INVESTIGATION OF THE SPANISH RIVER AREA OF THE NORTH CHANNEL OF LAKE HURON

II. BENTHIC INVERTEBRATE COMMUNITY STRUCTURE AND SEDIMENT TOXICITY; WITH REFERENCE TO BIOLOGICAL SEDIMENT GUIDELINES

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Abstract

The results of surveys of invertebrate community structure, sediment chemistry and sediment toxicity from 1988 and 1990 in the Spanish River mouth and Whalesback Channel are summarized. In 1988 17 sites were sampled at the mouth of the Spanish River. These data suggested severely degraded inverebrate communities in the Whalesback Channel area associated with high levels of metals, particularly nickel, copper and zinc, in the sediments. As a result of these data a subsequent, more extensive, survey was conducted including more than 40 sites in the Whalesback and North Channel. These data were compared with results from 49 reference sites in the North Channel sampled as part of an Environment Canada programme to develop biological sediment guidelines. Comparison with the reference site data show that there is extensive impairment in the Whalesback Channel and most of the channel has a degraded benthic community, thus impairment extends a considerable distance beyond the area of concern boundary. This is shown both from the comparison with the reference sites from the North Channel and from the predictions based on the entire Great Lakes reference sites. Furthermore, it would appear that there is evidence of some effect being felt in the North Channel in the area where the major water exchange is occurring between the Whalesback and North Channel. A comparison of the environmental characteristics at those sites where degraded communities occur provides strong evidence that the impairment is associated with high levels of metals, particularly copper, nickel and zinc. However, it is not possible to distinguish any particular metal of concern as their distributions are highly correlated.

Sediment toxicity data do not confirm that the degraded benthic communities are related to high metal levels. However, there are some confounding factors that may explain the lack of concordance in these data.

Finally, it is possible from the reference site data to set targets that will indicate recovery of the benthic community and also to establish sediment concentrations for metals at which a recovery can be expected. The numeric criteria we would propose for the impacted area are 1490 m^2 Chironomidae for inshore waters and for *D. hoyi* in the offshore waters 1637 m^2 .

Introduction

In 1980 the lower Spanish River and its harbour area were designated as an "Area of Concern" based on a summary assessment undertaken in 1980. The problems identified were tainting of fish flesh, degraded benthic fauna and indications of nutrient enrichment, restrictions on domestic water use, livestock watering and impaired fish habitat. In addition concentrations of PCBs and some metals in the harbour sediments were found to exceed provincial guidelines for the open water disposal of dredge spoils.

Ongoing abatement at the E.B. Eddy Forest Products Limited pulp and paper mill in Espanola has resulted in significant improvements in water quality and recovery of benthic invertebrate communities in the Spanish River has been documented by consultants (Spanish River RAP 1988). There has also been a reduction in fish tainting and potable water taste and odour problems (Spanish River RAP 1988). However, results of sediment analyses in 1986 in the harbour area continued to show elevated metal concentrations, particularly nickel and copper, which may originate from metal mining activity in the Sudbury area.

The National Water Research Institute (N.W.R.I.) of Environment Canada, with the support of the Great Lakes Cleanup Fund, conducted extensive sampling of the sediments in the Spanish River harbour area and the depositional zones of the Whalesback Channel and North Channel in 1988 and 1990. The study was intended to identify far field effects from the Spanish River mouth on benthic invertebrate communities and document the extent of sediment contamination.

Description of Spanish River

The Spanish River watershed (14,000 km^2) is located on the Canadian Shield, and from its headwaters the river flows south and enters the North Channel of Lake Huron near the village of Spanish. The watershed consists of network of rivers and lakes regulated by numerous control structures which are operated to maximize hydro electric power generation in the downstream reaches. Significant tributaries to the Spanish River include the Wakonissin, Vermillion and Aux Sables rivers. The Vermilion R. drains the greater part of the Sudbury metal mining basin and its confluence with the Spanish R. is just upstream of Espanola.

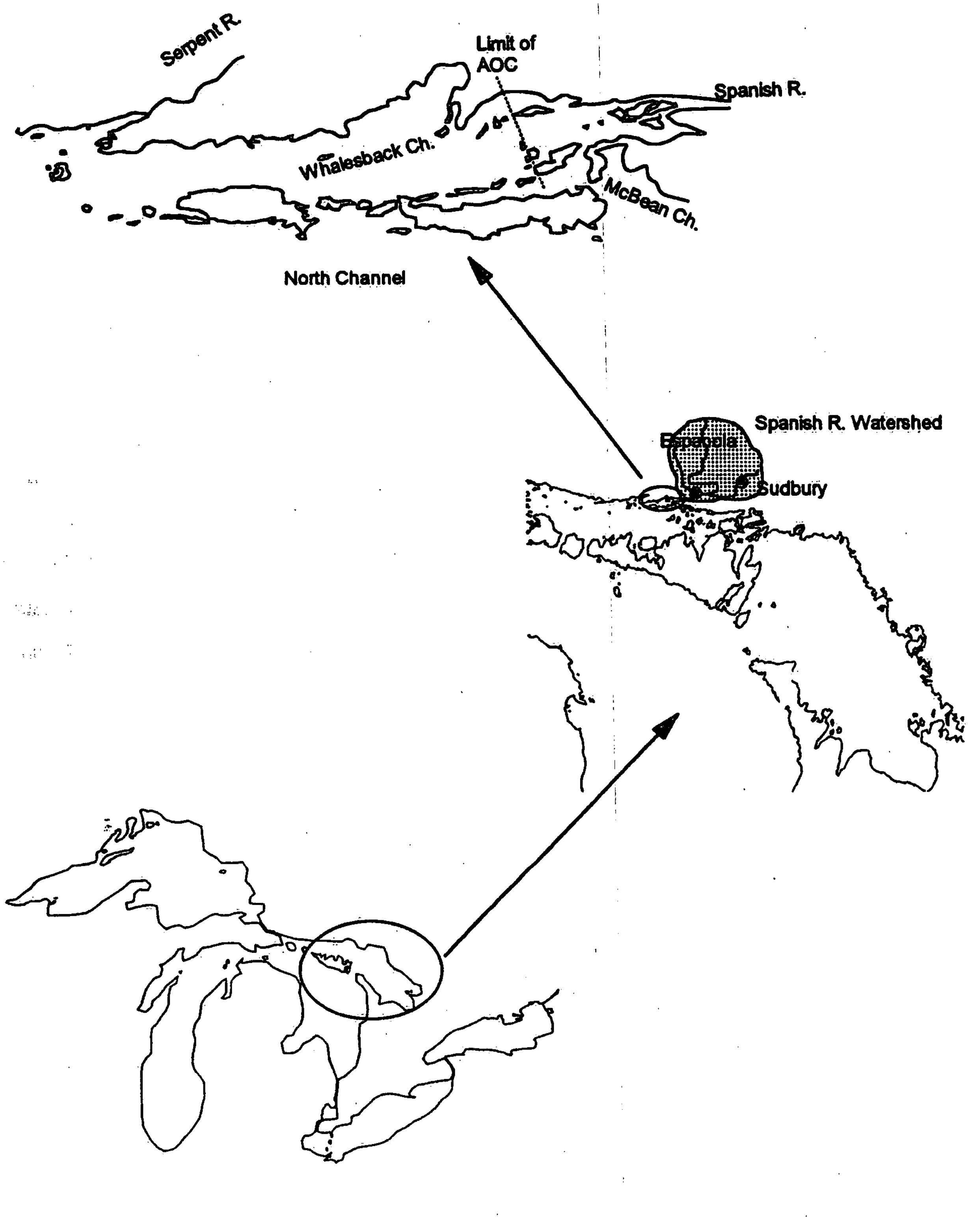


Figure 1. North Channel Study Area

The Area of Concern includes the reach of river below Espanola (52 km) and the harbour area west of the river mouth to a north south line between Kirke and Greene Islands (Figure 1). To investigate the far field effects of the Area of Concern the study area was expanded to include the whole of the Whalesback Channel, the McBean Channel and the North Channel (Fig. 1). In addition to provide reference information 335 sites sampled in the entire Great Lakes (Reynoldson *et al.* 1995a) were used as a basis for comparison.

Methods

Sampling areas

The location of each site was established in the field using either Loran C or a hand-held Geographical Positioning System (GPS). At each site, samples were taken of sediment for chemical and physical analysis; in addition, samples were collected for the community structure of the benthic macroinvertebrates and in 1990 for whole-sediment exposures in the laboratory with the oligochaete worm *Tubifex tubifex*. Sites were sampled once in June or July in 1988 and 1990. In 1988 17 sites were sampled, concentrating on the Whalesback Channel (Fig. 2) and particularly depositional zones. In 1990 49 sites were sampled to provide more complete coverage of the Whalesback Channel and to investigate possible effects in the North Channel. In 1988 only sediment chemistry and invertebrate community structure were examined. In 1990 sediment toxicity was also examined.

In addition data are presented from an Environment Canada programme developing biological sediment guidelines that sampled 335 "reference sites" in the Great Lakes. From these data expected or normal conditions for invertebrate communities, sediment characteristics and toxicity test responses are being established (Reynoldson *et al.* 1995a, 1995b). In particular 49 "reference sites" from the North Channel (Fig. 3) have been used for comparison purposes.

Field and Laboratory Techniques

Sediments were characterized from samples taken using a benthos corer. Samples for geochemical analysis (Table 1) were taken from the surface 2 cm of the core. After sampling, the sediment was homogenized in a glass dish with a nalgene spoon.

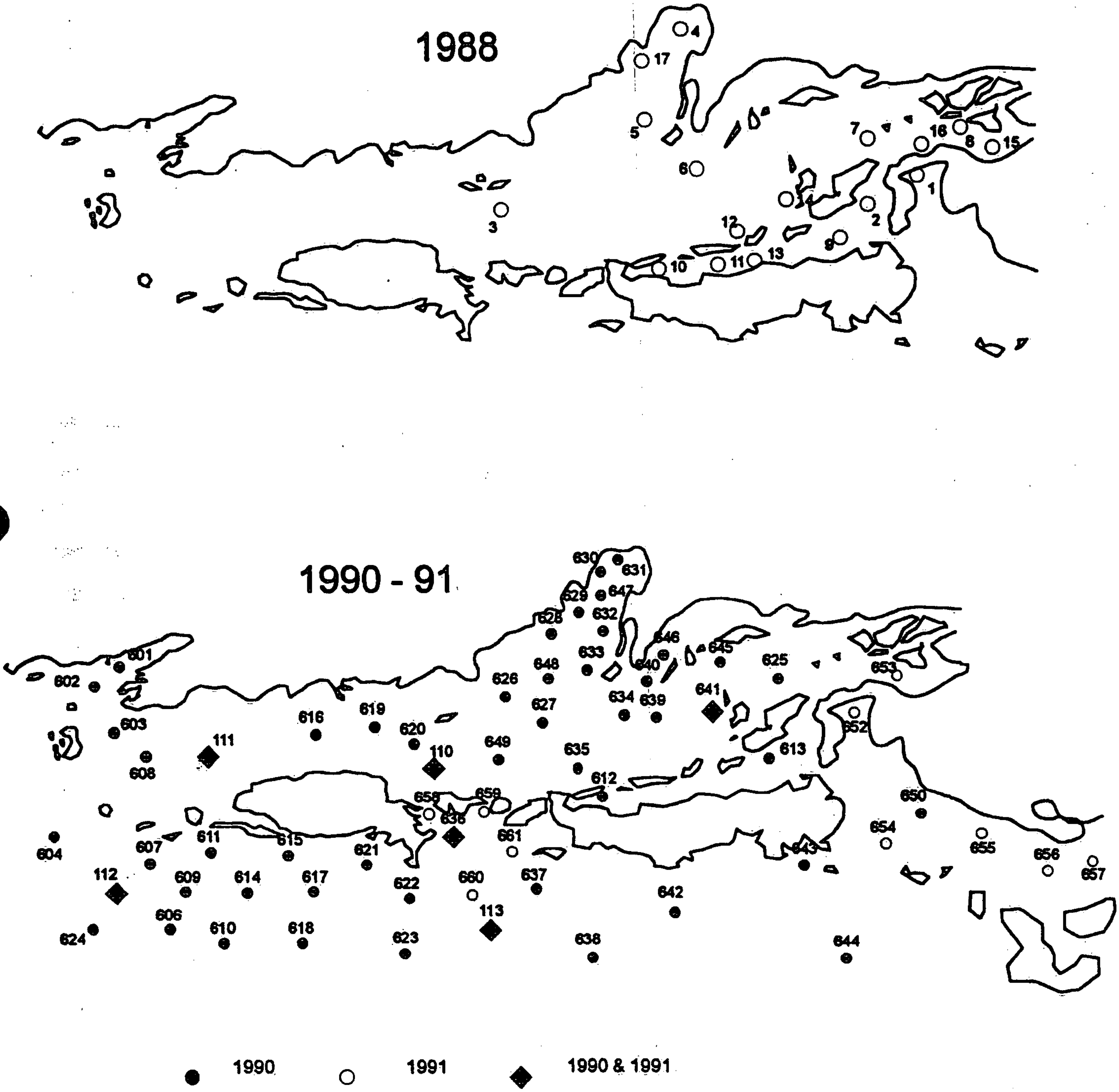


Figure 2. Sampling Sites - Spanish River Study Area 1988, 1990 & 1991

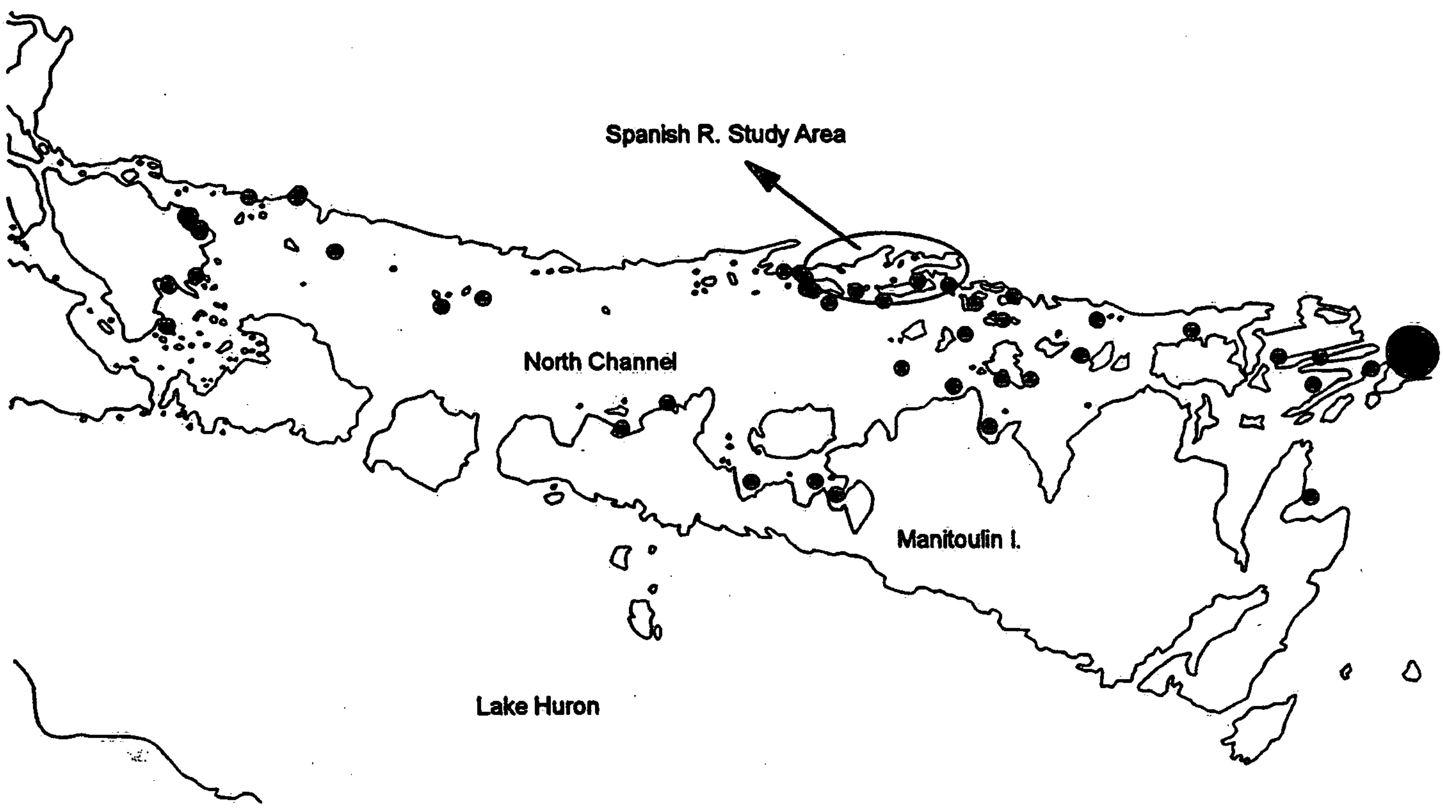


Figure 3. Location of Reference Sites - North Channel Area

Table 1. *Summary of sediment variables measured by NWRI in the N. Channel and Spanish River Area.*

Variable	SPANISH 1988	WHALESBACK 1990	Reference 1991-93
Major Ions			
SiO_2	yes	yes	yes
TiO_2	yes	yes	yes
Al_2O_3	yes	yes	yes
Fe_2O_3	yes	yes	yes
MnO	yes	yes	yes
MgO	yes	yes	yes
CaO	yes	yes	yes
Na_2O	yes	yes	yes
K_2O	yes	yes	yes
Nutrients			
P_2O_5	yes	yes	yes
LOI	yes	yes	yes
TN	no	no	yes
TP	no	no	yes
TOC	no	no	yes
Metals			
V	yes	yes	yes
Cr	yes	yes	yes
Co	yes	yes	yes
Ni	yes	yes	yes
Cu	yes	yes	yes
Zn	yes	yes	yes
As	yes	yes	yes
Cd	no	no	yes
Pb	yes	yes	yes
Physical			
Gravel		yes	yes
Sand		yes	yes
Silt		yes	yes
Clay		yes	yes

The sample was divided as follows:

Samples for the determination of particle size distribution were placed into a plastic pill jar and stored at ambient temperature in the field. Upon return to the laboratory, samples were freeze-dried and analyzed following the method of Duncan and LaHaie (1979).

The remaining sediment in the glass dish was stored in a 500 mL plastic container at 4°C in the field and shipped to the National Water Research Laboratory for freeze drying and analyses of metals, major ions and nutrients.

Samples for the identification and enumeration of benthic invertebrates were taken from the top 10 cm of a benthos core (I.D. 6.6cm, area 34.2 cm^2, x 292.3 to convert to no. m^2). At each site three such cores were taken. Each core tube is considered a replicate sample unit and was removed and the contents placed into a plastic bag and kept cool until sieved. The contents of each bag were sieved through a 500μm mesh in the field as quickly as possible after sampling. If sieving could not be done in the field, 4% formalin was added to the bag and the replicate samples were stored at 4°C and sieved as soon as possible thereafter. After sieving the samples were placed in plastic vials (50 mL) and preserved with 4% formalin. Replicates with large amounts of organic material were placed in larger containers and again preserved with 4% formalin. After 24 h the formalin was replaced by ethanol.

Samples were sorted with a low power stereo microscope (100-400X) and identified to the species or genus level where possible using appropriate identification guides. As required (Chironomidae and Oligochaeta) slide mounts were made for high power microscopic identification. Type specimens of all identified specimens were submitted to experts (R.O. Brinkhurst for Oligochaeta; B. Bilyj and D. Oliver for Chironomidae; G. Mackie for Mollusca) for confirmation. The confirmed type specimens are being maintained as a reference collection.

Whole-Sediment Toxicity Tests

A mini-ponar sampler was used to obtain five replicate field samples of sediment for laboratory bioassays with the oligochaete worm *Tubifex tubifex*. Each replicate sample was placed in a plastic bag and held at 4°C until tests could be conducted. Tests were conducted, in sets of six to seven, over a period of approximately six months. A clean control sediment from Long Point, Lake Erie, was also tested with each set of samples to provide biological quality assurance. Complete details of the culture of organisms and conditions for toxicity testing with *T. tubifex* are described elsewhere (Reynoldson *et al.* 1991, Reynoldson *et al.* 1994). Tests with *T. tubifex* were conducted in 250 mL glass beakers containing 60 to 100 mL of sieved (500 µm mesh), homogenized sediment with approximately 100 to 140 mL of overlying carbon-filtered, dechlorinated and aerated Lake Ontario water (pH 7.8 to 8.3, conductivity 439 to 578 µohms/cm, hardness 119 to 137 mg/L). The sediment was allowed to settle for 24 h prior to addition of the test organisms. Tests were initiated with the random addition of 4 organisms per beaker for *T. tubifex* adults that were 8 to 9 weeks old. Tests were conducted at 23±1°C with a 16L:8D photoperiod. Tests were static with the periodic addition of distilled water to replace water lost during evaporation. Each beaker was covered with a plastic petri dish with a central hole for aeration using a Pasteur pipette and air line. Dissolved oxygen concentrations and pH were measured at the beginning, middle and end of each exposure period. Tests were terminated after 28 d by passing the sediment samples through a 500 µm mesh sieve and a 250 µm mesh sieve at test completion. Endpoints measured in the tests were survival and production of cocoons and young.

Data Analysis

Data analysis was based on the procedures described by Wright *et al.* (1984). Pattern analysis was used to describe the biological structure of the data at the reference sites and correlation and multiple discriminant analysis (MDA) was conducted to relate the observed biological structure to the environmental characteristics.

The biological structure of the data was examined using two pattern recognition techniques, cluster analysis and ordination. The mean values from the five replicates for the numeric taxonomic data were used as descriptors of the benthic invertebrate community. These community data were not transformed and the raw scores were used because numeric differences are thought to be important community descriptors. The Bray and Curtis association measure was used because it performs consistently well in a variety of tests and simulations on different types of data (Faith *et al.* 1987). Clustering of the reference sites was done using an agglomerative hierarchical fusion method with unweighted pair group mean averages (UPGMA). The appropriate number of groups was selected by examining the group structure and, particularly, the spatial location of the groups in ordination space. Ordination was used to reduce the variables required to identify the structure of the data. A multi-dimensional scaling (MDS) method of ordination was used, *i.e.*, Semi- Strong-Hybrid multidimensional scaling. Multi-dimensional scaling methods use rank order rather than metric information and, thus, avoid the problematic assumptions of linearity inherent in many ordination techniques (Belbin 1991). This is of particular value when relating ordination scores to environmental characteristics. All clustering and ordination was done using PATN (Belbin 1993), a pattern analysis software package developed by CSIRO in Australia. The prediction of community structure based on reference site data was done using a model based on 216 sites, using discriminant analysis in the method described by Reynoldson *et al.* (1995b).

Results

1988 study

At the 17 sampling sites the Chironomidae (midges) and Tubificidae (worms) were the two numerically dominant families, followed by the sphaeriid molluscs (clams) and the chaoborid midges (phantom midges). Generally however the number and type of organisms found were low. The results from the 1988 sampling have been compared with the reference sites from the North Channel (Table 2). The average number of total organisms in the area sampled in 1988 is an order of magnitude lower than the overall average for the North Channel area. Furthermore the diversity of families and species is 4 -5 times less, although it must be acknowledged that the number of sites sampled was fewer. However these coarse scale indicators do suggest a reduction in both numbers and diversity of species in the Spanish River mouth area.

Table 2. A comparison of benthic invertebrates abundance and diversity in the North Channel and Spanish River study area.

	Reference sites * (47)	1988 sites (17)	1990 sites (41)
Avg. No. m^2	5344.3	741.1	507.8
No. Families	26	7	11
No. spp/genera	101	17	34

*Note: reference site data adjusted for use of 250μm mesh according to the conversion factor of 0.58 reported by Reynoldson et al. 1989.

In the North Channel reference sites the dominant families are respectively the Chironomidae (midges), Haustoridae (scuds), Sphaeriidae (clams), Asellidae (sow bugs) and Tubificidae (worms). Eighty percent of the organisms found belong to these five families. It is notable that three of these families (Haustoridae, Asellidae, Sphaeriidae) were virtually absent (Fig. 4) from sites sampled in 1988 (Fig. 2). Only the tubificid worms occurred at numbers similar to those observed in the North Channel reference sites (Fig. 4).

The spatial pattern of the benthic communities sampled in 1988 has been examined by clustering and ordination of the species level data and extrapolating the assemblages observed

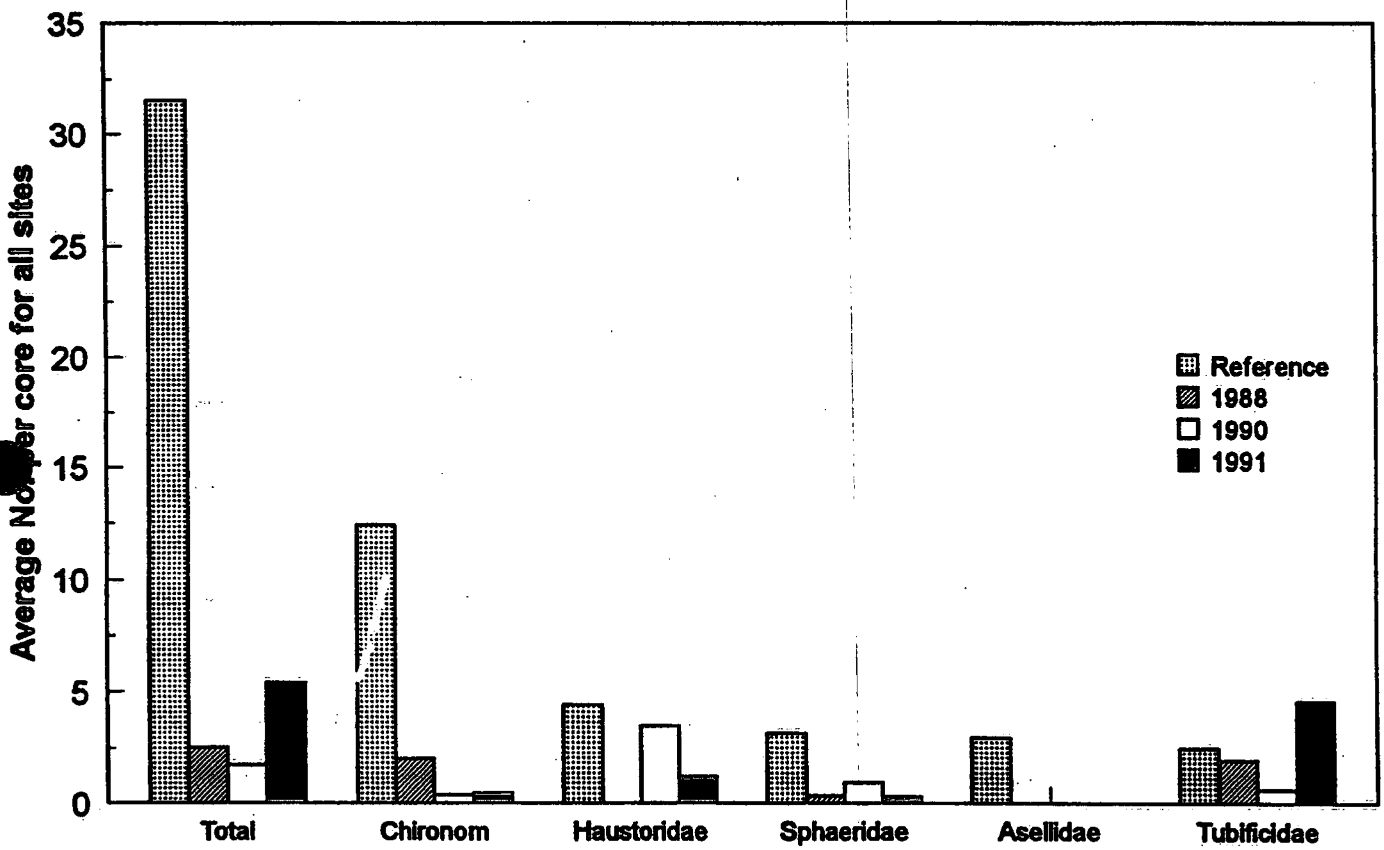
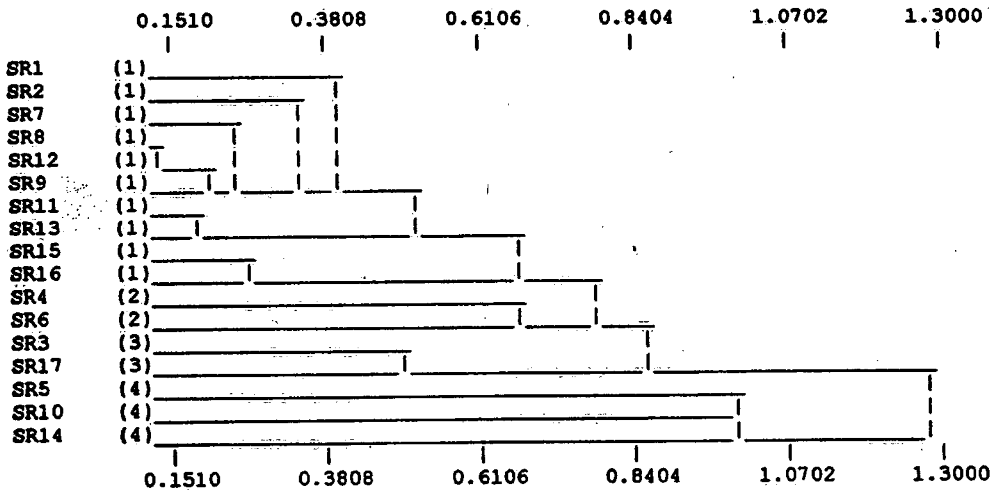


Figure 4. Summary comparison of major families in N. Channel reference sites and the Spanish River Study Area in 3 study years

from this analysis to a map of the sampling area. Ten of the sites fall into a single group (Fig 5), which when displayed geographically (Fig. 6) include all the sites in the southern part of the study area.

Figure 5 *UPGMA Cluster analysis of benthic species sampled in the Spanish River area of the North Channel (1988 - species level).*



The average number of organisms in each of the four groups of sites is shown for the total number of invertebrates found (Table 3) and for those taxa that were best correlated with the ordination vectors. These are, respectively, *Ilyodrilus templetoni* (0.8150), other unidentified Tubificidae (0.7833), *Heterotrissocladius* sp. (0.7566) and other unidentified Chironomidae (0.6825). The least impacted area (Gp 1) has comparatively high numbers and the greatest diversity of taxa with a total of 5 families and 11 genera or species. These sites form a discrete geographic group along the southern shore of the Spanish River mouth and the channel just north of Aird Island. This area also has the lowest average values for all the analyzed metals (Cu, Ni, Zn, As, V, Pb, Co). The remaining seven sites form less geographically and biologically distinct groups. The ordination plot of individual sites (Fig. 6) shows Gp 1 sites to form a distinct cluster in the centre of the plot. The Gp 2 sites have similar numbers of animals as Gp 1, but lower diversity. A total of only 4 families and 6 genera/species were found. The main difference between Gp 1 and Gp 2 was the absence of Chironomidae in Gp 2, however, tubificid worms occurred in similar numbers to Gp 1. One site (4) has high numbers of *Chaoborus*, which accounts for the high average number of animals at the two

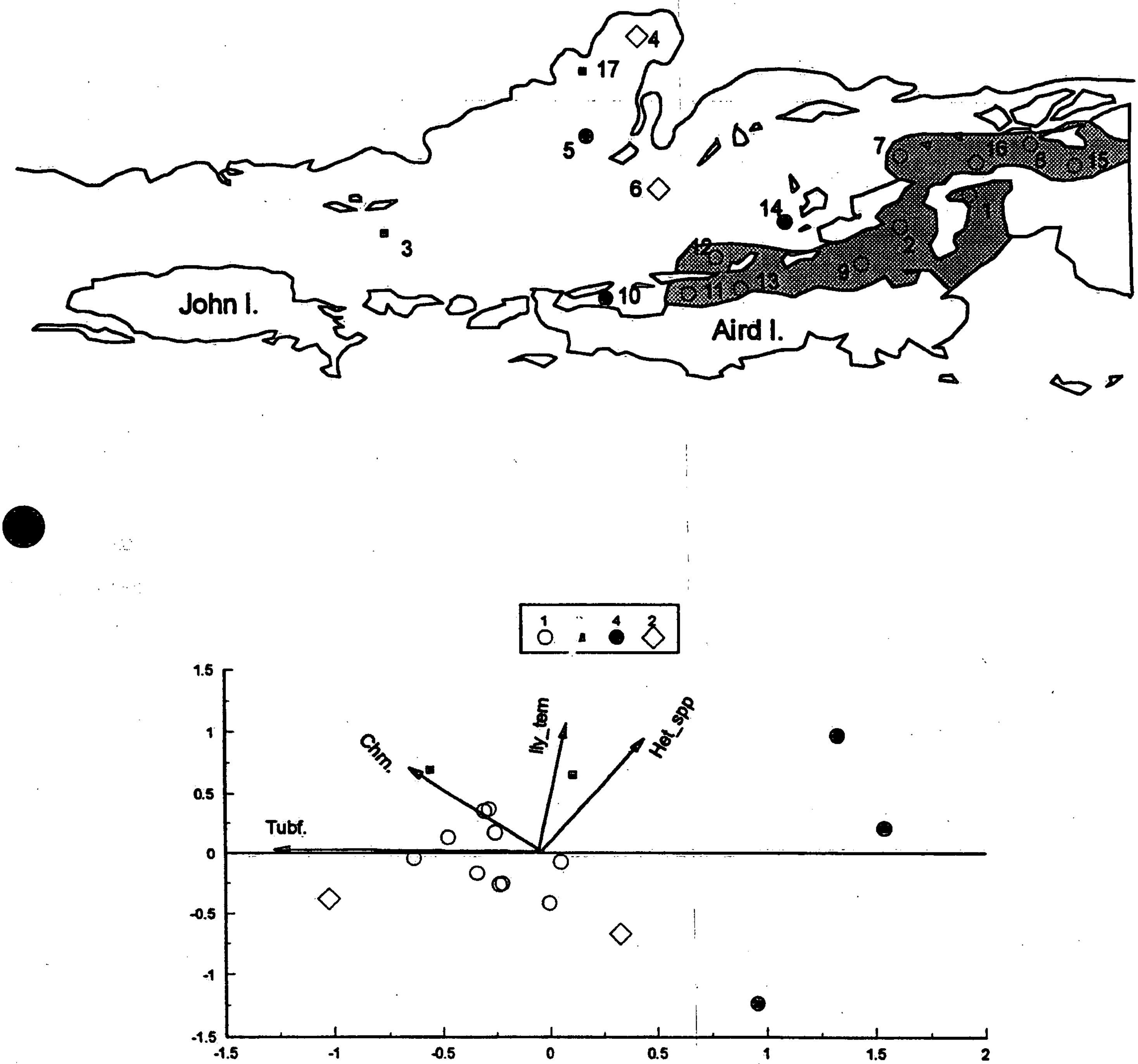


Figure 6. Ordination and geographic extent of 1988 community groups formed from cluster analysis.

sites. This particular organism is only semi-benthic and spends much of the time feeding in the water column, and is not exposed, as much, to sediment associated contaminants. The sites forming Groups 3 and 4 have the lowest diversity and numbers of organisms (Table 3) and include the majority of sites in the main part of the Whalesback Channel (Fig. 6).

Table 3. Average numbers of organisms and values for selected geophysical sediment attributes for sites in groups formed by cluster analysis in the Spanish River mouth area and at 49 North Channel reference sites.

Variable	Reference sites	Gp 1 sites	Gp 2 sites	Gp 3 sites	Gp 4 sites
Biological (No. core)*					
Total organisms (avg)	18.3	6.1	7.2	1.3	0.4
No Families (avg)	7.1	2.7	2.5	2.0	1.0
No Genera/species (avg)	13.6	3.0	3.5	1.0	1.0
I. templetoni	0.0	0.1	0.0	0.2	0.1
Tubificidae	1.4	2.3	2.3	0.3	0.0
Heterotrissocladius spp	0.5	0.0	0.0	0.0	0.1
Chironomidae	7.2	2.5	0.2	0.7	0.0
Geophysical					
Depth (m)	14.5	10.8	11.9	17.2	11.6
Metals (ug.g dry wt)					
Cu	34.9	79.7	111.0	174.0	139.0
Ni	115.0	295	310.7	1032.0	686.3
Zn	135.7	177.8	204.0	339.0	313.7
As	7.4	21.6	44.0	18.0	18.5
V	50.5	69.2	82.0	112.0	96.0
Pb	35.6	45.1	47.0	104.0	87.0
Co	17.3	19.8	27.0	56.0	30.5
Major Elements					
SiO2	67.7	67.0	64.0	57.8	64.0
Al2O3	11.5	10.7	10.0	11.7	11.1
Fe2O3	4.4	4.8	7.9	8.1	6.7
MgO	1.8	1.6	1.5	1.8	1.8
CaO	1.8	2.0	1.9	1.6	1.8
Na2O	1.9	3.1	2.8	2.4	2.7
K2O	2.7	2.3	2.3	2.4	2.3
MnO	0.2	0.2	0.1	0.6	0.4
P2O5	0.2	0.2	0.2	0.3	0.2
LOI	7.1	7.8	7.6	17.2	11.6

*Note: reference site data adjusted for use of 250μm mesh according to the conversion factor of 0.58 reported by Reynoldson et al. 1989.

These 1988 data when compared with the reference sites from the North Channel show a large qualitative reduction in the numbers of individuals in the Spanish River area and in the diversity of taxa at both family and species level (Table 3) expressed on an average per site basis. Furthermore, there appears to be a gradation of effect in the Spanish River mouth from the less impaired Gp 1 sites to the most severely impaired Gp 3 and 4 sites which have representatives of only one or two species and one or two individuals per core.

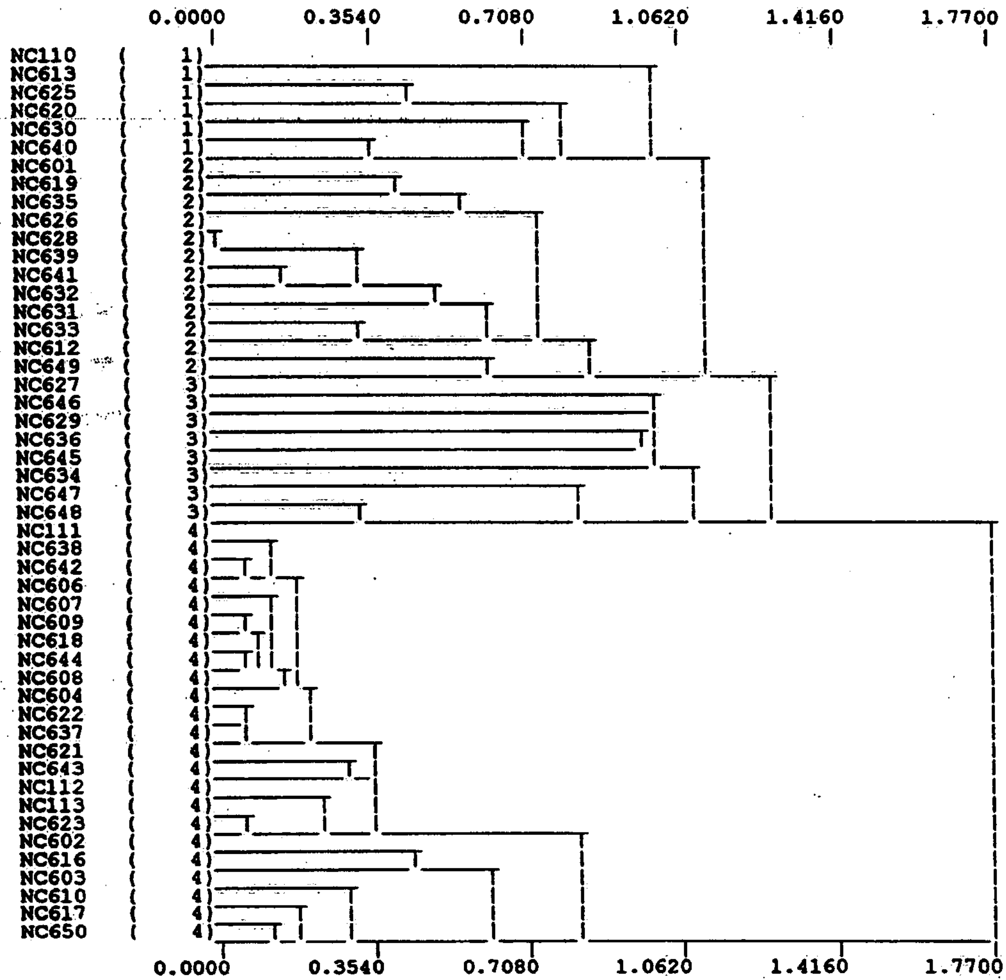
To explain these qualitative differences in the benthic invertebrate community we have examined sediment geophysical attributes for which data were collected. Water depth has a significant role (through temperature and grain size) on the distribution and abundance of benthic fauna, however the depth at both the reference sites and the site groups from the 1988 study (Table 3) are in the same range, the greater depth of the Gp 3 sites (17.2m) may have a slight effect on numbers. The values for the major elements suggest that there are no major discontinuities in sediment type that would account for the observed differences in the benthic fauna. There is a slight elevation in iron (Fe_2O_3) and manganese (MnO) at the more impacted sites (Table 3) and sodium is elevated in all the 1988 study sites relative to the reference sites. The organic content (LOI) is higher at the Gp 3 and Gp 4 sites, approximately twice the background values recorded at the reference sites. The most obvious differences in sediment quality between the reference sites and the Spanish River sites and between the groups of sites in the Spanish River area are concentrations of heavy metals. Average values for copper (Table 3) range from double the reference value (Gp 1) to five times the reference value (Gp 3). Nickel average values range from double the reference condition (Gp 1) to ten times the reference value (Gp 3). All the other metals measured show values elevated above the average value for the North Channel: vanadium two times, zinc two and a half times, lead three times, cobalt three and a half times and arsenic five times.

These data provided strong circumstantial evidence of a degraded benthic fauna due to sediment contamination, particularly metals. In order to confirm that this was a sediment associated impairment and to better define the geographic extent of the impairment a more extensive survey was undertaken in 1990.

1990 Study

In 1990 49 sites were sampled (Fig. 2) and the sampling area was extended into the North Channel to provide a more comprehensive assessment of the relationship of the "Area of Concern" to the Whalesback and North Channels. Furthermore, we incorporated an estimate of sediment toxicity based on laboratory testing of sediment as well as geochemical sediment characterization and community structure assessment.

Figure 7. *UPGMA cluster analysis of benthic species sampled in the Spanish River area of the North Channel (1990).*



Invertebrate Community Structure

In 1990 a total of 11 invertebrate families and 34 genera or species were identified from 41 sampling stations from which data were available. The average number of individuals per m^2 was 507.8. The abundance is similar to that of 1988 (Table 2) and considerably lower than the reference sites, and although the diversity is greater than in 1988 is still only a third of that observed in the reference area (Table 2). Families occurring in these sites were notably the Haustoridae (scuds), Ephemeridae (mayflies), Valvatidae (snails) (Fig. 4) and two other worm families the Lumbriculidae and Naididae.

Again the spatial pattern of the benthic communities was examined by clustering and ordination of species and genus level data. To examine the pattern in the invertebrate community structure the data were log transformed and rare species (< 0.4 individuals per core) were not included in the data matrix. This resulted in 9 of the 34 taxa being excluded.

From the dendrogram we have distinguished four groups of sites (Fig. 7). These have been plotted on the map of the study area (Fig. 8) and show a clear separation between the North Channel (Gp 4) and the Whalesback Channel (Gps 1-3). We have examined the species based ordination and related the overall correlation of both the species matrix and the sediment data with the species ordination scores (Table 4), the mean values for those variables best correlated with the pattern in the invertebrate communities are also shown for each site group (Table 4).

Table 4. Relationship of species and sediment attributes to ordination vectors and mean (with SD) values for selected species and sediment attributes from groups formed by cluster analysis of species data.

Variable	Correlation	Gp 1	Gp 2	Gp 3	Gp 4	Reference
D. hoyi	0.7680	0.1 (0.3)	0.5 (1.8)	0.2 (0.4)	5.6 (3.0)	4.5 (6.6)
Pisidium sp	0.4995	0.1 (0.2)	0.7 (0.4)	0.8 (2.0)	0.9 (0.7)	0.3 (2.1)
I. templetoni	0.4809	0.2 (0.2)	0.0 (0.0)	0.0 (0.0)	0.0 (0.1)	0.0
Procladius sp	0.4439	0.5 (0.3)	0.1 (0.2)	0.1 (0.2)	0.0 (0.1)	1.5 (1.8)
Potassium	0.6041	2.3 (0.1)	2.3 (0.1)	2.3 (0.1)	2.7 (0.4)	2.7
Sodium	0.5667	2.2 (0.5)	2.0 (0.4)	2.1 (0.2)	1.7 (0.3)	1.9
Copper	0.5560	137.6 (20.9)	118.7 (41.3)	115.5 (41.1)	76.4 (43.5)	34.9
Nickel	0.5265	617.2 (148.8)	551.0 (191.8)	585.7 (229.4)	321.0 (220.5)	115.0
Depth	0.4706	17.8 (7.9)	20.2 (9.6)	17.5 (9.0)	27.0 (8.8)	

There is little difference between the communities in three of the groups (Gps 1-3) in the Whalesback Channel, all have low numbers of organisms. There are some slight differences in the numbers of *Procladius, Pisidium* and *Ilyodrilus* between the three groups. The most noticeable and important difference is the low number of *Diporeia hoyi* in the sites (Gp's 1-3) in the Whalesback channel in comparison with the Gp 4 sites and the North Channel reference sites. For purposes of comparison we have included the values for the same taxa at the reference sites. The numbers of

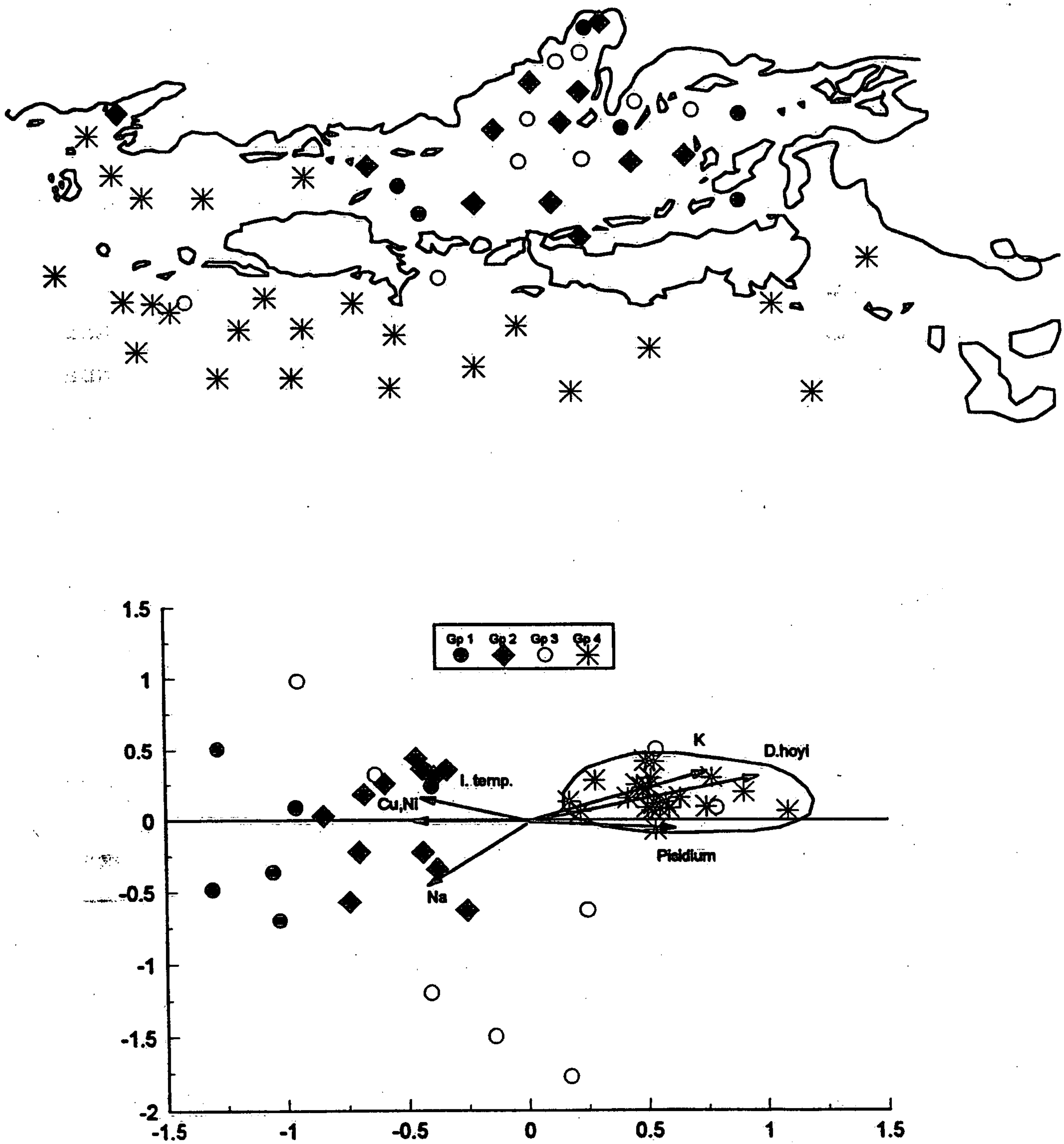


Figure 8. Ordination and site groups from community structure cluster analysis (25 species > 0.4/sample) Spanish River study area 1990.

Diporeia in the reference sites is similar to those found in the Gp 4 North Channel sites included in the study, although *Procladius* numbers are lower than the reference site average. Of the sediment variables that are best related to the community structure (Table 4), there is little difference in the two major elements (K and Na) and again values are similar to those found at the reference sites. However, the two metals copper and nickel are both elevated in the Whalesback Channel and are almost double the values in the Gp 4 sites, and these in turn are almost double the reference site average (Table 4).

The sites have been plotted in ordination space (Fig. 8). The least impacted sites (Gp 4) are separated on the first axis and form a discrete group. Those variables best correlated with the ordination matrix are indicated by arrows showing the orientation of the variable, the relative importance of the variable is indicated by the length of the arrow. These are generally oriented along the first vector, particularly *Diporeia*, *Pisidium* and *Ilyodrilus* and the metals copper and nickel. This confirms the interpretation that *Diporeia* is structurally an important part of the benthic community and that its abundance is associated with metal concentration in the sediment.

Data have been collected on invertebrate species from 345 reference sites in the Great Lakes, at the time of writing data from 216 of these sites have been used in a multivariate model that allows prediction of invertebrate communities from environmental characteristics. This model updates that presented by Reynoldson *et al.* (1995b) based on 91 sites. Using 79 taxa we were able to identify six community assemblages in the Great Lakes. There was a strong geographic component to the six assemblages indicated by the distribution of sites through the lakes (Table 5).

Table 5. *Geographic distribution of six community assemblages from 216 reference sites in the Great Lakes.*

Lake	Gp 1	Gp 2	Gp 3	Gp 4	Gp 5	Gp 6
Ontario		1		4	6	
Erie	33	3		10		
Huron		1		1		
Georgian Bay		16	2	7		
North Channel			26	1	17	
Michigan	5		5		12	20
Superior	3		7		35	1

Of 44 North Channel sites included in the model, 59% are in Gp 3, which is predominantly

a North Channel group. The remainder are in Gp 5 which is a L. Superior group. The dominant taxa in these two groups of sites are in Gp 3 the chironomids; *Procladius* sp (9.4%), *Chironomus* sp and *Tanytarsus* sp (7.6%) and *Pisidium* sp (5.7%). Other taxa present in relatively high numbers in this community are *D. hoyi* and Tubificid worms. In Gp 5 *D. hoyi* is dominant and comprises 41% of the total abundance followed by *Pisidium* sp (8.7%), *Stylodrilus heringianus* (8.5%) and *Heterotrissocladius* (6.0%), together these four taxa account for over 60% of the benthic invertebrate species in this community assemblage. In fact Gp 5 is more typical of oligotrophic conditions and Gp 3 is represented by more mesotrophic species. We have examined the relationship between environmental characteristics and community structure in these Great Lakes communities. Using nine predictor variables, five sediment characteristics (percent silt and LOI and concentration of aluminium, calcium and sodium) and four water column attributes (depth, pH, nitrate and alkalinity), we can correctly predict the community assemblage at a site 90% of the time (Reynoldson *et al.* 1995b). This approach was used to predict the community assemblages in the Spanish River area sites sampled in 1990. The list of predictor variables was modified for predicting the Spanish River sites as water samples were not taken. The variables available from the 1990 Spanish River samples were tested against the reference data assemblage and ten variables were selected as the best predictors of the 216 reference sites: water depth, latitude, longitude, percent sand, silt and LOI, and concentration in the sediment of calcium iron, nickel and copper. Using a discriminant model developed from the reference sites we predicted the probability of which community assemblage would occur at 46 of the Spanish River area sites (Table 6) for which data were available for all ten variables. Twenty nine of the sites were predicted to Gp 5 and in only five with a probability of less than 70%. Fifteen sites were predicted as being Gp 3 sites but of these only four had a probability that this was the correct group and in nine of the remaining 11 sites Gp 5 the community was almost as likely to be Gp 5. The distribution of the predicted sites is shown in Figure 9.

In order to compare the actual community with the predicted community we have plotted the reference sites and the Spanish River sites predicted to that reference group in the same ordination

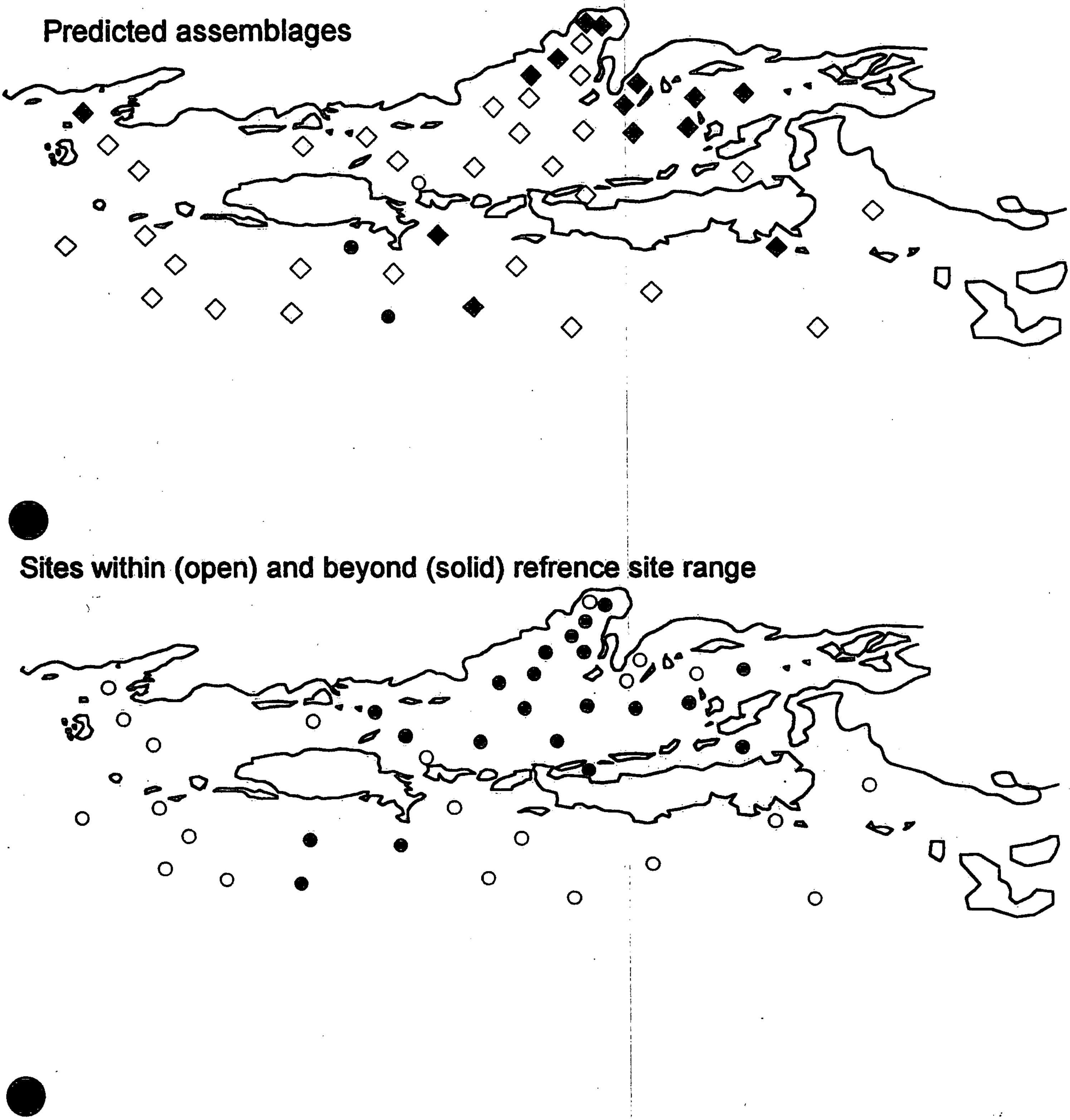


Figure 9. Predicted and observed community assemblages in the Spanish River area

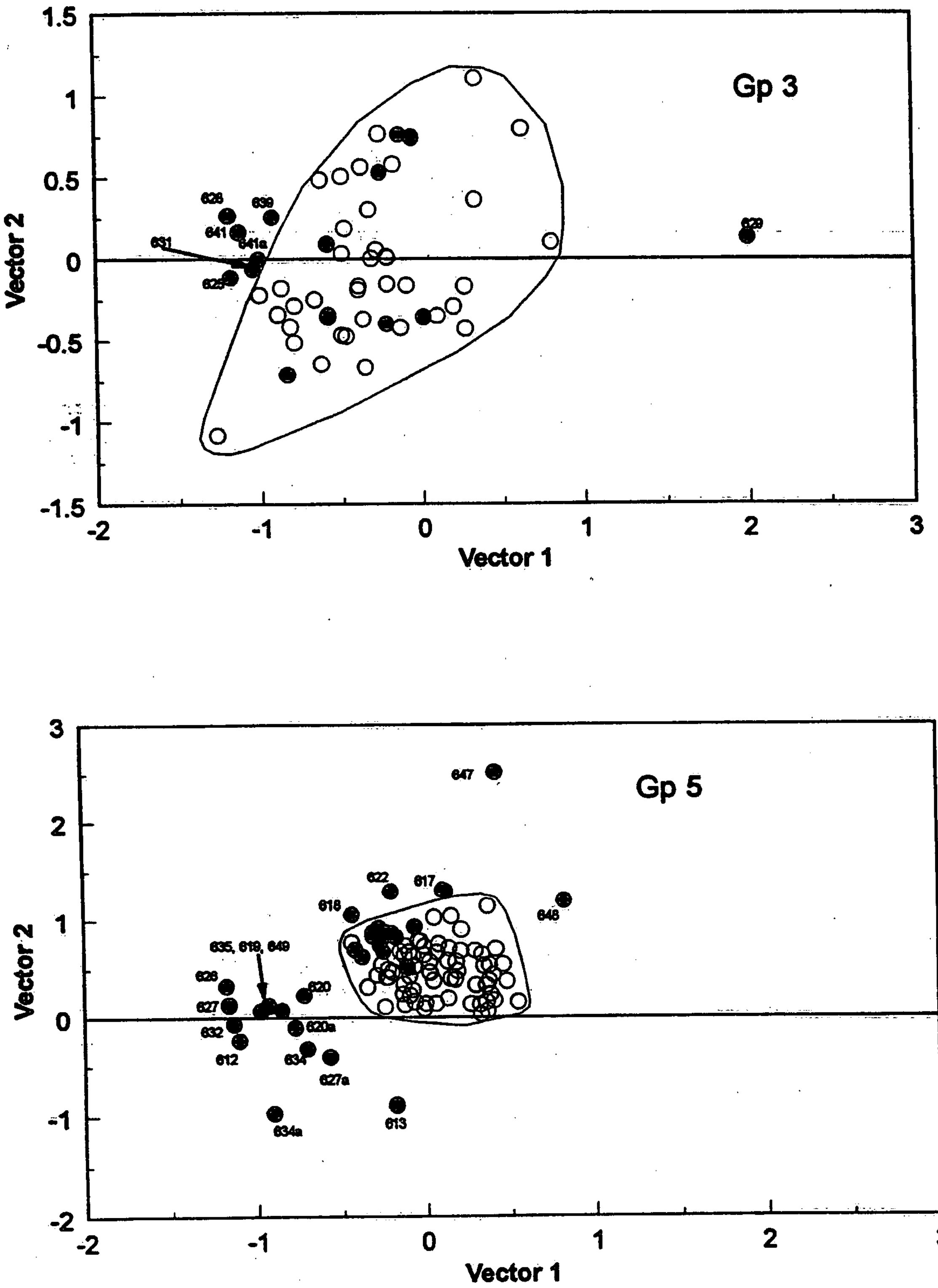


Figure 10. Ordination of reference (open and Spanish River area (solid) sites based on invertebrate community structure

space (Fig. 10). For those Spanish River sites predicted to Gp 5 twelve lay within the envelope of the reference sites (Fig. 10). The remaining 17 were outside the range of variation observed in the reference sites (Fig. 10) and are considered as impaired. A comparison of the abundance of the dominant species in this community assemblage (Fig. 11) shows even those sites that "passed" had reduced numbers of the four most abundant taxa, those that "failed" had severely reduced numbers. Eight of the sites predicted to have a Gp 3 community had such an assemblage of organisms (Fig. 10). The remaining seven sites were outside the range of variation observed in this community (Fig. 10) and again the numbers of organisms in the sites that "failed" were extremely low (Fig. 11), particularly the chironomids. The clam, *Pisidium* sp, did not appear to be affected by the contamination, as numbers at reference sites and Spanish River area sites were similar (Fig. 11). Based on the species that have been most reduced in numbers (Fig. 11) the amphipod *Diporeia* and the chironomid species appear most sensitive to the contaminants present.

Table 6. Predicted community groups for 1990 Spanish River area sites.

Site	Predicted Gp (Probability)	Site	Predicted Gp (Probability)
113	3 (0.774)	628	3 (0.550) 5 (0.450)
602	3 (0.580) 5 (0.421)	629	3 (0.500) 5 (0.500)
603	5 (0.6[illegible]6) 3 (0.303)	630	3 (0.522) 5 (0.479)
604	5 (0.720)	631	3 (0.691) 5 (0.309)
606	5 (0.[illegible]08)	632	5 (0.710)
607	5 (0.834)	634	5 (0.783)
608	5 (0.571) 3 (0.429)	635	5 (0.872)
609	5 (0.572) 3 (0.418)	636	3 (0.599) 5 (0.401)
610	5 (0.882)	637	5 (0.687) 3 (0.312)
612	5 (0.788)	638	5 (0.789)
613	5 (0.742)	639	3 (0.587) 5 (0.411)
616	5 (0.791)	640	3 (0.540) 5 (0.460)
617	5 (0.561) 3 (0.435)	641	3 (0.548) 5 (0.452)
618	5 (0.898)	642	5 (0.725)
619	5 (0.609) 3 (0.390)	643	3 (0.754)
620	5 (0.909)	644	5 (0.386) 3 (0.302) 2 (0.231)
621	1 (0.586) 3 (0.201)	645	3 (0.809)
622	5 (0.561) 3 (0.341)	646	3 (0.655) 5 (0.344)
623	2 (0.480) 6 (0.433)	647	5 (0.632) 3 (0.368)
625	3 (0.792)	648	5 (0.803)
626	5 (0.905)	649	5 (0.955)
627	5 (0.906)	650	5 (0.964)

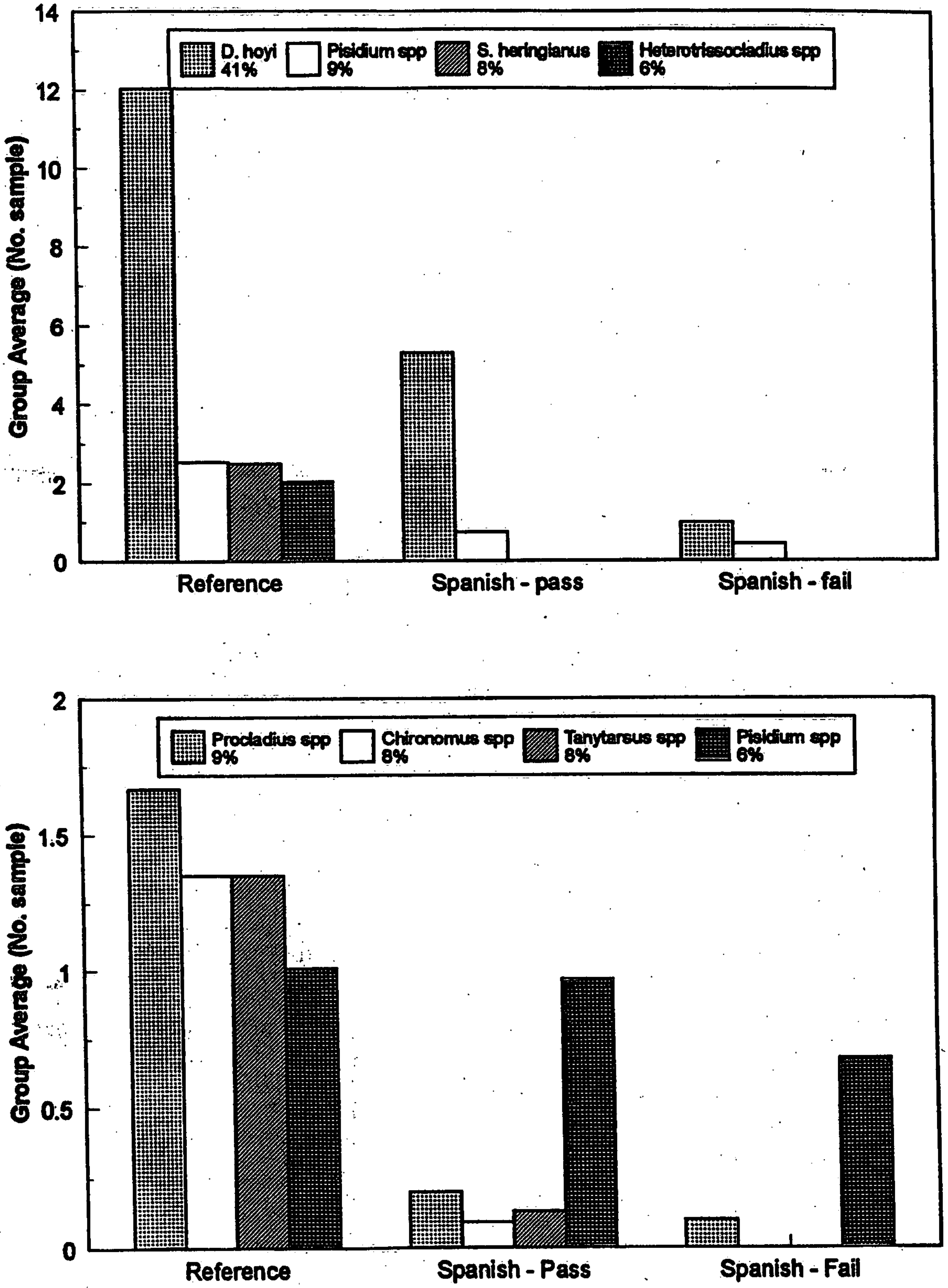


Figure 11. Abundance of dominant taxa in reference and Spanish River area sites.

Finally we have plotted the geographic distribution of the sites that were within (unimpaired) and outside (impaired) the range of variation observed in the reference sites (Fig. 10). This shows that those sites that were most affected were almost exclusively in the Whalesback Channel (Fig. 9). Only three sites in the North Channel appeared to be impaired. These three sites are adjacent to the passage through which the major exchange of water occurs between the Whalesback and North Channels (Rosa 1995). This suggests there is transfer of contaminants between the two channels that is having a deleterious effect on benthic communities.

Sediment Toxicity

Sediment samples from 46 locations were available for laboratory assessment of sediment toxicity using the *Tubifex tubifex* (Oligochaeta) reproductive test. We examined three test endpoints to assess the degree of sediment associated toxicity in the study area: survivorship of adults; production of cocoons and; production of young.

From correlation analysis we examined the relationship between the sediment variables and the number of cocoons and young produced in the test (Table 7). The metals zinc, lead and copper have the highest correlation with the numbers of cocoons produced. Surprisingly, this correlation is positive but may be due to the fact that four of these sites are sandy and while the concentrations are low the metals may be more available.

To establish a decision point on whether a test result can be considered to indicate sediment toxicity we have used data from the array of reference sites in the Great Lakes (Reynoldson *et al.* 1995a) for which we have established normal responses for four toxicity tests, including *T. tubifex*. From these reference sites criteria have been established from which sediment toxicity is indicated (Day *et al.* 1995). In the case of *T. tubifex*, in unfed tests, these values are respectively 24 cocoons and 21 young per 4 adult worms. The values for each test site and the reference sites are illustrated in Figure 12, together with the criteria value that indicates toxicity is present. Sixteen sites fail to meet the criteria for the number of cocoons produced and six sites failed to meet the criteria for the number of young produced. The sites were respectively separated into two groups for each toxicity endpoint, those that meet the criteria and those that failed and the Mann-Whitney non-parametric test for independent means used for each of the sediment attributes. Those variables that were

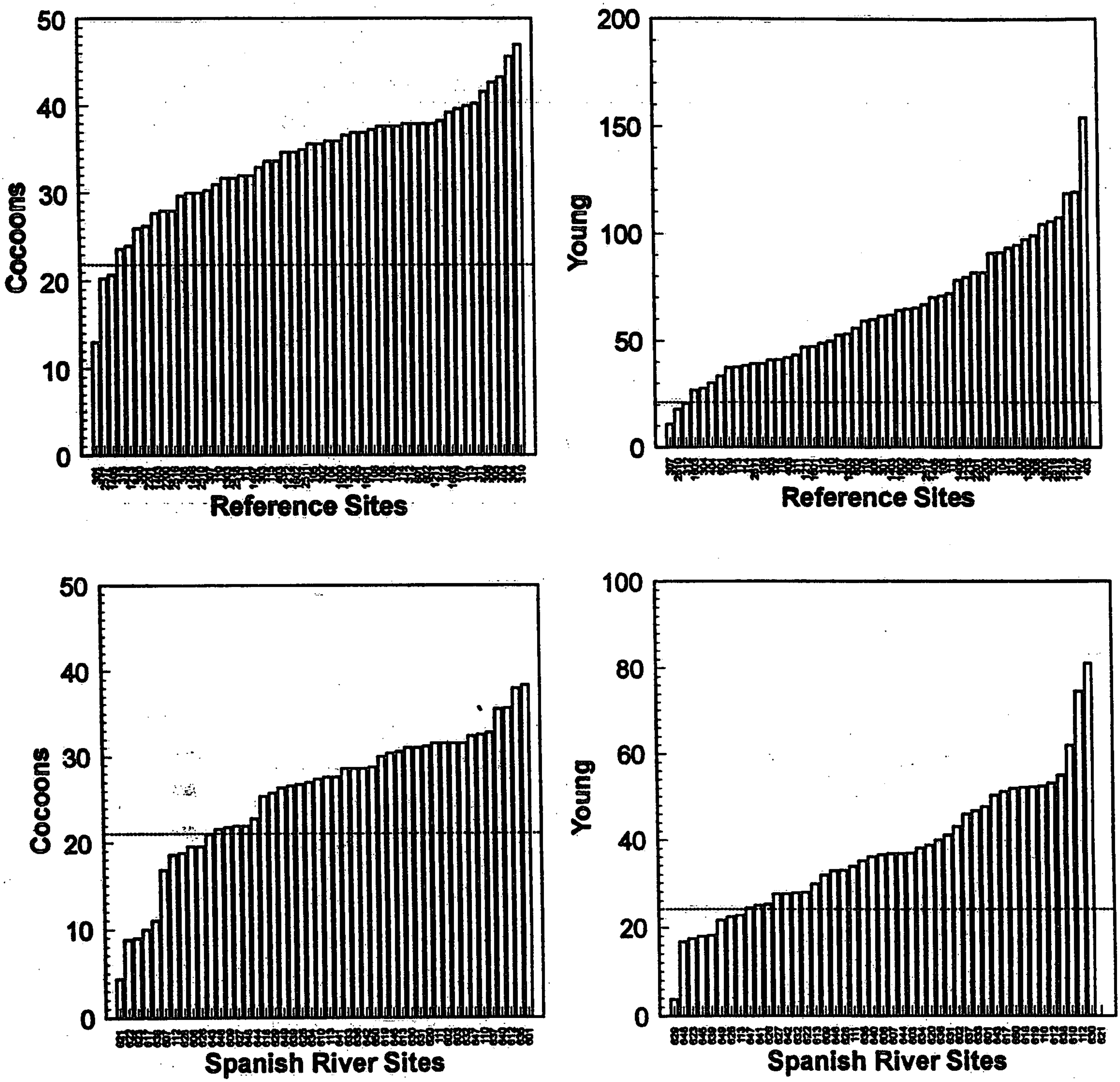


Figure 12. Comparison of T. tubifex bioassay results from reference and Spanish River area sites (criteria value indicated by dashed line).

significantly different (P < 0.05) in the two groups distinguished by their toxicity are indicated in Table 8.

Table 7. ***Correlations between sediment toxicity and sediment chemistry, those correlations significant at the P > 0.01 level indicated in bold.***

Variable	Cocoons	Young
Zinc	**0.5922 (1)**	0.2764 (8)
Lead	**0.5487 (2)**	0.3190 (3)
Copper	**0.5259 (3)**	0.2411 (10)
Magnesium	**-0.5097 (4)**	**-0.4159 (1)**
Potassium	**-0.4860 (5)**	-0.3024 (5)
Calcium	**-0.4646 (6)**	**-0.3526 (2)**
Nickel	**0.4630 (7)**	0.1833 (13)
Silica	**0.4090 (8)**	0.2454 (9)
Sodium	**0.4049 (9)**	0.3151 (4)
Cobalt	**0.3925 (10)**	0.1746 (14)
LOI	0.3663 (11)	0.1669 (15)
Aluminium	-0.3467 (12)	-0.2962 (6)
Chromium	0.3311 (13)	0.1927 (12)
Manganese	-0.3260 (14)	0.0921 (19)
Arsenic	0.3247 (15)	0.2797 (7)
Silt	0.3017 (16)	0.1985 (11)
Vanadium	0.2662 (17)	0.1563 (16)
Sand	-0.2594 (18)	-0.1212 (18)
Phosphorus	-0.1627 (19)	0.0430 (20)
Iron	0.0935 (20)	0.0240 (21)
Titanium	0.0920 (21)	-0.1423 (17)
Clay	-0.0110 (22)	0.0098 (22)

For both endpoints the metals zinc, copper, lead and nickel show the greatest difference in the two groups of sites. However, contrary to expected the higher concentrations are found in those sites that pass the criteria and those sites failing to produce cocoons or young have lower metal values. From the relationship between the community structure data and metal values in the sediment and the fact that toxicity occurred in some sediments we would have expected to see a positive relationship between concentrations of metals and sediment toxicity. In fact the reverse appears to be the case. There are a number of possible explanations:

1. The impairment in the benthic communities is not associated with sediment associated contaminants.
2. The observed toxicity is not related to total metal concentrations and total metal concentrations are a poor indicator of bioavailability in this test.

3. The bioavailability is being confounded by other attributes of the sediment.

4. A single species test provides little information about whole community response.

Table 8. Mean values in ug/g dry weight for those variables that are significantly different (P < 0.05) in groups of sites passing and failing the T. tubifex reproductive test.

Cocoons	Fail	Pass	Prob	Young	Fail	Pass	Prob
Zinc	189.4	295.2	0.001	Magnesium	2.86	2.09	0.003
Copper	68.3	116.7	0.001	Zinc	151.2	274.5	0.005
Lead	50.9	88.4	0.001	Nickel	195.6	490.2	0.006
Nickel	306.7	529.2	0.003	Potassium	2.95	2.45	0.006
Cobalt	32.6	45.9	0.022	Lead	37.4	81.0	0.007
LOI	6.8	9.3	0.024	Copper	54.8	106.7	0.010
Chromium	90.8	100.5	0.034	Silica	58.8	62.3	0.011
				Arsenic	11.8	24.2	0.020
				Aluminium	13.3	12.2	0.031

Finally, we have examined the spatial distribution of those sites that failed to meet the toxicity criteria (Fig. 13). Most noticeable is that in contrast to the community structure response the majority of the sites are not in the Whalesback Channel but the North Channel. This explains much of the apparent anomaly in the relationship between metals and toxicity. The twelve sites in the North Channel (Fig. 13) that produced the lowest numbers of cocoons (average 14.9) had the highest proportion of sand (18.7%) and the lowest organic content (5.5%). We suspect that the response at these sites is different to the five sites with reduced cocoon production (average 20.8) in the Whalesback Channel (Fig. 13), which had the highest organic content (9.7%) and lowest level of sand (0.0%). The apparent toxicity in the twelve North Channel sites is likely due to low organic content (Reynoldson *et al.* 1991) and high sand levels perhaps together with metal contamination and greater availability of those metals present. This we consider to be a different response to that observed in the sites in the Whalesback Channel. It is also noteworthy that the area where toxicity is apparent in the North Channel co-incides with the one region in the North Channel where communites were impaired (Fig. 9). This is the vicinity associated with the greatest exchange of suspended materials from the Whalesback Channel (Rosa 1995) and may suggest a high rate of exposure to contaminants in this area. There is little difference in metal levels in the Whalesback Channel between those sites

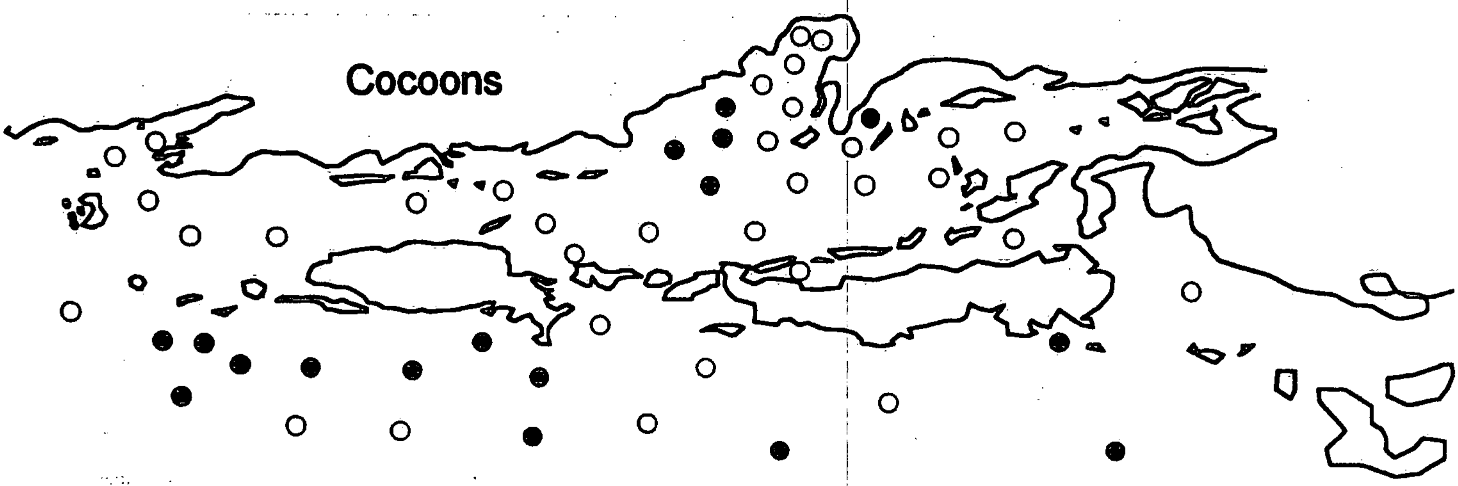


Figure 13. Sites that meet (open) and fail (solid) toxicity criteria

that passed and the five that are considered toxic, although nickel, copper and arsenic have slightly higher concentrations. We can provide no explanation for the reduced reproduction at these sites and can only speculate that it is associated with either the particular metal fractions present or due to other unmeasured contaminants.

Three of the seven sites with reduced young production are those with a high proportion of sand (618, 621, 623). Of the others site 635 had particularly high levels of nickel (607 ppm), copper (128 ppm) and zinc (300 ppm), site 112 had a very high proportion of clay (78.3%) and site 618 had a particularly low organic content (2.5%). The sample for sediment analysis at site 614 was lost. Of these sites we consider only site 635 shows toxicity the low numbers at the other sites are probably due to physical sediment characteristics.

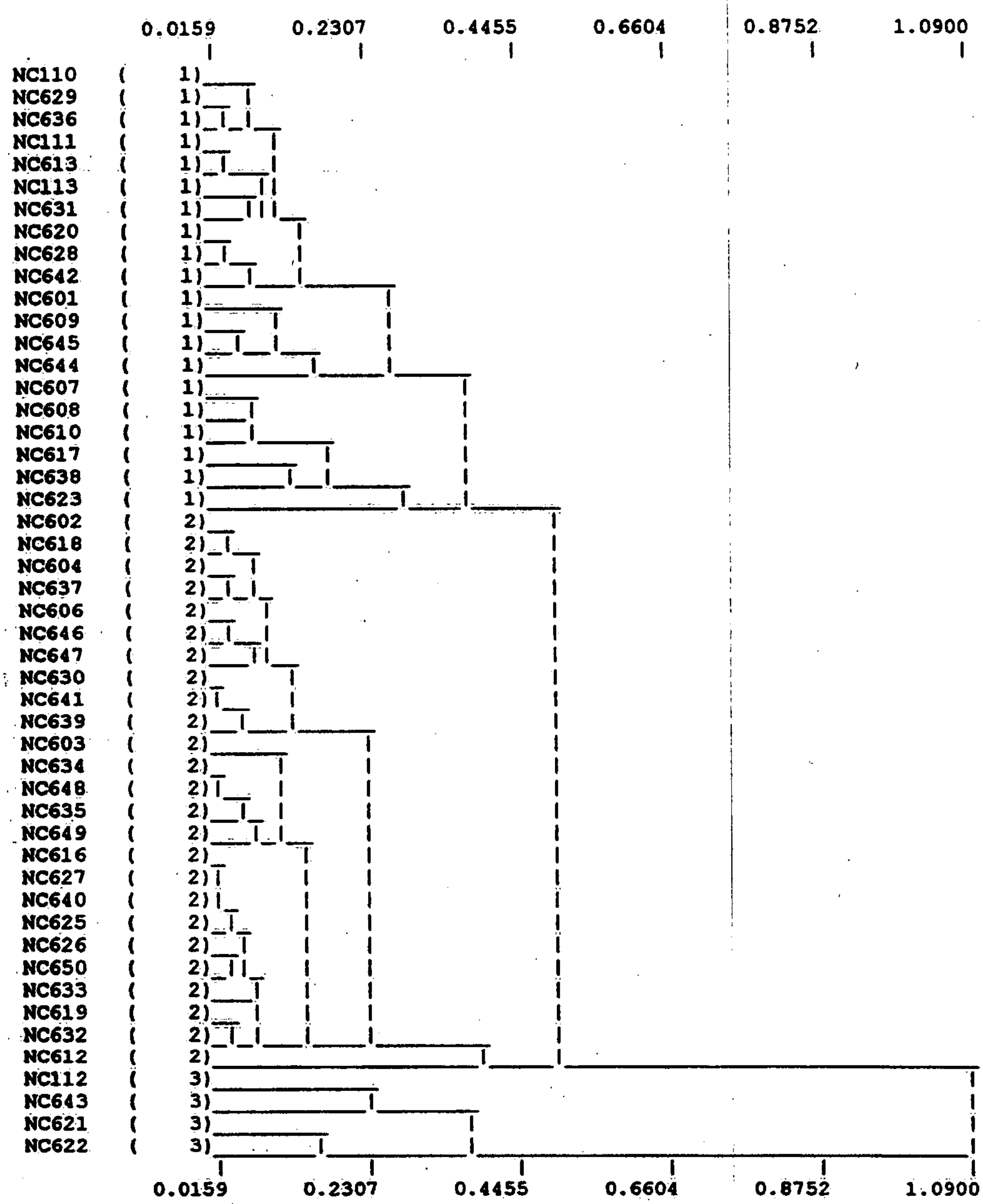
Sediment Chemistry

Finally we have examined the pattern of the measured sediment attributes to determine if there was evidence of a spatial pattern that may relate to the observed biological effects. Data were available from 49 sites. Some samples for particle size (8 sites) and % loss on ignition (LOI) (3 sites) were lost and values were substituted by taking the average of the closest sites at a similar depth (Table 9). Examination of spatial pattern for 24 sediment attributes was undertaken by multivariate analysis using the same clustering and ordination methods as in the analysis of spatial pattern of community structure.

Table 9. Sites for which particle size and LOI data missing.

Missing site	Sites used to establish average value	Missing site	Sites used to establish average value
Particle Size		**LOI**	
602	601, 603	601	SE1 from 1988
110	620, 649	111	608, 616
608	111, 603		
610	606, 609		
618	617, 623		
625	645, 641		
637	113, 638, 642		
647	632, 630, 629		

Figure 14. *Dendrogram of Spanish River area sites, based on 24 sediment attibutes from 1990.*



The dendrogram suggests that there are three groups of sites (Figure 14). A small group (Gp 3) of four sites and two larger, similar sized, groups of sites. Using the Kruskal Wallis non-parametric test we examined those variables which differed the most in the three groups. Twelve of the 24 variables showed significant differences (Table 10) in the three groups. Five of these are metals, six major elements and LOI. The four sites forming Gp 3 have much lower concentrations of the majority of major elements and metals than the other sites. Concentrations of most of these 12 sediment attributes in Gp 3 are very similar to the average values for the North Channel reference sites (Table 10).

Table 10. *Average values for selected variables in 3 groups of sites from the Spanish River area and North Channel reference sites, ordered by decreasing degree of difference in the three groups.*

Variable	Gp 1	Gp 2	Gp 3	Reference
Sulphur	1405	2655	250	n.a.
LOI	7.8	9.8	3.2	7.1
Potassium	2.6	2.3	2.9	2.7
Nickel	389	555	124	115
Copper	88	118	40	35
Zinc	242	299	121	136
Cobalt	38.7	48.1	16.2	17.3
Phosphorus	0.2	0.2	0.1	0.2
Iron	7.4	8.2	5.1	4.4
Lead	74	87	27	36
Manganese	0.6	0.6	0.2	0.2
Aluminium	12.4	12.1	13.6	11.5

Groups 1 and 2 both have much higher values for both sulphur and metals and the difference between the groups is the degree to which values are elevated above Gp 1 and the reference sites. Group 2 has the highest values, particularly of sulphur, nickel and copper.

We have plotted the sites in ordination space to establish how discrete the groups of sites are and the plot suggests that in fact many of the sites form a continuous gradient rather than fall into discrete groups (Fig. 15). Sites toward the left side of the plot (Fig. 15) have high metal concentrations and those to the left tend to have low metal levels. Similarly sites located toward the top of the plot have high sulphur levels and those on the bottom have low sulphur levels. With the exception of sites in Gp 1 the sites are primarily oriented along a gradient of increasing sulphur and metal concentrations from the bottom right hand side of the plot to the top left hand corner.

The geographic distribution of the sites (Fig. 15) shows the majority of those forming Gp 2, with the highest metal and sulphur concentrations, to be located inside the Whalesback Channel and

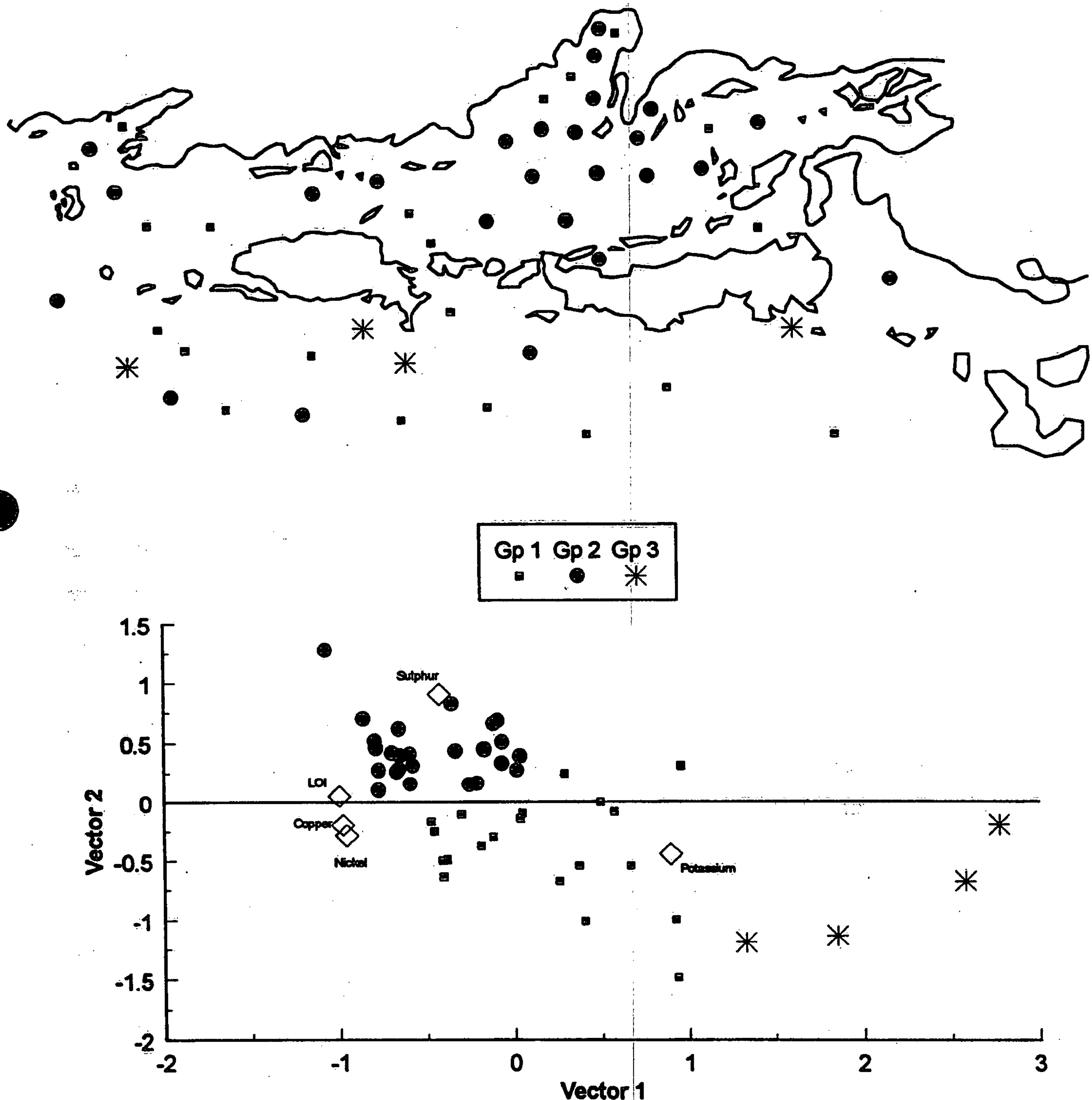


Figure 15. Site groups from cluster analysis and ordination of 24 sediment attributes in the Spanish River Study Area 1990.

those forming Gps 1 and 3, with lower sulphur and metal levels, to be outside the Whalesback Channel.

To provide a regional context to the sediment characteristics of the Spanish River area we compared 22 sediment atttributes (Table 11) for the reference sites in the North Channel (Fig. 3) with those for the sites in the Spanish River area.

Table 11. Sediment attributes used to compare reference sites with 1990 study sites in the Spanish River area, together with correlation values for SSH ordination.

Variable	Correlation
Zinc	0.9523
Nickel	0.9349
Copper	0.9284
Cobalt	0.8871
Chromium	0.8701
Lead	0.8643
Silica	0.8509
Vanadium	0.8385
Iron	0.8358
Titatnium	0.7806
Sand	0.7389
Aluminium	0.7288
Magnesium	0.7284
Arsenic	0.7129
Clay	0.7012
LOI	0.6581
Potassium	0.6243
Silt	0.4773
Manganese	0.4702
Phsophorus	0.4485
Sodium	0.3074
Calcium	0.1029

The data have again been plotted in ordination space (Fig. 16) and show the majority of sites to be distributed primarily the first ordination vector. The reference sites (open circles in ordination plot) have been enclosed by a hand drawn polygon and 15 Spanish River area sites fall within the envelope of variation associated with the reference sites. These 15 sites (open circles on map) are primarily located in the North Channel (12), the Serpent River mouth and two sites, away from the main flow, in the Whalesback Channel. Cluster analysis of the 98 sites (49 reference and 49 Spanish River) produced three large groups of sites. A group made up of 29 reference sites and 5 Spanish

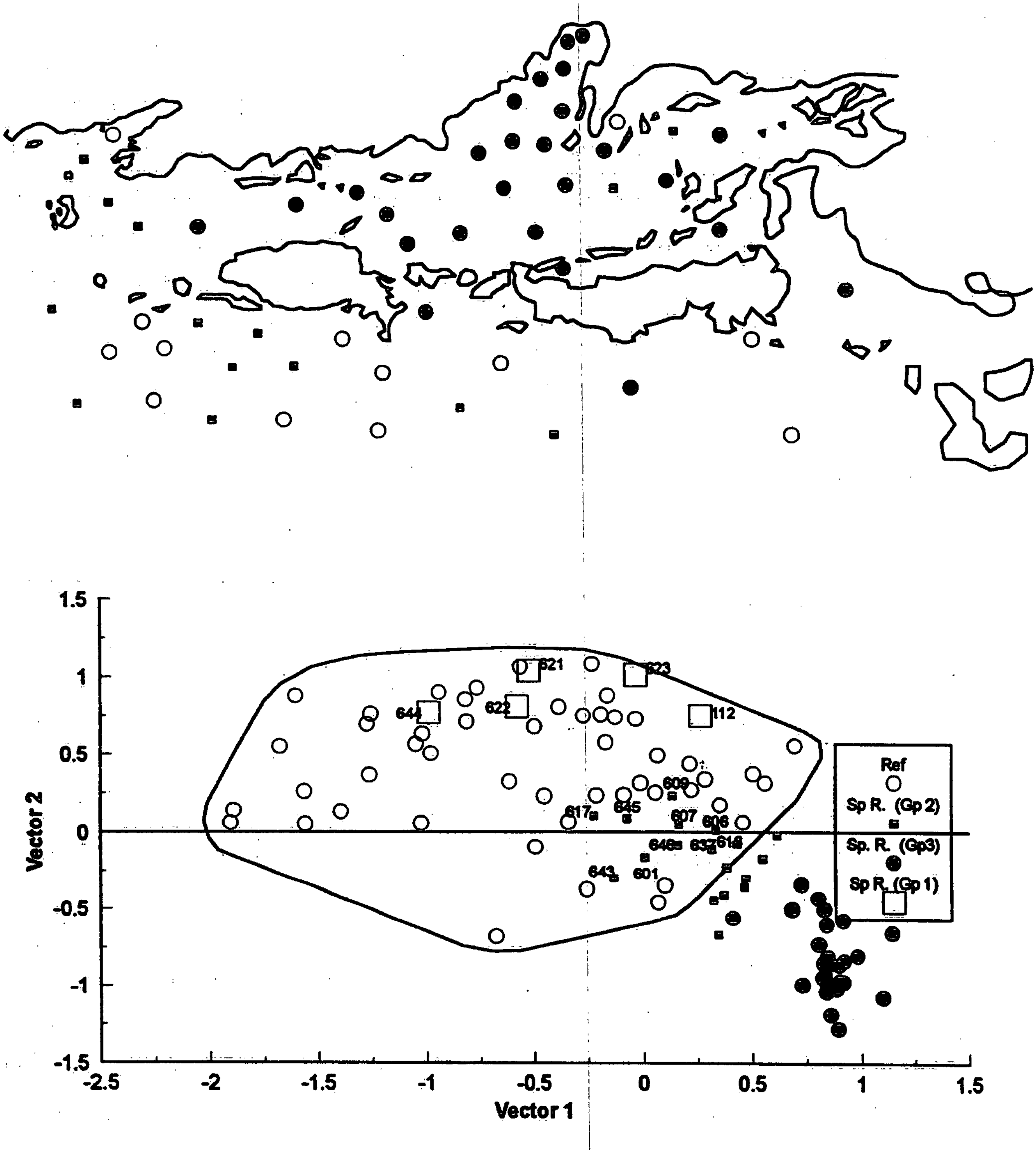


Figure 16. Comparison of North Channel reference sites and Spanish River area sites in ordination space, based on 22 sediment attributes..

River sites (112, 621, 622, 623, 644 - open squares on ordination plot). A second group of sites made up of 20 reference sites and 18 Spanish River sites, these are indicated by small squares in Figure 16 and although some are outside the envelope of reference sites cannot be distinguished by cluster analysis. The third group is made up exclusively of 26 Spanish River sites (solid circles), the majority of which are located in the Whalesback Channel. These data show the Whalesback Channel to be different to the greater part of the North Channel (Fig. 16) and that the diffrence is due to elevated metal concentrations, Particularly zinc, nickel and copper (Table 10). The spatial pattern (Fig. 16) also suggests exchange of sediment material from the Whalesabck Channel to the North Channel through the passages between the islands. Those areas of the North Channel where sediment metal concentrations are elevated are associated with those passages (Fig. 16).

Conclusions and Summary

Data collected from the 1988 and 1990 surveys indicated that there were both elevated metal concentrations and impaired invertebrate communities in the Whalesback Channel, without regional data it was difficult to provide a broader context for the significance of the effects on the invertebrate communities. The fact that there are data available from reference sites in the North channel provides such a context to make a quantitiative assessment of the extent of the deleterious effects in and beyond the area of concern and to provide targets to define recovery of the impacted area.

The reference site data show that there is extensive impairment in the Whalesback Channel and almost the entire area has a degraded benthic community, this impairment extends a considerable distance beyond the boundaries of the area of concern. This is evident both from the comparison with the reference sites from the North Channel and from the predictions based on the entire Great Lakes reference sites. Furthermore, it would appear that there is evidence of some effect being felt in the North Channel in the area where the major water exchange is occurring between the Whalesback and North Channel. A comparison of environmental characteristics at those sites where degraded communities occur and reference sites provides strong evidence that the impairment is associated with high levels of metals, particularly copper, nickel and zinc. However, it is not possible to distinguish any particular metal of concern as their occurrence is highly correlated.

Sediment toxicity data do not confirm that the degraded benthic communities are related to high metal levels. However, there are some confounding factors that may explain the lack of concordance in these data. First, only one test species was used, the tubificid worm *Tubifex tubifex*. In fact the community structure data suggest that the Tubificidae was the least impacted group and showed relatively little change in numbers in the study area (Fig. 4, Table 3). The most affected taxa were the amphipod *Diporeia* and the Chironomidae (midges). Unfortunately, at the time of this study, the capability to run bioassays with these taxa was unavailable. It would seem that in this case the wrong species was selected for testing and demonstrates the importance of running a battery of species rather than relying on single species tests. The second possible explanation is that the test was responding not to whole metal concentration but to a particular fraction, and that total metal concentration is a poor indicator of bioavailability. This test appears to be responding to other sediment attributes than metal concentration, particularly the proportion of sand and clay (which effects availability) and the amount of organic material which is related to food availability. This latter issue has since been addressed through a methodological change and animals are now fed at the beginning of the assay.

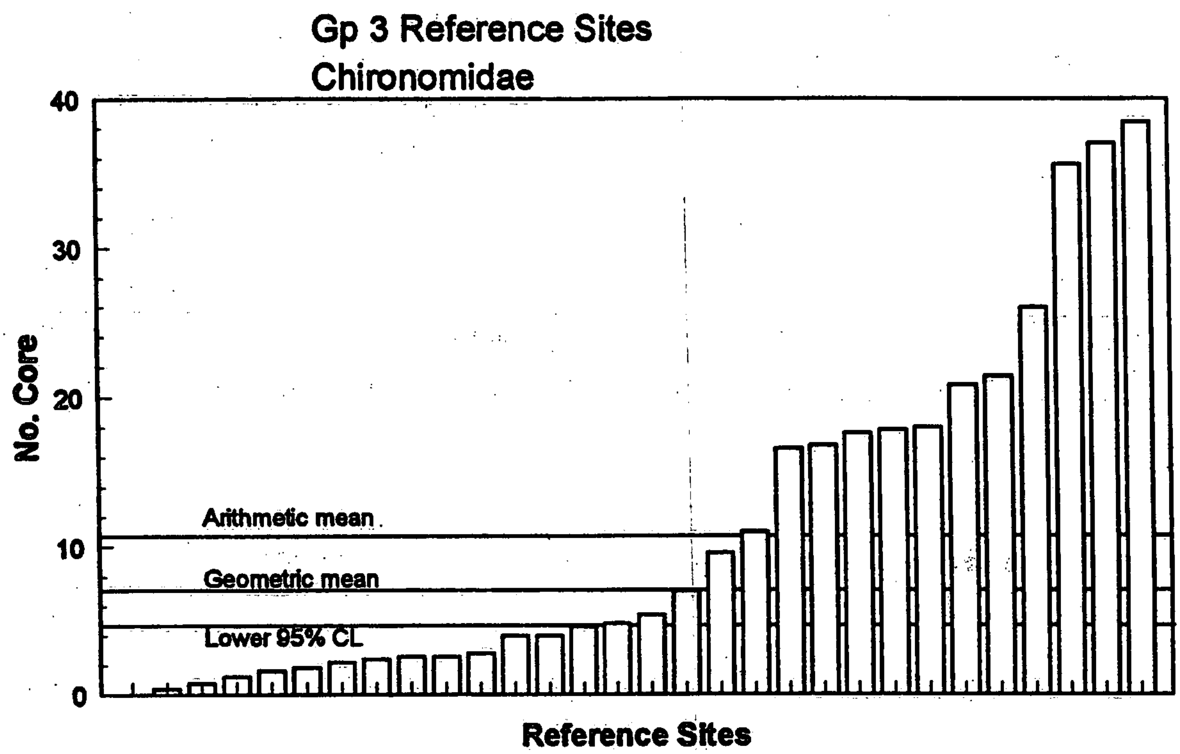
Finally, it is possible from the reference site data to set targets that will indicate recovery of the benthic community and to establish sediment concentrations for metals at which a recovery can be expected. From our reference site data base we have established that two different communities would be expected to occur in the area (Fig. 9). In the shallower, more sheltered inshore, areas a community where chironomid midges and molluscs are most abundant should occur. In the more open waters, and in the North Channel, a community with more oligotrophic species, particulalrly *D. hoyi*, the oligochaete *S. heringianus* and the chironomid *Heterotrissocladius* is expected. The actual numeric targets have been derived from the North Channel reference sites that were included in the Gp 3 and Gp 5 assemblages. From the North Channel there were 30 and 16 reference sites respectively in the two groups. From these sites we determined that for Gp 5 sites (offshore) only *D. hoyi* occurred in sufficient numbers to derive a single species criteria. Similarly for the nearshore sites (Gp 3) a number for the family Chironomidae was consisdered most appropriate, as no single genus was sufficiently abundant. For both taxa the distribution among the sites was contagious (Table 12) and therefore a criteria value was established by calculating the lower 95% confidence limit calculated from the geometric mean using a log (x+1) transformation.

The numeric criteria we would propose for the impacted area are 1490 m^2 Chironomidae for inshore waters and for *D. hoyi*, in the offshore waters, 1637 m^2. Selection of the appropriate criteria should be based on the predictive model which is used to assign sites to either a Gp 3 or Gp 5 assemblage. We would also strongly encourage the use of the entire community and a comparison of the entire assemblage using the multivariate approach described earlier. Reliance on single taxa may be unreliable, and even in the reference sites it can be seen that using this approach alone indicates some sites as being impacted (Fig. 17). However, as a first approximation and a general target these numeric targets may be useful.

Table 12 Mean numbers of target species in North Channel reference sites and proposed criteria for establishing non-degraded invertebrate communities in the North Channel.

	Chironomidae Inshore - Gp 3	*Diporeia hoyi* Offshore - Gp 5
Arithmetic $\bar{x}$ (no. core) Variance	11.2 133.0	11.3 50.7
Geometric $\bar{x}$ Derived variance Confidence interval	7.5	9.3
Lower 95% C.L. (no. core)	5.1	5.6
Criteria expressed in no.m2 (using 250μ mesh)	1491	1637

To establish the sediment remediation targets for achieving a non-degraded benthic invertebrate community we have assumed that the observed degradation is related to metal concentrations in the sediment. We have derived clean up targets for three metals, copper, nickel and zinc, as these particular elements were best correlated with the observed community effects. The proposed target for remediation are based on values found in the sediment at the 49 reference sites (Fig. 3). Examination of the statistical distribution of the three metals shows both copper and zinc to approximate a normal distribution (Fig. 18). Nickel concentration clearly does not follow a normal distribution. The geographic distribution of the three elements have been expressed as values above



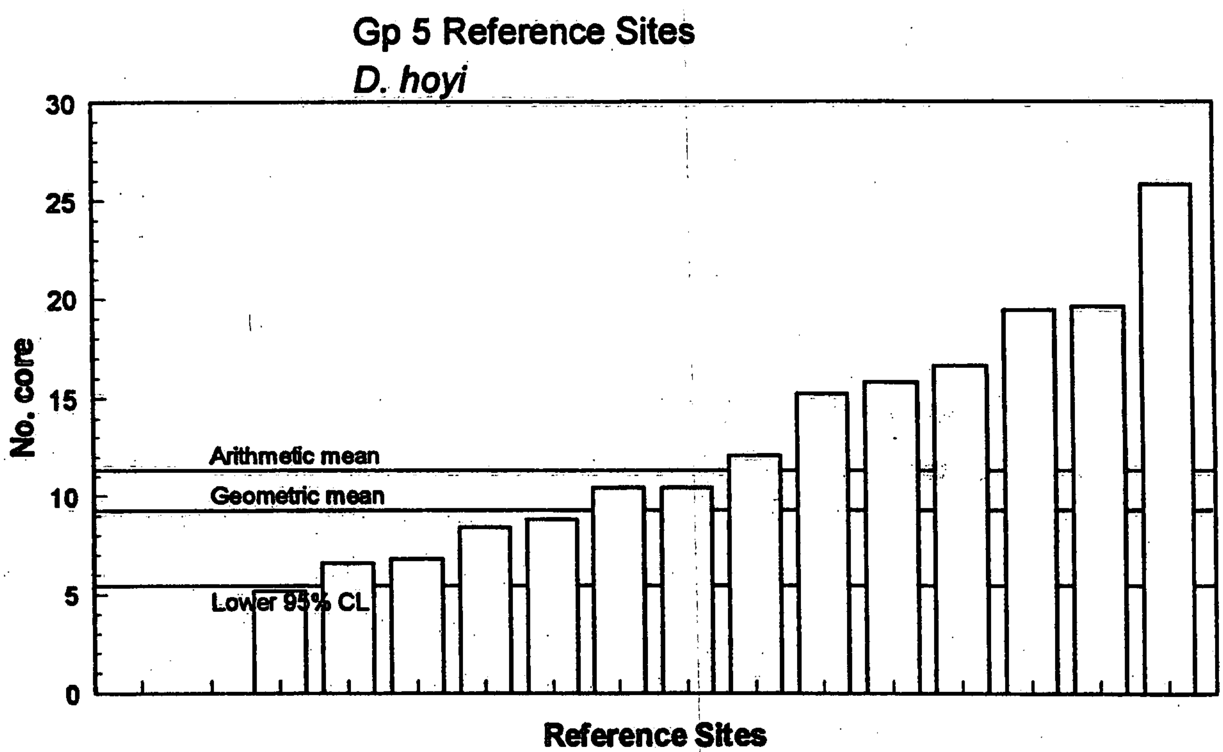


Figure 17. Distribution of two taxa for which criteria have been set from North Channel reference sites.

and below the mean values (copper and zinc) and above and below what appear to be two distributions (Fig. 18) for nickel. For copper and zinc there is no clear geographic pattern to the distribution of sediment with elevated metal levels (Fig. 19). The elevated concentration at some sites is likely associated with local conditions and there is a strong correlation with physical sediment attributes for copper with sand (-0.752) and LOI (0.835) and for zinc with LOI (0.735) and TOC (0.657). The nickel concentration appears to show a geographic pattern and the highest concentrations occur in the vicinity of the Whalesback Channel (Fig. 19). Also the correlation between nickel concentration and physical sediment attributes was much lower, the best correlatuion being with LOI (0.446). This suggests that local conditions are less important in determining the concentration and that a larger scale process may be of more importance.

Table 13. *Values for three metals (ug.g Dry Wt)) at reference sites in the North Channel.*

	Nickel	Copper	Zinc
Mean	115	35	136
S.D.	87	18	69
95% C.L.	24.4	4.9	19.4
Upper 95% C.L. - (Proposed target)	139.4	39.9	155.1
Background Conc	50	40	100-120
OMOEE LEL	16	16	120
OMOEE SEL	75	110	820

In establishing targets we have again calculated 95% confidence intervals (Table 13). however, in this case we are proposing the upper 95% confidence interval as the target. As this is derived from reference sites with acceptable invertebrate communities we believe these are reasonable remediation targets. The target values for copper and zinc are similar or close to background levels reported by Mudroch (1995) from sediment cores taken in the Spanish River area. This suggests that values at reference areas represent historic conditions and are reasonable targets. It is also noteworthy that both the background, reference site mean values and targets are above the Ontario Ministry of Environment (OMOEE) Lowest Effect Level (LEL) concentrations (Persaud *et al.* 1992). The target value for nickel (139 ug.g) is almost three times the background concentration from core data. This reflects the fact that values in the reference area are elevated, however, because the

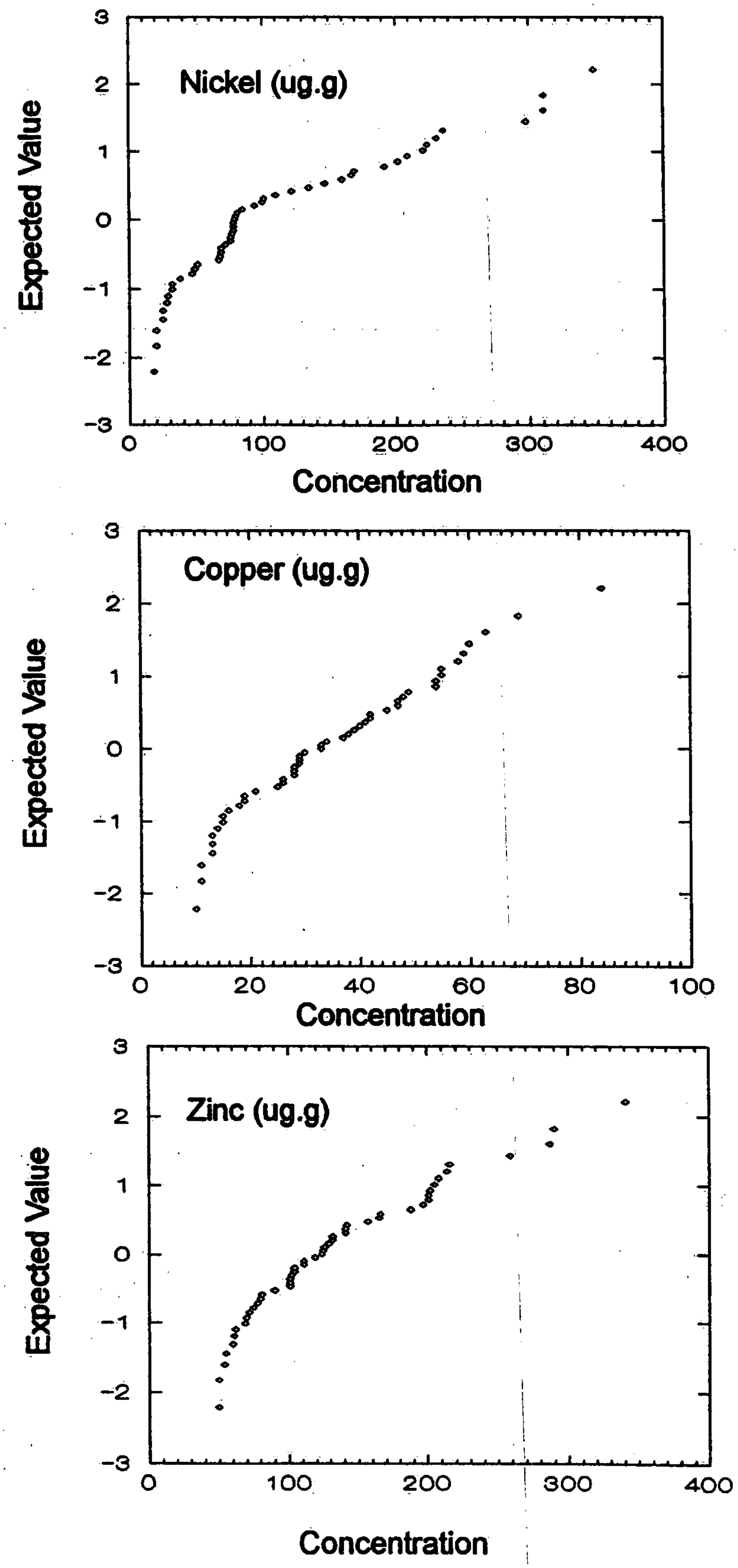


Figure 18. Probability plots of expected values for a normal distribution for three metals in North Channel reference sites.

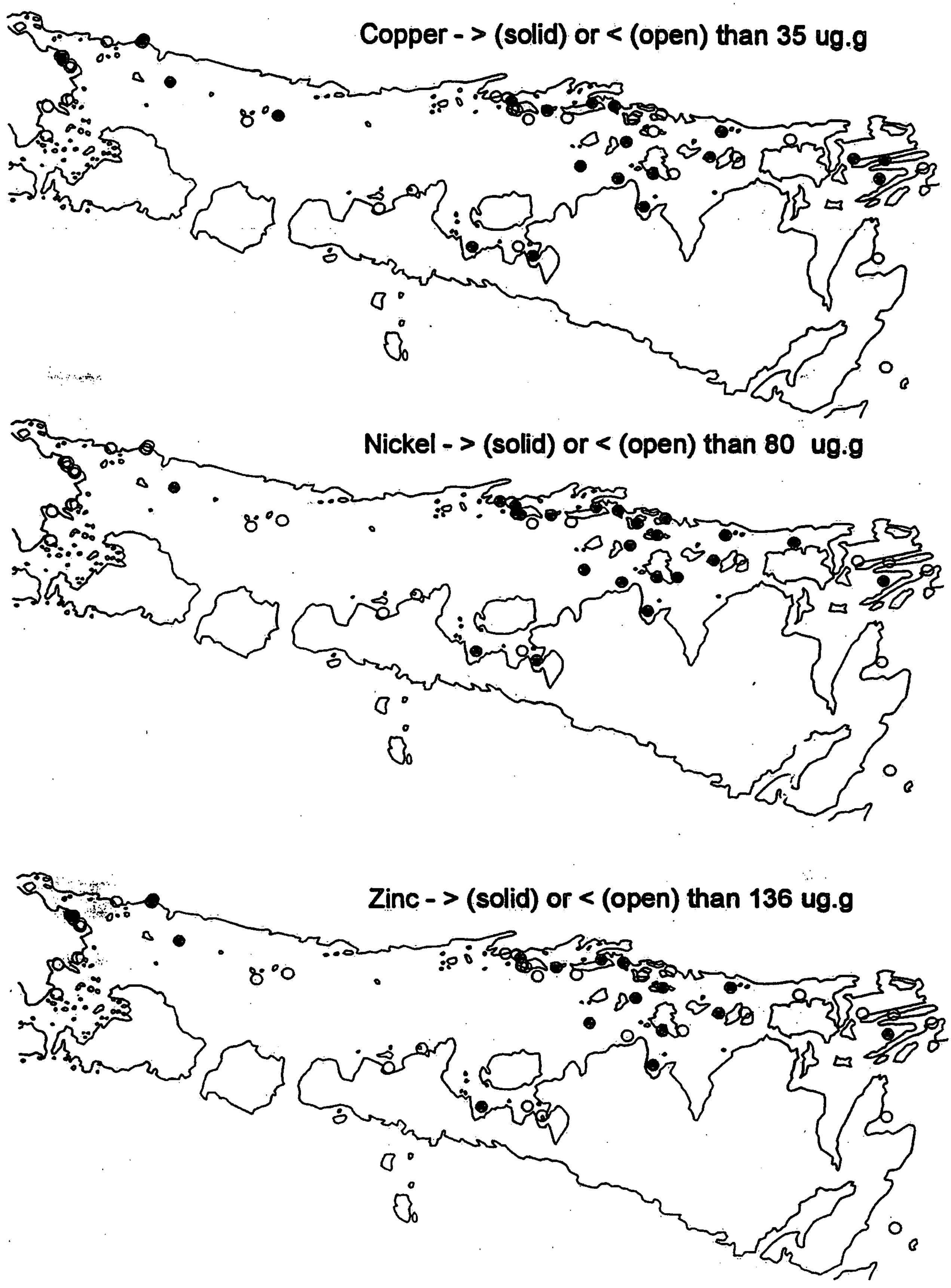


Figure 19. Concentration of three metals at reference sites in the North Channel.

invertebrate communities are considered to be unimpaired and can tolerate these levels we consider this to be an acceptable remediation target for this area. Again it is notweorthy that the proposed value exceeds the OMOEE Severe Effect Level criteria (Table 13).

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