2	R4-3	R7	R8	R9	R10
Anisitsiellidae						0.4										0.2			
Arrenuridae									0.2										
Asellidae	0.03				11.6														
Bosminidae	0.03	0.4													0.2	0.2			
Caenidae	0.03	0.2																	
Ceratopogonidae	4.3	0.4	0.8		2.4	0.4	1.6	1.2					0.2		0.2	0.8			
Chironomidae	72.2	16.4	9.2	6.4	17.6	15.6	13.2	13.4	4.0	4.4	33.0	2.0	8.0	4.4	5.8	18.4	2.8	1.0	0.8
Chydoridae	0.5		0.4	2.0		1.0	0.8	0.4	1.0	5.0	1.2	12.4	0.2		0.4	2.0			
Daphnidae	0.1		0.4	0.2						0.4	0.2				1.2		0.4	0.8	1.0
Dipseudopsidae	0.3		0.4		0.2														
Elmidae	0.03																		
Empididae	0.4																		
Enchytraeidae	2.3																0.2	9.8	2.2
Ephemeridae	5.0	1.8	1.0		0.6	2.4	2.4	1.4					4.2	2.4	3.0	1.6			
Gammaridae			0.2		1.8												0.2		
Glossiphoniidae	0.1				0.4														
Halicaridae	0.03	0.2											0.2						
Haustoriidae					0.4			0.2	0.6	0.4	0.6	0.2	0.8	1.8	1.6	0.6	2.8	9.2	7.6
Holopedidae	0.03																		
Hyalellidae					21														
Hydrobiidae	0.6	0.6	0.2		21.8	1.8	2.6	1.2					0.2	0.4	0.2	0.2			
Hygrobatidae	0.1	0.4										0.2		0.6	0.4	0.8	0.2		
Lebertiidae	0.2															0.2			
Leptoceridae	0.4			0.2	5		0.4	0.6					0.2			0.6			
Limnesiidae	0.03				0.2														
Lumbriculidae	4.0				0.2												1.2	3.2	
Lymnaeidae					1														
Macrothricidae	6.4		0.6	3.2	2.8	0.2	0.4	0.4	1.0	3.4	4.2	54.6		0.2		2.2	3.8	0.2	
Naididae	2.2	0.4	0.2	25.8	0.2	1.6	1.2	1.2	1.6	0.2	8.8	20.4	0.6	0.4	1.0	3.2	7.4		
Pionidae	0.1					0.2			0.2							1.2			
Plagiostomidae	0.6	0.6		0.2			0.2						0.2	0.2					
Planariidae				0.2					0.2										
Planorbidae					3.8								0.2					0.2	
Polycentropodidae	0.03																		
Sabellidae	3.0	0.4	0.2		2.0	9.4	5.2	8.6	0.6				0.4	1.0	1.2				
Sialidae	0.2																		
Sphaeriidae	10.6	4.4	0.6		18.2	1.8	3.4	1.0	3	6.2	3.6	2.4	1.8	2.2	2.2	2.6	2.0	0.2	0.4
Spongillidae	163.4		0.2	6															
Trhypachthoniidae	0.4																		
Tubificidae	43.3	20.0	33.4	225.8	62.4	9.4	11	4.8	66.8	120.4	214.2	138.8	8.6	5.4	9.0	15.0	2.4	3.8	1.2
Unionidae	0.1																		
Valvatidae	0.2		0.6		4.2	1.6	2.4	1.0		0.2	0.2					0.8			

Table A2. Benthic invertebrate densities in Nipigon Bay (per 33 cm^2 – area of core tube).

Taxon	**6974**	**E4**	**E5**	**E6**	**E8-1**	**E8-2**	**E8-3**	**E12**	**E14**	**E15**	**E16**	**R1**	**R4-1**	**R4-2**	**R4-3**	**R7**	**R8**	**R9**	**R10**
P. Annelida																			
Cl. Oligochaeta																			
F. Enchytraeidae																			
Mesenchytraeus sp.	2.3																0.2	9.8	2.2
F. Lumbriculidae																			
Stylodrilus heringianus	4.0			0.2													1.2	3.2	
F. Naididae																			
Arcteonais lomondi			12.8					0.2						0.4	0.2	0.2	0.2		
Ophidonais serpentina										0.6									
Piguetiella blanci	0.1		0.2									0.2				0.2	6.2		
Piguetiella michiganensis	1.8		3.6							0.2	0.2		0.2		0.4	0.2			
Slavina appendiculata			0.6							0.8	1.8						0.4		
Specaria josinae	0.4			0.2	1.6	1.2	1.2	0.4				0.2			0.4				
Stylaria lacustris													0.4						
Uncinais uncinata								1.0								0.4			
Vejdovskyella comata																0.8	0.2		
Vejdovskyella intermedia		0.2	8.4						0.2	7.2	18.4					1.4	0.4		
F. Tubificidae																			
Aulodrilus americanus	1.2	1.8		9.0	0.4	0.2	0.6	0.2				0.2							
Aulodrilus limnobius	0.3	7.6	33.8	0.2	0.4	1.4	0.4	0.2											
Aulodrilus pigueti			1.2	0.2	4.6	8.6	3.4	0.2											
Aulodrilus pluriseta		13.8	12.4					6.4		0.8	2.2	3.0							
Dero sp.			0.2																
Ilyodrilus templetoni			1.2																
Limnodrilus hoffmeisteri			1.0	0.4				0.8	0.4	0.2	2.0					0.2			0.2
Limnodrilus udekemianus	0.1			16.4	0.4				7.2				6.6	5.0	0.4				
Potamothrix bedoti										0.2									
Potamothrix moldaviensis		0.6	0.2																
Potamothrix vejdovskyi	0.04	2.4	1.4			0.4	0.4	26.2	13.6	3.8	11.2	2.4	1.4						
Spirosperma ferox	9.0			6.6				1.0			0.2			0.2		0.2			
Immature tubificids with cheatal hairs	3.9	3.0	130.2	2.2	1.2			5.8	56.4	164	25.4	5.4	0.6	0.2	1		0.6	0.2	0.2
Immature tubificids without cheatal hair	27.0	4.2	38.8	20.6	2.4	0.4		26.0	39.6	45.2	97.8	9			7.6	14.6	1.8	3.6	0.8
Quistadrilus multisetosus	12.7		5.6	6.8					3.2										
Cl. Polychaeta																			
F. Sabellidae																			
Manayunkia speciosa	3.0	0.2		2.0	9.4	5.2	8.6	0.6				0.4	0.4	1.0	1.2				
C. Hirudinea																			
F. Glossiphoniidae																			
Placobdella picta	0.03																		
Helobdella stagnalis	0.1			0.4															
P. Nematoda	7.1	23.0	10.6	11.0	35.0	26.4	13.2	25.4	14.0	3.2	13.2	5.4	9.6	9.4	8.4	9.8	7.6	6.8	3.2
P. Platyhelminthes																			
Unknown Turbellaria	0.1															0.6			1.2
F. Plagiostomidae																			
Hydrolimax sp.	0.6		0.2			0.2						0.6	0.2	0.2					
F. Planariidae			0.2					0.2											
P. Arthropoda																			
O. Amphipoda																			
F. Haustoriidae																			
Diporeia hoyi				0.4			0.2	0.6	0.4	0.6	0.2		0.8	1.8	1.6	0.6	2.8	9.2	7.6
F. Hyalellidae																			
Hyalella azteca				21															
F. Gammaridae																			
Gammarus sp.		0.2		1.8													0.2		
O. Isopoda																			
F. Asellidae																			
Caecidotea sp.	0.03			3.0															
Lirceus sp.				8.6															
O. Prostigmata	0.03					0.2	0.2												
F. Arrenuridae																			
Arrenurus sp.								0.2											
F. Halicaridae	0.03											0.2	0.2						
F. Hygrobatidae																			
Hygrobates sp.	0.1										0.2	0.4		0.6	0.4	0.8	0.2		
F. Lebertiidae																			
Lebertia sp.	0.2															0.2			
F. Limnesiidae																			
Limnesia sp.	0.03			0.2															
F. Trhypachthoniidae	0.4																		
F. Pionidae																			
Neotiphys sp.	0.03				0.2			0.2								1.2			
Piona sp.	0.03																		
F.Anisitsiellidae																			
Bandakia sp.					0.4											0.2			
O. Cladocera																			
F. Macrothricidae	6.4	0.6	3.2	2.8	0.2	0.4	0.4	1.0	3.4	4.2	54.6			0.2		2.2	3.8	0.2	
F. Daphnidae	0.06	0.4	0.2						0.4	0.2					1.2		0.4	0.8	1.0
F. Chydoridae	0.5	0.4	2.0		1	0.8	0.4	1.0	5.0	1.2	12.4		0.2		0.4	2.0			
F. Bosminidae	0.03											0.4			0.2	0.2			
O. Ostracoda	21.8	45.2	2.2	62.4	29.2	27.4	22.4	11.6	6.4	8.6	28.6	3.0	0.2	0.2	2.0	6.0	2.4	3.4	9.2
Cl. Copepoda																			
O. Harpacticoida	1.5	60.0	152.2	6.2	57.4	49.2	22.6	0.2	4.4	0.4	9.8	2.2	0.2	0.2		0.2			
O. Cyclopoida	6.4	7.4	12.0	7.6	4.8	3.2	4.6	4.4	5.4	0.6	2.2	1.0	5.6	5.4	6.6	6.4	7.8	4.8	2.0
O. Calanoida	0.4	1.0	2.4	1.2	0.8	0.6	0.4	6.2	3.6		1.0	1.0	3.2	0.2	8.2	4.0	6.4	3.2	1.6

Table A2. Continued.

Taxon	6974	R1	E4	E5	E6	E8-1	E8-2	E8-3	E12	E14	E15	E16	R4-1	R4-2	R4-3	R7	R8	R9	R10
Cl. Insecta																			
F. Ceratopogonidae																			
Probezzia sp.	4.3	0.4	0.8		2.4	0.4	1.6	1.2					0.2		0.2	0.8			
F. Chironomidae																			
Ablabesmyia(Asayia) annulata	0.6	0.2	0.2			0.2	0.6	0.6											
Ablabesmyia sp.	1.9	0.2	1			0.2	0.4						0.4		0.4				
Chironomus sp.	0.1	1.0	1	1.4			0.8	0.2						0.2		3.8		0.2	
Cladopelma sp.	0.04					0.2	3	0.6											
Cladotanytarsus sp.	2.3					0.2										0.2			
Cladotanytarsus sp. B																0.4			
Cricotopus sp.	0.1								0.4										
Cryptochironomus sp.	1.5		0.4		3.2		0.2	0.2								0.6			
Cryptotendipes sp.	2.0	0.4				2.2		2	0.6			0.2	0.8	0.2	0.2				
Demicryptochironomus cuneatus		0.2														0.2			
Demicryptochironomus sp.	0.5				0.2	0.6		0.4											
Dicrotendipes modestus																0.4			
Dicrotendipes sp.	0.04				0.2										0.2				
Epoicocladius sp.	0.3	0.2	0.2		0.2	0.4	0.4	0.6					0.2						
Harnischia sp.	0.7	0.6	0.6			0.6	0.4	1.0					0.6		0.6	0.6			
Heterotrissocladius oliveri																			
Heterotrissocladius sp.	0.2				0.2				0.2		2.0					0.4	1.0	0.4	0.8
Hydrobaenus sp.										1.4				0.2	0.2				
Larsia sp.		0.8														0.4			
Micropsectra sp.		0.2									29.4								
Microtendipes sp.	0.3															0.4			
Monodiamesa sp.	0.6														0.2				
Nilothauma sp.	0.04																		
Pagastiella sp.	0.9	2.0	0.6			0.2	0.2	0.8											
Parachironomus sp.	0.2																		
Paracladopelma undine		0.4														0.4			
Paracladopelma sp.	0.9																0.2	0.2	
Parakiefferiella sp.	0.9	0.6	0.2		0.2	0.4		0.2		0.2	0.6	0.2	0.4	0.2		3.4			
Paralauterborniella sp.	9.0				4.6	1.0	0.2	1.6	0.2										
Paratendipes sp.	3.5																		
Paratanytarsus sp.	0.04				0.4														
Pentaneura sp.	1.5		0.4		0.2														
Polypedilum simulans/digitifer	3.6				0.4							0.2							
Polypedilum(Tripodura) scalaenum	9.3	1.0			2.4	0.2									0.4	0.4			
Polypedilum sp.					0.2														
Potthastia gaedi group	0.04																		
Potthastia longimana group	0.3	0.2			0.6	0.4													
Procladius sp.	8.4	8.0	4.6	5.0	1	8.4	6.4	5.0	2.6	2.0	0.8	1.2	5.2	3.6	3.6	4.2	1.2	0.2	
Protanypus sp.																	0.2		
Psectrocladius sp.							0.2												
Stempellinella sp.	0.7	0.2			0.4	0.2										0.4			
Stictochironomus sp.	0.04											0.2	0.2						
Tanytarsus sp.	11.9						0.2				0.2					1.6			
Tribelos sp.	8.0	0.2			2.4														
Zavrelimyia sp.																0.2			
Unknown Chironomidae	1.9				0.8	0.2	0.2	0.2		0.8			0.2			0.4	0.2		
F. Empidae																			
Hemerodromia sp.	0.4																		
O. Ephemeroptera																			
F. Ephemeridae																			
Ephemera sp.					0.2										0.4				
Hexagenia limbata	0.3	0.2	0.8		0.4	2.0	1.2	0.8					0.6			0.4			
Hexagenia sp.	4.6	1.6	0.2			0.4	1.2	0.6					3.6	2.4		1.2			
F. Caenidae																			
Caenis sp.	0.03	0.2																	
O. Trichoptera																			
F. Dipseudopsidae																			
Phylocentropus sp.	0.3		0.4		0.2														
F. Leptoceridae																			
Oecetis sp.	0.4			0.2	5		0.4	0.6					0.2			0.6			
Mystacides sp.	0.03																		
F. Polycentropodidae																			
Polycentropus sp.	0.03																		
F. Sialidae																			
Sialis sp.	0.2																		
O. Coleoptera																			
F. Elmidae																			
Dubiraphia sp.	0.03																		

Table A2. Continued.

Taxon	6974	E4	E5	E6	E8-1	E8-2	E8-3	E12	E14	E15	E16	R1	R4-1	R4-2	R4-3	R7	R8	R9	R10
P. Mollusca																			
Cl. Bivalva																			
F. Sphaeridae																			
Musculium transversum					0.2														
Musculium sp.				7.2		0.6		0.2											
Pisidium casertanum	0.2																		
Pisidium compressum	0.03																		
Pisidium sp.	10.2	0.6		10.8	1.6	2.8	1.0	2.8	6.2	3.6	2.4	4.4	1.8	2.0		2.6	2.0	0.2	0.4
Sphaerium simile														0.2					
Sphaerium striatinum				0.2											0.2				
Sphaerium sp.	0.2																		
F. Unionidae																			
Lampsilis siliquoidea	0.1																		
Cl. Gastropoda																			
F. Planorbidae																		0.2	
Gyraulus sp.				0.6									0.2						
Planorbidae immature				3.2															
F. Valvatidae																			
Valvata lewisi									0.2	0.2						0.2			
Valvata tricarinata	0.1	0.4		4.2	1.0	1.0	0.6									0.2			
Valvata sp.	0.1	0.2			0.6	1.4	0.4									0.4			
F. Hydrobiidae																			
Amnicola limosus	0.4	0.2		2	0.8	1.8	1.0					0.6	0.2	0.4	0.2	0.2			
Pyrgulopsis lustrica	0.03			2.6	1.0	0.8	0.2												
Unknown Hydrobiidae				17.2															
Hydrobiidae immature	0.1																		
F. Lymnaeidae																			
Fossaria sp.				1.0															
P. Porifera																			
F. Spongillidae	163.4		0.2	6.0															

APPENDIX B: BEAST Community Structure Ordinations

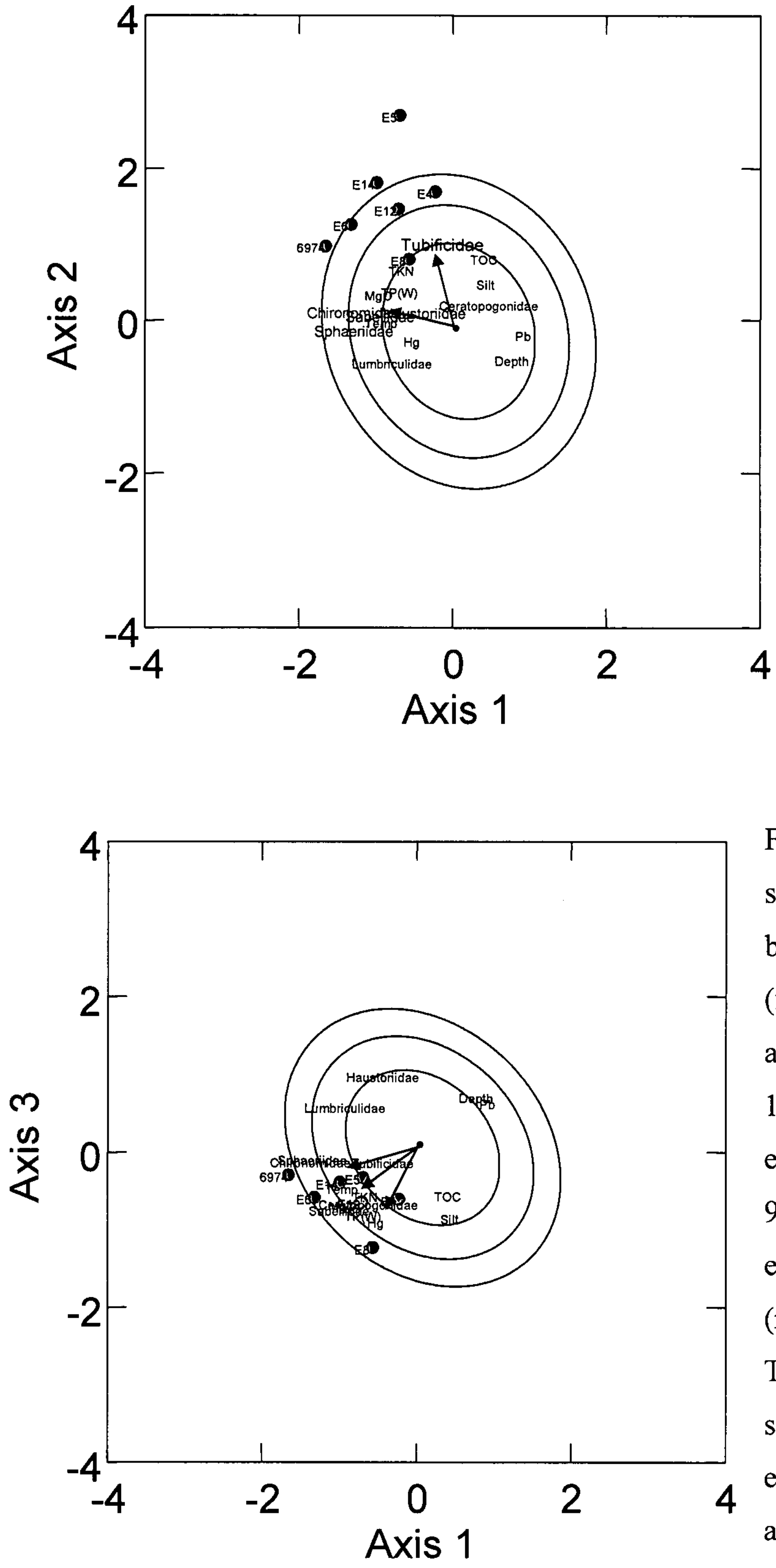

Figure B1. Ordination of a subset of Nipigon Bay sites using benthic community data (family abundance). Site scores are plotted on axes 1 & 2 (top) and 1 & 3 (bottom) with 90% (smallest ellipse), 99% (middle ellipse), and 99.9% (largest ellipse) probability ellipses for Group 5 reference sites (reference site scores not shown). The contributions of most significant families and environmental variables are shown as vectors. Stress = 0.14.

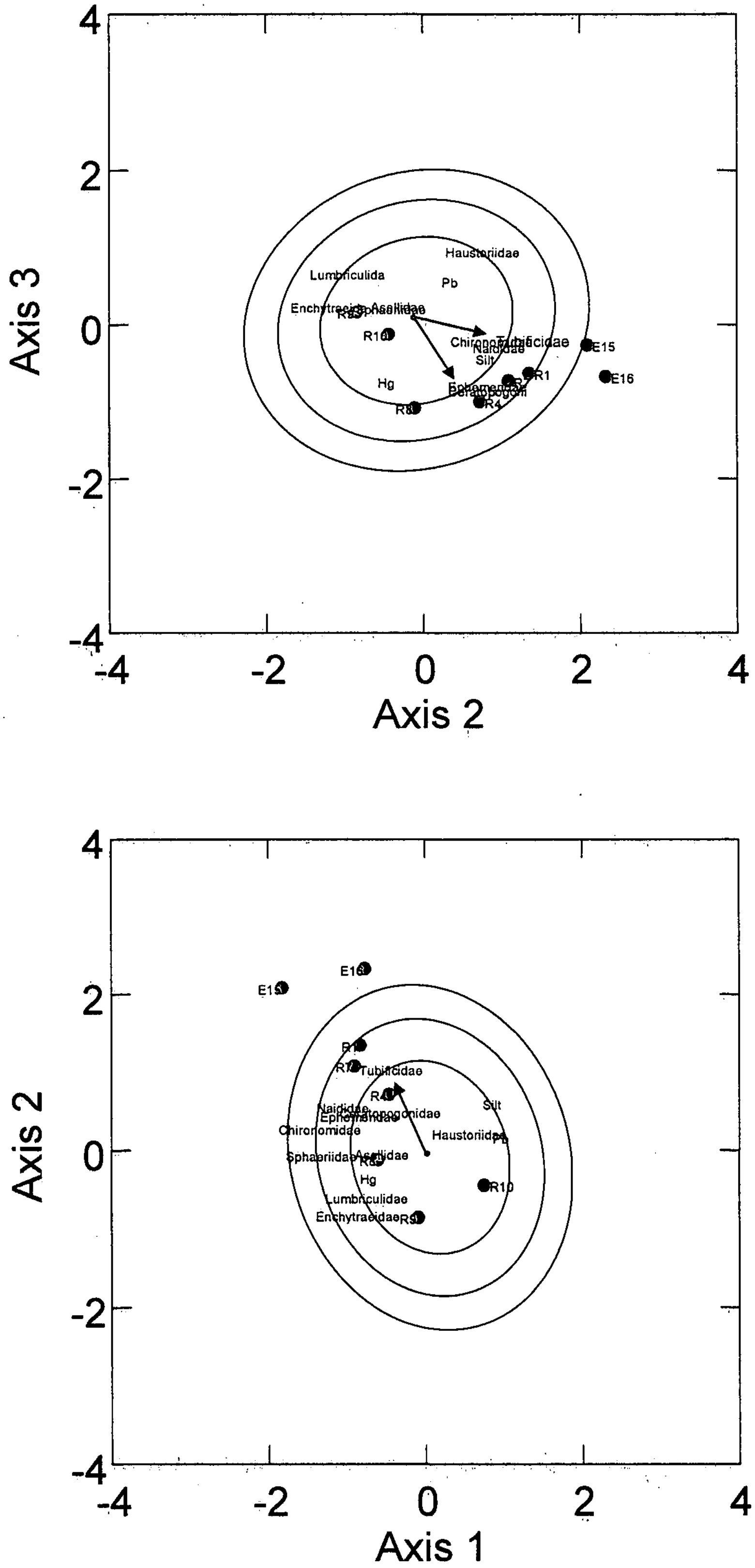

Figure B2. Ordination of a second subset of Nipigon Bay sites using benthic community data. Site scores are plotted on axes 2 & 3 (top) and 1 & 2 (bottom), showing 90% (smallest ellipse), 99% (middle ellipse), and 99.9% (largest ellipse) probability ellipses for reference sites (reference site scores not shown). The contributions of most significant families are shown as vectors. Stress = 0.15.

APPENDIX C: Toxicity Test Water Quality Parameters

Table C1. Water quality parameter measurements in laboratory toxicity tests.

Chironomus riparius

	Day O					Day 10				
Site	pH	Conductivity	temp	D.O.	Ammonia	pH	Conductivity	temp	D.O.	Ammonia
R7	8.1-8.3	229-254	21.6-22.1	8.2-8.4	0	8.0-8.2	248-291	22.7-22.8	7.8-7.9	0
R8	8.0-8.1	216-228	21.5-21.7	8.3	0	7.9-8.0	247-264	22.3-22.9	7.6-7.9	0
R9	7.9-8.1	255-298	21.4-21.6	8.2-8.4	0	8.0-8.1	294-326	22.6-22.9	7.8-8.0	0
R10	8.1-8.2	291-325	21.4-21.6	8.3	0	8.0-8.1	316-362	22.3-22.9	7.8-8.1	0
6974	8.3-8.4	359-390	21.5-21.6	8.1-8.3	0	8.2-8.4	322-374	22.5-22.9	7.9-9.4	0
E14	8.4	370-410	22.6-22.8	8.0-8.2	0	8.2	360-380	23.3-23.4	8.1-8.3	0
E15	8.4	410-440	22.2-22.6	8.2-8.3	0	8.2-8.3	370-410	23.4	8.3-8.4	0
E16	8.4-8.5	410-430	22.5-22.6	8.1-8.2	0	8.3-8.4	380-400	23.3-23.4	8.3	0
E12	8.3-8.4	370-420	22.6-22.8	7.8-8.2	0	8.3-8.4	360-390	23.2-23.4	8.3-8.4	0
R1	8.4-8.5	350-410	22.3-22.5	8.0-8.2	0	8.4	330-370	23.3	8.0-8.2	0
R4	8.4-8.5	317-336	22.1-22.3	8.5-8.7	0	8.3-8.4	320	22.2-22.4	7.8-8.2	0
E4	8.4	313-348	21.9-22.3	8.3-8.8	0	8.3-8.4	310	22.1-22.2	7.9-8.0	0
E5	8.4-8.5	331-369	21.8-22.3	8.3-8.4	0	8.4	300	21.9-22.3	8.1-8.2	0
E6	8.3	300-335	23.6	8.1-8.3	0	8.1-8.2	320-360	23.3	7.7-7.9	0
E8	8.2-8.3	329-348	23.2-23.6	8.3	0	8.2-8.3	320-370	22.8-23.2	8.0-8.1	0

Hyalella azteca

	Day 0					Day 28				
Site	pH	Conductivity	temp	D.O.	Ammonia	pH	Conductivity	temp	D.O.	Ammonia
R7	8.4	209-234	22.7-22.9	8.7-8.8	0	7.8-9.3	245-352	22.2-22.1	7.8-10.3	0
R8	8.3-8.4	207-213	22.8-22.9	8.4-8.7	0	8.0-9.6	238-320	22.0-2.1	8.4-10.6	0
R9	8.2-8.3	238-250	22.8-22.9	8.7-8.9	0	8.2-8.3	238-63	21.7-21.9	7.8-9.5	0
R10	8.3-8.4	269-289	22.7-22.9	8.6-8.8	0	8.2-9.1	304-391	21.7-21.9	7.9-9.2	0
6974	8.5-8.6	309-338	22.8-22.9	8.6-8.8	0	8.5-9.1	272-380	21.4-21.6	8.7-9.3	0
E14	8.3-8.4	323-356	22.1-22.3	8.3-8.5	0	8.3-8.4	290-380	23.0-23.2	8.3-8.5	0
E15	8.3-8.5	339-378	22.3-22.4	8.3-8.4	0	8.1-8.2	330-400	23.1-23.3	8.3-8.4	0
E16	8.4-8.5	317-377	22.0-22.3	8.2-8.4	0	8.2-8.4	290-390	22.9-23.3	8.2-8.3	0
E12	8.3-8.4	309-339	22.3-22.4	8.3-8.4	0	8.2-8.3	330-350	23.0-23.3	8.2-8.3	0
R1	8.4-8.5	216-313	21.5-22.0	8.3-8.5	0	8.3-8.4	280-320	23.2-23.4	8.1-8.3	0
R4	8.4-8.5	331-348	21.9-22.1	8.4-8.5	0	8.4-8.5	270-330	22.2-22.5	8.4-8.6	0
E4	8.3-8.4	287-341	21.9-22.3	8.2-8.4	0	8.4-8.5	270-320	22.4-22.7	8.2-8.5	0
E5	8.5	334-364	22.0-22.3	8.2-8.3	0	8.4	260-290	22.7-22.9	8.4-8.6	0
E6	8.3-8.4	n/a	22.4-22.5	7.8-8.3	0	8.3-8.4	n/a	21.6-21.8	8.2-8.4	0
E8	8.5	336-366	22.1-22.0	8.3-8.4	0	8.3-8.4	220-330	22.6-22.7	8.2-8.4	0

***Hexagenia* spp.**

	Day 0					Day 21				
Site	pH	Conductivity	temp	D.O.	Ammonia	pH	Conductivity	temp	D.O.	Ammonia
R7	8.0-8.2	245-259	22.4-22.9	9.0-9.3	0	8.1	297-305	22.1-22.6	8.1-8.4	0
R8	7.7-7.8	227-245	22.6-23.1	9.0-9.2	0	8.1	257-273	22.1-22.6	8.1-8.4	0
R9	7.7-8.0	277-298	23.0-23.1	9.0-9.1	0	8	309-331	22.22.3	8.2-8.4	0
R10	7.9-8.1	285-308	22.7-23.1	9.1	0	8.0-8.1	329-349	22.1-22.5	8.2-8.3	0
6974	8.2-8.5	352-382	23.2-22.6	8.8-9.2	0	8.1-8.2	383-387	22.0-22.7	8.0-8.4	0
E14	8.4-8.5	410-430	22.9-23.0	8.5-8.6	0	8.1-8.2	380-390	22.9-23.1	8.0-8.3	0
E15	8.5	430-450	22.9-23.0	8.4-8.6	0	8.1-8.2	390-420	22.9-23.1	8.1-8.3	0
E16	8.5-8.6	430-440	22.6-22.9	8.4-8.5	0	8.1-8.2	380-420	22.9-23.0	8.2-8.5	0
E12	8.4	390-430	22.6-23.0	8.4-8.6	0	8.0-8.1	380-430	22.7-23.1	7.8-8.4	0
R1	8.5	380-470	22.4-22.9	8.4-8.7	0	8.2-8.3	370-400	22.8-23.0	8.1-8.4	0
R4	8.5	337-353	21.5-22.0	8.4-8.5	0	8.7	300-330	21.9	8.3-8.4	0
E4	8.4	314-332	21.9-22.0	8.4	0	8.5	290-330	22.0-22.4	8.0-8.3	0
E5	8.5	340-368	21.1-22.0	8.2-8.4	0	8.4-8.5	300-320	21.8-22.4	7.9-8.2	0
E6	8.4-8.5	346-360	21.6-22.0	8.3-8.6	0	8.5-8.6	330-360	21.8-22.0	8.2-8.3	0
E8	8.5-8.6	356-409	21.3-21.9	8.4-8.5	0	8.7	330-360	22.1-22.4	8.1-8.4	0

Tubifex tubifex

	Day 0					Day 28				
Site	pH	Conductivity	temp	D.O.	Ammonia	pH	Conductivity	temp	D.O.	Ammonia
R7	7.9-8.0	228-337	21.2-21.5	7.8-8.0	0	8.2	243-364	22.2-22.5	8.1-8.4	0
R8	7.9	262-283	21.3-21.7	7.9-8.1	0	8.1-8.2	254-279	22.1-22.6	8.3-8.5	0
R9	8.0-8.2	299-353	21.0-21.6	7.8-8.3	0	8.1	259--362	22.5-22.6	8.3-8.5	0
R10	8.1-8.2	314-358	21.1-21.5	7.9-8.3	0	8	310-335	22.0-22.3	8.4-8.5	0
6974	8.1-8.3	334-408	21.1-21.6	7.8-8.1	0	8.0-8.1	327-398	22.1-22.2	8.4-8.5	0
E14	8.2-8.3	380-410	21.8-22.1	7.6-8.1	0	8.0-8.1	310-360	22.5-22.8	7.9-8.3	0
E15	8.2-8.3	266-411	22.1-22.7	7.8-7.9	0	8.1-8.2	240-330	22.1-22.8	8.1-8.3	0
E16	8.1-8.4	329-433	21.6-22.0	7.8-8.0	0	8.2	270-340	22.6-22.7	7.2-8.1	0
E12	8.3	331-388	21.6-21.9	7.8-7.9	0	7.8-7.9	280-320	22.6-22.9	8.0-8.3	0
R1	8.3-8.4	268-335	21.9-22.1	7.7-8.0	0	8.3-8.4	210-300	22.6-22.7	8.0-8.2	0
R4	8.2-8.3	329-431	22.2-22.6	8.1-8.2	0	8.3-8.4	n/a	22.1-22.4	8.2-8.4	0
E4	8.0-8.1	203-383	22.8-23.0	6.0-7.2	0	8.5	260-310	21.3-21.5	8.3-8.4	0
E5	8.2-8.3	340-418	22.8-23.1	6.2-6.8	0	8.5-8.6	310-410	21.4-21.8	8.2-8.4	0
E6	8.0-8.2	383-414	22.3-22.5	8.1-8.3	0	8.3	n/a	21.4-21.9	8.2-8.5	0
E8	7.9-8.3	355-435	22.9-23.2	5.9-7.2	0	8.6-8.7	270-360	21.6-21.7	8.2-8.4	0

Note: Numbers represent the range between the 5 replicates used for the tests

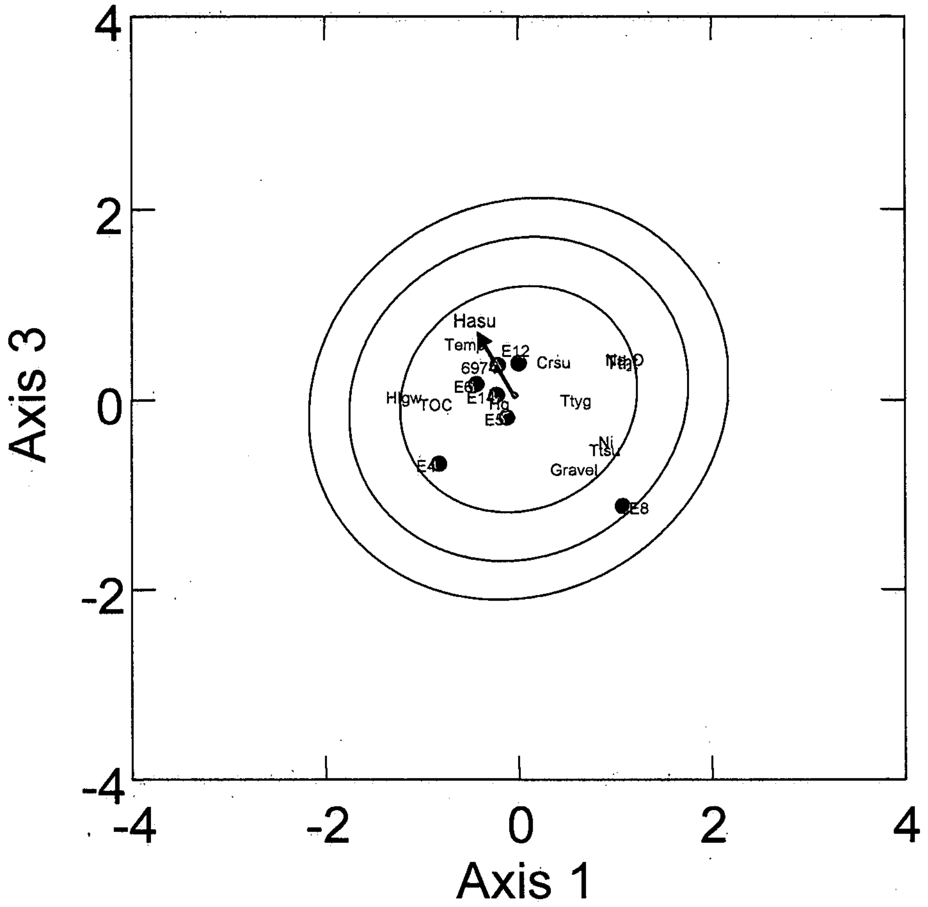

Figure D1. Assessment of a subset of test sites using 10 toxicity test endpoints, summarized on Axes 1 and 3, showing 90%, 99%, and 99.9% probability ellipses around reference sites (individual scores not shown). [*Tubifex* hatch (Ttht), *Hyalella* growth (Hagw), *Hyalella* survival (Hasu), *Tubifex* young production (Ttyg), *Chironomus* survival (Crsu), *Chironomus* growth (Crgw), *Hexagenia* growth (Hlgw)]. Stress level = 0.103.

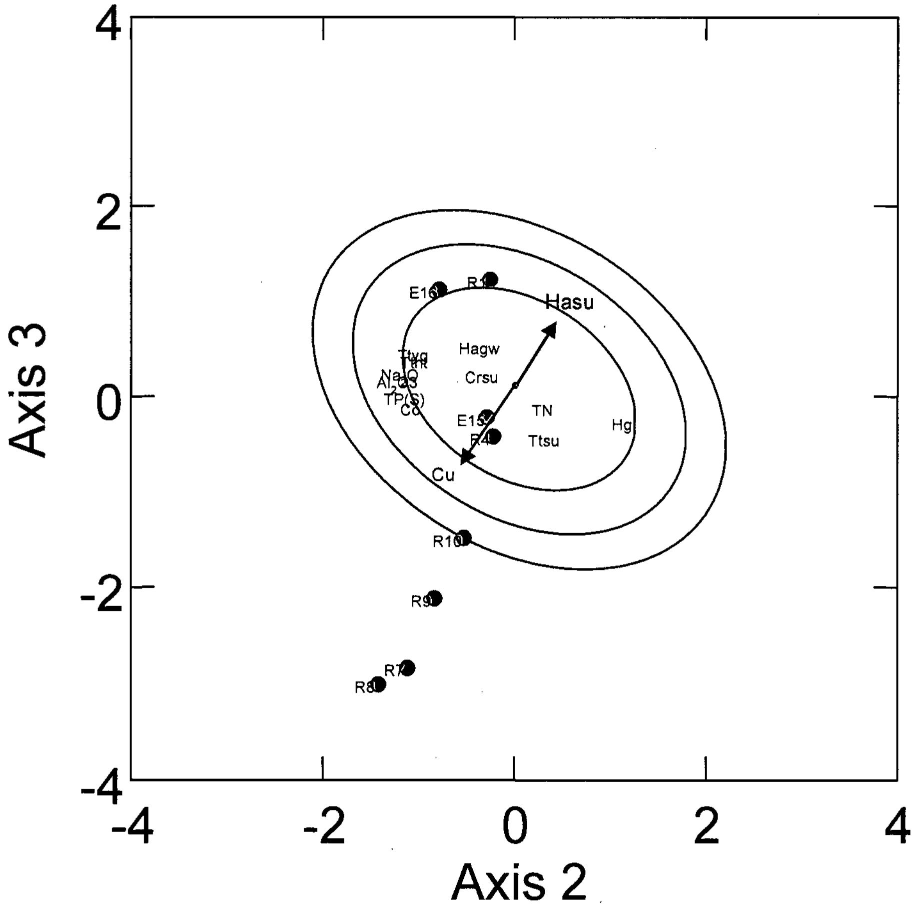

Figure D2. Assessment of a subset of test sites using 10 toxicity test endpoints summarized on Axes 2 and 3, showing 90%, 99%, and 99.9% probability ellipses around reference sites (individual scores not shown). The contributions of most significant endpoint and environmental variables are shown with arrows. [*Tubifex* hatch (Ttht), *Hyalella* growth (Hagw), *Hyalella* survival (Hasu), *Tubifex* young production (Ttyg), *Chironomus* survival (Crsu), *Chironomus* growth (Crgw), *Hexagenia* growth (Hlgw)]. Stress level = 0.098.

APPENDIX E: Toxicity-Contaminant Relationships

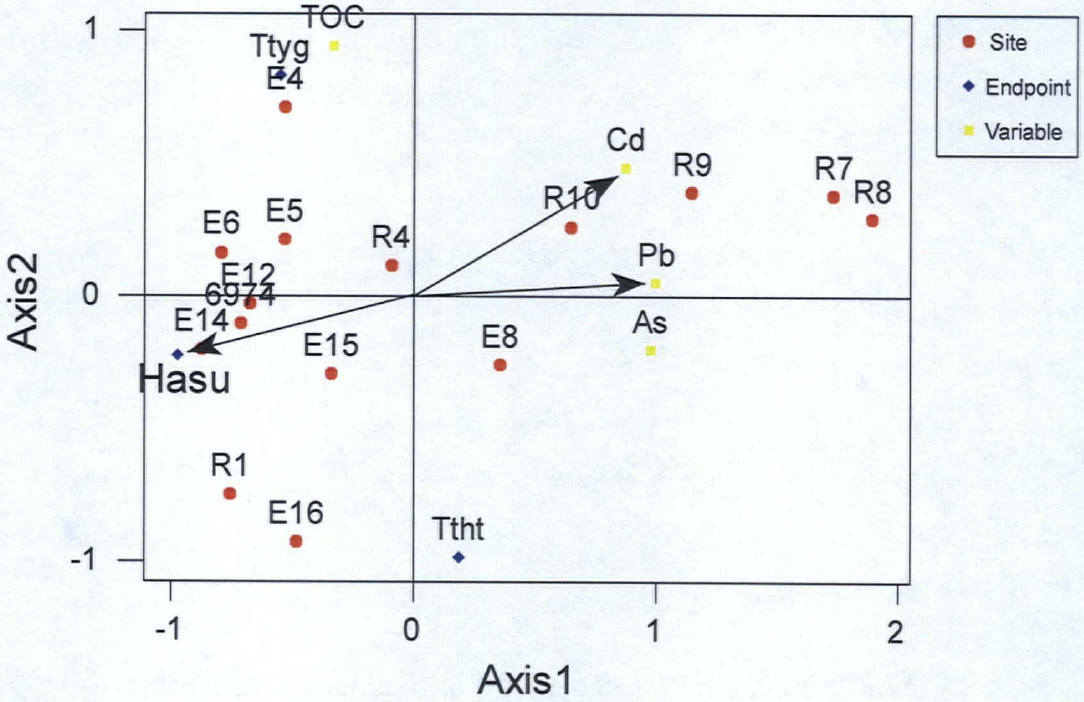

Figure E1. Toxicological response of Nipigon Bay sites represented by 2-dimensional HMDS (stress = 0.04). The direction of maximum correlations of *Hyalella* survival endpoint (Hasu) and cadmium (Cd) and lead (Pb) variables with sites are shown as vectors. High values for Axes 1 & 2 correspond to sites with high relative toxicity to *Hyalella* survival

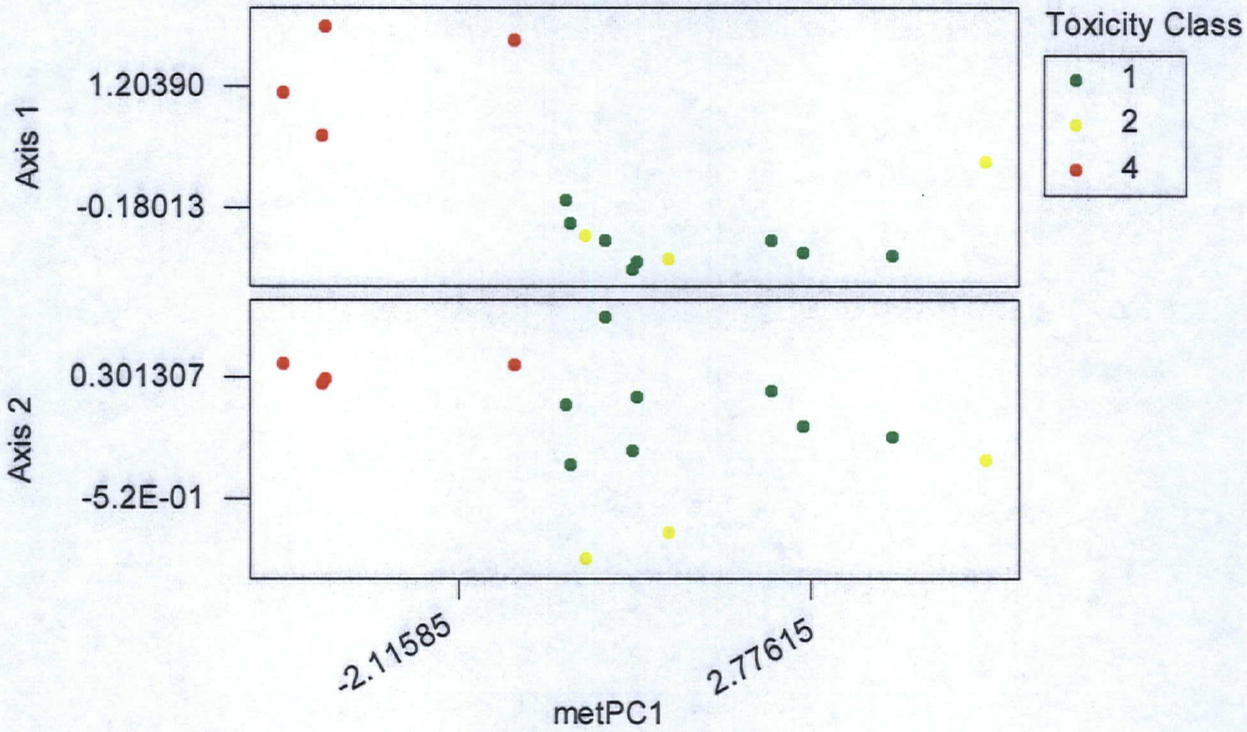

Figure E2. Nipigon Bay sediment toxicity relationships to contaminant concentrations based on integrated toxicity descriptors (HMDS axes) and integrated metal descriptor (see text for derivation of variables). Sites are colour-coded by toxicity class as determined by BEAST assessment with reference sites. High values for Axis 1 and 2 correspond to sites with high relative toxicity to *Hyalella* survival (see text for derivation of variables).

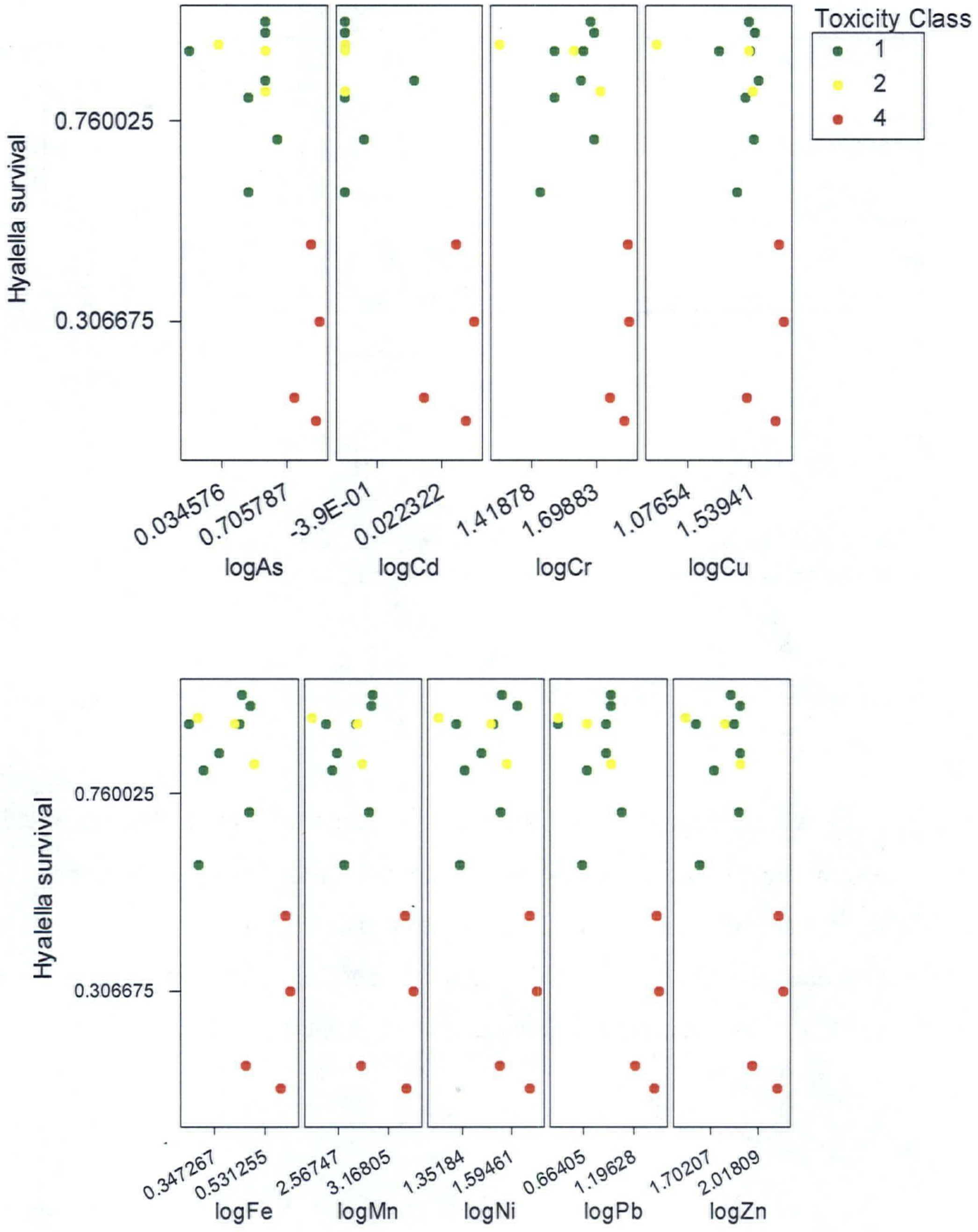

Figure E3. Nipigon Bay sediment toxicity relationships to contaminant concentrations based on individual toxicity endpoint and individual metal concentrations. Sites are colour-coded by toxicity class as determined by BEAST assessment with reference sites.

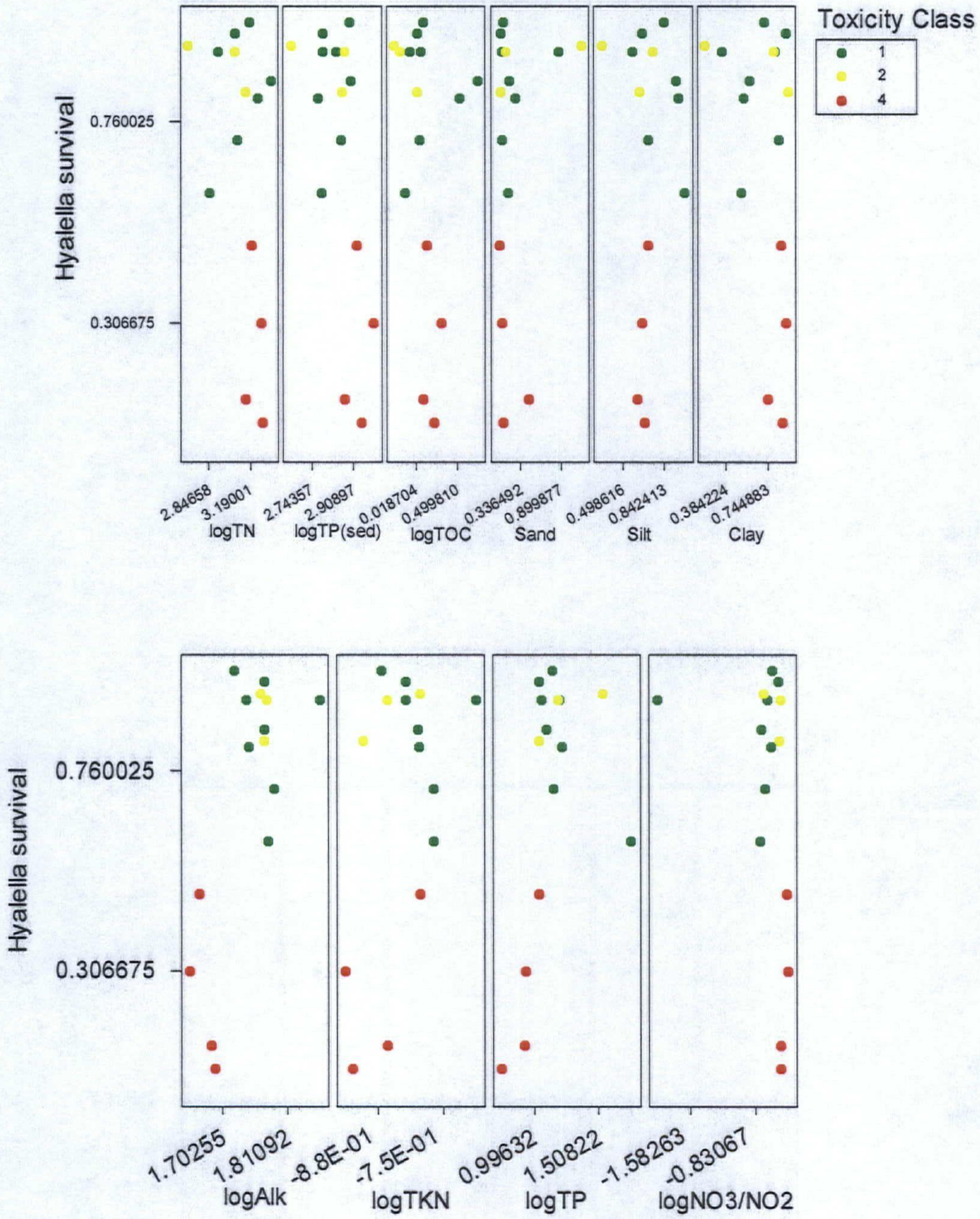

Figure E4. Nipigon Bay sediment toxicity relationships to contaminant concentrations based on individual toxicity endpoint and individual sediment nutrient concentrations and particle size (top), and individual toxicity endpoint and overlying water (bottom). Sites are colour-coded by toxicity class as determined by BEAST assessment with reference sites.

APPENDIX F: Quality Control Results

Table F1. Coefficients of variation (CV, %) for field replicated sites.

	CV	
Parameter	**E8**	**R4**
Al	10.48	6.12
Alkalinity	0.17	9.33
As	0	0
Ca	3.1	2.69
Cd	0	0.42
Clay	16.93	4.38
Co	0.05	0.04
Cr	7.34	0.04
Cu	3.7	0.02
Fe	0.05	1.67
Hg	0	16.67
K	7.14	6.67
LOI	2.41	1.85
Mg	2.62	2.13
Mn	5.35	2.27
Na	10	11.11
NH_3	0	0
Ni	2.68	3.32
No_3/No_2	5.88	0
P_2O_5	0	0
Pb	-	4.97
Sand	10.51	15.28
Silt	6.28	5.61
SiO_2	0.38	1.78
Sr	6.24	8.49
Ti	0	0
TKN	11.76	5.88
TN	9.52	8.35
TOC	12.5	5.13
TP (Sediment)	8.73	9.14
TP (Water)	66.67	0
V	4.55	5.08
Zn	5.82	1.46

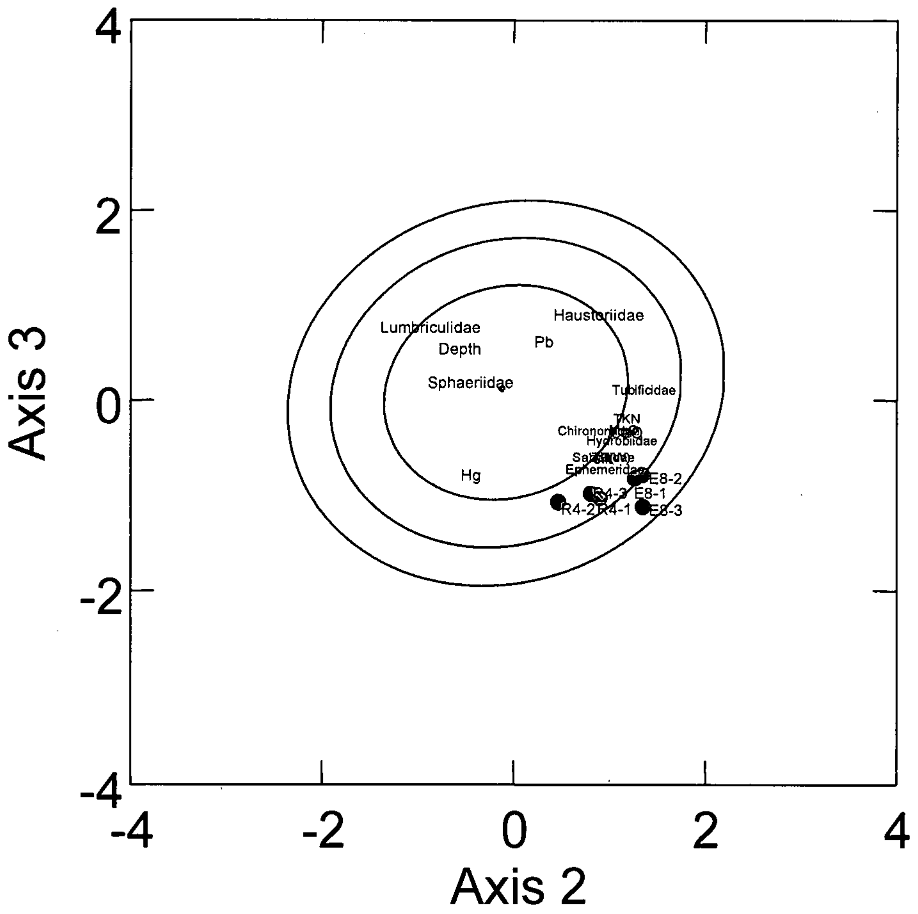

Figure F1. Location of field-replicated sites in benthos ordination space.

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