ANALYSIS OF BENTHIC MACROINVERTEBRATE SAMPLES FROM ST. MARYS RIVER SEDIMENT CORES 1987

AUGUST 1990

Ontario
Environment
Environnement

ISBN 0-7729-7362-8

ANALYSIS OF BENTHIC MACROINVERTEBRATE SAMPLES FROM ST. MARYS RIVER SEDIMENT CORES

1987

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Report prepared for:

Water Resources Branch
Ontario Ministry of the Environment

Reprinted June 1991
AUGUST 1990

PIBS 1173

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Foreword

This report presents information about benthic macroinvertebrates identified in sediment cores collected in the St Marys River in 1987. It is one of several component studies completed by the Ontario Ministry of the Environment during the 1986-1987 MISA Pilot Site Study for the purpose of assessing the impact of discharges from Algoma Steel Corporation to St Marys River.

The benthic species and benthic community composition were analyzed in relation to core depth, sample distance from contaminant sources, and contaminant levels.

Data and conclusions from this survey and other component studies will be incorporated into the forthcoming St Marys River Pilot Site Study Report.

Acknowledgements

The contract liaison officer gratefully acknowledges the following for their contributions to the study:

- Great Lakes Section field staff (Emery Law, Greg Hobson, Rick Savage) for logistical support and for the processing of core samples;

- Staff of the Trace Organics and Inorganics Trace Contaminants Section of the Ministry's Laboratory Services Branch for the chemical analysis of sediment samples; and

- Keith Somers of Great lakes Section for his suggestions regarding statistical analysis and for his assistance during the review of the draft report.

This study was funded, in part, by Environment Canada under the terms of the Canada-Ontario Agreement respecting Great Lakes Water Quality.

Executive Summary

In January, 1990, Tarandus Associates Limited was contracted by the Ontario Ministry of the Environment to complete the identification, enumeration, and statistical analysis of benthic invertebrate samples collected from 5 stations in the St. Marys River in 1987. The sampling locations consisted of 4 stations (155, 157, 169, and 87) downstream of the Sault Ste. Marie locks and 1 control station (52) upstream of Algoma Steel.

The objectives of the study were:

1) to identify, enumerate and tabulate the benthic macroinvertebrates from sediment core samples; and

2) to summarize and interpret the benthic data by examining relationships between the benthic community and various environmental factors.

Twenty benthic invertebrate taxa were identified at the 5 stations. A greater number of taxa were found at the downstream stations than at the upstream station. Six invertebrate species collected in this survey were not found in previous benthic surveys of the St. Marys River (McKee *et al.*,1984; Burt *et al.*, 1988). These species were the naidids *Pristinella jenkinae, Pristinella acuminata, Vejdovskyella intermedia* and *Arcteonais lomondi,* and the tubificids *Limnodrilus profundicola,* and *Isochaetides freyi.*

The upstream station was dominated by chironomids such as Cryptochironomus sp., *Parachironomus* sp., and the Tanytarsini. The downstream stations 155 and 169 were characterized by large numbers of naidid oligochaetes, whereas stations 157 and 87 were dominated by tubificid oligochaetes. The large numbers of oligochaetes observed at the downstream stations suggests organically enriched conditions at these locations.

Benthic invertebrate abundance generally decreased with increasing sediment depth at all stations, with the exception of station 87 where total abundance peaked in the middle of the core. Statistically significant negative correlations were found between total abundance and core depth at stations 52, 155, and 157.

Benthic invertebrate diversity (Shannon—Weaver Index) ranged from a high of 2.91 at station 155 to a low of 2.17 at station 87. Diversities were significantly greater at stations 155, 157, and 169 than at stations 52 and 87. Diversity also varied considerably with core depth at all stations, but generally decreased with increasing depth. The exception was station 87, where diversity was highest at the mid-core depth.

Discriminant analysis of the stations based on the communities revealed by cluster analysis indicated that the downstream communities were associated with sediments with high concentrations of metals, PAHs, phosphorus, and organic carbon. In contrast, the upstream station 52 occurred in sediments with relatively low concentrations of these parameters and higher levels of Kjeldahl nitrogen. Station 169 was characterized by sediments with higher levels of some PAHs, including dibenzo(a,h)anthracene and benzo(g,h,i)perylene, as well as a higher pH.

Various sediment parameters were significantly correlated with total benthic invertebrate abundance at some stations. Total abundance at station 52 was positively correlated with nutrient/organic parameters such as phosphorus, organic carbon and loss on ignition, as well as cadmium, lead, zinc, and some PAHs. Invertebrate abundance at station 155 correlated with sediment metals such as magnesium, manganese, nickel, and lead. Total abundance correlated negatively with lead and several PAHs at station 157. In contrast, few significant correlations were found between sediment parameters and total invertebrate abundance at stations 169 and 87.

Mantel's test showed no significant relationship between inter-site distances based on the principal components analysis of the benthic invertebrate community and the discriminant analysis of the sediment chemistry data. Consequently, the benthic community ordination does not significantly correlate with the sediment chemistry pattern. In all likelihood the benthos reflects particle size (data unavailable) rather than sediment chemistry.

In summary, it was found that the downstream benthic invertebrate communities are characterized by species which are relatively tolerant of environmentally degraded conditions. The sediments at the downstream stations generally had high levels of metals, PAHs, phosphorus, and organic carbon. In contrast, the upstream station 52, although exhibiting a lower invertebrate abundance and fewer taxa, is characterized by pollution-intolerant invertebrate species. Sediments at this station had low levels of metals, PAHs, phosphorus, and organic carbon.

Sommaire

En janvier 1990, Tarandus Associates Limited a été engagé par le Ministère de l'environnement de l'Ontario afin de compléter l'identification, l'énumération et l'analyse statistique des échantillons d'invertébrés benthiques recueillient dans cinq stations de la rivière St-Marie en 1987. Quatres stations (155,157,169 et 87) ont été localisé en aval de l'écluse de Sault St-Marie et une station contrôle (52) en amont de l'Algoma Steel.

Les objectifs de l'étude sont:

1) identifier , énumérer et classifier les macro-invertébrés benthiques des échantillons de sédiments; et

2) résumer et interpréter les données benthiques en vérifiant la relation entre les communautés benthiques et les divers facteurs environnementaux.

Vingt taxa d'invertérbrés benthiques ont été identifié dans les cinq stations. Un nombre plus élevé de taxa ont été recueilli dans les stations en aval plutôt que dans les stations en amont. Six espèces d'invertébrés identifiés dans cette étude n'ont pas été recueilli dans les études benthiques antérieures de la rivière St-Marie (McKee et *al,.* 1984; Burt *et al,.* 1988). Ces espèces sont les naidids *Pristinella jenkinae, Pristinella acuminata, Vejdovskyella intermedia et Arcteonais Lomondi,* et les tubicifids *Limnodrilus profundicola,* et *Isochaetides freyi.*

La station en amont est dominée par les chironomides tel le *Cryptochironimus* sp., *Parachironomus* sp., et les Tanytarsinis. Les stations 155 et 169 en aval sont caracterisées par un nombre élevé de naidid oligochaete, tandis que les stations 157 et 87 sont dominées par les tubicifides oligochaetes. Le nombre élevé d'oligochaetes observé dans les stations en aval indique des conditions riches en matière organique.

L'abondance d'invertébré benthique générallement décroît avec une augmentation de l'épaisseur des sédiments et ce dans toutes les stations, à l'excèption de la station 87 laquelle indique une abondance dans le centre de la carotte d'échantillonnage recueilli. Une corrélation négative significative a été observé entre l'abondance total et l'épaisseur de la carotte pour les stations 52, 155 et 157. La diversité d'invertébré benthique (Shannon-Weaver Index) varie de 2.91 a 2.17 pour la station 155 et 87 respectivement. La diversité a été significativement plus élevé aux stations 155, 157 et 169 qu'aux stations 52 et 87. Aussi, la diversité varie considérablement avec l'épaisseur de l'échantillon pour chacune des stations, mais générallement diminue avec une augmentation de l'épaisseur. Par contre, la station 87 démontre une diversité plus élevé a la moitié de l'épaisseur de la carotte d'échantillonnage.

Une analyse discriminatoire des stations basé sur les communautés identifiées par une analyse de classe démontre une association entre les communautés en aval et les sédiments à forte concentration en métals, en HPA, en phosphore et en carbone organique. Par ailleur, les sédiments de la station 52 ne contiennent que *de* faible concentration de c'est dit composé mais, contient un taux élevé en azote kjeldahl. La station 169 est caracterisée par des sédiments plus élevé en HAP, incluants dibenzo *(a,h)* anthracène et benzo (g,h,i) pérylene, ainsi qu'un pH plus élevé.

Une corrélation significative a été démontré entre divers paramètres sédimentaires et l'abondance total d'invertébrés benthiques pour quelques une des stations. L'abondance total à la station 52 corrèle positivement avec les paramètres nutriments/ organiques tel le phosphore, le carbone organique et la perte de combustion et, le cadmium, le plomb,le zinc et quelques HAP. L'abondance d'invertébrés à la station 155 corrèle avec les métaux tel le magnesium, le manganese, le nickel et le plomb contenu dans le sédiments. Une corrélation négative entre l'abondance total et le plomb et, plusieurs HAP a la station 157 a été observé. Par contre, une faible corrélation a été observé entre les paramètres sédimentaires et l'abondance total d'invertébré la station 169 et 87.

Le test de Mandel n'a démontré aucune relation significative entre la distance séparant les sites et l'analyse discriminatoire de la composition chimique des sédiments et ce basé sur l'analyse des principaux compose de la communauté benthique. Par conséquent, l'organisation des communautés benthique ne démontre aucune corrélation significative avec l'organisation chimique des sédiments. Selon toute probabilité, le benthos est associera la grosseur des particules (données non-disponibles) plutôt que la composition chimique des sédiments.

En résume, il a été demontré que les communautes d'invertébrés benthiques *en* amont sont caracterisées par des espèces qui sont relativement tolérantes à la dégradation des conditions environnementales. Les sédiments des stations en amont en général, ont un taux élevé de métals, de HAP, de phosphore et de carbon organic. Par contre, la station 52 en aval, en plus de démontrer *une* faible abondance en invertébré et taxa, cette station est caracterisée par des espèces d'invertébrés intolérantes à la pollution. Les sédiments de cette station ont un faible taux en métals, HAP, phophore et carbon organique.

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Introduction

In January, 1990, Tarandus Associates Limited was contracted by the Ontario Ministry of the Environment (MOE) to complete the identification, enumeration, and statistical analysis of benthic invertebrate samples collected at five stations in the St. Marys River in 1987 (Figure 1).

The objectives of the study were:

1) to identify, enumerate and tabulate benthic macroinvertebrates in sediment core samples from each station; and

2) to summarize and interpret the benthic data and examine relationships between the benthic community and various environmental factors.

The benthic invertebrate community of the St. Marys River has been well documented (Veal, 1968; Heady *et al.*, 1978; McKee *et al.*, 1984; Burt *et al.*, 1988). Veal (1968) found in a 1967 survey that the benthic community was severely impaired along the Sault Ste. Marie, Ontario waterfront due to industrial and municipal discharges to the St. Marys River. Several toxic contaminants were identified in the sediments, including oils, phenols, cyanide and naphthalene. The impacted benthic community extended along the Canadian shoreline for at least 4 km downstream of the major industrial discharges.

Results of a 1973 survey (Hamdy *et al.*,1978) confirmed the findings of Veal (1968). The macroinvertebrate community in the St. Marys River was altered downstream of the discharges from the steel and paper mills. High concentrations of iron, zinc, cyanide, oils, and phenols were observed in the sediments below the steel plant main trunk sewer outfall and the paper mill outfall.

Further benthic surveys in 1983 and 1985 by McKee *et al.* (1984) and Burt *et al.* (1988) reported benthic communities and zones of impairment similar to those described above.

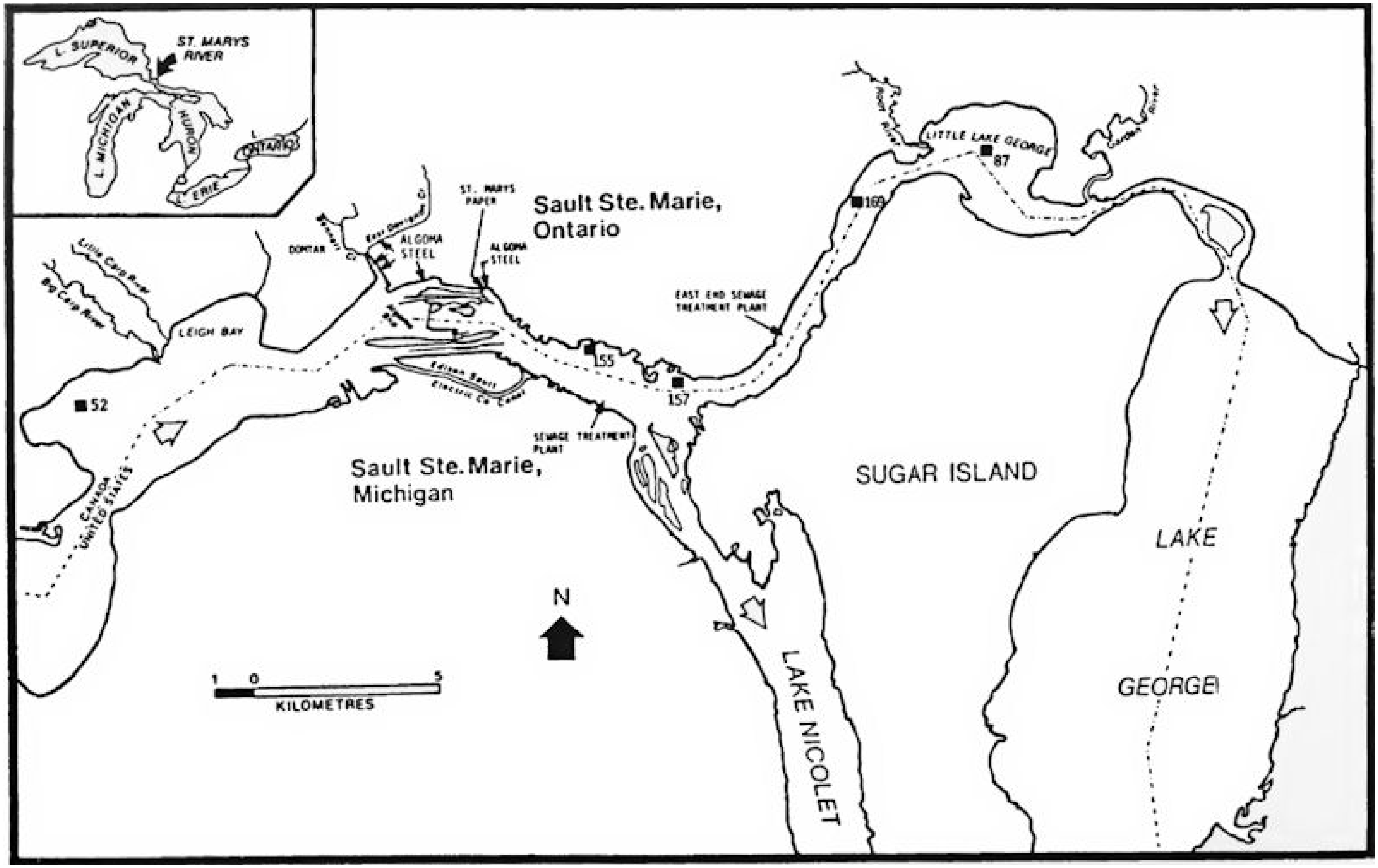


Figure 1. St. Marys River sediment core sampling locations.

Study Methods

Sediment Core Collection

Sediment cores were collected at five stations in the St Marys River by Tarandus Associates Limited between the 21st and the 24th of September, 1987. At each station, a diver completed an initial reconnaissance of the substrate conditions to locate areas suitable for coring. Cores were generally taken from areas with silty sediments. Where suitable sediments were found, three replicate cores, each 6.8 cm in diameter, were collected. The plastic core tubes *were* capped underwater by the diver and then taken to the surface for sectioning by MOE representatives. The length of core collected varied between stations.

The top 20 cm of each sediment core was sectioned at 2 cm increments. One-quarter of each 2 cm-thick section from each of the three replicate cores were composited, washed through a 500 um sieve and the filtrate transferred to a sample jar. All samples were preserved with buffered 5% formalin. The remaining three-quarters of each core section was combined with its replicates and homogenized in preparation for subsequent chemical analyses by MOE. All chemical analyses were conducted according to documented methods (MOE, 1983).

Invertebrate Identification and Enumeration

A total of 50 benthic macroinvertebrate samples were examined, 10 for each station. Each sample was manually washed, picked, and sorted to separate all organisms from associated debris. All samples were picked in their entirety and processed with the use of a stereomicroscope at magnifications ranging from 15X to 300X. Organisms found in each sample were sorted into similar taxonomic groups and placed in separate labelled vials for subsequent identification.

All benthic invertebrates were identified to the lowest practical taxonomic level by Dr. Richard Vineyard of the Royal Ontario Museum, Toronto, Ontario. Prior to identification, tubificids and chironimids were cleared and mounted on labelled microscope slides with the use of Canada balsam. In cases where the immature forms of some invertebrates prevented identification to species, classification was usually completed to the level of genus.

All sorted invertebrate samples were provided on labelled slides to MOE. In addition, a reference collection was prepared for use in confirming identifications and to ensure the repeatability of the benthic invertebrate classification in future studies. Slides were labelled with the species identification, date, station, and core depth.

All species counts were tabulated by station and core depth (Appendix II) and also converted to abundance counts (number/m^2) for subsequent statistical analysis (Appendix III).

Statistical Analyses

Statistical methods were generally selected because of their recognized utility in delineating spatial and temporal variation, or ability to quantitatively summarize associations and trends. A brief summary of the rationale and application, and the mathematical formula for each analysis is presented below.

1) Indices

Indices are a simple method of summarizing complex data. They are derived variables such as a ratio of one variable divided by a standard variable. When applied to invertebrate data, such indices generally involve ratios of numbers of taxa and numbers of individuals in the collected samples. These indices have interpretive value as data summaries.

i) Shannon-Weaver (or Shannon-Weiner) Diversity Index (H')

Diversity is a measure of the distribution of observations among categories (e.g. species). When applied to communities of invertebrates, diversity calculations incorporate the counts of organisms within each taxonomic group. A low diversity is the result of a concentration of invertebrates in few categories; and conversely, a more uniform distribution of organisms among all categories results in a high diversity. The formula for the Shannon-Weaver diversity index, H' is:

$$H' = -\sum_{i=1}^{s} N_i/n \log_2 N_i/n$$

$$= -1.447 \sum_{i=1}^{s} N_i/n \log_2 N_i/n$$

where n = the total number of individuals in the sample

N = the number of individuals in the "i" th sample

ii) Tests for Differences between Diversity Indices

The Shannon-Weaver diversity indices calculated for each station were tested to resolve the null hypothesis: that the diversities at each station are equal. The equations used in this test (Zar, 1984) are presented below:

$$t = \frac{H'_1 - H'_2}{s_{H'_1 - H'_2}}$$

where $s_{H'_1 - H'_2} = \sqrt{s^2_{H'_1} + s^2_{H'_2}}$

The variance of H' may be calculated as follows:

$$s^2_{H'} = \frac{\Sigma f_i \log^2 f_i - (\Sigma f_i \log f_i)^{2/n}}{n^2}$$

where s = the standard deviation of the sample
f_i = the number of observations in category "i"
n = the sample size

The degrees of freedom (DF) associated with the above t-test can be estimated by:

$$v = \frac{(s_{H'_1} + s_{H'_2})^2}{(s_{H'_1})^2 / n_1 + (s_{H'_2})^2 / n_2}$$

iii) Coefficient of Community (CC)

The coefficient of community is a measure of community association defined as the number of species shared by two samples expressed as a percentage. Although CC tends to over-value (or emphasize) rarer species, this weakness is compensated by comparing results from CC with those from another measure, the Percentage Similarity of Community (PSc), described later. Both CC and PSc can be evaluated further with the use of cluster analysis.

$$CC = c / (a+b-c) \bullet 100$$

where a = the number of species in the first sample
b = the number of species in the second sample
c = the number of species occurring in both samples

iv) Percentage Similarity of Community (Psc)

Percentage Similarity of Community is a measure of community association that includes the relative abundance of each species. PSc neglects (or de-emphasizes) the rarer species that CC over-values, and for this reason PSC and CC are usually used together. In combination, these techniques reveal whether the similarity between. samples is due to the sharing of most species or to the occurrence of the species in approximately the same proportion (Johnson and Brinkhurst, 1971). Following is the formula used to determine Psc:

$$PSc = 100 - 0.51 \Sigma | a' - b' |$$

$$= \Sigma \min (a', b')$$

where a' and b' are the respective percentages of the total number of invertebrates in each of samples A and B for each species.

2) Cluster Analysis

Benthic invertebrate communities were defined using cluster analysis, which reduces the species abundance data to a graphical summary. The resultant groups or clusters characterize relatively homogeneous species assemblages (Green, 1979). The significance of the group separation relative to environmental variables can be evaluated by multiple discriminant analysis, which is discussed on the following page.

In order to confirm the robust nature of the results, several cluster analysis techniques were used, including:

i) Minimum Variance Clustering (Ward's Method)
ii) Group Average Clustering
iii) Centroid Clustering

Cluster analysis was completed on abundance data, presence/ absence data, and PSc and CC coefficients using two statistical packages: SYSTAT (Wilkinson, 1988) and Statistical Ecology (Ludwig and Reynolds, 1988).

Some problems may be encountered in the use of cluster analysis, including: (i) the subjective choice of clustering method and similarity measure will affect the outcome; and (ii), clusters may be produced when they do not exist (Jackson *et al.*, 1989). The patterns revealed by the cluster analyses were confirmed with the use of Principal Components Analysis (PCA).

3) Principal Components Analysis

Principal components analysis (PCA) was used to analyze the benthic invertebrate data and to verify station groupings defined by the cluster analysis. PCA is a technique for deriving linear combinations of the original variables, called principal components, that are orthogonal to one another, and that successively account for the largest portion of the residual sample variance (Rogers, 1971). This method, as with most multivariate statistics that reduce the dimensionality of multivariate observations, is used to generate a smaller number of variables that summarize most of the information contained in the original variables.

The "factor loadings" produced during principal components analysis are the correlation coefficients between each original variable and each principal component. Since species abundance data rarely conforms with the linearity assumptions associated with the use of correlations and covariances in PCA (Ludwig and Reynolds, 1988), we chose to use rank correlations in the PCA's (Rising and Somers, 1989). The data were ranked prior to completing the PCA, and the first two or three factors were graphed for presentation in this report.

The PCA's were calculated using SYSTAT computer software and presented graphically using the SYGRAPH computer package (Wilkinson, 1988).

4) Discriminant Analysis

Discriminant analysis was used to contrast the defined benthic communities with the measured sediment parameters and to examine the communities with respect to environmental conditions. Discriminant analysis is a multivariate technique used to distinguish groupings (e.g. communities) on the basis of a series of quantitative descriptors (e.g. sediment chemistry). The resultant discriminant axes are discriminant functions or linear combinations of the sediment chemical variables that maximize differences between the groups of communities. Each axis is interpreted with correlation coefficients (r) between the discriminant functions and the original sediment parameters.

Thirty-one sediment variables were used to discriminate between the benthic communities (Table 1). Grain (particle) size data were extremely limited and therefore could not be used in the analysis.

Table 1 : Sediment Parameters used in discriminant analysis. Associated abbreviations are given in brackets.

METALS	ORGANICS	NUTRIENTS	OTHERS
Chromium (Cr)	Acenaphthene (ACNE)	Total Kjeldahl	pH
Lead (Pb)	Acenaphthylene (ACNY)	Nitrogen (TKN)	Moisture
Zinc (Zn)	Anthracene (ANTH)	Loss on	Oil &Grease
Cadmium (Cd)	Benzo(a)anthracene (BAA)	Ignition (LOI)	(SOLEXT)
Iron (Fe)	Benzo(a)pyrene (BAP)	Total	
Manganese (Mn)	Benzo(b)fluorene (BBF)	Phosphorus (TP)	
Nickel (Ni)	Benzo(k)fluoranthene (BKF)	Total Organic	
Magnesium (Mg)	Chrysene (CHRY)	Carbon (TOC)	
	Dibenzo(a,h)anthracene (DAHA)		
	Fluoranthene (FLAN)		
	Fluorene (FLUO)		
	Benzo(g,h,i)perylene (GHIP)		
	Indeno(1,2,3-cd)pyrene (INP)		
	Naphthalene (NAPH)		
	Phenanthrene (PHEN)		
	Pyrene (PYR)		

All variables were logarithmically transformed prior to use in discriminant analysis. The three missing data values for pH at station 52, and the two missing values for TP and TKN at station 155 were replaced by the station mean values of these parameters.

Discriminant analysis was completed on the benthic communities defined by the cluster analysis, as well as on individual sampling stations. Discriminant analysis was conducted using SYSTAT computer software. Double precision was used during the analysis, as discriminant analysis is particularly sensitive to rounding errors (Green, 1979).

5) Correlation Analysis

Correlation analysis measures the degree that variables vary together, or the intensity of association (Steel and Torrie, 1980). The correlation coefficient (r) is a measure of this association. Where linear correlation is small, r is near zero. In contrast, high correlation is represented by r near +1 or -1.

Pearson's correlation coefficient is used when the data are normally distributed. If the data are not normally distributed, a nonparametric coefficient should be used (e.g. Spearman's rank correlation). The use of both coefficients presumes that a linear relationship exists between the variables. Pearson's correlation coefficient may exaggerate the overall importance of very large values in the data, and it may be biased when there are many zeros in the data (Ludwig and Reynolds, 1988).

Pearson's correlation coefficients and Spearman's rank correlations were calculated between log-transformed total benthic abundances and log-transformed sediment data. Comparisons between the two sets of coefficients were made to evaluate the bivariate nature of the relationships between the various parameters.

6) Mantel's Test

Mantel's test (Mantel, 1967) was used to examine the data for any non-random association existing among distance matrices. The distance matrices were based on the PCA of benthic invertebrates and on the discriminant analysis of sediment-chemistry data for all stations. Mantel's test is a randomization procedure that calculates the probability that two distance matrices are more similar than would be expected by chance (Jackson and Somers, 1989).

Distance matrices were calculated according to Euclidean distances, and Mantel's test was completed with the use of BASIC computer software (Somers, 1989).

Results and Discussion

Species Composition and Abundance

In total, 20 benthic invertebrate genera or species were identified at the 5 sampling stations in the study area (Appendix I). The stations downstream of industrial and municipal discharges had more taxa than the upstream control station. For example, station 157 had the highest number of species, whereas station 52 had the lowest (Table 2). More invertebrate taxa were found in the surface layers of the cores, and sixteen of the 50 samples contained no organisms. One adult dipteran species was also found in the top layer of the core from station 155. This individual was considered an artifact, given that adult diptera are never aquatic (Pennak, 1978).

Six invertebrate species found in this survey were not found in previous benthic surveys of the St. Marys River (McKee *et al.*,1984; Burt *et al.*, 1988). These species were the naidids: *Pristinella jenkinae, Pristinella acuminata, Vejdovskyella intermedia, Arcteonais lomondi*, and the tubificids: *Limnodrilus profundicola*, and *Isochaetides freyi*.

Table 2: Number of taxa found at each station and each associated core depth.

Core Depth (cm)	Station				
	52	155	157	169	87
0-2	4	8	5	7	0
2-4	1	2	3	2	1
4-6	3	3	2	3	1
6-8	0	3	4	2	3
8-10	0	2	4	0	3
10-12	0	2	2	0	2
12-14	0	1	1	2	3
14-16	0	1	1	0	2
16-18	0	0	0	1	0
18-20	0	0	0	0	2
TOTAL	8	22	22	17	17

Core depth distributions of the various invertebrate species, by number/sample and number/m^2 for each station are presented in Appendix II and III respectively. Total abundances of benthic invertebrate species found at each station for all depths are summarized in Table 3 below and in Figure 2.

Table 3 : Total abundance (number/m^2) of species found at all core depths at sampling stations.

Taxon or Species	STATION				
	52	155	157	169	87
Oligochaeta					
NAIDIDAE					
Pristinella jenkinae	0	1101	734	367	0
Pristinella acuminata	367	1469	367	1469	0
Pristinella osborni	0	367	0	0	0
Vejdovskyella intermedia	0	0	0	367	0
Slavina appendiculata	0	4406	734	2203	0
Stylaria lacustris	0	734	0	1469	0
Arcteonais lomondi	0	1469	0	0	0
Naididae (immature)	0	1836	734	367	367
TUBIFICIDAE					
Limnodrilus udekemianus	0	0	367	0	367
Limnodrilus profundicola	0	0	0	0	734
Limnodrilus hoffmeisteri	0	0	0	0	1101
Limnodrilus sp.	0	0	2570	0	2570
Quistadrilus multisetosus	0	2203	1101	1101	0
Aulodrilus pluriseta	0	0	734	0	0
Aulodrilus piqueti	0	0	367	0	0
Isochaetides freyi	0	0	0	367	0
Tubificidae (immature)	734	1469	3671	2203	2937
Diptera					
CHIRONOMIDAE					
Cryptochironomus sp.	367	0	0	0	0
Parachironomus sp.	734	0	0	0	0
Tanytarsini	734	0	0	0	0
Total	2936	15054	11379	9913	8076

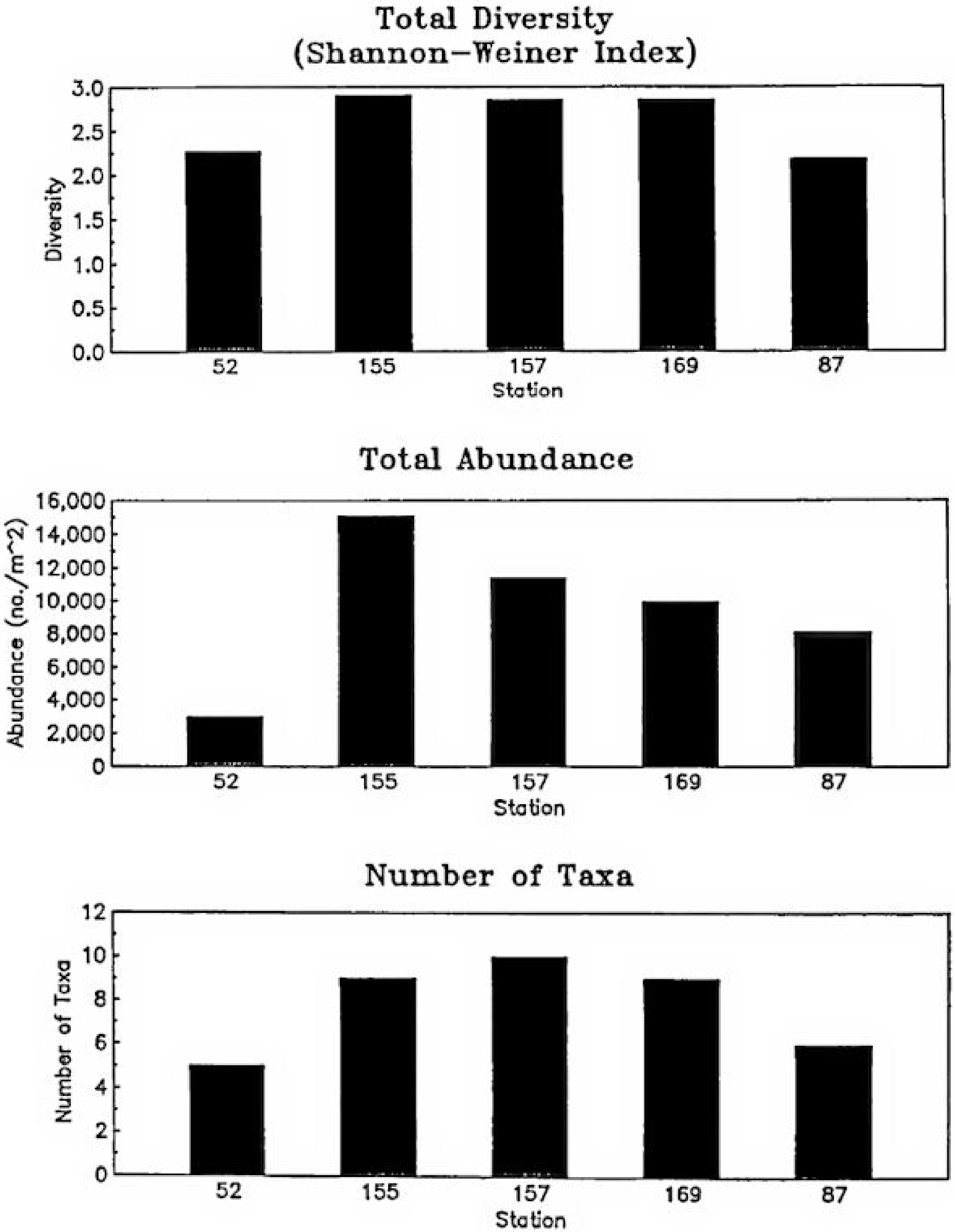


Figure 2: Total diversity, abundance, and number of taxa at all sampling stations.

Immature tubificids were the only benthic invertebrates common to all sampling stations; however the densities were higher at the downstream sites, especially at stations 157 and 87.

Station 52, located upstream of Algoma Steel, was dominated by chironomids such as *Cryptochironomus* sp., *Parachironomus* sp., and Tanytarsini. These species were not observed at any of the downstream stations and comprised 62% of the total individuals found. Most oligochaete species were absent at this station, with the exception of *Pristinella acuminata* and immature tubificids. A higher percentage of chironomids relative to oligochaetes has been found to be indicative of oligotrophic conditions (Wetzel, 1983). The exclusion of chironomid species from downstream stations could be due to organic enrichment at these stations, as well as toxic conditions from higher metal and organic contaminant levels.

The benthic community at station 155, downstream of Algoma Steel and St. Marys Paper, was dominated by the order Naididae. Dominant naidid species included *Slavina appendiculata, Pristinella acuminata, Arcteonais lomondi* and immature naidids. The tubificid *Quistadrilus multisetosus* was also common. The naidid oligochaete, *Arcteonais lomondi* was only found at this station.

Station 157 was dominated by tubificids such as *Limnodrilus* spp., *Quistadrilus multisetosus* and immature individuals. The tubificids *Aulodrilus pluriseta* and *Aulodrilus piqueti* were also found at this station, but not observed at any other station. Tubificids such as *Limnodrilus* spp. and *Quistadrilus multisetosus* are characteristic of areas showing organic enrichment (Lauritsen *et al.*, 1985; Cook and Johnson, 1974), whereas *Aulodrilus* spp. indicate more mesotrophic conditions (Nalepa and Thomas, 1976). It should also be noted that *Limnodrilus* spp. are not necessarily confined to polluted waters (Hynes, 1971; Brinkhurst and Cook, 1974).

Station 169, located below the sewage treatment plant (STP) outfall, was dominated by the order Naididae. Naidid species found here include *Slavina appendiculata, Pristinella acuminata,* and *Stylaria lacustris*. Immature tubificids were also found in relatively large numbers. The absence of various *Limnodrilus* species is noteworthy, as some organic enrichment from the STP outfall would be expected.

Station 87, located in Little Lake George, was dominated by tubificids, which comprised 95% of the total number of individuals found. Dominant tubificid species included *Limnodrilus* sp., *Limnodrilus hoffmeisteri*, and immatures. *Limnodrilus hoffmeisteri* and *Limnodrilus* *profundicola* were found only at this station. Naidid species were absent at this station. The dominance of the various tubificid species, especially *Limnodrilus hoffmeisteri*, would indicate organic enrichment. Little Lake George may act as a settling area for suspended solids and associated nutrients from the St. Marys River and the Root River. Station 87 was also characterized by high tubificid densities (especially *L. hoffmeisteri*) in the 1973 survey of Hamdy *et al.* (1978).

Stations located downstream of the Sault Ste. Marie locks had higher total invertebrate abundances than the upstream control site. (Table 3). Station 155 had the highest total abundance (15,053 individuals/m^2) and station 52 had the lowest (2,937 individuals/m^2).

Invertebrate abundance generally decreased as core depth increased for all stations, with the exception of station 87, where total abundance peaked in the 8-10 cm core depth. A station-by-core-depth summary of total abundances is presented in Table 4. Significant correlations were found between total abundance and depth at station 52 (r=-0.797, p=0.006), station 155 (r=-0.836, p=0.003), and station 157 (r=-0.802, p=0.005).

Usually, invertebrates found at the deeper core depths were tubificids. The majority of the naidid oligochaetes were associated with shallower sediment depths. Oligochaete species frequently segregate vertically within the sediments. Naidids are usually concentrated at the sediment-water interface, rarely more than 2-4 cm below the surface (Milbrink, 1973), whereas tubificid oligochaetes are most abundant 2-4 cm below the surface, but can be found at depths of up to 15 cm (Wetzel, 1983). Robbins *et al.* (1989) also found that tubificids occurred between 0 and 15 cm in sediment cores collected from Lake Erie. Some oligochaetes were found at depths greater than 15 cm in the cores taken from the St. Marys River, but they may have been displaced deeper into the sediment during core sampling.

Table 4: Station-by-core-depth summary of total benthic invertebrate abundance (number/m^2).

Core Depth (cm)	Station 52	155	157	169	87
0-2	1469	8444	2570	5507	0
2-4	367	734	1101	1101	367
4-6	1101	1836	1469	1101	367
6-8	0	1469	1836	734	1469
8-10	0	1101	2937	0	1836
10-12	0	734	734	0	1469
12-14	0	367	367	734	1101
14-16	0	367	367	0	734
16-18	0	0	0	734	0
18-20	0	0	0	0	734
Total	2937	15052	11381	9911	8077

The total density of oligochaetes is frequently used to assess the effects of pollution (Carr and Hiltunen, 1965; Howmiller and Beeton, 1971). The original index proposed by Wright and Tidd (1933) states that an oligochaete density of less than 1,000/m^2 indicates negligible organic pollution, a density of between 1,000/m^2 and 5,000/m^2 indicates mild organic pollution, and more than 5,000/m^2 indicates severe organic pollution. Using these criteria, all the downstream stations would be considered severely polluted, and the upstream control station would be considered not polluted. Others have suggested that an oligochaete density greater than 10,000/m^2 can *be* considered severely organically polluted (Mozley and Alley, 1973). Based on this criterion only stations 155 and 157 would be described as severely polluted.

Goodnight and Whitley (1960), suggested that the relative abundance of oligochaetes to other benthic organisms can be used to assess the extent of enrichment. Areas with greater than 80% oligochaetes are considered "highly polluted", and areas less than 60% indicate "good condition". Using this approach, the downstream stations are all considered highly polluted or enriched, whereas the control station is considered to be in good condition.

All the above "pollution indices" generally indicate that the downstream stations are organically enriched, compared to the upstream control station.

Benthic Invertebrate Diversity

The Shannon-Weaver diversity indices for all stations and core depths are presented in Table 5 below. In some cases the index could not be calculated (NA) as no organisms were found.

Table 5: Benthic invertebrate diversities for all sampling stations and core depths (Shannon-Weaver index).

Core Depth (cm)	Station				
	52	155	157	169	87
0-2	1.51	2.41	2.24	2.47	NA
2-4	0.00	1.00	1.59	0.92	0.00
4-6	1.59	1.38	0.81	1.59	0.00
6-8	NA	1.51	1.93	1.00	1.51
8-10	NA	0.92	1.76	NA	1.53
10-12	NA	1.00	1.00	NA	0.81
12-14	NA	0.00	0.00	1.00	1.59
14-16	NA	0.00	0.00	NA	1.00
16-18	NA	NA	NA	0.00	NA
18-20	NA	NA	NA	NA	1.00
TOTAL DIVERSITY*	2.26	2.91	2.85	2.85	2.17

* - Total diversity is for all depths at each station

The benthic invertebrate diversity fluctuated a great deal with core depth at all stations. This is probably due to the small sample size. Diversity generally decreased with increasing core depth, with the exception of station 87, where diversity peaked at mid-core depths (6-14 cm).

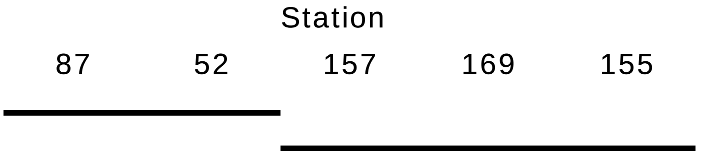
The total invertebrate diversity ranged from a high of 2.91 at station 155 to a low of 2.17 at station 87 (Figure 2). The diversities at all stations were compared statistically to reveal significant differences. Calculated t-values, degrees of freedom and underscoring diagrams are presented in Table 6. Benthic invertebrate diversities at stations 52 and 87 were not significantly different from each other, and the diversities at stations 155, 157 and 169 were not significantly different ($p=0.05$).

Table 6: t-values, degrees of freedom, and underscoring diagrams for the statistical comparison of station diversities.

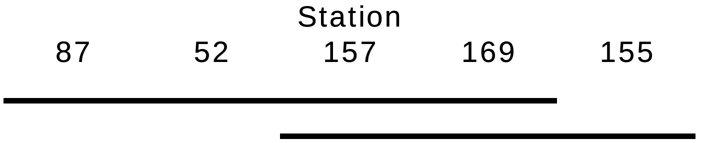
Station	Station	Calculated t-value	Degrees of Freedom	Table t-value 0.05	Table t-value 0.01
52	155	3.171	23	2.069	2.807
	157	2.264	35	2.031	2.727
	169	2.589	27	2.052	2.771
	87	0.315	29	2.045	2.756
155	157	0.239	55	2.005	2.670
	169	0.276	57	2.000	2.660
	87	2.926	40	2.021	2.704
157	169	0.000	57	2.000	2.660
	87	2.259	52	2.010	2.680
169	87	2.486	44	2.015	2.690

Underscored stations are not significantly different:

Level of Significance = 0.05



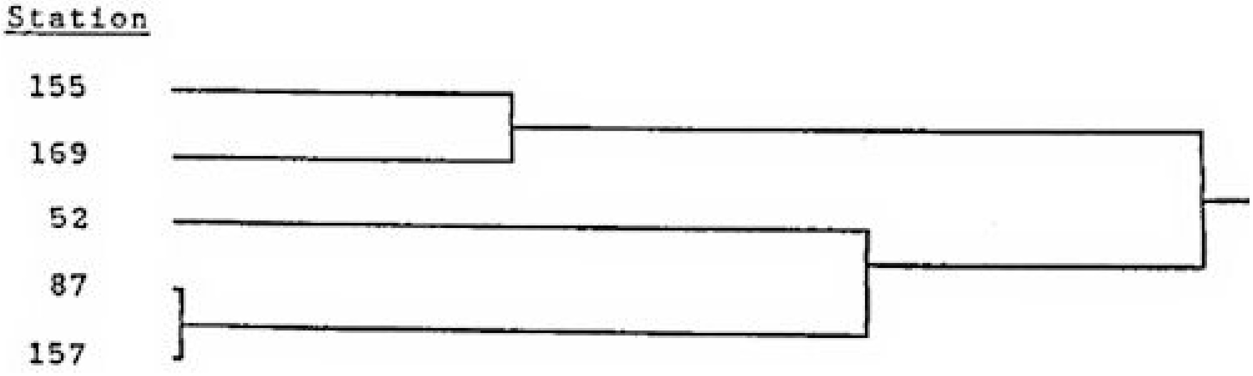
Level of Significance = 0.01



Benthic Community Classification

The benthic invertebrate communities were defined by means of cluster analysis. Based on the total species composition at each station, the cluster analysis split the five sampling locations into three groups or communities. The taxonomic composition of the three communities (A, B, and C) is shown in Table 7. The cluster analysis results were similar for all clustering techniques employed (Figure 3).

Figure 3: Example dendrogram from cluster analysis using euclidean distance and centroid linkage procedure.



Principal components analysis (PCA) was used to verify station groupings revealed by cluster analysis (Figure 4). The component loadings and percent of total variance for the principal components are presented in Table 8. More than 70 % of the variation is explained by the first two factors. The PCA results generally confirm those of the cluster analysis. Stations 157 and 87 (community B) group together, influenced by the relative abundances of the various *Limnodrilus* species and immature tubificids. Stations 155 and 169 (community A) also group together and are influenced strongly by the relative abundances of the various naidid species, such as *Slavina appendiculata* and *Pristinella acuminata*, as well as the tubificid *Quistadrilus multisetosus*. The benthic community at station 52 (community C) is distinct and is represented by the high relative abundance of the chironomid species *Cryptochironomus* sp., *Parachironomous* sp. and Tanytarsini.

Table 7: Species composition (mean number/m^2) of the benthic invertebrate communities as defined by cluster analysis. The stations representing each community are in brackets.

	Benthic Community		
	A	B	C
Taxon or Species	(155, 169)	(157, 87)	(52)
Oligocheata			
NAIDIDAE			
Pristinella jenkinae	734	367	0
Pristinella acuminata	1469	184	367
Pristinela osborni	185	0	0
Vejdovskyella intermedia	185	0	0
Slavina appendiculata	3305	367	0
Stylaria lacustris	1102	0	0
Arcteonais lomondi	735	0	0
Naididae (immature)	1102	551	0
TUBIFICIDAE			
Limnodrilus udekemianus	0	367	0
Limnodrilus profundicola	0	367	0
Limnodrilus hoffmeisteri	0	551	0
Limnodrilus sp.	0	2570	0
Quistadrilus multisetosus	1652	551	0
Aulodrilus pluriseta	0	367	0
Aulodrilus piqueti	0	185	0
Isochaetides freyi	185	0	0
Tubificidae (immature)	1836	3304	734
Diptera			
CHIRONOMIDAE			
Cryptochironomus sp.	0	0	367
Parachironomus sp.	0	0	734
Tanytarsini	0	0	734
Total	12490	9731	2937

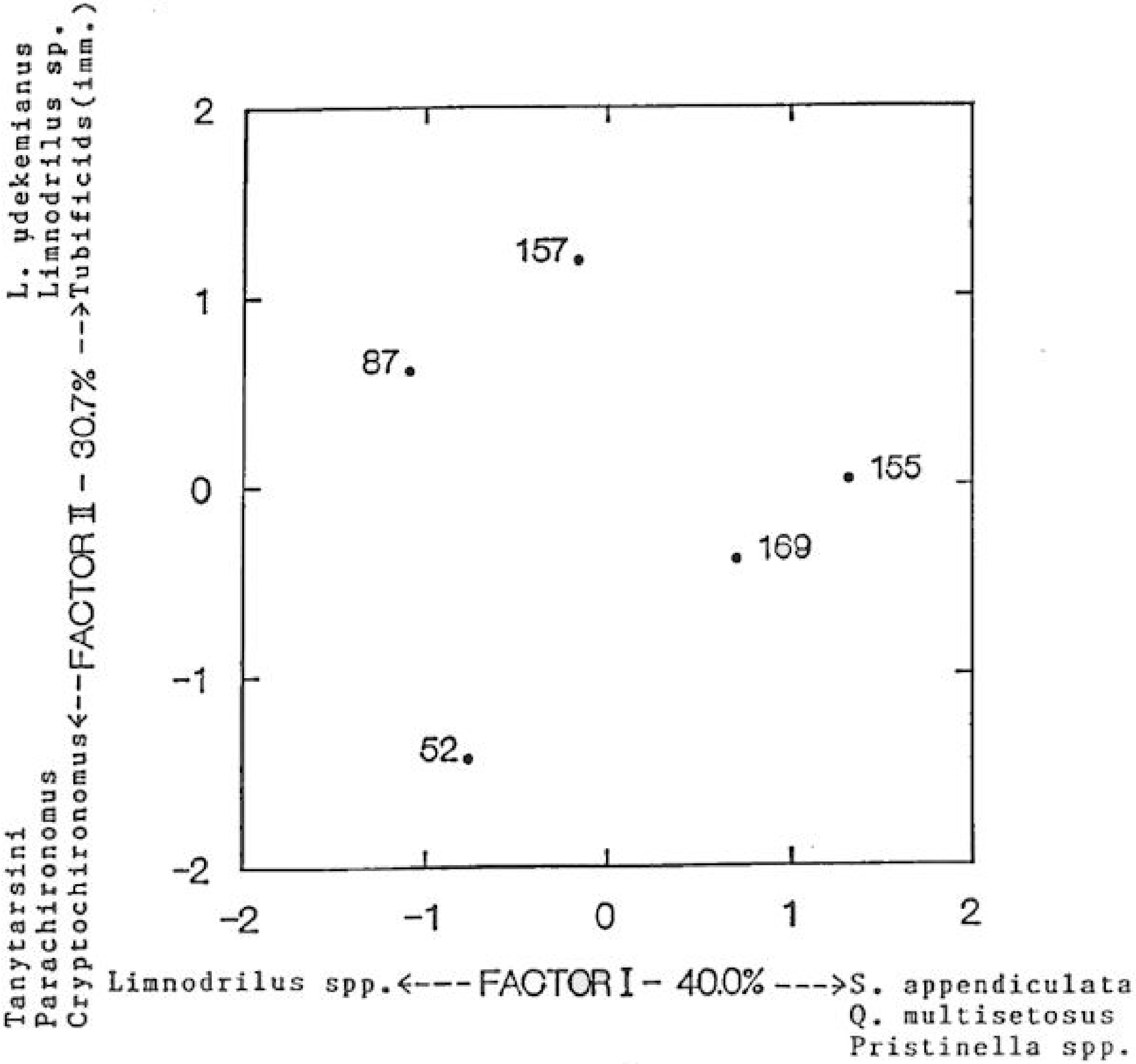


Figure 4: PCA of benthic invertebrate abundance.

Table 8: Component loadings and percent of total variance for the PCA of the benthic invertebrate abundances.

Taxon or Species	Component Loadings	
	Factor I	Factor II
Slavina appendiculata	0.989	0.146
Quistadrilus multisetosus	0.944	0.281
Pristinella acuminata	0.943	-0.274
Pristinella jenkinae	0.848	0.402
Stylaria lacustris	0.837	-0.197
Arcteonais lomondi	0.731	0.014
Pristinella osborni	0.731	0.014
Naididae (immature)	0.677	0.649
L. profundicola	-0.607	0.341
L. hoffmeisteri	-0.607	0.341
L. udekemianus	-0.570	0.821
Limnodrilus sp.	-0.570	0.821
Tubificidae (immature)	-0.188	0.923
Tanytarsini	-0.428	-0.803
Cryptochironomus sp.	-0.428	-0.803
Parachironomus sp.	-0.428	-0.803
Aulodrilus piqueti	-0.091	0.665
Aulodrilus pluriseta	-0.091	0.665
Isochaetides freyi	0.395	-0.217
Vejdovskyella intermedia	0.395	-0.217
Percent of Total Variance	40.02	30.71

Environmental Quality Evaluation

Figure 5 illustrates the separation in discriminant space of the three groups of stations defined by the cluster analysis and the PCA. The correlations between the various sediment parameters and the first two discriminant functions are given in Table 9.

The first discriminant axis (DA I) indicates that communities A and B are characterized by sediments with high concentrations of metals, PAHs, TP, oil and grease, and TOC, whereas community C occurred in sediments with relatively low concentrations of these parameters and higher levels of TKN. The absence of chironomid species, and the dominance of pollution-tolerant oligochaetes in communities A and B could be due to toxic levels of various metals, PAHs, and oil and grease.

The second discriminant axis (DA II) separates communities A and B in discriminant space (Figure 5). This axis indicates that community B occurred in sediments with high magnesium, TKN, and TP. Community B was more organically enriched than community A, which would explain the dominance of tubificids, especially the various species of *Limnodrilus* found in community B. Lang-Dobler (1979) found that a group of tubificids represented by *L. hoffmiesteri*, *L. udekemianus*, and *L. profundicola* were associated with high TP levels in the sediment. These species were exclusive to community B, which was characterized by a mean TP concentration of 1.01 mg/g, almost twice that of community A and over 4 times higher than community C.

The analysis suggests that both communities A and B reflect degraded environmental conditions with respect to metals, PAHs, and oil and grease contamination, as well as higher levels of TP and TOC relative to community C. Community B is also more organically enriched with respect to TKN and TP than community A. The mean concentrations of all sediment parameters associated with each community are presented in Table 10.

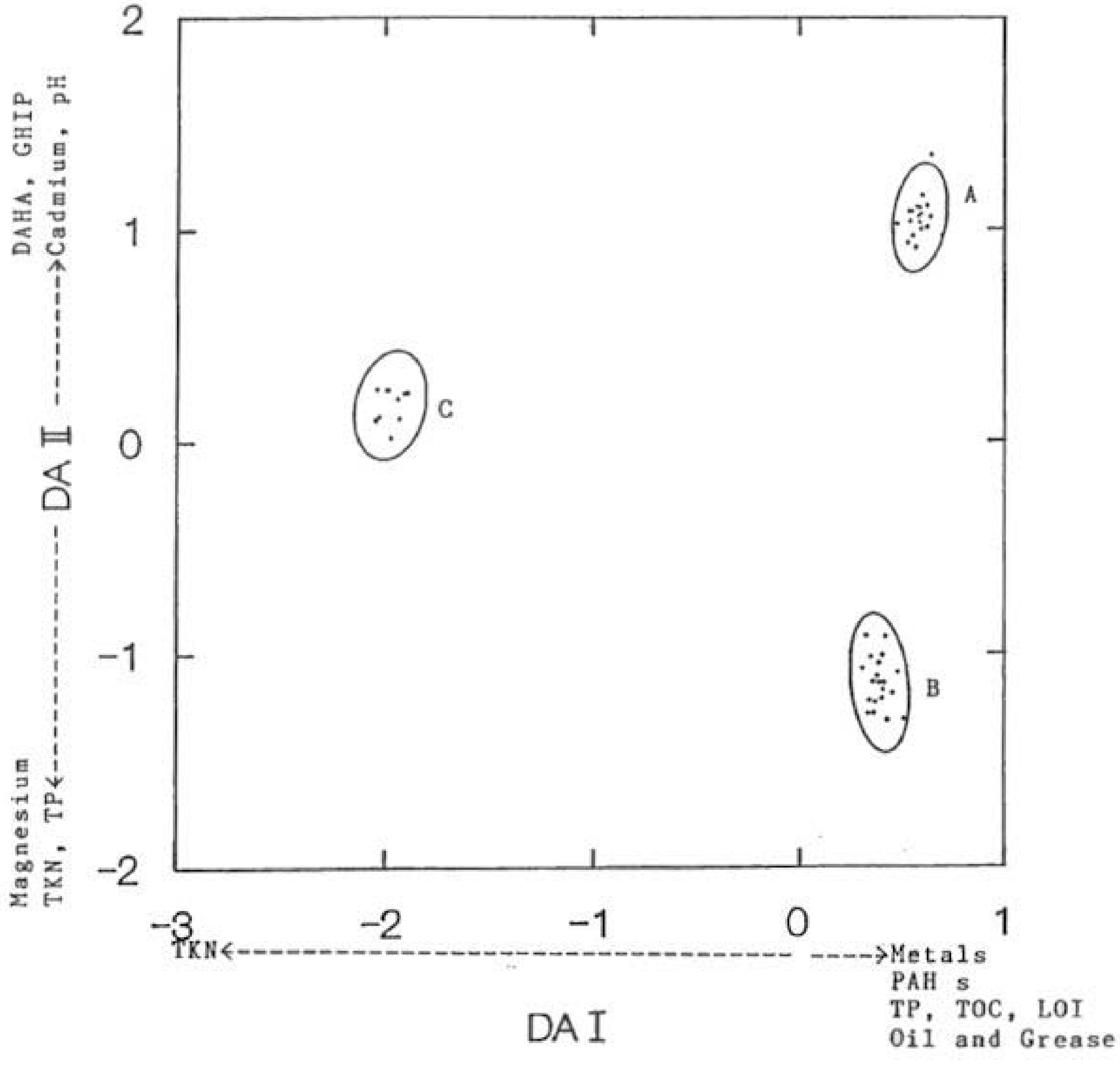


Figure 5: Plot of the benthic invertebrate communities in discriminant space as defined by the first two discriminant functions.

Table 9: Correlations between the sediment parameters and the first two discriminant functions for the benthic invertebrate communities.

Parameter	Discriminant Function	
	I	II
Chromium	0.740	-0.217
Iron	0.929	-0.007
Manganese	0.942	-0.002
Nickel	0.723	-0.250
Lead	0.897	-0.034
Zinc	0.914	-0.094
Cadmium	0.515	0.583
Magnesium	0.345	-0.537
pH	-0.034	0.635
Moisture	0.048	-0.158
TKN	-0.494	-0.643
TP	0.706	-0.633
LOI	0.370	0.091
SOLEXT	0.423	-0.313
TOC	0.612	0.087
Acenaphthene	0.524	-0.018
Acenaphthylene	0.587	0.174
Anthracene	0.755	0.299
Benzo(a)anthracene	0.812	0.209
Benzo(a)pyrene	0.830	0.281
Benzo(b)fluorene	0.841	0.253
Benzo(k)fluoranthene	0.801	0.326
Chrysene	0.831	0.255
Dibenzo(a,h)anthracene	0.695	0.445
Fluoranthene	0.852	0.146
Fluorene	0.601	0.178
Benzo(g,h,i)perylene	0.800	0.374
Indeno(1,2,3-cd)pyrene	0.812	0.345
Naphthalene	0.538	0.321
Phenanthrene	0.759	0.096
Pyrene	0.829	0.153

Table 10: Mean concentrations of the sediment parameters associated with benthic invertebrate communities. All units are expressed as µg/g, dry weight unless otherwise stated. Superscripts indicate communities that are not significantly different. ANOVA was completed on log-transformed data.

Parameter	Benthic Community			ANOVA Results	
	A (155, 169)	B (157, 87)	C (52)	F	P
Chromium	79.30^{1}	94.40^{1}	27.50	34.171	0.000
Iron	69500.01^{1}	64300.00^{1}	12020.00	144.680	0.000
Manganese	858.50^{1}	765.50^{1}	131.00	180.325	0.000
Nickel	29.40^{1}	34.80^{1}	11.32	32.839	0.000
Lead	141.40^{1}	129.65^{1}	11.34	96.698	0.000
Zinc	414.50^{1}	445.50^{1}	43.10	125.149	0.000
Cadmium	2.84	1.02^{1}	0.58^{1}	35.46	0.000
Magnesium	4245.00^{1}	5460.00	3760.00^{1}	15.98	0.000
pH	6.47^{1}	5.93	6.27^{1}	15.65	0.000
Moisture (%)	72.00	73.80	72.00	0.651	0.526
TKN (mg/g)	1.58	2.77^{1}	3.19^{1}	44.15	0.000
TP(mg/g)	0.58	1.01	0.23	197.733	0.000
LOI (mg/g)	130.50^{1}	122.60^{1}	98.90	3.977	0.025
SOLEXT	10482.20^{1}	5858.10^{1}	5708.00	8.911	0.001
TOC (mg/g)	89.90^{1}	82.70^{1}	50.3	14.490	0.000
ACNE	0.09	0.09	0.04	NA	NA
ACHY	0.21	0.16	0.05	NA	NA
ANTH	0.42	0.26	0.01	NA	NA
BAA	1.88	1.27	0.02	NA	NA
BAP	2.65	1.53	0.04	NA	NA
BBF	2.98	1.83	0.06	NA	NA
BKF	1.46	0.82	0.02	NA	NA
CHRY	2.40	1.48	0.02	71.740	0.000
DANA	0.47	0.24	0.04	NA	NA
FLAN	3.28	2.40	0.04	68.512	0.000
FLUO	0.14	0.11	0.04	NA	NA
GHIP	1.88	0.90	0.04	NA	NA
INP	2.13	1.09	0.04	NA	NA
NAPH	0.96	0.42	0.04	NA	NA
PHEN	1.22	0.97	0.07	NA	NA
PYR	2.83^{1}	2.10^{1}	0.06	57.107	0.000

NA - one or more of the communities had no variance.
Parameter abbreviations as per Table 1.

Discriminant analysis was also completed on all sampling stations separately. This allows the sampling stations themselves to be treated as separate communities. Figure 6 illustrates the separation in discriminant space of the 5 stations and Table 11 presents the correlations between the sediment parameters and the first two discriminant functions.

The first discriminant axis (DA I) indicates that the downstream stations 155, 157, 169, and to a certain extent station 87, occurred in sediments with high concentrations of metals, PAHs, TP, and TOC, whereas station 52 occurred in sediments with relatively low concentrations of these parameters and higher levels of TKN.

The second discriminant axis (DA II) separates station 169 from the remaining stations (Figure 6). This axis indicates that station 169 occurred in sediments with high pH and high levels of some PAHs including dibenzo(a,h)anthracene (DAHA) and benzo(g,h,i)perylene (GHIP).

The analysis suggests that stations 155, 157, 169 and to a certain extent station 87 reflect degraded environmental conditions due to metals and PAH contamination, as well as higher TP and TOC levels relative to station 52. Station169 is also characterized by a higher sediment pH and elevated levels of some organics such as dibenzo(a,h)-anthracene and benzo(g,h,i)perylene. The higher pH and elevated levels of some PAHs could reflect additional inputs from the upstream STP. The mean concentrations of all sediment parameters for each station are compared in Table 12.

Both discriminant analyses generally revealed the same environmental conditions with respect to the sampling stations and benthic invertebrate communities. The downstream stations (155, 157, 169, and 87) and downstream communities (A and B) reflect degraded environmental conditions with respect to metals and PAH contamination, as well as high levels of TP and TOC. This is illustrated by the dominance of oligochaetes at these stations and communities. Station 52 and community C represent relatively clean environmental conditions with respect to metals, organics, TP and TOC. The dominance of chironomids and the absence of large numbers of oligochaetes reflect the relatively unpolluted conditions at this station.

Table 11: Correlations between the sediment parameters and the first two discriminant functions for the individual stations.

Parameter	Discriminant Function	
	I	II
Chromium	0.838	0.349
Iron	0.980	0.026
Manganese	0.979	0.032
Nickel	0.798	0.429
Lead	0.928	0.085
Zinc	0.959	0.122
Cadmium	0.457	-0.269
Magnesium	0.386	0.820
pH	-0.163	-0.574
Moisture	0.183	0.504
TKN	-0.517	0.624
TP	0.679	0.459
LOI	0.519	0.108
SOLEXT	0.382	0.101
TOC	0.731	0.012
Acenaphthene	0.633	0.337
Acenaphthylene	0.703	0.009
Anthracene	0.826	-0.166
Benzo(a)anthracene	0.867	-0.224
Benzo(a)pyrene	0.855	-0.321
Benzo(b)fluorene	0.882	-0.238
Benzo(k)fluoranthene	0.820	-0.353
Chrysene	0.875	-0.226
Dibenzo(a,h)anthracene	0.708	-0.442
Fluoranthene	0.914	-0.072
Fluorene	0.719	0.180
Benzo(g,h,i)perylene	0.791	-0.443
Indeno(1,2,3-cd)pyrene	0.834	-0.314
Naphthalene	0.648	0.064
Phenanthrene	0.856	0.109
Pyrene	0.896	-0.085

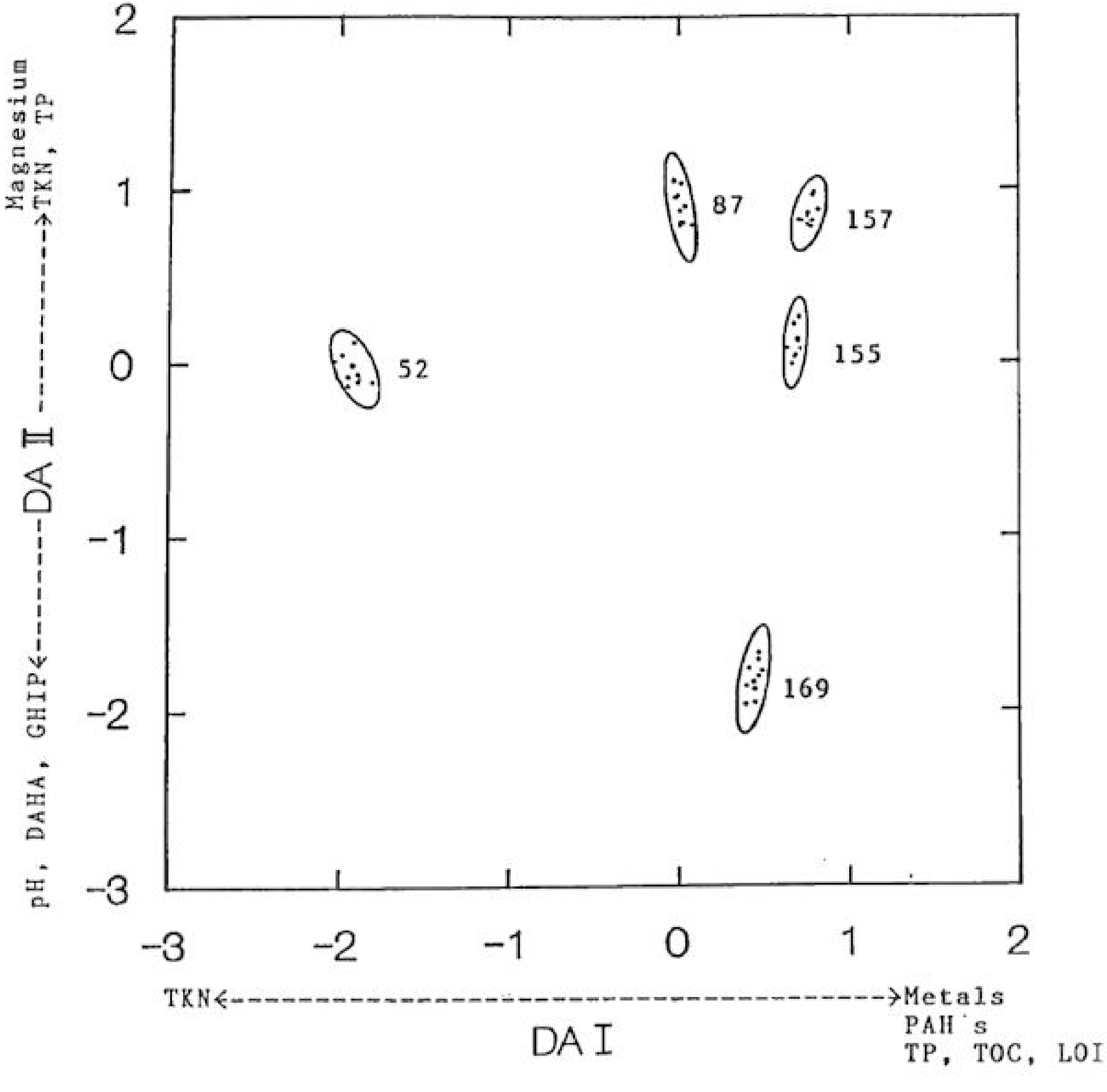


Figure 6: Plot of the individual sampling stations in discriminant space as defined by the first two discriminant functions.

Table 12 : Mean concentrations of sediment parameters associated with sampling stations. All units are expressed as µg/g, dry weight unless otherwise stated. Superscripts indicate communities that are not significantly different. ANOVA was completed on log-transformed data.

	Station					ANOVA Results	
Parameter	52	155	157	169	87	F	P
Chromium	27.50	103.90^1	124.80^1	54.70^2	64.00^2	75.034	0.000
Iron	12020.00	79100.02^1	85500.00^1	59900.00	43100.00	315.218	0.000
Manganese	131.00	998.00^1	979.00^1	719.00	552.00	277.945	0.000
Nickel	11.32	40.20^1	41.80^1	18.60	27.80	62.227	0.000
Lead	11.34	186.00^1	167.50^1	96.80^2	91.80^2	77.128	0.000
Zinc	43.10	515.00^1	613.00^1	314.00^2	278.00^2	162.681	0.000
Cadmium	0.58^1	3.80	0.68^1	1.87^2	1.36^2	41.594	0.000
Magnesium	3760.00	5280.00^1	5400.00^1	3210.00	5520.00^1	69.528	0.000
pH	6.27^1	6.38^1	5.65	6.57^1	6.21^1	20.124	0.000
Moisture (%)	72.00^1	77.80^1	77.10^{1,2}	66.20^3	70.50^{1,3}	13.253	0.000
TKN (mg/g)	3.19^1	1.74^2	2.38	1.43^2	3.15^1	30.252	0.000
TP (mg/g)	0.23	0.58^1	0.99^2	0.57^1	1.03^2	96.191	0.000
LOT (mg/g)	98.90^1	152.00^2	156.00^2	109.00^1	89.20^1	15.145	0.000
SOLEXT	5708.00^1	9184.40^{1,2}	13787.00^2	11780.00^2	17929.20^2	5.190	0.002
TOC (mg/g)	50.30^1	100.80^2	107.90^2	79.00	57.50^1	24.595	0.000
ACNE	0.04	0.12	0.10	0.06	0.07	NA	NA
ACHY	0.05	0.25	0.23	0.16	0.09	NA	NA
ANTH	0.01	0.49	0.37	0.36	0.15	NA	NA
BAA	0.02	1.85	1.83	1.90	0.71	NA	NA
BAP	0.04	2.41	2.08	2.88	0.99	NA	NA
BBF	0.06	3.03	2.55	2.93	1.10	NA	NA
BKF	0.02	1.34	1.07	1.58	0.56	NA	NA
CHRY	0.02	2,52^1	2.08^1	2.27^1	0.89	56.493	0.000
DANA	0.04	0.44	0.30	0.50	0.17	NA	NA
FLAN	0.04	3.89^1	3.45^{1,2}	2.67^2	1.35	81.549	0.000
FLUO	0.04	0.19	0.14	0.08	0.07	NA	NA
GHIP	0.04	1.58	1.09	2.18	0.72	NA	NA
INP	0.04	2.16	1.42	2.09	0.76	NA	NA
NAPH	0.04	1.56	0.69	0.36	0.15	NA	NA
PHEN	0.07	1.65	1.38	0.79	0.56	NA	NA
PYR	0.06	3.30^1	3.05^1	2.36^1	1.48	65.148	0.000

NA - one or more of the communities had no variance.
Parameter abbreviations as per Table 1.

Correlation analysis was also performed to examine relationships between total benthic invertebrate abundance and the various sediment parameters at each station. Total abundances and all the sediment parameters were log-transformed prior to analysis. Both Pearson's correlation coefficient (r) and Spearman's rank correlations (r_s) were calculated. Both correlations, r and r_s can be compared to confirm that parametric assumptions are met by the data. Only significant correlations for both r and r_s are discussed. Some caution should be used in interpreting the statistical significance of the large number of correlations between total abundances and the various sediment parameters at each station, since the various sediment parameters may not be independent of each other.

The correlations between sediment metal concentrations and total benthic invertebrate abundance are presented in Table 13. Significant relationships were observed for some metals at stations 52, 155, and 157. Positive correlations were found between cadmium, lead, and zinc concentrations, and total abundance at station 52. Although abundance counts were only available from the top 3 depth increments of the sediment core, this positive correlation indicates that the higher cadmium, lead, and zinc levels were associated with the higher abundance counts.

Significant correlations of sediment magnesium, manganese, nickel, and lead concentrations with total abundance were observed at station 155. Manganese, nickel, and lead were negatively correlated to total abundance, possibly indicating toxic inhibition of the benthic community. Magnesium was positively correlated to total abundance, indicating greater benthic invertebrate abundance with higher sediment levels of magnesium. Total abundance at station 157 was negatively correlated with lead levels, possibly indicating a toxic effect on the benthic community.

As noted above, total abundance at stations 155 and 157 was negatively correlated to lead levels in the sediment. Sediments at these stations had mean lead concentrations of 186 µg/g and 167.5 µg/g, respectively (Table 12), which were 15 to 17 times higher those found at the control station.

Correlations between sediment chemistry and nutrient parameters, and total benthic invertebrate abundance are presented in Table 14.Significant relationships were observed for some parameters at stations 52, 157, and 169. The total abundance at station 52 was positively correlated to TP, TOC, and LOI. Abundances at stations 157 and 169 were positively correlated to sediment moisture levels and TKN, respectively.

The results of the correlations between the various PAH compounds and total benthic invertebrate abundance are presented in Table 15.Significant relationships were observed at station 52 and station 157. Correlations could not be obtained for 13 of the 16 PAHs at station 52 because their concentrations exhibited no variance. The significant positive relationships that were observed for chrysene, fluoranthene, and pyrene, however, should be interpreted with extreme caution, since most of the PAH compounds were at very low concentrations and were considered tentative values for information purposes only.

A number of negative correlations were found at station 157, possibly suggesting a toxic impact on benthic invertebrate abundance at this station. Significant negative correlations were found between total abundance and the concentrations of anthracene, benzo(a) anthracene, benzo(a)pyrene, benzo(b)fluorene, and chrysene.

Mantel's test indicated that no significant association exists between distance matrices based on the PCA of the benthic invertebrate communities and those based on discriminant analysis of the sediment chemistry data (p=0.275). Spearman's test statistic also showed no significant association (p=0.217).

The weak association between the two distance matrices could be due several factors. These include: (i) the use of two different statistical tests (PCA and discriminant analysis); (ii) the effects of substrate characteristics (sediment particle sizes); and/or (iii) the unknown effects of other undetermined environmental parameter(s) not evaluated in the discriminant analyses. In addition, the response of the benthic community at each station could differ because the sediment chemistry varies from station to station.

Table 13 : Correlations and associated P-values between sediment metal concentrations and benthic invertebrate abundance. Data was log-transformed prior to analysis. Significant relationships are in bold type. r = Pearson's Correlation Coefficient; r_s = Spearman's Rank Correlation.

Metal	Corr. Coef.	Station				
		52	87	155	157	169
Cd	r	0.870 (0.001)	0.373 (0.289)	0.637 (0.048)	-0.101 (0.781)	0.114 (0.755)
	r_s	0.785 (0.007)	0.168 (0.642)	0.468 (0.172)	-0.240 (0.504)	-0.042 (0.908)
Cr	r	0.064 (0.860)	0.354 (0.315)	-0.634 (0.049)	-0.157 (0.665)	-0.384 (0.273)
	r_s	-0.136 (0.707)	0.302 (0.397)	-0.434 (0.210)	-0.263 (0.462)	-0.541 (0.107)
Fe	r	0.504 (0.137)	0.359 (0.308)	-0.671 (0.034)	-0.292 (0.413)	-0.086 (0.813)
	r_s	0.601 (0.066)	0.404 (0.247)	-0.424 (0.222)	-0.298 (0.402)	-0.221 (0.540)
Mg	r	-0.061 (0.866)	0.360 (0.307)	0.816 (0.004)	-0.447 (0.196)	-0.111 (0.759)
	r_s	-0.265 (0.459)	0.365 (0.300)	0.742 (0.014)	-0.668 (0.035)	-0.204 (0.572)
Mn	r	0.437 (0.206)	0.339 (0.339)	-0.749 (0.013)	-0.406 (0.245)	-0.169 (0.641)
	r_s	0.506 (0.136)	0.460 (0.181)	-0.761 (0.011)	-0.562 (0.091)	-0.413 (0.235)
Ni	r	0.316 (0.374)	0.398 (0.255)	-0.795 (0.006)	-0.486 (0.154)	0.150 (0.679)
	r_s	0.232 (0.520)	0.486 (0.154)	-0.834 (0.003)	-0.771 (0.009)	-0.003 (0.993)
Pb	r	0.811 (0.004)	0.224 (0.534)	-0.789 (0.007)	-0.643 (0.045)	-0.398 (0.254)
	r_s	0.798 (0.006)	0.351 (0.320)	-0.806 (0.005)	-0.794 (0.006)	-0.469 (0.172)
Zn	r	0.785 (0.007)	0.401 (0.250)	-0.580 (0.079)	-0.114 (0.754)	-0.387 (0.269)
	r_s	0.788 (0.007)	0.588 (0.074)	-0.569 (0.086)	0.028 (0.940)	-0.521 (0.122)

Notes:

(1) Parameter Abbreviations as per Table 1.

(2) Correlations with probabilities between 0.01 and 0.05 should be interpreted with caution as actual probabilities may be smaller.

Table 14 : Correlations and associated P-values between sediment chemistry and nutrient parameters, and benthic invertebrate abundance. Data was log-transformed prior to analysis. Significant relationships are in bold type. r_s = Pearson's Correlation Coefficient; r_s . Spearman's Rank Correlation.

Param.	Corr. Coef.	Station				
		52	155	157	169	87
pH	r	-0.148 (0.752)	-0.434 (0.210)	0.145 (0.689)	0.094 (0.796)	0.299 (0.402)
	r_s	-0.412 (0.358)	-0.355 (0.314)	0.028 (0.940)	0.035 (0.923)	-0.166 (0.646)
Moist	r	0.552 (0.098)	0.269 (0.453)	0.718 (0.019)	0.571 (0.085)	-0.357 (0.311)
	r_s	0.790 (0.007)	0.516 (0.127)	0.660 (0.038)	0.605 (0.064)	-0.079 (0.827)
TKN	r	0.545 (0.103)	-0.454 (0.259)	0.363 (0.303)	0.757 (0.011)	-0.153 (0.673)
	r_s	0.713 (0.021)	-0.197 (0.641)	-0.104 (0.775)	0.833 (0.003)	-0.266 (0.458)
TP	r	0.708 0.022	-0.301 (0.468)	0.278 (0.437)	-0.233 (0.517)	0.136 (0.707)
	r_s	0.735 (0.016)	-0.010 (0.980)	0.383 (0.274)	-0.354 (0.316)	0.203 (0.574)
SOLEXT	r	-0.539 (0.108)	-0.281 (0.431)	-0.207 (0.566)	0.429 (0.216)	-0.353 (0.265)
	r_s	-0.500 (0.141)	0.147 (0.686)	-0.018 (0.960)	0.343 (0.332)	-0.202 (0.575)
TOC	r	0.829 (0.003)	-0.078 (0.831)	0.082 (0.822)	0.451 (0.191)	0.390 (0.317)
	r_s	0.768 (0.009)	-0.191 (0.598)	-0.182 (0.615)	0.480 (0.161)	0.458 (0.183)
LOI	r	0.826 (0.003)	-0.015 (0.968)	-0.231 (0.321)	0.408 (0.242)	0.351 (0.320)
	r_s	0.768 (0.009)	-0.389 (0.266)	-0.244 (0.497)	0.344 (0.331)	0.383 (0.275)

Notes:

(1) Parameter Abbreviations as per Table 1.

(2) Correlations with probabilities between 0.01 and 0.05 should be interpreted with caution as actual probabilities may be smaller.

Table 15 : Correlations and associated P-values between sediment PAH concentrations and benthic invertebrate abundance. Data was log-transformed prior to analysis. Significant relationships are in bold type. r = Pearson's Correlation Coefficient; r_5 = Spearman's Rank Correlation.

PAH	Corr. Coef.	Station				
		52	155	157	169	87
ACNE	r	NA	-0.162 (0.655)	-0.426 (0.220)	-0.099 (0.786)	-0.141 (0.698)
	r_s	NA	-0.454 (0.188)	-0.563 (0.090)	-0.133 (0.714)	-0.264 (0.462)
ACNY	r	NA	-0.112 (0.759)	-0.251 (0.484)	-0.249 (0.487)	0.061 (0.868)
	r_s	NA	-0.236 (0.511)	-0.089 (0.807)	-0.476 (0.164)	-0.127 (0.727)
ANTH	r	NA	-0.242 (0.501)	-0.669 (0.034)	-0.155 (0.669)	-0.133 (0.714)
	r_s	NA	-0.343 (0.333)	-0.774 (0.009)	-0.182 (0.614)	-0.290 (0.416)
BAA	r	NA	-0.206 (0.568)	-0.689 (0.027)	-0.331 (0.350)	-0.142 (0.696)
	r_s	NA	-0.416 (0.232)	-0.795 (0.006)	-0.453 (0.189)	0.112 (0.758)
BAP	r	NA	-0.332 (0.349)	-0.644 (0.044)	-0.463 (0.178)	-0.139 (0.703)
	r_s	NA	-0.444 (0.198)	-0.777 (0.008)	-0.534 (0.112)	0.113 (0.715)
BBF	r	NA	-0.422 (0.224)	-0.659 (0.038)	-0.381 (0.277)	-0.189 (0.602)
	r_s	NA	-0.540 (0.107)	-0.807 (0.005)	-0.516 (0.126)	-0.043 (0.905)
BKF	r	NA	-0.426 (0.219)	-0.627 (0.053)	-0.369 (0.294)	-0.141 (0.698)
	r_s	NA	-0.522 (0.122)	-0.777 (0.008)	-0.516 (0.126)	0.129 (0.722)
CHRY	r	0.694 (0.026)	-0.305 (0.392)	-0.664 (0.036)	-0.363 (0.303)	-0.131 (0.718)
	r_s	0.766 (0.010)	-0.431 (0.214)	-0.826 (0.003)	-0.469 (0.172)	0.108 (0.767)
DAHA	r	NA	-0.273 (0.445)	-0.671 (0.034)	-0.461 (0.180)	-0.062 (0.865)
	r_s	NA	-0.258 (0.471)	-0.605 (0.064)	-0.502 (0.139)	0.145 (0.689)

Notes:

(1) Parameter Abbreviations as per Table 1.

(2) Correlations with probabilities between 0.01 and 0.05 should be interpreted with caution as actual probabilities may be smaller.

Table 15: (Continued)

PAH	C. Coef.	Station				
		52	155	157	169	87
FLAN	r	0.793 (0.006)	-0.226 (0.530)	-0.619 (0.057)	-0.195 (0.590)	-0.129 (0.723)
	r_s	0.860 (0.001)	-0.385 (0.272)	-0.835 (0.003)	-0.296 (0.406)	-0.016 (0.966)
FLUO	r	NA	-0.175 (0.629)	-0.194 (0.591)	-0.000 (1.000)	-0.311 (0.382)
	r_s	NA	-0.251 (0.485)	-0.180 (0.619)	-0.058 (0.874)	-0.351 (0.320)
GHIP	r	NA	-0.361 (0.305)	-0.537 (0.109)	-0.417 (0.231)	-0.112 (0.759)
	r_s	NA	-0.252 (0.430)	-0.373 (0.288)	-0.497 (0.144)	0.147 (0.685)
INP	r	NA	-0.390 (0.265)	-0.592 (0.071)	-0.468 (0.172)	-0.107 (0.768)
	r_s	NA	-0.252 (0.483)	-0.483 (0.157)	-0.574 (0.083)	0.132 (0.716)
NAPH	r	NA	-0.424 (0.223)	-0.301 (0.398)	0.211 (0.559)	-0.251 (0.484)
	r_s	NA	-0.570 (0.086)	-0.348 (0.325)	-0.073 (0.840)	-0.479 (0.162)
PHEN	r	NA	-0.215 (0.551)	-0.579 (0.080)	0.610 (0.061)	-0.139 (0.703)
	r_s	NA	-0.320 (0.363)	-0.736 (0.015)	0.424 (0.222)	-0.394 (0.260)
PYR	r	0.566 (0.088)	-0.203 (0.574)	-0.603 (0.065)	-0.186 (0.606)	-0.124 (0.732)
	r_s	0.643 (0.045)	-0.385 (0.272)	-0.826 (0.003)	-0.355 (0.314)	0.025 (0.945)

Notes:

(1) Parameter Abbreviations as per Table 1.

(2) Correlations with probabilities between 0.01 and 0.05 should be interpreted with caution as actual probabilities may be smaller.

Conclusions

The following summarizes the analysis of the benthic macroinvertebrate data from the 1987 St. Marys River sediment cores:

1. More benthic invertebrate species were found at the downstream stations than at station 52, the upstream control site.

2. The total benthic invertebrate diversity ranged from a high of 2.91 at station 155 to a low of 2.17 at station 87. Benthic invertebrate diversities did not significantly differ among stations 155, 157, and 169 and diversities at stations 52 and 87 were not significantly different.

3. Diversity varied with core depth at all stations, but generally decreased with increasing core depth. The exception was station 87, where diversity was higher at the mid-core depths.

4. Stations located downstream of the Sault Ste. Marie locks and industrial sources had higher total invertebrate abundances than the upstream control site. Station 155 had the highest total abundance (15,053 individuals/m^2) and station 52 had the lowest (2,937 individuals/m^2).

5. Benthic invertebrate abundance generally decreased as core depth increased for all stations, with the exception of station 87 where total abundance peaked in the middle of the core. Significant relationships were found between total abundance and core depth at station 52 ($r=-0.797$, $p=0.006$), station 155 ($r=-0.836$, $p=0.003$), and station 157 ($r=-0.802$, $p=0.005$).

6. The downstream benthic communities were characterized by large numbers of oligochaetes, whereas the upstream station was characterized by various chironomid species. Stations 155 and 169 were dominated by naidid oligochaetes and stations 157 and 87 were dominated by tubificid oligochaetes.

7. The large numbers of oligochaetes at the downstream stations and the discriminant analyses indicate organic enrichment at these sites.

8. Sediment cores at the downstream stations were characterized by high concentrations of metals, PAHs, TP, and TOC. In contrast, upstream station 52 had relatively low concentrations of these parameters and higher levels of TKN. Station 169 was also characterized by sediments with higher levels of some PAH contaminants including dibenzo(a,h)anthracene and benzo(g,h,i)perylene, and a higher pH.

9. Significant correlations were found between several sediment parameters, such as metals, PAHs and nutrients, and total benthic invertebrate abundance at some stations.

10. The multivariate summary of the invertebrate community based on principal components analysis did not correlate significantly with the summary based on a discriminant analysis of the sediment chemistry data. This result suggests that other factors such as sediment particle size also influences the biotic community.

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Appendix I

Species List

Species List

Oligocheata

Naididae

Pristinella ienkinae
Pristinella acuminata
Pristinela osborni
Vejdovskyella intermedia
Slavina appendiculata
Stylaria lacustris
Arcteonais lomondi
Naididae (immature)

Tubificidae

Limnodrilus udekemianus
Limnodrilus profundicola
Limnodrilus hoffmeisteri
Limnodrilus sp.
Quistadrilus multisetosus
Aulodrilus pluriseta
Aulodrilus piqueti
Isochaetides freyi
Tubificidae (immature)

Diptera
Chironomidae
Cryptochironomus sp.
Parachironomus sp.
Tanytarsini

Diptera (adult, head damaged, antennae gone) **

** — found in top layer, considered an artifact as there are no adult aquatic Diptera.

Appendix II

Species Counts

TAXON	Station 12										
Depth	0-2	2-4	4-6	6-8	8-10	10-12	12-14	14-16	16-18	18-20	TOTAL
NAIDIDAE											
Pristinella jenkinae											0
Pristinella acuminata			1								1
Pristinella osborni											0
Vejdovskyella intermedia											0
Slavina appendiculata											0
Stylaria lacustris											0
Arcteonais lomondi											0
Nadidae (immature)											0
TUBIFICIDAE											
Limnodrilus udekemianus											0
Limnodrilus profundicola											0
Limnodrilus hoffmeisteri											0
Limnodrilus sp.											0
Quistadrilus multisetosus											0
Aulodrilus pluriseta											0
Aulodrilus piqueti											0
Isochaetides freyi											0
Tubificidae (immature)	1		1								2
CHIRONOMIDAE											
Cryptochironomus sp.	1										1
Parachironomus sp.	0	1	1								2
Tanytarsini	2										2
Total	4	1	3	0	0	8	0	0	0	0	8

TAXON	Station 155										
Depth	0-2	2-4	4-6	6-5	8-10	10-12	12-14	14-16	16-18	18-20	TOTAL
NAIDIDAE											
Pristinella jenkinae	1			1		1					3
Pristinella acuminata	2				2						4
Pristinella osborni								I			I
Vejdovskyella intermedia											0
Slavina appendiculata	11		1								12
Stylaria lacustris	2										2
Arcteonais lomondi	3			1							4
Nadidae (immature)	1		1	2							5
TUBIFICIDAE											
Limnodrilus udekemianus											0
Limnodrilus profundicola											0
Limnodrilus hoffmeisteri											0
Limnodrilus sp.											0
Quistadrilus multisetosus	2	1	3								6
Aulodrilus pluriseta											0
Aulodrilus piqueti											0
Isochaetides freyi											0
Tubificidae (immature)	1	1				1	1				4
CHIRONOMIDAE											
Cryptochironomus sp.											0
Parachironomus sp.											0
Tanytarsini											0
Total	23	2	5	4	3	2	1	1	0	0	41

TAXON	Station 157									
Depth	0-2	2-4	4-6	6-5	8-10	10-12	12-14	14-16	16-18	18-20
NAIDIDAE										
Pristinella jenkinae				1	1					
Pristinella acuminata				1						
Pristinella osborni										
Vejdovskyella intermedia										
Slavina appendiculata	2									
Stylaria lacustris										
Arcteonais lomondi										
Nadidae (immature)	2									
TUBIFICIDAE										
Limnodrilus udekemianus					1					
Limnodrilus profundicola										
Limnodrilus hoffmeisteri										
Limnodrilus sp.					4	1	1	1		
Quistadrilus multisetosus	1		1	1						
Aulodrilus pluriseta	1	1								
Aulodrilus piqueti		1								
Isochaetides freyi										
Tubificidae (immature)	1	1	3	2	2	1				
CHIRONOMIDAE										
Cryptochironomus sp.										
Parachironomus sp.										
Tanytarsini										
Total	7	3	4	5	8	2	1	1	0	0

TAXON	Station 169									
Depth	0-2	2-4	4-6	6-5	8-10	10-12	12-14	14-16	16-18	18-20
NAIDIDAE										
Pristinella jenkinae		1								
Pristinella acuminata	2	2								
Pristinella osborni										
Vejdovskyella intermedia	1									
Slavina appendiculata	5		1							
Stylaria lacustris	4									
Arcteonais lomondi										
Nadidae (immature)	1									
TUBIFICIDAE										
Limnodrilus udekemianus										
Limnodrilus profundicola										
Limnodrilus hoffmeisteri										
Limnodrilus sp.										
Quistadrilus multisetosus	1		1	1						
Aulodrilus pluriseta										
Aulodrilus piqueti										
Isochaetides freyi							1			
Tubificidae (immature)	1		1	1			1		2	
CHIRONOMIDAE										
Cryptochironomus sp.										
Parachironomus sp.										
Tanytarsini										
Total	15	3	3	2	0	0	2	0	2	0

TAXON	Station 87									
Depth	0-2	2-4	4-6	6-5	8-10	10-12	12-14	14-16	16-18	18-20
NAIDIDAE										
Pristinella jenkinae										
Pristinella acuminata										
Pristinella osborni										
Vejdovskyella intermedia										
Slavina appendiculata										
Stylaria lacustris										
Arcteonais lomondi										
Nadidae (immature)							1			
TUBIFICIDAE										
Limnodrilus udekemianus					1					
Limnodrilus profundicola							1	1		
Limnodrilus hoffmeisteri				1		1				1
Limnodrilus sp.		1	1	1	2			1		1
Quistadrilus multisetosus										
Aulodrilus pluriseta										
Aulodrilus piqueti										
Isochaetides freyi										
Tubificidae (immature)				2	2	3	1			
CHIRONOMIDAE										
Cryptochironomus sp.										
Parachironomus sp.										
Tanytarsini										
Total	0	1	1	4	5	4	3	2	0	2

Appendix III

Species Abundances

TAXON	Abundance (number/m^2) - Station 52										
Depth	0-2	2-4	4-6	6-5	8-10	10-12	12-14	14-16	16-18	18-20	TOTAL
NAIDIDAE											
Pristinella jenkinae											
Pristinella acuminata			367								367
Pristinella osborni											
Vejdovskyella intermedia											
Slavina appendiculata											
Stylaria lacustris											
Arcteonais lomondi											
Nadidae (immature)											
TUBIFICIDAE											
Limnodrilus udekemianus											
Limnodrilus profundicola											
Limnodrilus hoffmeisteri											
Limnodrilus sp.											
Quistadrilus multisetosus											
Aulodrilus pluriseta											
Aulodrilus piqueti											
Isochaetides freyi											
Tubificidae (immature)	367		367								734
CHIRONOMIDAE											
Cryptochironomus sp.	367										367
Parachironomus sp.		367	367								734
Tanytarsini	734										734
Total	1468	367	1101	0	0	0	0	0	0	0	2936

TAXON Depth	Abundance (number / m^2) - Station155 0-2	2-4	4-6	6-5	8-10	10-12	12-14	14-16	16-18	18-20	TOTAL
NAIDIDAE											
Pristinella jenkinae	367			367		367					1101
Pristinella acuminata	734				734						1468
Pristinella osborni								367			367
Vejdovskyella intermedia											0
Slavina appendiculata	4039		367								4406
Stylaria lacustris	734										734
Arcteonais lomondi	1101			367							1468
Nadidae (immature)	367		367	734	367						1835
TUBIFICIDAE											
Limnodrilus udekemianus											0
Limnodrilus profundicola											0
Limnodrilus hoffmeisteri											0
Limnodrilus sp.											0
Quistadrilus multisetosus	734	367	1101								2202
Aulodrilus pluriseta											0
Aulodrilus piqueti											0
Isochaetides freyi											0
Tubificidae (immature)	367	367				367	367				1468
CHIRONOMIDAE											
Cryptochironomus sp.											0
Parachironomus sp.											0
Tanytarsini											0
Total	8443	734	1835	1468	1101	734	367	367	0	0	15049

TAXON	Abundance (number/m^2) - Station 157										
Depth	0-2	2-4	4-6	6-5	8-10	10-12	12-14	14-16	16-18	18-20	TOTAL
NAIDIDAE											
Pristinella jenkinae				367	367						734
Pristinella acuminata				367							367
Pristinella osborni											0
Vejdovskyella intermedia											0
Slavina appendiculata	734										734
Stylaria lacustris											0
Arcteonais lomondi											0
Nadidae (immature)	734										734
TUBIFICIDAE											
Limnodrilus udekemianus					367						367
Limnodrilus profundicola											0
Limnodrilus hoffmeisteri											0
Limnodrilus sp.					1469	367	367	367			2570
Quistadrilus multisetosus	367		367	367							1101
Aulodrilus pluriseta	367	367									734
Aulodrilus piqueti		367									367
Isochaetides freyi											0
Tubificidae (immature)	367	367	1101	734	734	367					3670
CHIRONOMIDAE											
Cryptochironomus sp.											0
Parachironomus sp.											0
Tanytarsini											0
Total	2569	1101	1468	1835	2937	734	367	367	0	0	11378

TAXON	Abundance (number/ m^2) - Station 169										
Depth	0-2	2-4	4-6	6-5	8-10	10-12	12-14	14-16	16-18	18-20	TOTAL
NAIDIDAE											
Pristinella jenkinae		367									367
Pristinella acuminata	734	734									1468
Pristinella osborni											0
Vejdovskyella intermedia	367										367
Slavina appendiculata	1836		367								2203
Stylaria lacustris	1469										1469
Arcteonais lomondi											0
Nadidae (immature)	367										367
TUBIFICIDAE											
Limnodrilus udekemianus											0
Limnodrilus profundicola											0
Limnodrilus hoffmeisteri											0
Limnodrilus sp.											0
Quistadrilus multisetosus	367		367	367							1101
Aulodrilus pluriseta											0
Aulodrilus piqueti											0
Isochaetides freyi							367				367
Tubificidae (immature)	367		367	367			367		734		2202
CHIRONOMIDAE											
Cryptochironomus sp.											
Parachironomus sp.											
Tanytarsini											
Total	5507	1101	1101	734	0	0	734	0	734	0	9911

TAXON	Abundance (number/m^2) - Station 87										
Depth	0-2	2-4	4-6	6-5	8-10	10-12	12-14	14-16	16-18	18-20	TOTAL
NAIDIDAE											
Pristinella jenkinae											
Pristinella acuminata											
Pristinella osborni											
Vejdovskyella intermedia											
Slavina appendiculata											
Stylaria lacustris											
Arcteonais lomondi											
Nadidae (immature)							367				367
TUBIFICIDAE											
Limnodrilus udekemianus					367						367
Limnodrilus profundicola							367	367			734
Limnodrilus hoffmeisteri				367		367				367	1101
Limnodrilus sp.		367	367	367	734			367		367	2569
Quistadrilus multisetosus											0
Aulodrilus pluriseta											0
Aulodrilus piqueti											0
Isochaetides freyi											0
Tubificidae (immature)				734	734	1101	367				2936
CHIRONOMIDAE											
Cryptochironomus sp.											0
Parachironomus sp.											0
Tanytarsini											0
Total	0	367	367	1468	1835	1468	1101	734	0	734	8074