Benthic macroinvertebrates and sediment characteristics of Hamilton Harbour in 1984, and changes between 1964 and 1984.

Cam Portt [1], Vic Cairns [2], Charles K. Minns [2], and Robert Bonnell [2]

[1] C. Portt and Associates, 56 Waterloo Avenue
Guelph, Ontario N1H 3H5

[2] Great Lakes Laboratory for Fisheries and Aquatic Sciences
867 Lakeshore Road
Burlington, Ontario L7S 1A1

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Cam Portt, Victor W. Cairns, Charles K. Minns, and Robert Bonnell

Great Lakes Laboratory for Fisheries and Aquatic Sciences
Bayfield Institute
Fisheries and Oceans Canada
867 Lakeshore Road
Burlington, Ontario
L7S 1A1

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Portt, C., Cairns, V.W., Minns, C.K., and Bonnell, R. 2014. Benthic macroinvertebrates and sediment characteristics of Hamilton Harbour in 1984, and changes between 1964 and 1984. Can. Manusc. Rep. Fish. Aquat. Sci. 3056: vi-46 p.

A survey of the benthic macroinvertebrates and sediment chemistry in Hamilton Harbour was conducted in 1984. Results were compared to a 1964 survey done at the same sites, prior to extensive efforts to reduce the nutrient and contaminant loadings to the harbour. A large toxic zone, devoid of all macroinvertebrates, in 1964 had shrunk to one site in 1984. Concentrations of metals especially Fe and Zn, and PAH levels remained high in the sediments. Invertebrate density had increased throughout the harbour between 1964 and 1984. Average oligochaete density increased by an order of magnitude from 5000 m^{-2} in 1964 to over 45,600 in 1984. The proportion of pollution tolerant worm species decreased. Although Sphaeriidae clams and several chironomid genera had appeared in the harbour by 1984, few other benthic taxa were present. Low oxygen levels in the deepest areas and the elevated sediment contaminants continued to restrict the composition of the benthic fauna.

RÉSUMÉ

Portt, C., Cairns, V.W., Minns, C.K., et Bonnell, R. 2014. Macroinvertébrés benthiques et caractéristiques des sédiments dans le port de Hamilton en 1984, et changements entre 1964 et 1984. Rapp. manus. can. sci. halieut. aquat. 3056:vi-46 p.

Une étude sur les macroinvertébrés benthiques et la chimie des sédiments dans le port de Hamilton a été effectuée en 1984. Les résultats de cette étude ont été comparés à ceux d'une étude menée en 1964 dans les mêmes sites, avant que des efforts considérables soient déployés pour réduire la charge en nutriments et les concentrations de contaminants dans le port. Une grande zone toxique, qui était dépourvue de macroinvertébrés en 1964, a rétréci pour ne constituer qu'un seul site en 1984. Les concentrations de métaux, en particulier de fer et de zinc, et les concentrations d'hydrocarbures aromatiques polycycliques dans les sédiments sont demeurées élevées. La densité d'invertébrés dans l'ensemble du port a augmenté entre 1964 et 1984. La densité moyenne des oligochètes a augmenté et est passée de 5 000 m^2 en 1964 à plus de 45 600 m^2 en 1984. La proportion des espèces de vers tolérant la pollution a diminué. Bien que des sphaeriidés et plusieurs espèces des genres chironomidés aient fait leur apparition dans le port en 1984, il n'y avait pas beaucoup d'autres taxons benthiques. Les faibles niveaux d'oxygène dans les zones les plus profondes et les concentrations élevées de contaminants dans les sédiments ont continué de restreindre la composition de la faune benthique.

INTRODUCTION

Hamilton Harbour on Lake Ontario is one of the 42 Areas of Concern on the Great Lakes (International Joint Commission 1987). The harbour experiences severe hypolimnetic oxygen depletion during periods of thermal stratification from mid June to mid September. Several models have been developed to predict the effectiveness of various management strategies in reducing oxygen demand (Polack and Haffner 1978: Poulton 1982; Snodgrass and Ng 1985). Harbour waters consistently exceed Ontario's water quality objectives for ammonia, turbidity, dissolved oxygen, phenols, cyanide, zinc, and iron (M.O.E. 1985). Harbour sediments are heavily contaminated with PCBs, arsenic, copper, zinc, mercury, lead, cadmium, phosphorous, and Kjeldahl nitrogen exceeding Ontario's guidelines for dredged sediment disposal (M.O.E. 1985).

Johnson and Matheson (1968) described the benthic community and sediment characteristics present in 1964 at 46 sites in Hamilton Harbour and 25 sites in adjacent Lake Ontario. They found that a 2 km area near the industrialized south shore of the harbour was devoid of macrobenthos. The remainder of the benthic community was dominated by oligochaetes, particularly *Limnodrilus hoffmeisteri* and the sewage worm *Tubifex tubifex*. The harbour's benthic community differed considerably from that in adjacent Lake Ontario.

Between 1960 and 1984, substantial efforts had been made to reduce the municipal and industrial loadings to the harbour. Until the early 1960s the harbour received untreated effluent from the municipalities of Hamilton, Burlington, Dundas and Waterdown. By 1950 it had been referred to as the "largest septic tank in Canada" (in Matheson 1958). Hamilton installed primary sewage treatment in 1963 and secondary in 1973. By 1979, all four municipalities provided secondary treatment and their capacities had been increased. Similar improvements were undertaken by the industrial sector. Total loadings of ammonia, cyanide, phenols and solvent extractables from industrial sources were reduced by 90 % between 1967 and 1983 (M.O.E. 1985). In 1985, treated municipal effluents contributed 75 % of the nutrient loadings, as well as over 60 % of the summer inflow to the bay. The steel industry along the south shore discharged treated effluent and cooling water producing more than 90 % of the total phenol, iron, and cyanide loadings (M.O.E. 1985).

Total ammonia loadings had also decreased from 24,000 kg /day in 1967 to 857 in 1987 (Barica, 1990). Phosphorous loadings had decreased from 1600 kg / day in 1974 to 700 kg / day in 1985 (Charlton and Le Sage 1996). However, algal blooms still occurred in the harbour, with chlorophyll levels typical between 20 - 70 mg m^{-3} since 1976 (Harris et al. 1980). They also found that dissolved oxygen levels in the hypolimnion continued to decrease to zero by July between 1974 and 1977. Polak and Haffner (1978) estimated 80 % of the D.O. demand was from consumption in the water column and 20 % due to sediment oxygen demand. A large part of this pelagic oxygen demand is due to the nitrification of the toxic un-ionized ammonia during the spring. Ammonia from the municipal effluents builds up over winter when nitrifying bacteria are inactive and has reached maximum levels of 1.7 mg/L in late winter. As the water warms, ammonia declines at a maximum rate 0.5 mg/L per month in June (Barica 1990).

Benthic communities are sensitive indicators of water and sediment quality. Being sedentary, they integrate over their life span (0.5 - 2 years) changing conditions in both the sediments and water column (Wiederholm 1980). Reductions in contaminant loadings to the harbour between 1964 and 1984 should be reflected in the macrobenthic community. This study was undertaken to assess the status of the sediments and associated macrobenthos in Hamilton Harbour, and to determine what changes had occurred over the 20 years between the 1964 study of Johnson and Matheson (1968) and a resurvey in 1984. The data analysis and manuscript preparation had been completed by 1988 but the final manuscript was not printed.

METHODS

SAMPLE COLLECTION

Sampling techniques followed those used in 1964 by Johnson and Matheson (1968). Sediment was collected from 47 locations in the harbour (Figure 1) in the autumn between October 2-4, 1984. Sampling locations coincided as close a possible with those of the 1964 study. Site locations from 1984, based on Loran C coordinates, are listed in appendix 1. Locations were taken from original maps of Murray Johnson for the 1964 locations. Three of the 1964 sites locations were in areas that had been in-filled during the intervening 20 years. Water depth was measured, and dissolved oxygen concentration and temperature determined within 0.5 m of the substrate at each site with an YSI oxygen meter. At each site, two sediment samples were collected using a nine inch Ekman dredge (0.05 m^2). From one of the Ekman samples, sediment cores (6 cm deep and 5 cm diameter) were taken transferred to a solvent rinsed glass jar and retained frozen for sediment chemistry and particle size. The second Ekman sample was washed through a Tyler #30 mesh (0.58 mm) screen and the residue preserved in 10% formalin. In 1985, additional sediment samples were collected at 25 of the locations for polyaromatic hydrocarbons (PAH) and chlorinated organics.

SEDIMENT ANALYSIS

Sediment samples were freeze dried and homogenized. Loss on ignition (LOI) was determined by heating weighted subsamples to 550°C for 6 hours. Particle size distribution was determined using a combined sieve/sedigraph technique of Dr. Norm Rukavina, Technologies Research Branch, Environment Canada. Major element (Si, Al, Fe, Mg, Ca, Na, K, Ti, Mn, P) and metal (Ni, Co, Cr, V, Cu, Pb, Zn, As) levels were determined by X-ray fluorescence. The 1985 frozen samples were analyzed for pesticides, PCB, and PAH levels by National Water Research Institute, Environment Canada. Sample extraction used acetone-hexane, cleaned in dichloromethane and analysed using HPLC coupled with mass spectrometric detection.

BENTHOS ANALYSIS

A few drops of eosin stain were added to the preserved sample residues to assist in sorting and removal of the macroinvertebrates. All macroinvertebrates visible to the naked eye were removed from the samples. Oligochaetes were separated from the other taxa present, and their total blotted weight was determined to the nearest mg. A subsample of the whole oligochaetes from each sample (mean = 115 individuals) was weighed to the nearest mg and the total number of individuals in the entire sample was estimated by dividing the total weight by the subsample weight and multiplying by the number of individuals in that subsample.

Oligochaete species composition was determined at only 25 sites including all the 19 sites where Johnson and Matheson (1968) had examined the oligochaete species composition. Three randomly selected subsamples (mean = 128 individuals) from each site were placed in basic ethanol to remove the eosin dye, then slide mounted on glass slides using polyvinyl lactophenol. After clearing, each individual was examined under a microscope and identified to species where possible using the unpublished literature Key to Oligochaetes of the Great Lakes by Carol Loveridge and David Cook 1976, and the literature Aquatic Oligochaeta of the World by Brinkhurst and Jamieson 1971. Immature individuals which could not be identified to species were placed into two groups: those with hair setae, and those without hairs. Most of the immatures with hairs in Hamilton Harbour are likely *Tubifex tubifex,* while those without hairs are one of the *Limnodrilus* species.

Most of the chironomid species were identified under a dissecting scope or put on glass slides in temporary water mounts for identification to genus following Oliver et al. (1978). The remaining macroinvertebrates present were identified to genus or family where possible following keys in Pennak and keys for the *Pisidium* in Herrington (1962).

STATISTICAL ANALYSIS

Cluster analysis to compare community structure, based on the technique of Boyle et al. (1984), was used to identify oligochaete species assemblages at the 25 sites where they were idenfified to species. The percent dissimilarity between oligochaete samples i and i' was calculated as follows:

Di -I' = (Sum Pi – Pi’) /w

where Pi = percent of individuals in sample i of species j; Pi’ = percent of individuals in sample I’ of species j; and w = total number of individuals in sample i plus the total number of individuals in sample I’. Sites were clustered based on minimum percent dissimilarity between samples not in the same group, with added provision that the percentage (p) of the intergroup dissimilarities between all possible pairs of sites in the two groups must be less than a predefined maximum dissimilarity (Dmax). The dissimilarity between subsamples from the same location is termed within-cell d(Dw). The dissimilarity between subsamples from two different locations is termed between-cell d (Db). If normality and quality of variance options are approximately met the "*t*" statistic may be used to compare between-cell and within-cell D. Where Db is significantly larger than Dw the communities sampled in the two cells are considered different. A probability value of 50 % was used (Legendre et al. 1985). Dmax was calculated by regressing percent dissimilarity versus the "*t*" statistic and using this regression to calculate percent dissimilarity which corresponds to the upper confidence limit ($p > 0.95$).

Discriminant analysis (Nie et al. 1975) of the relative abundance of the oligochaete species was used as an aid to evaluate the difference in species composition between clusters. The discriminant functions were then used to classify the 1964 oligochaete communities reported by Johnson and Matheson (1968) according to the clusters derived from the 1984 data. Clustering of the sites based on the metal and PAH concentrations in the sediments used the same dis-similarity method.

RESULTS AND DISCUSSION

TEMPERATURE AND DISSOLVED OXYGEN

During October 2-4, 1984, surface water temperature ranged from 19°C at site 47 (depth 1m) to 12°C at site 23 (depth 22m) with the exception of site 38 where surface temperature was 24.5°C. Heated industrial effluents from the steel mills discharge into the

Ottawa Street Slip where site 38 is located. At the time of sampling in early October, water temperature had declined from the summer maxima. The temperature difference between 1m and 22 m was only 7°C indicating that fall turnover was beginning. However, an oxygen gradient was still very obvious. Dissolved oxygen ranged from 7.2 mg l^{-1} to less than 0.1 mg l^{-1} and was consistently less than 0.5 mg l^{-1} at depths greater than 17 m (Figure 2). Dissolved oxygen profiles at several locations in the harbour in early October 1984 indicated that oxygen concentrations were generally less than 1.0 mg l^{-1} at depths below 13 m.

SEDIMENT CHARACTERISTICS

Sediment particle size generally decreased with increasing depth (Table 1). The proportion of sediment in the clay-size was anomalously high at sites 38 and 39, located in the Ottawa Street Slip, when compared to other sites of similar depth. When data from sites 38 and 39 were excluded, regression analyzes indicated that depth accounted for 79 % of the variation in proportion of sediment within the clay size-fraction. When mapped, sites having greater than 50 % clay sized-fraction occurred below the 10 m contour at the west end of the harbour and near the 15 m depth contour on the east side of the harbour (Figure 3). In the central basin of the harbour the clay size-fraction accounted for 65 to 81 % of the sediment, which is comparable to the range of 72 to 76 % reported for the depositional basin of Lake Ontario (Kemp and Thomas 1976). However the highest clay concentrations reported in 1964 by Johnson and Matheson (1968) were in the range of 31 to 33 %. Given that the sedimentation rate in the centre of the harbour was estimated to be 1.2 mm yr^{-1} (Nriagu et al. 1983) and that our samples were homogenates of the top 6 cm of sediment, it is unlikely the difference since 1964 was a result of deposition over the intervening 20 years. It is likely, in part, due to a difference in the methods used for particle analysis in the two studies.

The distribution of silt was variable, ranging from 2 to 65 % (Table 1), with the highest proportions occurring at intermediate depths and in the Windermere Basin (sites 46 and 47 at 65 % and 63 % respectively). Windermere Basin receives runoff from Redhill Creek, a steep gradient tributary via the creek, and effluent from the Hamilton sewage treatment plant (STP). Sand accounted for less than 5 % of the sediment in the central basin but was the major component at some locations that were shallow and/or close to shore (sites 1, 7, 11, 14, 29, 33), or near the canal (site 35, 36) joining the harbour with Lake Ontario across the barrier beach. Gravel was present at only 3 sites (1, 18, 42).

Loss on ignition, as a measure of organic content, ranged from 1.7 % to 15.1 % of the dry weight (Table 1). Loss on ignition was correlated with increased depth, which accounted for 50 % of the variation in LOI. In 1964, LOI ranged from 1.8 - 24.2 % of dry weight (M. Johnson personal communication). The area of high LOI present in 1964 along the south shore and the Ottawa Street Slip was no longer evident. This is probably the result of the Hamilton sewage outflow having been moved in 1964 from the Ottawa Street Slip (containing sites 37 and 39) to Redhill Creek which drains into the shallow Windermere Basin (sites 46 and 47). If data from this area in 1964 are excluded, comparison with the 1964 data indicated little change in LOI or the relationship between LOI and depth over the 20 year interval.

SEDIMENT CHEMISTRY

The concentrations of major elements in the sediment from the central basin of Hamilton Harbour (Table 2) were comparable to that reported for the western depositional basin of Lake Ontario (Thomas and Mudroch 1979). The underlying geology and soils would be similar as in the harbour. Silicon, Fe, Ca and Al were the dominant major elements. The exception was the levels of Fe_2O_3 and P_2O_5, which were about three times greater in the harbour than in the lake sediments. High levels of iron are a result of the high loadings to the harbour from past industrial effluents, which were reported to be 10,900 kg day^{-1} in 1983 and 36,000 kg day^{-1} in 1977 (Ontario Ministry of Environment [OME], 1985). Johnson and Matheson (1968) estimated iron loadings in 1964 to have been 63,000 kg day^{-1}. At that time Fe_2O_3 made up more than 25% of the dry weight of the sediments in an area of 2 km^2 along the industrial south shore, and the maximum was 75 % at site 37 (Johnson and Matheson 1968). In 1984, the percent of Fe_2O_3 was less than 25 % of the sediment at all locations except 38 and 39, within the Ottawa Street Slip, where it was 44 %. There was little change in the iron concentration in the rest of the harbour between 1964 and 1984.

The concentration of P_2O_5 exceeded 1.0 % at sites 13, 14 and 32. Site 32 is located near the outfall of the Burlington STP. In 1964, Johnson and Matheson (1968) found that total phosphorous concentration exceeded 1.0 % in the central basin and at several sites along the south shore. In 1984, levels of P_2O_5 in the harbour center were in the range of 0.8 - 0.9 %. The high levels of phosphorous in the sediments presumably result not only from the high loadings but also from co-precipitation with iron which facilitates phosphorous retention in the sediments. Historical effluence from the steel industry contained high levels of pickle liquor waste which, as a source of $FeCl_2$ and $FeSO_4$, would cause co-precipitation of the phosphorous in the water (Sedlak 1999).

Concentrations of some metals Ni, Co, and V in sediments from the harbour center were less than those reported in the surficial sediments of the western depositional basin of Lake Ontario (OME 1985), but levels of Cd, Cu, Pb, and especially Zn in the harbour were more elevated (Table 3) (Kemp and Thomas 1976). Arsenic concentrations in Lake Ontario sediments were not available for comparison. Elevated levels of Cu, Pb, Cr, and Zn reflect the industrial use and the loadings to the harbour which were estimated at 160 kg day^{-1}, 49, 140, and 1200 kg day^{-1} in 1977 respectively (OME 1985). An 85 % reduction in Zn loading to the harbour from the steel industries was achieved between 1977 and 1983 (OME 1985) with loadings in 1983 of about 200 kg day^{-1}.

The data revealed that sites 38 and 39 in the Ottawa Street Slip were anomalous in many respects. The highest concentrations of Fe, Ca, Mn, and Cr and lowest concentrations of Si, Al, Mg, K, and Sn occurred at these two locations close to the steel mills. The proportion of clay in the sediment size-fractions, LOI, and the metals Pb, Zn and As were also higher at these two sites than at other sites with comparable depth. Clustering of the sediment metal concentrations in Figure 4 indicated that sites 39, 37 and 38 were separated (Group II and V) from the other sites in the harbour. Group I were nearshore sites in the west end and Group III were mostly mid harbour sites.

When data for sites 38 and 39 were excluded, concentrations of Fe, Mn, As and Pb were positively correlated with depth, while Si, Na, Ca and Mg were negatively correlated with depth (Table 4). Iron Fe_2O_3 and MnO were strongly auto-correlated and correlated with LOI, all of which are influenced by the REDOX potential at the level of anoxia in the sediments. A large proportion of the metals in Hamilton Harbour are bound to the Fe-Mn oxides and organic compounds (OME 1985). Sediments from Lake Ontario had positive correlations between Fe, Si, and Al (Mudroch personal communications), which suggests that in the lake, a large proportion of the naturally occurring Fe is absorbed onto the fine clay particles or is present as ferroaluminum silicates (Nriagu 1978). In the harbour, the high proportion of clay sized particles at sites 37, 38 and 39 (where iron ore deposits were highest), suggests that much of the sediment in the slip was particulate ferric hydroxides. Cu and Ni were more highly correlated with LOI than with Fe and MnO concentrations which was consistent with the results of Nriagu and Cohen (1980), who found Cu, Ni, Pb and Cr were enriched in the humic acids of Lake Ontario sediments.

Pesticide concentrations were low in the harbour sediments (Table 5). Endrin, heptachlor epoxide, mirex and BHC were not detected in any of the samples. PAH levels at the sites varied by three orders of magnitude (Table 6). The highest concentrations were consistently found at sites 23 and 39. Pyrene, anthracene, and fluorene was up to an order of magnitude higher at site 23 or 24 (Randal Reef) than at other sites including 39 (Table 6). Plots of the log of PAH concentrations versus depth showed that sites along the south shore had consistently higher levels that elsewhere at sites with similar depth. PCB concentrations varied by an order of magnitude, with highest levels occurring in Windermere Basin (sites 46 and 47; Table 5). There was no apparent relationship between PCB concentrations and depth. Clustering of sites using the PAH levels indicated that sites 23 and 29 were dissimilar to other locations. Likewise the cluster of sediment pesticide levels showed that sites 46 and 47, 36 and 39 formed separate groups from the other sites in the harbour (Figures 4 and 5).

BENTHIC MACROINVERTEBRATES

The benthic fauna of Hamilton Harbour was dominated by oligochaetes. Density ranged from 0 at site 37 in the Ottawa Street Slip, to over 470,000 m^{-2} at site 47 in Windermere Basin. In 1984, oligochaete abundance was typically between 10^4 to 10^5 m^{-2} throughout most of the harbour (Figure 6). Abundance increased between 1964 and 1984 by an order of magnitude in the central basin of the harbour. For all sites within the harbour, oligochaete density averaged 45,615 m^{-2} in 1984 compared to 5036 m^{-2} in 1964. In 1984, the toxic zone was reduced to 1 site compared to 1964 when the area devoid of any macroinvertebrates extended over an area of about 2 km^2.

Johnson and Matheson (1968) reported that the toxic zone lacking oligochaetes coincided closely with the area where Fe_2O_3 exceeded 25% of the sediment weight. In 1984, Fe_2O_3 concentrations were greatest (44.3 %) at site 37, the only location where no oligochaetes were present, yet Fe_2O_3 levels at site 38, where oligochaetes were present at low numbers, was nearly identical (44.17 %). Mortality at site 37 was not due to the iron alone or other metals, since except for Cr, metal concentrations were higher in the central basin of the harbour than at site 38. Cr was only slightly higher at site 37 than at site 25 (490 and 480 ppm respectively (=mg/kg), yet oligochaetes were abundant at site 25 (Table 3, Figure 6, Appendix 2). High concentrations of several PAHs were observed at site 39, PAH concentrations were not measured at sites 37 or 38 (Table 6). Another possible cause of the absence of oligochaetes at site 37 and low density at site 38 may have been that their lethal temperature was periodically exceeded in that area due to the discharge of cooling water from the steel industry.

A total of 8 oligochaete species were identified in the family Tubificidae, in addition to a few individuals of the family Naididae which were not identified to species in the 1984 samples (Appendix 2). *Limnodrilus hoffmeisteri* was ubiquitous throughout the harbour in both 1964 and 1984 (Figure 7). The sewage worm *Tubifex tubifex* was present less frequently in 1984 than in 1964, while *Quistradrilus multisetosus* and *Limnodrilus claparedianus* were present at a great proportion of the sites in 1984. The oligochaetes: *L. maumeensis*, *Aulodrilus pluriseta, Ilyodrilus templetoni* and the naidids were present in 1984 but not observed in 1964, while the opposite was true for *L. udekemianus, Spirosperma ferox* (as Peloscolex) and *Potomothrix moldaviensis* (as Euilyodrilus in 1964) (Figure 7).

The most abundant mature species among the mature oligochaetes was *Q. multisetosus*, which accounted for an average of 42% of the mature oligochaetes identified in 1984, followed by *L. hoffmeisteri* which was 32% of those identified (Figure 8). *T. tubifex*, *L. cervix*, *L. maumeensis,* and *A. pluriseta*, accounted for 10 - 15 % of the mature oligochaetes where present, while *L. claparedianus* and *I. templetoni* each accounted for less than 5%. Where present, the mean relative abundance of *Q. multisetosus* was much higher in 1984 than in 1964, while the relative abundance of the other species observed in both years was lower in 1984 (Figure 8). The distributions of *L. hoffmeisteri*, *Q. multisetosus*, and *Tubifex tubifex*, were not related to depth. *L. claparedianus* and *L. maumeensis* were more common at intermediate depths, while *L. cervix*, and the naidids were present at the shallower nearshore sites (Figure 9). *L. maumeensis* was restricted to sites along the south shore.

The proportion of immature worms that could not be identified to species in our samples ranged from 62 % to 97 % (mean = 85%) of the oligochaetes examined (Appendix 2). This was higher than in 1964 when the range was 0 to 79 % (mean = 37 %; Johnson and Matheson 1968). In 1984, a mean of 76 % of the immatures did not have hair setae and are presumed to have been *Limnodrilus* spp. The remaining 24 % of immatures with hair setae were likely mostly *Tubifex*. Johnson and Matheson did not find any immature tubificids with hairs in the 1964 samples collected in August and early September. This change is consistent with a later sample season in 1984 after the oligochaetes had finished reproduction.

Cluster analysis base on the relative abundance of mature oligochaetes in 1984 identified 3 species assemblages and one outlier (Figure 10 and Table 7). The largest group, Assemblage III was present at 14 of the 25 sites, mostly in the central basin and along the southern industrial shore. The nucleus of the sites where this assemblage was present, defined as sites which showed no significant difference (p > 0.99) among all possible paired combinations (Figure 11 = matrix), consisted of sites from the deep central basin where *Q. multisetosus* and *L. hoffmeisteri* together accounted for 84 - 100 % of the mature oligochaetes (Table 7, Figure 12). At some of the peripheral sites in this group, *L. maumeensis, T. tubifex*, or *A. pluriseta* were also abundant, but in all cases *Q. multisetosus* and *L. hoffmeisteri* accounted for at least 50 % of the total mature worms.

Assemblage II was present at 6 sites located in the western end and along the north shore of the harbour (Figure 12). Depths ranged from 4 to 12 m at these sites where the Naididae were present, or where *L. cervix, L. claparedianus* and naidids combined accounted for 39 to 55 % of the mature oligochaetes present. These sites also represent the zone of the harbour with highest water quality. Assemblage I was present at 4 sites, the 2 shallow sites (1 m) in the southeast corner of the harbour (Windermere Basin) and single sites along the north (site 8) and south shore (site 21) in 14 and 17 m depth respectively. At these 4 sites *L. hoffmeisteri* was clearly dominate accounting for 77 to 92 % of the mature oligochaetes. Assemblage IV was present only at site 40, the only site where T. tubifex was the most abundant oligochaete species. Although site 40 was an outlier, its species composition was not significantly different ($p < 0.95$) from 4 of the sites where assemblage III was present (Figure 12).

Discriminant analysis of the relative abundance resulted in 3 significant discriminant functions ($p > 0.99$), which correctly classified all 25 sites according to the species assemblages present (Table 8). When these functions were applied to the 1964 data, the results indicated that Assemblage I (*L. hoffmeisteri* dominant) was present at 7 sites, Assemblage II (*L. cervix*, and /or *L. claparedianus* relatively abundant) was present at 5 sites, and Assemblage IV (*T. tubifex* dominant) was present at 7 sites (Figure 12). Assemblage III, which characterized the central basin sites in 1984, was not present in the 1964 samples due to the low abundance of *Q. multisetosus*. In 1964, sites with the outlier Assemblage IV, containing the pollution tolerant *Tubifex*, were more numerous across the harbour.

Chironomids were present at only 8 of 26 sites (all <= 12 m deep), with a total of 8 genera present in the harbour during 1984 (Table 9). In 1964, chironomids were present at 6 of the 26 sites (all <= 14.6 m deep), with only 4 genera present. Average density of chironomids had increased from 10.5 m^{-2} in 1964 to 53.8 m^{-2} in 1984. Although the number of midge genera identified in 1984 was twice that observed in 1964, the most abundant genera present in 1984, (*Chironomus*, *Glyptotendipes* and *Procladius*) were also the most abundant in the earlier collections. The other 5 genera observed in 1984 were represented by so few individuals that they could easily go undetected. The mean density of midges at sites ≤ 12 m in 1984 was 47 m^{-2}. This was greater than the average of 18 m^{-2} at sites ≤12 m in 1964, but much less than the average of 140 m^{-2} reported for Toronto Harbour (depth 3.5 to 12.2 m) by Golini (1979).

Sphaeriids were present at 10 sites in 1984 with 9 species identified (Table 10), and averaged 10 m^{-2}. No sphaeriid clams were present in the 1964 samples from the harbour, although 7 of the 9 species that were observed in 1984 were present in adjacent Lake Ontario during 1964. One sphaeriid specimen was collected in 1965 inside the harbour near the canal to Lake Ontario (Johnson and Matheson 1968). In 1984, sphaeriids were much less abundant in the harbour than reported by Golini (1979) for Toronto Harbour, however our estimates of abundance are conservative since only individuals with tissues inside the shells were enumerated and these were in the minority. No gastropods were collected from within the harbour in 1964 or 1984.

Only two isopod specimens (*Caecidotea racovitzai*; formerly *Asellus*, sites 33 and 38), one amphipod (*Gammarus fasciatus*, site 13) and a single dragonfly nymph (*Argia* spp., site 46) were collected in 1984 from the 47 sites sampled. No other insects, leeches or flatworms were collected in the benthic samples from October 1984. Abundance of invertebrates in the samples is listed in Appendix 2. Only biomass of the total Oligochaeta was measured and is listed in Appendix 2. No biomass values exist for the chironomids, sphaeriids or other macroinvertebrates present in the samples from 1984.

COMMUNITY INDICATORS OF WATER QUALITY

During 1984, the presence of oligochaetes in the "toxic zone" along the south shore in which all macrobenthos were absent in 1964 indicates improved habitat quality in the harbour following pollution abatement in the 1970s. Oligochaete densities in the central basin of the harbour are comparable to that reported by Brinkhurst (1970) for the central basin of Toronto Harbour. The extremely high densities, up to 470,000 m^{-2}, in shallow Windermere Basin downstream from the Hamilton sewage treatment plant outfall (site 47) were greater than the 200,000 m^{-2}, that Brinkhurst (1970) reported in Toronto Harbour close to the Don River, the major source of organic waste to Toronto Harbour. Lang (1985) reported maximum oligochaete densities of 500,000 in Lake Geneva, while Caspers (1980) reported densities of 800,000 m^{-2} in the River Elbe under conditions of extreme organic enrichment, but with sufficient oxygen. The shallow water depth (<1 m) of the Windermere Basin, maintained high oxygen levels at the sediment surface, and the high bacteria and organic content of the sediments created an ideal environment to support the huge oligochaete population The shallow depth and warm temperatures allowed the basin to act as the harbour's "liver" to decompose, detoxify and nitrificate the sewage effluent entering Hamilton Harbour (Barica 1990).

The dominance of the oligochaete community by *L. hoffmeisteri*, *T. tubifex* and *Q. multisetosus* in 1984 is indicative of highly eutrophic conditions as is the abundance of other *Limnodrilus* species (Brinkhurst 1980; Spencer 1980; Howmiller and Scott 1977). Other hyper-eutrophic areas dominated by similar tubificid communities included Toronto Harbour (Brinkhurst 1970), inner Green Bay, Lake Michigan (Howmiller and Beeton 1970), and the inner Bay of Quinte prior to the implementation of phosphorous controls (Johnson and McNeil 1986). Within Hamilton Harbour, the decline in relative abundance of *Tubifex* and *L. hoffmeisteri* and increase in density of *Q. multisetosus* between 1964 and 1984 indicated improved habitat quality and is consistent with deceasing nutrient loadings (Brinkhurst 1980). The temporal shift in oligochaete community was similar to the spatial patterns in Toronto Harbour, where species dominance shifted from *T. tubifex* and *L. hoffmeisteri* to *Q. multisetosus* with increasing distance from the principal source of pollution (Brinkhurst 1970; Brinkhurst and Cook 1974). Similarly laboratory experiments by Chapman et al. (1982) showed that *Q. multisetosus* was the least tolerant to sewage sludge of these 3 species, while *L. hoffmeisteri* was the most tolerant. Their observations were verified by the absence of *Q. multisetosus* from sites 46 and 47 which are closest to the outfall of the Hamilton STP into the Windermere Basin.

The classification based on discriminant analysis (figure 12) clearly showed the shift toward a community dominated by Q. Multisetosus, as did the occurrence of naidids at 11 of the 25 sites. The Naididae family is considered indicative of mesotrophic conditions (Howmiller and Scott 1977), and were not observed in 1964. *A. pluriseta*, also considered indicative of mesotrophic conditions (Howmiller and Scott 1977), or eutrophic conditions (Milbrink 1983), was not found in 1964, but was present at 4 sites in 1984. However *Spirosperma ferox* (identified as *Peloscolex*) and *Potomothrix moldaviensis* (identified as *Euilyodrilus*), which are indicative of the same conditions, were present in 1964 but not observed in 1984.

The shift in species composition in the central basin from Assemblage I in 1964 to Assemblage III in 1984 is probably a result of decreased nutrient loading to the harbour. However this change was also confounded by the relocation of the sewage outfall in 1964 from the Ottawa Street Slip on the south shore into Redhill Creek which drains into Windermere basin. Site 40, where *Tubifex* was dominant in 1984 is within a 18 m deep sub-basin separated from the central basin of the harbour by a 5 m high ridge. The dominance of *T. tubifex* at this location may be due to detrital deposition from the outflow from Windermere Basin, or the influence of the Lake Ontario water from the canal.

The presence of sphaeriid clams in the 1984 samples was a further indication that conditions in the harbour had improved since 1964 when they were absent. However changes to the water quality of the harbour was not enough to alter the composition of the dominate chironomids, although the number of rare genera collected doubled between 1964 and 1984. Density of chironomids in Windemere Basin in 1984 was seven times higher than the maximum reported in the harbour in 1964.

The indications of improved habitat conditions, suggested by the macroinvertebrate species composition, appear in conflict with increased oligochaete density since 1964. An increase and dominance of oligochaetes is usually indicative of increasing organic pollution (Brinkhurst and Cook 1974; Lang 1985). The normal response to declining nutrient loading is a decrease in oligochaete abundance. Total or soluble phosphorous levels the central harbour showed little change, likely because high iron levels in the water react with the phosphorous to form insoluble precipitates which settle to the bottom (Forde 1979). However, phosphorous levels in Windermere Basin decreased from 36.8 ppm in 1964 to 5.42 ppm in 1974. Over the period 1960 to 1979, mean August chlorophyll *a* levels in Hamilton Harbour declined from 49 to 13 mg m^{-3} as water quality improved. The low oligochaete density in 1964 occurred during very high nutrient and Fe loadings. This suggests an inhibiting effect of the hyper-eutrophication or lethal effect of the industrial effluent from the metal industries on the oligochaetes themselves or the bacteria on which they fed. This is partially confirmed by the large 2 km area of the harbour nearest the effluent outfall that was devoid of any macroinvertebrates in 1964 (Johnson and Matheson 1968). The increased oligochaete abundance in 1984 may be due to decreased sediment toxicity.

A reduction of biological activity in contaminated sediments has implications for eutrophic systems such as Hamilton Harbour. First, if biological activity in the sediments is reduced, the biological component of the sediment oxygen demand (BOD) will also be reduced. The rate of decomposition in the sediment will be reduced and or organic matter will accumulate in the sediments. The high levels of sediment contaminates, Pb (< 500 ug/g), Zn(< 1700 ug/g), PAH levels up to 11 ug/g and PCB above 0.4 ug/g (Poulton 1987) would have adverse effects on the benthic community (Harlow and Hodson 1988). As contaminant loadings are reduced to a point where macroinvertebrate communities are re-established and abundance increase, as happened in Hamilton Harbour, sediment oxygen demand could increase. This oxygen demand results from macroinvertebrate respiration and also aerobic bacterial respiration occurring to greater depths in the sediment as a result of sediment ventilation and re-working by the burrowing oligochaetes. The increased sediment bioturbation would also resuspend and dissolve more nutrients buried in the sediments. Thus pollution controls which reduced contaminant loadings could result in a more rapid hypolimnetic deoxygenation, and this would obscure the effects of reduced nutrient loading until the reservoir of organic matter accumulated in the sediments during the toxic period is metabolized. Raddum et al. (1986) hypothesized that an increase in benthic macroinvertebrates observed following the liming of acid Norwegian lakes occurred due to accelerated microbial processing of the organic matter which had accumulated in the sediments under more acidic conditions.

Other studies showed that both chemical oxygen demand (COD) and BOD was reduced between 1960 and 1980 as a result of the reduced untreated sewage loadings to the harbour. Although models, used to predict various nutrient reduction strategies for the harbour, acknowledged the importance of sediment oxygen demand on the hypolimnetic oxygen budget (OME 1985; Snodgrass and Ng 1985), no attempts had been made to predict changes in sediment oxygen demand. We hypothesize that sediment oxygen demand increased and little or no improvement to hyplolimnetic oxygen levels during thermal stratification will be observed until the accumulated organic matter in the sediments is depleted.

Oligochaetes also influence the movement of contaminants within the harbour. Krantsberg and Stokes (1982) reported that release of Cu and Zn from Lake Ontario sediments was greater in the presence of tubificids compared to concentrations in the water of uncolonized microcosms. The burrowing activities of the macroinvertebrates increase the depth of the redox potential discontinuity due to their re-working of the sediments and / or increased water movement through the sediment (see Krantzburg 1985). In locations such as Hamilton Harbour where periodic anoxia occurs, these same mechanisms could increase the rate of metal and nutrient release to the water above the reduced sediments. Sedimentation rates in the harbour will eventually cover the contaminated sediments; however sediments near the industrial shore show evidence of resuspension from anchor scouring and ship movements (Rukavina and Versteeg 1996).

The oligochaete community may serve as a vector of contaminant transfer up the food chain to fish and other vertebrates. Oligochaetes formed over 75 % of the stomach contents of white perch (*Morone americanus*) captured in the central basin of the harbour during December

1984. Oliver reported high body burdens of PCB in the oligochaetes from the harbour and that they accumulated chlorinated hydrocarbons that could be passed on to fish (Oliver 1987). Should midges of the large *Chironomus* spp. become common in the harbour, they would further increase the rate of contaminant resuspension and foodweb transfer by their water pumping activities in their U shaped burrows, and their consumption by fish and insect eating birds during their emergence and mating swarms.

SUMMARY

Changes to the macroinvertebrate community between 1964 and 1984 indicate a positive response to nutrient and contaminant reductions which were undertaken over the same time period. The paradoxical increase in oligochaete abundance was probably a result of decreased toxicity which has allowed greater biological activity within the sediments. This may explain the failure of restoring the dissolved oxygen in the harbour by decreasing the nutrient loadings. Evaluation of the net flux of organic matter in the sediments should be undertaken to evaluate the long-term potential for reducing sediment oxygen demand under the proposed abatement scenarios.

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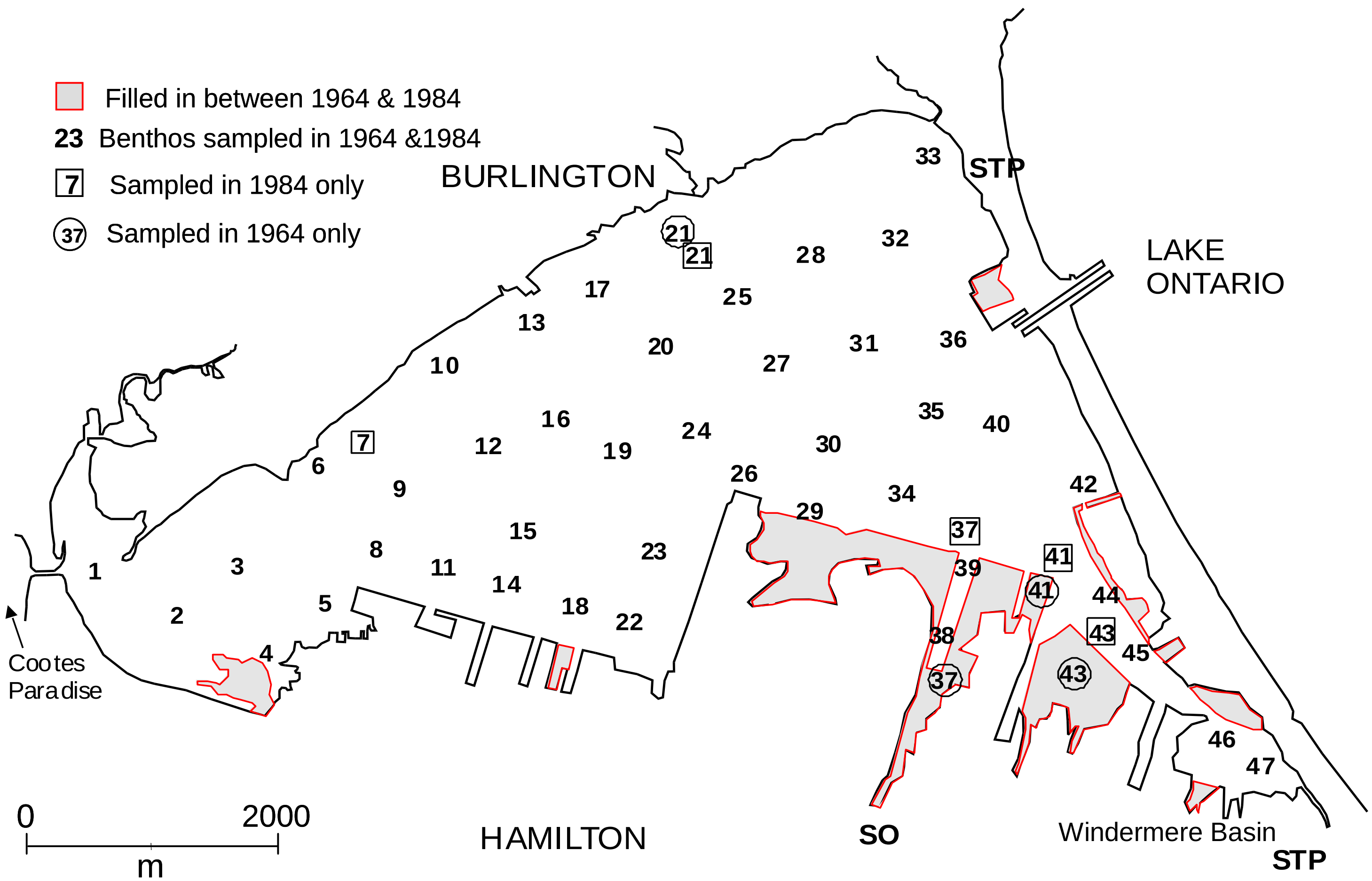

Figure 1. Sample locations in 1984 and 1964 (Johnson and Matheson 1968). Sites 21, 37, 41, and 43 differed between studies. There were no data from site 7 in 1964. Shaded areas were in-filled between 1964 and 1984. STP = sewage treatment plant; SO = sewage outflow.

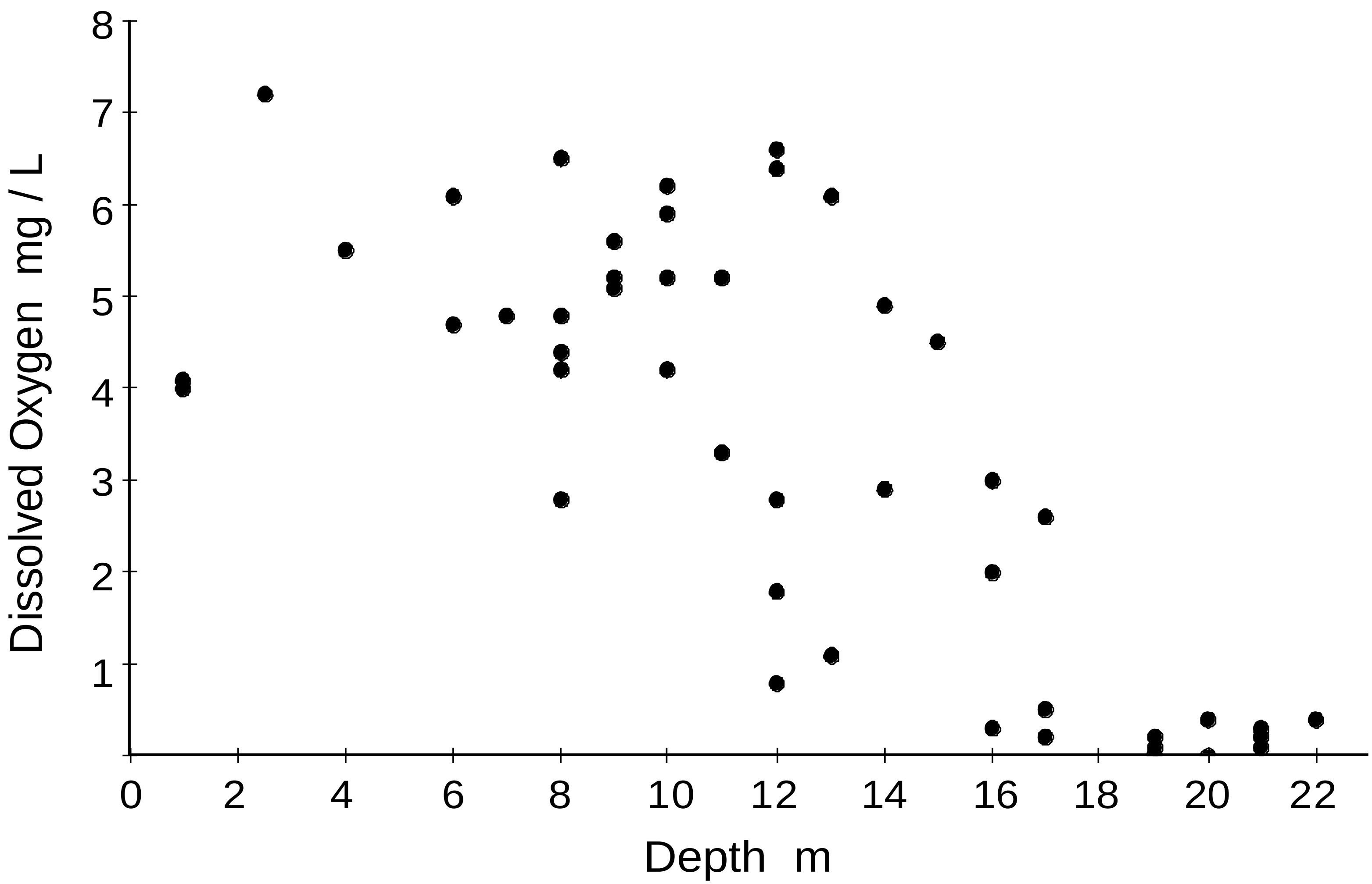

Figure 2. Dissolved oxygen values recorded 0.5m off bottom at Hamilton Harbour sites on October 2-4, 1984 during fall turnover.

Hamilton Harbour sediment texture 1984

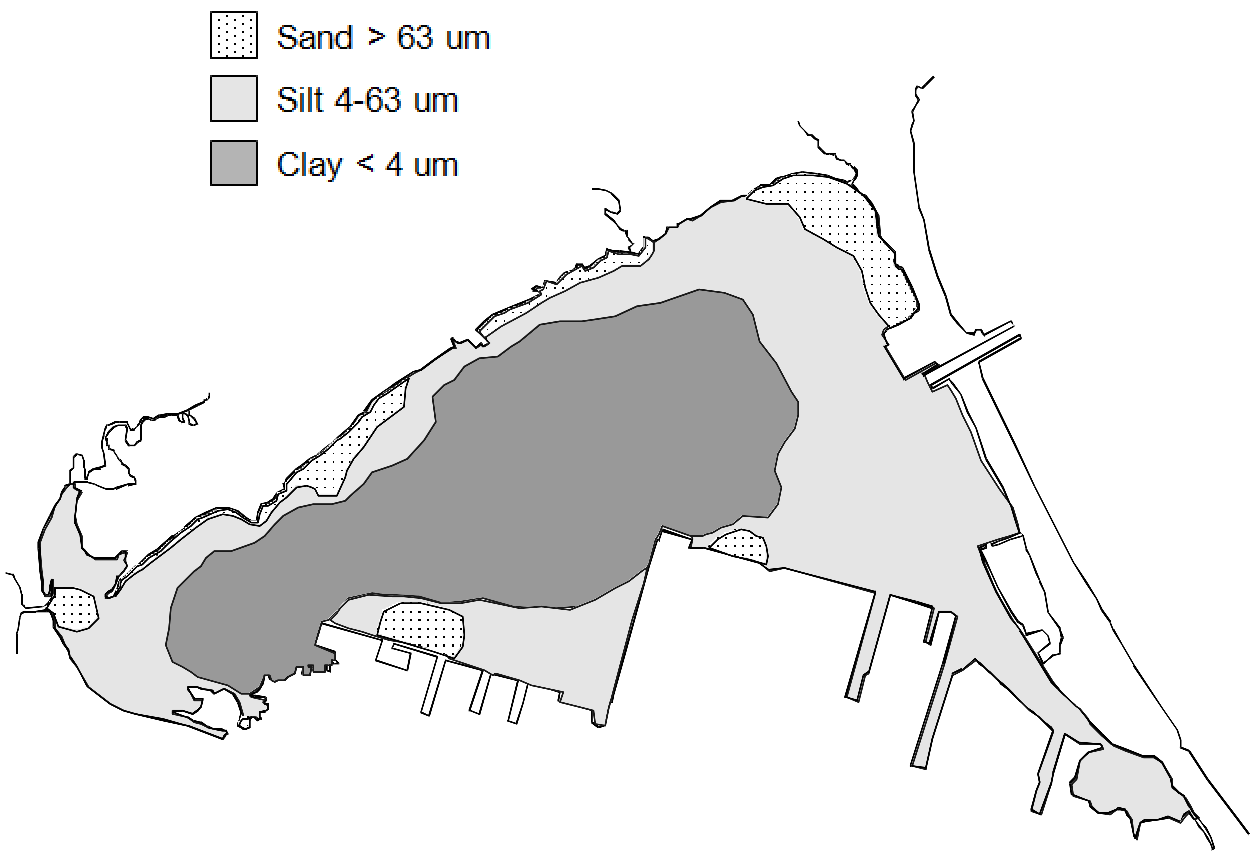

Figure 3. Distribution of sediment particle size (micron) from 1984 survey. Contour for clay at > 50 % of total particles.

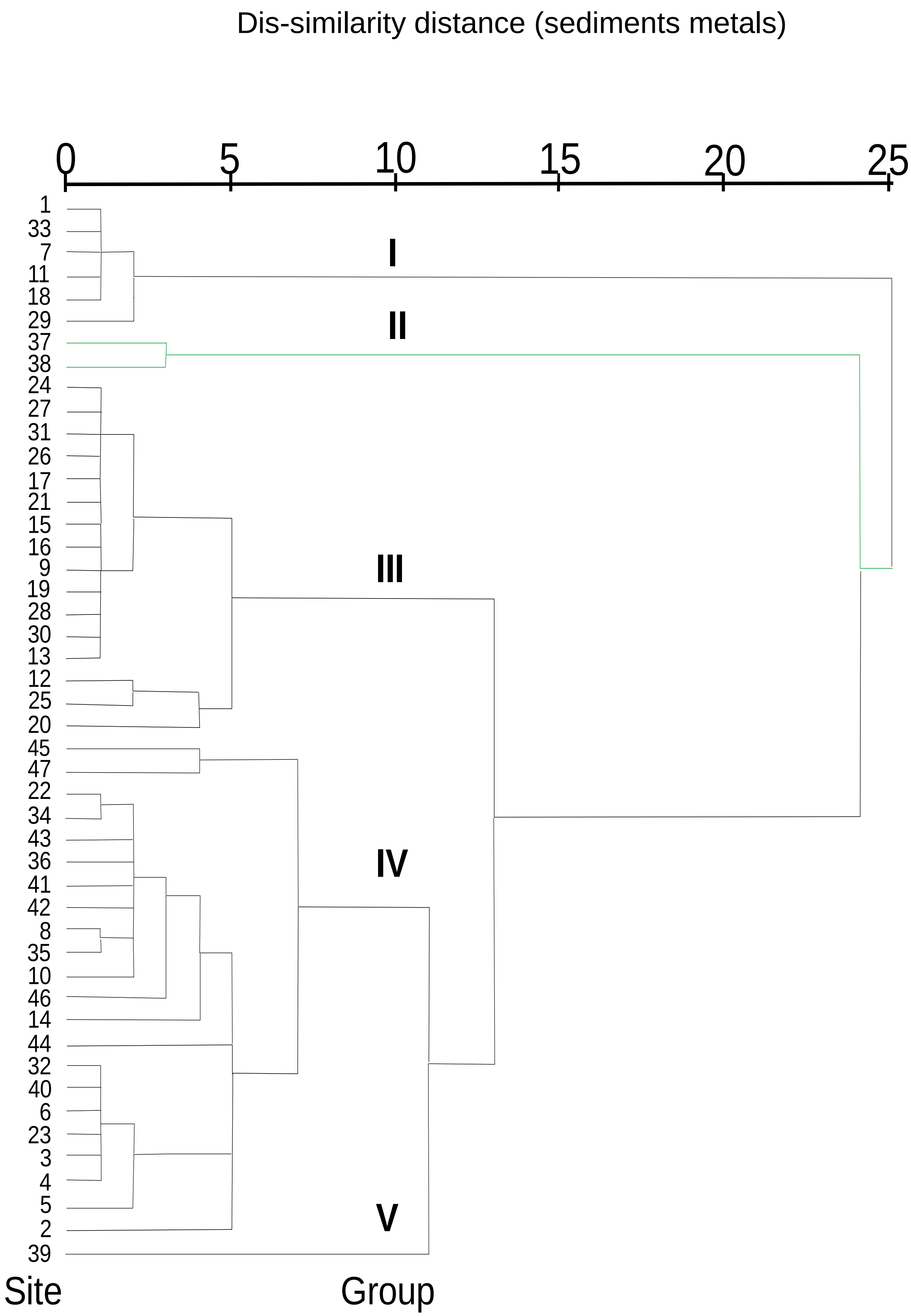

Figure 4. Averages linkage cluster of sediment metals from Hamilton Harbour sites sampled in 1986.

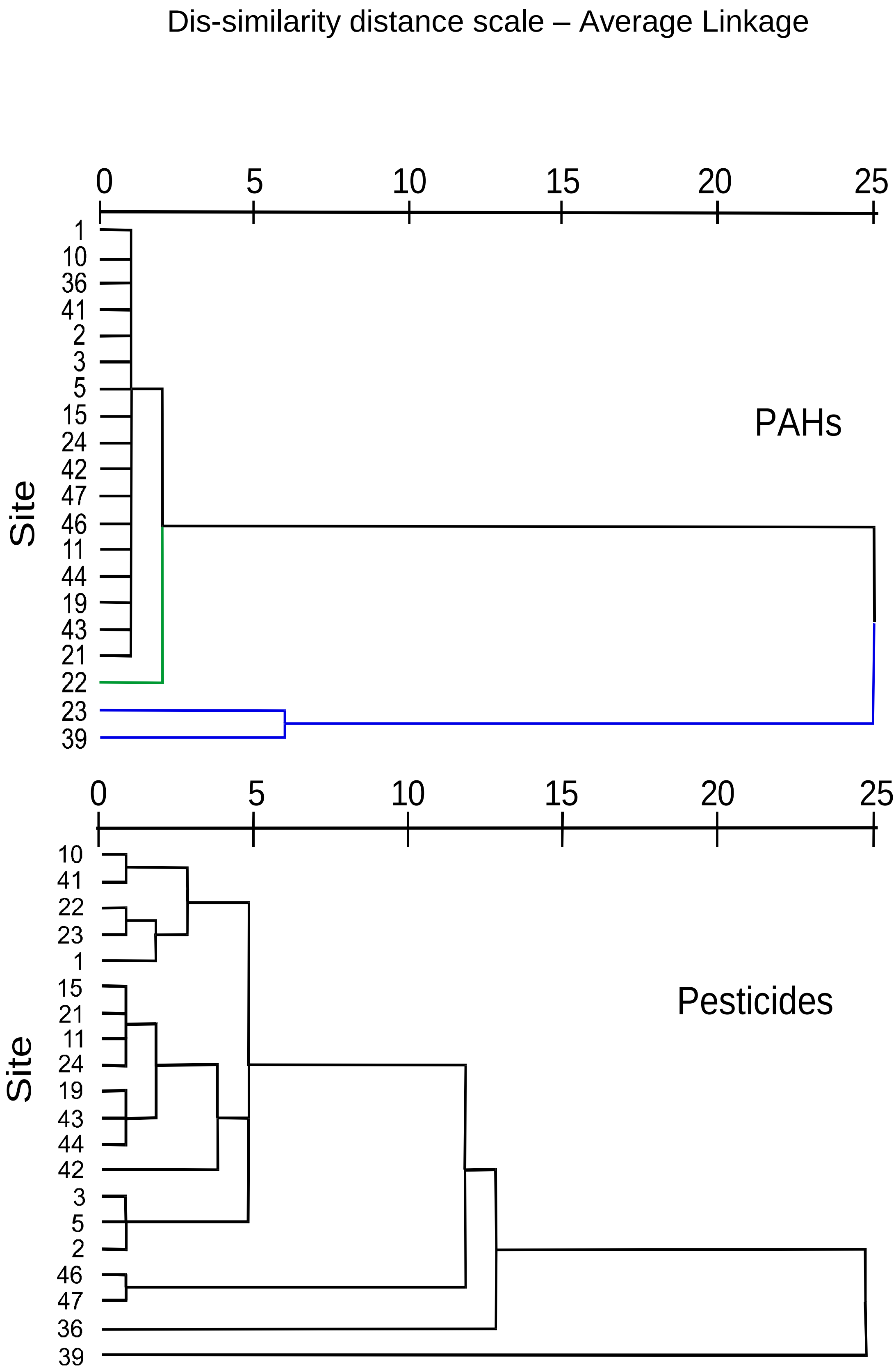

Figure 5. Cluster Analysis of Hamilton Harbour sites by sediment PAH levels and pesticides in 1986.

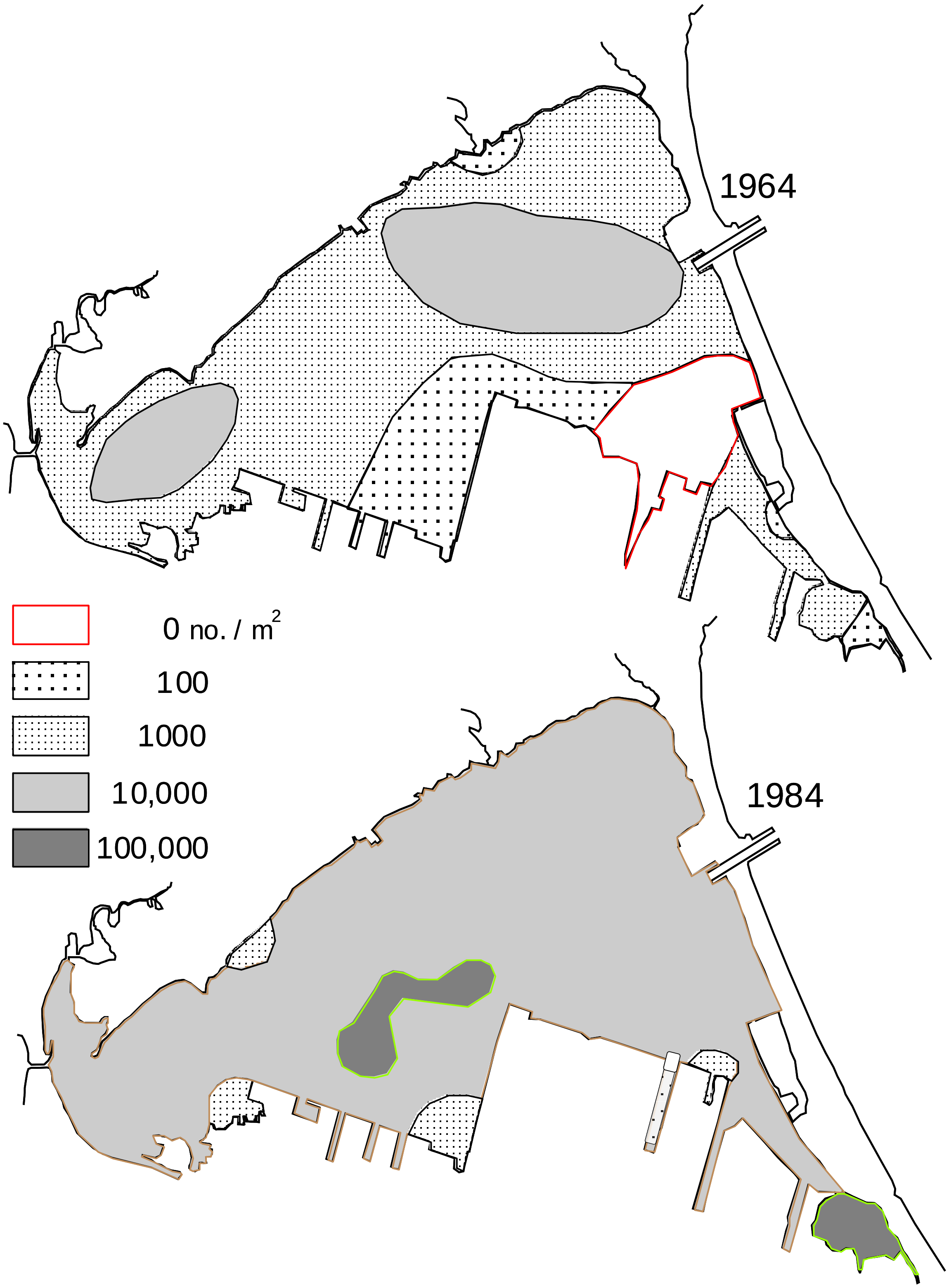

Figure 6. Abundance of total oligochaetes in Hamilton Harbour, 1964 vs. 1984.

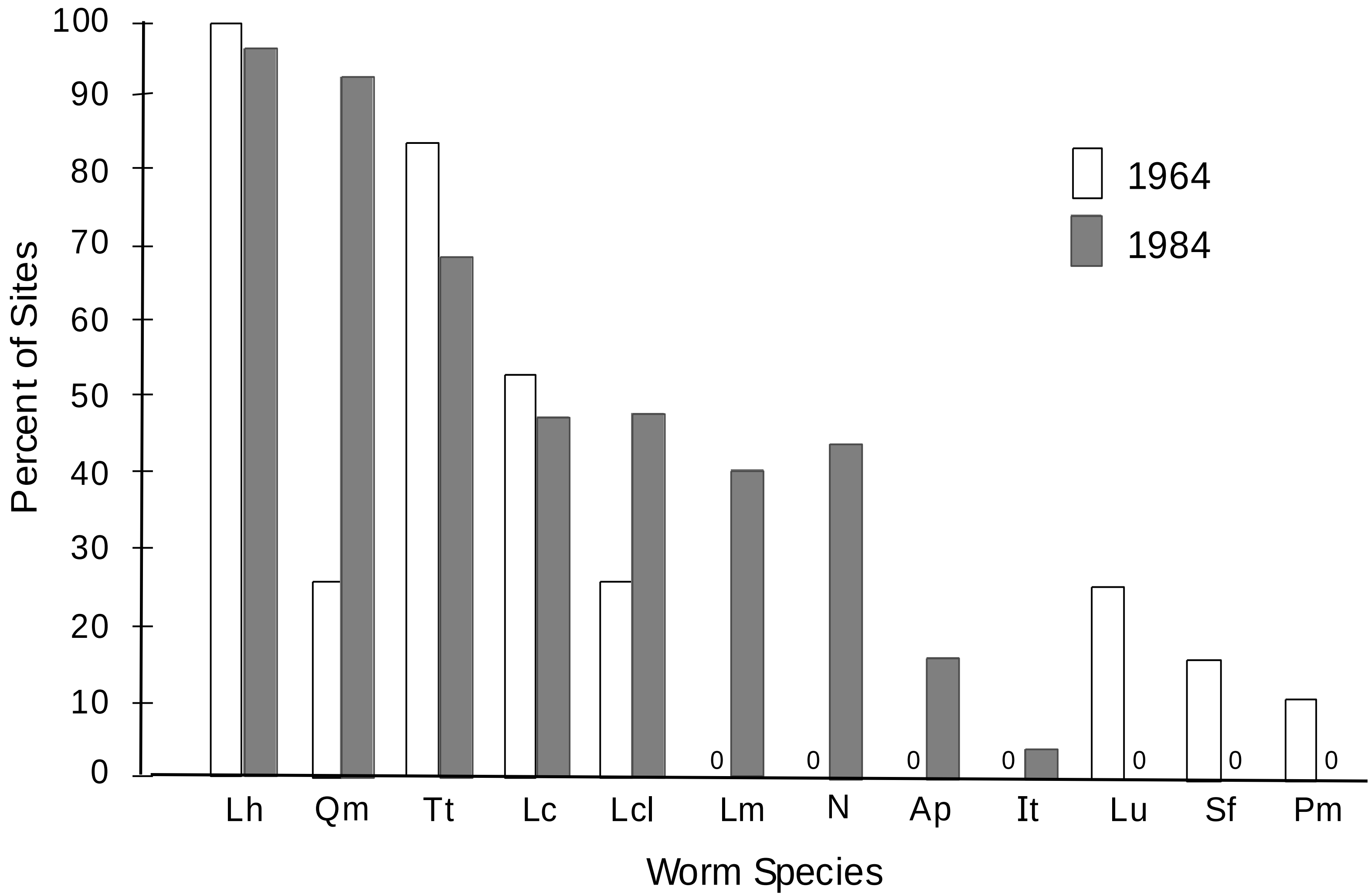

Figure 7. Percentage of sites with various oligochaete species in 1964 (n = 19 sites) and 1984 (n = 25 sites). Order of species abbreviated are: *Limnodrilus hoffmeisteri*, *Quistradrilus multisetosus, Tubifex tubifex*, Lc = *Limnodrilus cervix*, Lc l = *L. claparedianus*, *L. maumeesis*, Naididae, *Aulodrilus pluriseta*, *Ilyodrilus templetoni*, *L. udekemianus, Spirosperma ferox, Potomothrix moldaviensis*.

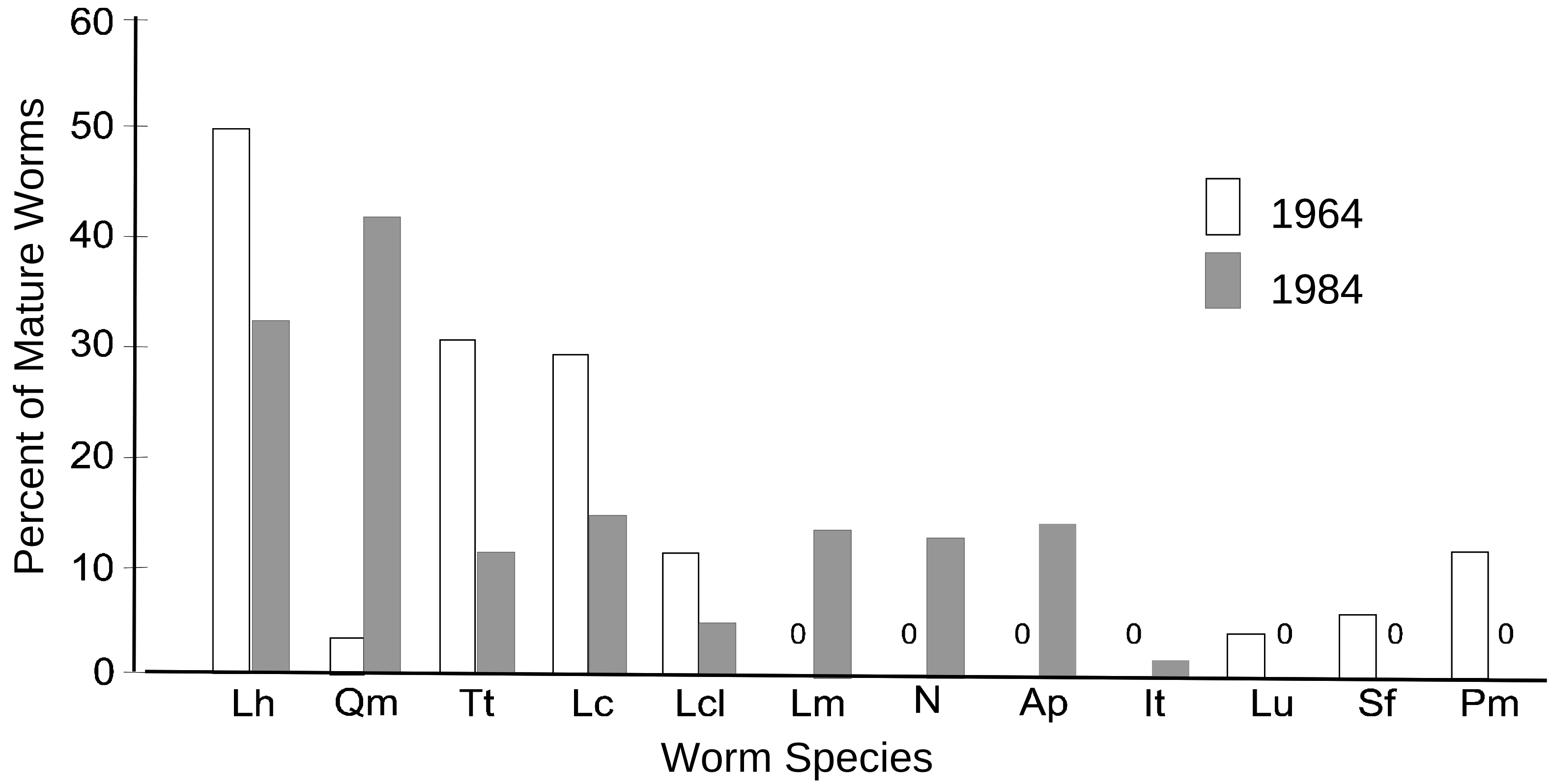

Figure 8. Percentage of mature oligochaetes in each common species in 1964 (n = 19 sites) and 1984 (n = 25 sites). Lc = Limnodrilus cervix, Lcl = L. claparedianus, others as in Figure 7.

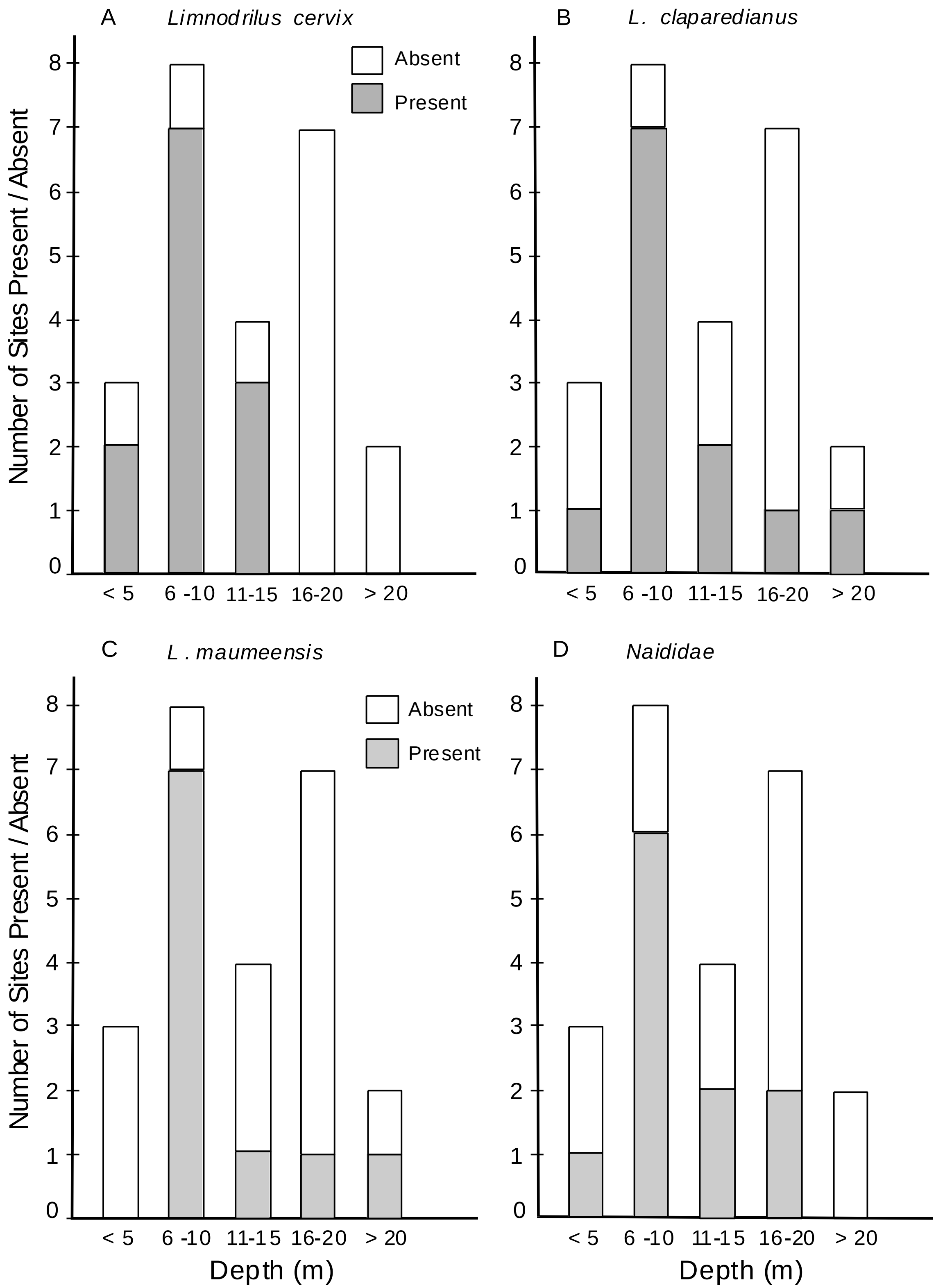

Figure 9. Depth distribution of three *Limnodrilus* species and the Naididae family in Hamilton Harbour in 1984.

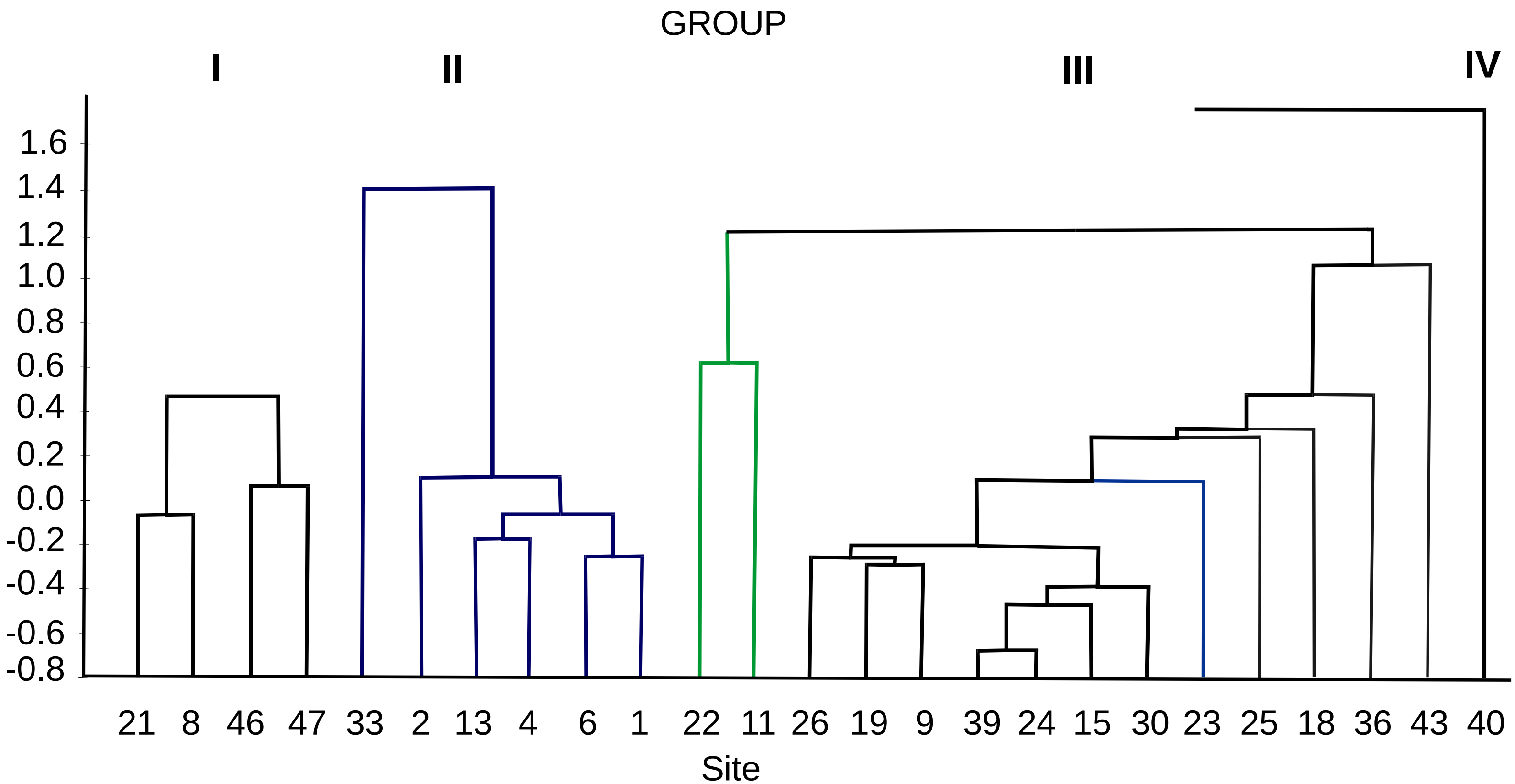

Figure 10. Dendrogram showing sampling sites clustered by relative abundance of mature oligocheates. Outlier site 40 (Group IV) was dominated by *Tubifex tubifex*.

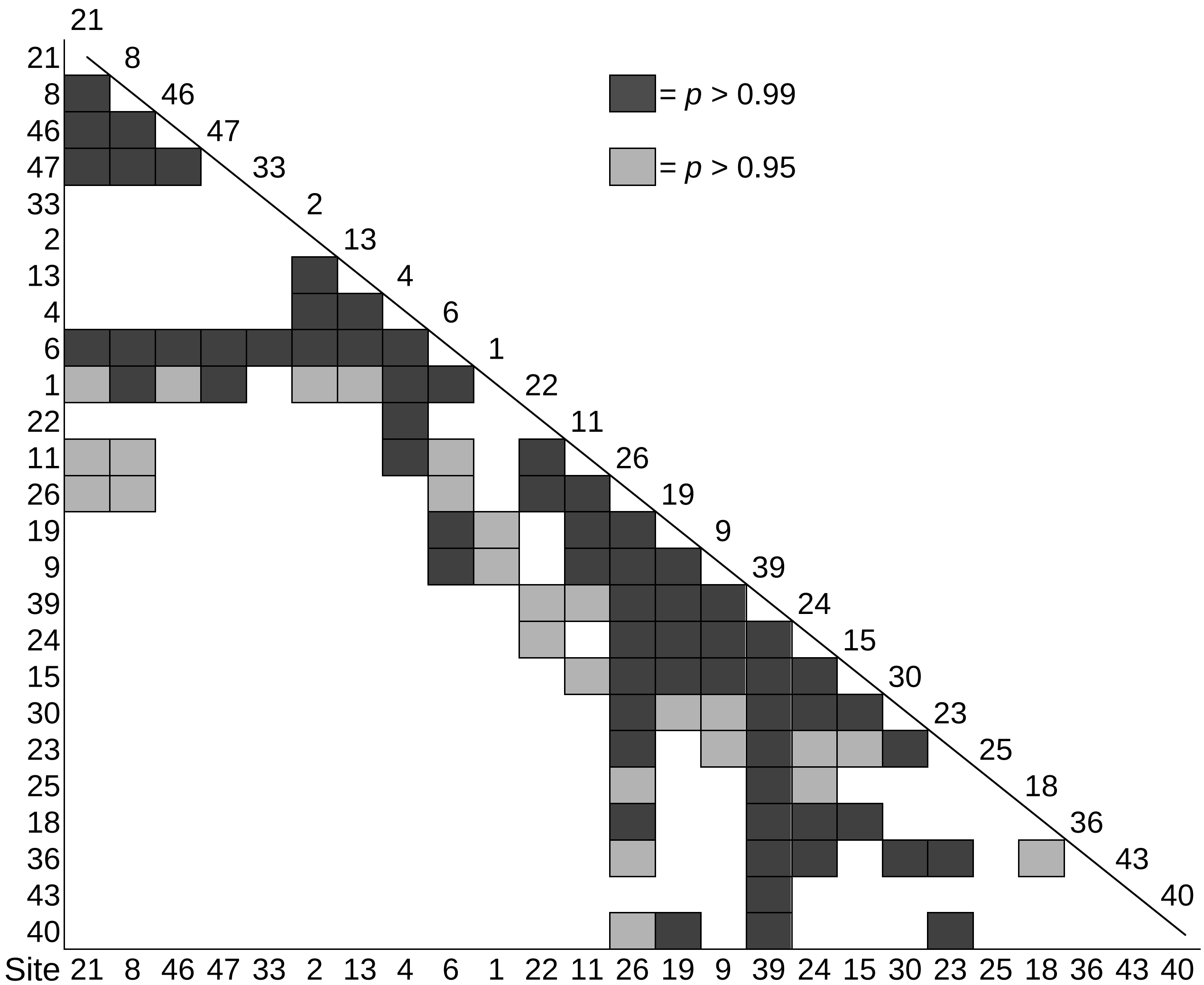

Figure 11. Dis-similarity matrix of 1984 sites arranged by cluster of mature oligochaete composition. Not significantly different at probability 0.99 (solid) and 0.95 (shaded).

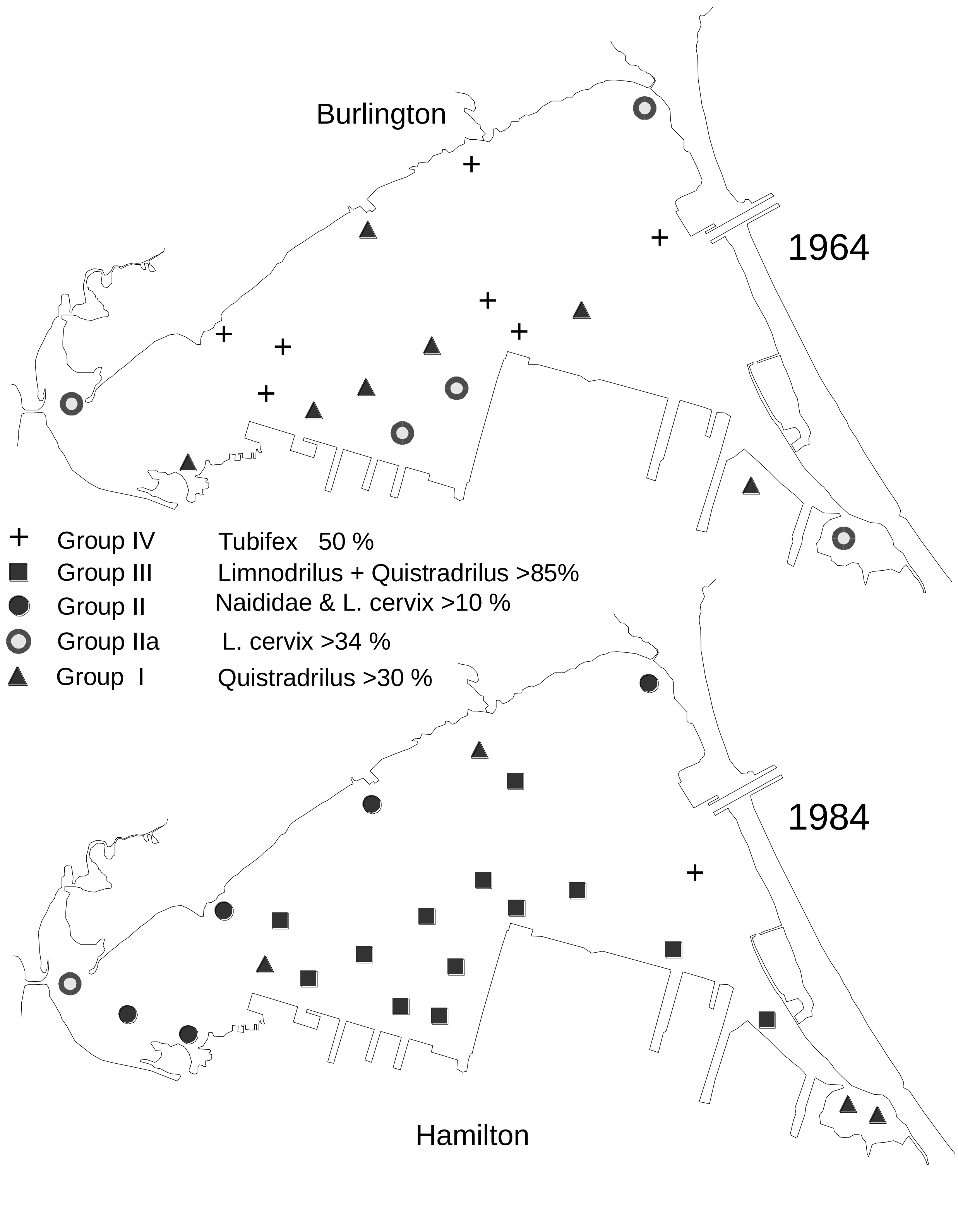

Figure. 12. Distribution of oligochaete species assemblages in Hamilton Harbour from 1964 and 1984 sites based on clustering analysis. The Naididae were absent at sites in Group IIa.

Table 1. Depth, loss on ignition, and particle size distribution of Hamilton Harbour sediments, 1984.

Site ID	Depth (m)	Moisture % wet	L.O.I. % dry weight	Gravel %	Sand %	Silt %	Clay %
1	4	56.4	2.7	16.8	66.7	6.2	10.3
2	8	75.3	7.7	-	1.3	48.4	50.3
3	11	79.7	9.0	-	0.3	40.9	58.8
4	8	-	8.5	-	5.6	37.8	56.6
5	10	77.4	9.5	-	1.2	31.6	67.2
6	10	-	8.1	-	10.4	31.4	58.3
7	12	-	1.7	-	86.3	1.7	12.1
8	14	-	7.3	-	20.8	25.3	53.8
9	16	-	12.5	-	1.4	24.6	73.9
10	6	45.1	6.1	-	45.0	8.8	46.2
11	10	78.6	2.3	-	54.2	12.8	33.0
12	19	-	14.0	-	0.5	22.9	76.6
13	12	-	11.1	-	4.2	32.6	63.2
14	13	-	7.0	-	48.7	18.5	32.8
15	19	82.1	13.4	-	0.4	18.9	80.7
16	21	-	15.1	-	0.4	28.9	70.7
17	19	-	14.1	-	0.2	22.0	77.9
18	9	-	5.1	9.2	30.2	25.6	35.3
19	23	78.3	13.0	-	0.5	27.9	71.6
20	21	-	14.6	-	0.6	31.3	68.1
21	17	80.2	13.3	-	0.7	43.7	55.6
22	8	65.5	5.3	-	8.7	52.5	38.8
23	22	57.2	10.5	-	10.2	38.2	51.6
24	20	82.1	13.7	-	1.7	34.4	63.9
25	17	-	14.4	-	0.9	33.7	65.4
26	19	-	14.0	-	2.4	37.1	60.5
27	17	-	13.8	-	1.0	41.6	57.4
28	12	-	11.8	-	1.5	37.5	61.1
29	11	-	6.8	-	90.0	2.6	7.3
30	16	-	13.2	-	2.8	40.8	56.4
31	16	-	11.8	-	2.6	43.9	53.6
32	10	-	13.0	-	6.4	53.9	39.8
33	6	-	2.8	-	58.6	25.3	16.2
34	12	-	5.8	-	24.7	49.7	25.6
35	14	-	7.0	-	38.8	36.0	25.2
36	12	48.1	5.4	-	42.9	17.7	39.4
37	3	-	13.8	-	0.8	50.6	48.6
38	9	-	13.7	-	2.9	46.6	50.5
39	13	72.7	11.5	-	2.0	35.3	62.7
40	15	-	11.2	-	2.3	50.2	47.5
41	9	58.4	9.5	-	15.1	46.7	38.2
42	20	64.4	9.3	7.4	22.8	37.7	32.1
43	7	65.7	9.8	-	22.4	41.9	35.7
44	8	68.3	10.4	-	23.5	52.0	24.5
45	8	-	7.9	-	4.5	52.5	43.0
46	1	70.8	5.6	-	1.9	65.2	32.9
47	1	65.9	6.8	-	1.3	62.7	36.0
Ave	12.5	-	9.7	11.13	16.4	34.6	48.2
S.E.	0.8	-	0.5	2.9	3.44	2.18	2.71

Table 2. Concentration (% dry weight) of major elements in Hamilton Harbour sediments collected in October 1984.

Site ID	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	TiO_2	MnO	P_2O_5
1	65.67	10.17	3.79	3.02	13.09	1.12	2.43	0.40	0.11	0.19
2	59.98	12.81	7.70	3.47	10.66	0.66	3.24	0.74	0.23	0.49
3	58.45	13.04	9.29	3.55	10.00	0.72	3.35	0.79	0.27	0.55
4	58.70	12.80	10.27	3.39	8.90	0.88	3.32	0.74	0.28	0.72
5	58.16	12.89	10.05	3.59	9.53	0.77	3.37	0.76	0.28	0.59
6	59.34	11.64	9.76	3.10	10.59	0.87	2.94	0.63	0.31	0.82
7	69.25	10.19	3.93	2.16	9.83	1.18	2.40	0.36	0.14	0.55
8	59.91	12.93	8.42	3.26	9.90	0.87	3.14	0.69	0.26	0.61
9	55.02	12.03	15.44	2.97	8.79	0.64	3.30	0.74	0.39	0.68
10	63.64	11.20	8.48	2.47	8.73	1.19	2.70	0.51	0.24	0.84
11	66.35	10.90	3.86	2.75	11.20	1.36	2.64	0.39	0.14	0.40
12	49.33	11.70	20.51	2.65	9.60	0.67	3.51	0.72	0.53	0.79
13	55.21	11.47	15.80	2.56	9.08	0.75	3.02	0.65	0.39	1.08
14	62.33	10.48	7.47	3.05	11.38	0.92	2.49	0.51	0.17	1.20
15	56.00	11.65	14.93	2.76	9.20	0.58	3.12	0.69	0.42	0.65
16	54.96	11.18	16.18	2.62	9.59	0.54	3.10	0.63	0.46	0.75
17	50.08	11.29	17.93	2.68	12.25	0.54	3.33	0.67	0.47	0.76
18	62.30	9.82	5.14	2.72	15.81	0.79	2.40	0.46	0.17	0.39
19	55.13	11.35	16.52	2.64	8.77	0.62	3.11	0.65	0.48	0.70
20	47.38	11.55	24.97	2.39	7.56	0.59	3.44	0.72	0.56	0.84
21	54.72	11.21	15.69	2.51	10.55	0.51	3.11	0.63	0.39	0.69
22	60.64	10.01	9.48	2.83	12.31	1.06	2.56	0.48	0.22	0.41
23	57.45	11.81	13.09	2.70	10.47	0.51	2.93	0.60	0.41	0.67
24	48.67	11.19	20.98	2.67	10.47	0.73	3.27	0.69	0.52	0.80
25	47.76	11.49	23.20	2.59	8.75	0.59	3.47	0.72	0.51	0.90
26	47.51	11.53	21.53	2.47	11.04	0.61	3.32	0.67	0.53	0.79
27	47.74	11.32	22.70	2.60	9.57	0.60	3.37	0.71	0.52	0.87
28	55.12	11.40	15.27	2.60	9.92	0.67	3.16	0.67	0.36	0.83
29	64.92	9.11	4.07	2.43	15.46	1.01	2.26	0.33	0.20	0.21
30	49.32	10.80	19.68	2.51	12.00	0.60	3.15	0.65	0.45	0.85
31	50.02	11.36	19.03	2.76	10.71	0.74	3.37	0.71	0.43	0.88
32	57.03	11.05	13.36	2.60	10.27	0.68	2.90	0.65	0.31	1.14
33	65.54	11.14	3.26	3.08	11.96	1.37	2.83	0.47	0.10	0.26
34	60.11	10.26	8.89	2.80	13.22	0.86	2.77	0.56	0.20	0.33
35	60.69	11.47	9.64	2.90	9.91	0.99	2.96	0.56	0.27	0.60
36	63.17	11.80	6.05	3.03	10.75	0.89	3.03	0.55	0.19	0.54
37	12.76	2.88	44.35	1.34	35.42	0.64	1.21	0.25	0.57	0.58
38	16.50	3.83	44.17	1.40	30.91	0.40	1.44	0.25	0.58	0.53
39	47.70	10.76	21.40	2.49	11.85	0.61	3.31	0.67	0.42	0.79
40	54.85	11.14	16.29	2.69	9.78	0.54	3.05	0.65	0.38	0.64
41	57.62	11.84	12.67	2.42	10.77	0.62	2.82	0.65	0.23	0.36
42	56.66	11.31	14.70	2.78	9.53	0.52	2.83	0.68	0.35	0.63
43	50.36	9.88	13.28	2.70	18.72	0.70	2.86	0.53	0.28	0.68
44	43.16	9.24	20.38	2.38	19.55	0.67	2.90	0.67	0.41	0.65
45	57.65	12.25	11.14	3.49	9.69	0.66	3.26	0.81	0.21	0.82
46	62.55	13.17	5.78	3.88	9.11	0.85	3.19	0.74	0.11	0.61
47	61.46	13.93	6.57	3.81	8.43	0.78	3.28	0.82	0.11	0.80
Ave.	54.87	11.03	14.19	2.77	11.82	0.76	2.96	0.61	0.33	0.67
S.E.	1.53	0.28	1.28	0.07	0.75	0.03	0.07	0.02	0.02	0.03

Table 3. Concentration of metals (mg kg^{-1} dry weight in ppm) in Hamilton Harbour sediments, 1984.

Site ID	As	AL	Cd	Co	Cr	Cu	Hg	Ni	Pb	Se	V	Zn
1	3	3160	1.14	10	33	27	0.12	25	57	0.9	30	252
2	16	4750	3.81	29	110	91	0.37	46	165	-	67	1610
3	18	5300	4.36	19	140	102	0.39	49	215	-	76	2270
4	23	3680	4.65	20	158	115	0.38	53	280	-	72	2600
5	16	5250	5.15	24	160	110	0.45	52	265	-	76	2740
6	21	3610	4.94	17	160	89	0.40	48	245	4.4	64	2690
7	7	5370	7.49	12	66	23	0.40	31	79	-	27	950
8	12	4420	4.40	20	130	86	0.40	42	195	-	67	1670
9	27	5940	6.59	21	305	130	0.60	56	440	4.9	87	4400
10	11	2170	4.40	15	150	64	0.17	49	195	2.4	51	2580
11	6	5800	6.33	11	67	36	0.62	28	73	-	28	545
12	28	6370	7.11	26	400	160	0.50	56	570	-	87	6000
13	25	1130	2.02	22	335	113	0.07	53	360	-	78	4090
14	12	5570	8.63	13	210	145	0.69	40	330	-	49	1695
15	29	6390	8.74	21	290	131	0.89	57	400	-	87	3710
16	29	6540	7.39	23	310	128	0.62	57	430	-	88	3450
17	30	5820	8.50	20	320	129	0.52	60	400	-	84	3500
18	4	3650	3.97	8	125	39	0.32	30	110	-	26	645
19	33	5950	7.15	21	325	136	0.68	56	470	6.9	89	4210
20	46	6070	7.93	17	400	149	0.46	56	690	-	91	6630
21	36	5920	8.78	21	310	130	0.74	60	390	-	82	3470
22	10	3840	3.88	13	125	95	0.57	34	150	-	45	1660
23	24	2550	2.11	18	200	95	0.30	47	270	2.1	73	2190
24	39	5920	6.63	21	360	140	0.42	53	470	-	79	5080
25	40	5800	8.78	25	480	155	0.38	55	550	-	90	6060
26	30	4450	8.51	23	420	132	0.58	51	430	-	80	4780
27	38	5770	7.95	21	360	155	0.51	53	470	-	82	5360
28	25	5880	14.6	21	360	158	0.99	53	370	-	79	3991
29	4	1410	0.27	17	103	21	0.05	25	34	-	27	273
30	25	5540	7.64	18	360	137	0.39	51	360	-	80	3620
31	36	5300	9.12	19	400	155	0.69	53	400	-	92	4400
32	23	3320	6.52	16	280	125	0.58	48	265	-	73	2910
33	2	1910	1.01	11	43	22	0.07	27	36	1.0	36	305
34	8	4710	6.87	12	145	58	0.48	32	140	-	49	1330
35	15	3850	4.11	18	170	92	0.31	41	185	4.9	57	1850
36	14	2470	1.58	15	120	48	0.10	36	88	-	51	745
37	33	4240	6.57	12	490	85	0.47	37	430	-	29	3270
38	34	1940	2.19	4	475	104	0.36	37	370	-	41	2960
39	23	6930	6.43	4	385	124	1.70	47	325	22.5	75	2930
40	29	4760	6.07	20	295	131	0.38	48	340	-	83	2740
41	18	2770	0.67	15	98	136	0.12	39	200	-	62	1610
42	15	4320	6.39	16	103	102	0.70	41	245	-	79	1820
43	12	5620	5.83	14	220	94	0.81	37	200	-	54	1750
44	13	4910	4.96	13	290	100	0.67	37	220	-	63	3150
45	5	6830	5.78	18	400	160	0.55	49	350	-	70	2030
46	2	6700	7.20	18	170	107	1.24	47	170	11.3	66	590
47	12	5630	4.23	25	305	138	0.66	56	205	-	72	815
Ave	20.4	4686	5.7	17	248	106	0.50	45	290	6.1	66	2721
S.E.	1.7	225	0.4	0.8	18.8	5.9	0.00	1.5	22.1	2.1	3.0	238.3
Ontario1	-	-	-	-	-	109	-	-	216	-	102	490
Ontario2	-	-	-	38	85	150	-	100	160	-	-	430

Table 4. Correlation matrix for depth, % clay, loss on ignition, major and minor elements in sediments from 45 sites (sites 37 and 38 excluded) in Hamilton Harbour, 1984. Correlation coefficients are significant at the 99 % levels unless otherwise indicated with + or *.

	Depth	%Clay	L.O.I.	Fe_2O_3	MnO	K_2O	P_2O_5	TiO_2	Al_2O_3	CaO	MgO	Na_2O	SiO_2	Zn
Depth														
%Clay	0.597													
L.O.I.	0.705	0.789												
Fe_2O_3	0.671	0.669	0.905											
MnO	0.803	0.766	0.926	0.947										
K_2O	0.351*	0.754	0.677	0.650	0.618									
P_2O_5	0.310*	0.520	0.596	0.562	0.520	0.458								
TiO_2	0.181+	0.653	0.601	0.533	0.466	0.883	0.487							
Al_2O_3	-0.102+	0.405	0.104+	-0.037+	-0.036+	0.669	0.198+	0.728						
CaO	-0.275+	0.482	-0.230+	-0.140+	-0.197*	-0.488	-0.364*	-0.461	-0.700					
MgO	-0.506	-0.050+	-0.348*	-0.473	-0.494	0.249+	-0.113+	0.401	0.717	-0.236+				
Na_2O	-0.574	-0.628	-0.839	-0.735	-0.715	-0.594	-0.439	-0.679	-0.189+	0.138+	0.144+			
SiO_2	-0.532	-0.603	-0.858	-0.956	-0.879	-0.652	-0.504	-0.562	0.055+	-0.079+	0.368*	0.735		
Zn	0.674	0.775	0.872	0.909	0.923	0.688	0.617	0.533	0.096+	-0.355*	-0.389	-0.594	-0.817	
Pb	0.696	0.803	0.885	0.876	0.880	0.711	0.665	0.604	0.189+	-0.439	-0.268+	-0.684	-0.774	0.954
As	0.750	0.771	0.887	0.862	0.902	0.669	0.558	0.505	0.146+	-0.411	-0.379	-0.671	-0.750	0.906
Cr	0.506	0.655	0.834	0.859	0.795	0.686	0.703	0.584	0.095+	-0.235+	-0.270+	-0.665	-0.821	0.839
V	0.588	0.826	0.885	0.800	0.800	0.857	0.612	0.838	0.465	-0.501	-0.012+	-0.810	-0.740	0.800
Cu	0.429	0.695	0.807	0.762	0.675	0.735	0.715	0.779	0.370*	-0.408	-0.009+	-0.744	-0.720	0.750
Ni	0.477	0.863	0.810	0.671	0.702	0.818	0.685	0.787	0.536	-0.587	0.049+	-0.691	-0.597	0.760
Co	0.312*	0.571	0.546	0.338*	0.434	0.648	0.336*	0.630	0.598	-0.498	0.248+	-0.474	-0.302*	0.507

Matrix continued:

	Zn	Pb	As	Cr	V	Cu	Ni
Zn							
Pb	0.954						
As	0.906	0.889					
Cr	0.839	0.873	0.759				
V	0.800	0.853	0.829	0.775			
Cu	0.750	0.850	0.723	0.830	0.868		
Ni	0.760	0.827	0.784	0.753	0.918	0.831	
Co	0.507	0.522	0.515	0.436	0.664	0.550	0.706

Table 5. Pesticide concentrations (ppb) in surficial sediments of Hamilton Harbour, 1986.

Site ID	Depth m	Total PCB	Total Chlordane	Dieldrin	HCB	DDE	TDE	*o,p'* DDT	*p,p'* DDT	% H_2O
1	4	142	0	2	0	4	4	0	4	56.4
2	8	316	3	0	0	3	3	0	0	75.3
3	11	365	2	0	0	3	2	0	0	79.7
5	10	376	2	0	0	3	2	0	0	77.4
10	6	124	0	0	0	0	0	0	0	45.1
11	10	547	0	0	0	4	4	0	0	78.6
15	19	827	0	0	0	4	3	0	0	82.1
19	21	622	0	0	0	4	3	0	0	78.3
21	17	768	0	0	0	5	3	0	0	80.2
22	8	467	0	0	0	5	3	0	9	65.5
23	22	154	0	0	0	3	3	0	16	57.2
24	20	391	0	0	0	4	3	0	0	82.1
36	12	231	3	0	0	4	6	2	0	48.1
39	9	458	0	3	2	3	10	0	21	72.7
41	9	166	0	0	0	0	0	0	2	58.4
42	20	317	4	0	0	6	3	0	6	64.4
43	7	860	2	0	0	9	3	0	9	65.7
44	8	814	0	0	0	8	2	0	7	68.3
46	1	949	4	3	0	9	3	0	10	70.8
47	1	1296	4	3	0	12	3	0	8	65.9
Ave	11.15	509.5	1.2	0.6	0.1	4.7	3.15	0.10	4.60	68.61
S.E.	1.46	71.6	0.4	0.3	0.1	0.7	0.46	0.10	1.36	2.49

Table 6. PAH concentrations (ppb) in surficial sediments of Hamilton Harbour (1986) at various depths (m).

Site ID	Site Depth	Total PCB	Acenaph-thene	Acenaph-thylene	Anthra-cene	B[*a*] An-thracene	Dibenz-Anthracene	Chrysene	Flour-anthene	B[*k*]Fluor-anthene	Fluorene	Nap-thalene	B[*ghi*] Perylene	Phenan-threne	B[*a*] Pyrene	Pyrene
1	4	14	45	31	84	261	79	3276	875	777	78	78	253	415	333	756
2	8	32	77	78	135	722	171	9482	1987	1750	187	506	926	879	383	1602
3	11	37	97	132	182	923	268	12133	2539	2288	254	649	1220	1169	1163	2053
5	10	38	111	144	259	1101	223	14296	2966	1428	287	889	1368	1407	733	2439
10	6	12	21	48	64	200	60	2600	604	553	68	141	273	279	272	506
11	10	55	274	439	686	2373	793	30386	7065	5463	868	2536	3023	3887	2890	5639
15	19	83	805	859	1362	3934	832	44138	121614	8252	1539	4245	4492	7368	4050	9992
19	21	62	296	545	772	2707	748	35304	7877	6773	959	3583	3583	4123	3523	6328
21	17	77	394	536	917	3246	986	39681	9393	7935	1067	3346	4121	4399	4108	7230
22	8	47	1353	2046	4833	10087	1798	18756	34847	20991	2868	4913	14891	14870	512	27758
23	22	15	6711	6280	54018	19394	3693	159188	81335	29625	12013	3041	17035	55391	17877	65308
24	20	39	857	1724	2007	4537	1006	53350	14929	10321	2446	5828	5297	9425	5624	11917
36	12	23	166	37	274	687	103	7274	1849	1206	290	334	530	1320	641	1560
39	9	46	2883	3680	6535	17440	3853	171938	43251	37109	7767	7472	14868	15456	20231	34534
41	9	17	59	52	201	502	69	5751	1279	1186	79	47	390	516	641	1035
42	20	32	374	277	470	1775	565	21545	5040	4299	513	1298	2030	2205	2269	4327
43	7	86	1193	583	662	3034	858	36478	8764	7907	720	2260	4119	2571	4068	7594
44	8	81	867	366	812	2810	655	27655	7117	6851	881	2238	2772	2958	3574	6218
46	1	95	207	58	334	1937	446	24395	6114	4186	528	156	2018	1701	2231	5744
47	1	130	158	69	265	1414	243	186200	4702	3381	355	134	1509	1533	1726	4605
count	20															20
Ave	11.2	51	847.4	899.1	3743.6	3954.2	872.3	45191.3	18207.3	8114.0	1688.1	2184.7	4235.8	6593.5	3842.3	10357.2
S.E.	1.5	7.2	344	348	2672	1212	242	12703	6981	2214	667	486	1148	2755	1219	3493

Table 7. Percentage of each species of mature oligochaetes from identified mature worms from Hamilton Harbour, 1984. Site order reflects the clusters identified by cluster analysis.

Site/species	21	8	46	47	33	2	13	4	6	1	22	11	19	9	39	24	15	30	23	25	18	36	43	40	26	**Ave.**
Tubifex tubifex	4	0	3	17	8	0	7	5	5	15	0	0	14	2	8	0	0	9	25	6	0	0	4	50	5	**7.5**
Quistradrilus multisetosus	16	11	0	0	15	15	19	20	11	0	44	29	36	48	69	69	79	76	56	55	75	82	50	30	58	**38.5**
Limnodrilus hoffmeisteri	80	77	93	83	8	12	22	20	42	45	14	21	48	50	15	20	21	15	6	14	8	0	8	20	32	**31.0**
Limnodrilus cervix	0	5	3	0	12	37	22	17	21	35	6	0	0	0	0	0	0	0	0	0	10	1	12	0	0	**7.2**
Limnodrilus claparedianus	0	2	-	-	0	5	9	7	5	5	3	7	2	0	0	9	0	0	0	0	1	0	3	0	0	**2.5**
Limnodrilus maumeensis	0	5	-	-	3	18	0	14	0	0	25	43	0	0	0	0	0	0	13	0	6	0	5	0	5	**6.0**
Aulodrilus pluriseta	0	0	-	-	0	0	0	0	0	0	0	0	0	0	8	0	0	0	0	22	0	14	12	0	0	**2.4**
Ilyodrilus templetoni	0	0	-	-	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0.1**
Naididae	0	0	1	-	54	13	20	15	16	0	8	0	0	0	0	3	0	0	0	2	0	3	5	0	0	**5.8**
# of species	3	5	4	2	6	6	6	8	6	4	6	4	4	3	4	4	2	3	4	5	5	4	8	3	4	**4.5**

Table 8. Standardized canonical discriminant function coefficients for three functions based upon relative abundance of oligochaete species.

Species	Function 1	Function 2	Function 3
Q. multisetosus	2.291	0.329	-0.093
L. hoffmeisteri	1.728	-0.811	0.205
L. claparedianus	0.092	0.373	0.020
L. maumeensis	2.030	-0.021	0.075
L. cervix	-0.496	0.165	-0.111
T. tubifex	0.698	0.548	0.914
A. pluriseta	0.984	-0.144	0.040
I. templetoni	-0.692	-0.400	-0.004

Table 9. Number of chironomids per Ekman dredge (0.05 m^2) in samples from Hamilton Harbour, 1984. None were present in samples from the other unlisted locations.

	Sample Site ID								
Genus	1	6	7	10	33	44	46	47	No. of Sites
Chironomus	23	-	2	2	16	-	4	1	6
Procladius	17	-	-	-	-	8	12	4	4
Rheotanytarsus	1	1	-	-	-	-	1	-	3
Zavrelimyia	-	-	-	-	1	-	-	-	1
Clinotanypus	1	-	-	-	-	-	-	-	1
Cryptochironomus	2	-	-	-	-	-	-	-	1
Glyptotendipes	-	-	-	-	-	-	24	-	1
Cricotopus	-	-	-	-	-	-	1	-	1
Total	44	1	2	2	17	8	42	5	-

Table 10. Number of sphaeriids per Ekman dredge (0.05 m^2) samples from Hamilton Harbour, 1984. No sphaeriids were present in samples from unlisted locations.

	Sample Site ID											
Species	1	6	14	19	25	27	31	34	35	43	44	Occurrence
Musculium partumeium	-	-	-	2	1	-	1	1	1	1	-	6
M. transversum	-	-	-	-	-	-	-	-	-	-	2	1
Pisidium fallax	-	3	-	-	-	-	-	-	-	-	-	1
P. compressum	-	-	1	-	-	4	-	-	-	-	-	2
P. casertanum	2	-	-	-	-	-	-	-	-	-	-	1
P. subtruncatum	-	-	1	-	-	-	-	-	-	-	-	1
P. variabile	-	-	-	-	-	-	-	-	1	-	-	1
Sphaerium corneum	-	-	1	-	-	-	-	-	-	-	-	1
S. nitidum	-	-	-	-	-	2	1	-	-	-	-	2
Total	2	3	3	2	1	6	2	1	2	1	2	-

Appendix 1. Sediment and benthic sample site locations, Hamilton Harbour October 2, 1984.

Site ID	Depth (m)	UTM Coordinates - NAD27 Northing	Easting	Decimal Degree Latitude	Longitude
1	4	4792238.1	590359.3	43.279510	-79.886385
2	8	4791911.3	590978.2	43.276600	-79.878858
3	11	4792327.7	591450.3	43.280103	-79.872811
4	8	4791572.2	591664.3	43.273304	-79.870464
5	10	4791997.2	592106.5	43.277149	-79.865032
6	10	4793147.0	592053.0	43.286476	-79.864675
7	12	4793318.8	592389.5	43.289042	-79.860991
8	14	4792456.7	592498.6	43.281343	-79.859658
9	16	4792950.6	592676.9	43.285655	-79.857585
10	6	4793994.3	593005.7	43.295078	-79.853068
11	10	4792287.4	593027.5	43.279582	-79.853291
12	19	4793316.9	593349.7	43.289015	-79.849241
13	12	4794314.7	593641.1	43.297782	-79.845366
14	13	4792148.5	593490.9	43.278378	-79.847492
15	19	4792597.2	593609.1	43.282304	-79.846007
16	21	4793526.1	593865.0	43.291153	-79.842774
17	19	4794588.0	594146.8	43.299669	-79.838651
18	9	4791987.1	594024.0	43.276789	-79.841120
19	21	4793032.1	594332.6	43.286104	-79.837245
20	21	4794111.2	594649.7	43.295851	-79.833197
21	17	4794887.2	594894.9	43.302876	-79.830044
22	8	4791854.6	594455.4	43.275630	-79.835469
23	22	4792441.4	594630.7	43.280714	-79.833716
24	20	4793439.3	594921.0	43.289841	-79.830017
25	17	4794545.5	595258.9	43.299974	-79.825620
26	19	4793093.8	595278.4	43.286580	-79.825323
27	17	4793992.1	595553.2	43.294522	-79.822016
28	12	4794856.5	595802.2	43.302607	-79.818880
29	11	4792773.9	595768.0	43.283643	-79.819227
30	16	4793334.0	595950.4	43.288718	-79.817228
31	16	4794359.6	596248.7	43.297953	-79.813227
32	10	4795008.6	596455.8	43.303388	-79.812288
33	6	4795666.0	596708.2	43.309748	-79.807424
34	12	4792922.8	596516.6	43.284972	-79.810120
35	14	4793614.6	596716.3	43.291405	-79.808068
36	12	4794190.4	596890.0	43.295717	-79.806365
37	3	4792568.7	596999.3	43.281541	-79.804394
38	9	4791765.5	596824.8	43.274741	-79.806510
39	13	4792302.9	596989.6	43.279268	-79.804462
40	15	4793487.2	597235.4	43.289833	-79.801255
41	9	4792354.9	597714.3	43.279556	-79.795307
42	20	4793002.4	597915.3	43.285395	-79.792962
43	7	4791768.2	598021.0	43.274193	-79.791779
44	8	4792130.2	598092.9	43.277508	-79.791136
45	8	4791636.8	598345.1	43.272989	-79.788127
46	1	4790835.0	598924.1	43.266189	-79.781539
47	1	4790716.0	599229.6	43.265398	-79.779343

Appendix 2a. Hamilton Harbour benthos Oct. 1984; number collected per 9" Ekman (0.05 m^{-2}).

Site ID	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Depth (m)	4	8	11	8	10	10	12	14	16	9
Total Oligochaeta	590	660	880	560	380	1140	230	1050	1250	970
Tubificidae:										
Immature with hairs	41	38	-	47	-	388	-	200	102	-
Immatures without hairs	476	445	-	375	-	668	-	740	974	-
Limnodrilus cervix	25	65	-	23	-	17	-	5	-	-
L. claparendianus	4	9	-	9	-	4	-	2	-	-
L. hoffmeisteri	33	21	-	30	-	37	-	86	87	-
L. maumeensis	0	32	-	18	-	0	-	4	-	-
Tubifex tubifex	11	0	-	7	-	4	-	0	4	-
Ilyodrilus templetoni	0	0	-	2	-	0	-	0	-	-
Quistadrilus multisetosus	0	27	-	28	-	9	-	13	83	-
Aulodrilus pluriseta	0	0	-	0	-	0	-	0	-	-
Naididae:	-	23	-	21	-	13	-	0	-	-
Mollusca										
Gastropoda:	0	0	0	0	0	0	0	0	-	-
Sphaeriidae:								-	-	-
Pisidium casertanum	2	-	0	-	-	0	-	-	-	-
P. compressum	0	-	-	-	-	0	-	-	-	-
P. fallax	0	-	-	-	-	3	-	-	-	-
P. subtruncatum	1	-	-	-	-		-	-	-	-
P. variable	0	-	-	-	-	0	-	-	-	-
Sphaerium corneum	1	-	-	-	-	0	-	-	-	-
S. nitidum	0	-	-	-	-	0	-	-	-	-
Musculium partumeium	0	0	0	0	-	0	-	-	-	-
M. transversum	0	-	-	-	-	0	-	-	-	-
Amphipoda:										
Gammarus fasciatus	0	0	0	0	-	0	-	-	-	-
Isopoda: *Caecidotea*	0	0	0	0	-	0	-	-	-	-
Chironomini:										
Chironomus anthracinus	23	0	0	0	-	0	2	-	-	2
Cryptochironomus	2	0	0	0	-	0	-	-	-	-
Glyptotendipes	0	0	0	0	-	0	-	-	-	-
Tanytarsini:										
Cladotanytarsus	1	-	0	0	-	1	0	-	-	-
Orthocladiinae:										
Cricotopus	0	-	0	0	-	0	-	-	-	-
Tanypodinae:										
Procladius	17	0	0	0	-	0	0	-	-	-
Clinotanypus	1	-	-	-	-	-	-	-	-	-
Zavrelimyia	0	-	-	-	-	-	-	-	-	-
Insecta: Odonata *Argia*	-	-	-	-	-	-	-	-	-	-
Totals	**638**	**660**	**880**	**560**	**380**	**1144**	**232**	**1050**	**1250**	**972**
Number taxa	14	8	n.a	10	n.a	10	n.a	7	5	n.a
Diversity **D**	2.013	1.078	n.a	1.422	n.a	1.278	n.a	0.862	0.561	n.a
Oligochaete biomass mg	721	1293	1389	981	770	1148	226	1598	2091	764

Appendix 2b. Hamilton Harbour benthos per Ekman (Oct.1984), cont.

Site ID	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
Depth (m)	10	19	12	13	19	21	19	9	23	21
Oligochaeta	770	1240	1350	1320	5170	3080	2130	1620	1480	2420
Tubificidae:										
Immature with hairs	128	-	247	-	1307	-	-	258	258	-
Immatures without hairs	599	-	831	-	3432	-	-	838	1063	-
Limnodrilus cervix	-	-	60	-	-	-	-	50	-	-
L. claparendianus	3	-	25	-	-	-	-	7	3	-
L. hoffmeisteri	9	-	61	-	90	-	-	45	76	-
L. maumeensis	18	-	-	-	-	-	-	28	-	-
Tubifex tubifex	-	-	20	-	-	-	-	-	23	-
Ilyodrilus templetoni	-	-	-	-	-	-	-	-	-	-
Quistadrilus multisetosus	13	-	51	-	341	-	-	394	57	-
Aulodrilus pluriseta		-	-	-	-	-	-	-	-	-
Naididae:	0	-	55	-	0	-	-	0	0	-
Mollusca										
Gastropoda:	-	-	-	-	-	-	-	-	-	-
Sphaeriidae:										
Pisidium casertanum	-	-	-	-	-	-	-	-	-	-
P. compressum	-	-	-	-	-	-	-	-	-	-
P. fallax	-	-	-	-	-	-	-	-	-	-
P. subtruncatum	-	-	-	-	-	-	-	-	-	-
P. variable	-	-	-	-	-	-	-	-	-	-
Sphaerium corneum	-	-	-	-	-	-	-	-	-	-
S. nitidum	-	-	-	-	-	-	-	-	-	-
Musculium partumeium	-	-	-	-	-	-	-	-	2	-
M. transversum	-	-	-	-	-	-	-	-	-	-
Amphipoda:										
Gammarus fasciatus	-	-	1	-	-	-	-	-	-	-
Isopoda: *Caecidotea*	-	-	-	-	-	-	-	-	-	-
Chironomini:										
Chironomus anthracinus	-	-	-	-	-	-	-	-	-	-
Cryptochironomus	-	-	-	-	-	-	-	-	-	-
Glyptotendipes	-	-	-	-	-	-	-	-	-	-
Tanytarsini:										
Cladotanytarsus	-	-	-	-	-	-	-	-	-	-
Orthocladiinae:										
Cricotopus	-	-	-	-	-	-	-	-	-	-
Tanypodinae:										
Procladius	-	-	-	-	-	-	-	-	-	-
Clinotanypus	-	-	-	-	-	-	-	-	-	-
Zavrelimyia	-	-	-	-	-	-	-	-	-	-
Insecta: Odonata *Argia*	-	-	-	-	-	-	-	-	-	-
Totals	770	1240	1351	1320	5170	3080	2130	1620	1482	2420
Number taxa	6	n.a	8	n.a	4	n.a	n.a	7	7	n.a
Diversity **D**	0.752	n.a	0.971	n.a	0.351	n.a	n.a	0.812	0.822	n.a
Oligochaete biomass mg	1050	2151	1789	1502	4102	5119	2483	979	1674	3331

Appendix 2c. Hamilton Harbour benthos per Ekman (Oct.1984), cont.

Site ID	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**
Depth (m)	17	8	22	20	17	19	17	12	11	16
Oligochaeta	2630	470	2600	4820	1260	2460	2260	560	870	1490
Tubificidae:										
Immature with hairs	556	112	672	927	263	566	-	-	-	418
Immatures without hairs	1859	277	1820	3304	683	1645	-	-	-	863
Limnodrilus cervix	-	4	-	-	-	-	-	-	-	
L. claparendianus	-	2	-	50	-	-	-	-	-	
L. hoffmeisteri	172	12	7	119	45	79	-	-	-	32
L. maumeensis		20	13	-	-	13	-	-	-	
Tubifex tubifex	9	-	27	-	19	13	-	-	-	19
Ilyodrilus templetoni	-	-	-	-	-	-	-	-	-	
Quistadrilus multisetosus	34	37	61	404	174	144	-	-	-	158
Aulodrilus pluriseta	-	-	-	-	70	-	-	-	-	
Naididae:	0	6	0	16	6	0	-	-	-	0
Mollusca										
Gastropoda:	-	-	-	-	-	-	-	-	-	-
Sphaeriidae:										
Pisidium casertanum	-	-	-	-	-	-	-	-	-	-
P. compressum	-	-	-	-	-	-	-	-	-	-
P. fallax	-	-	-	-	-	-	-	-	-	-
P. subtruncatum	-	-	-	-	-	-	-	-	-	-
P. variable	-	-	-	-	-	-	-	-	-	-
Sphaerium corneum	-	-	-	-	-	-	-	-	-	-
S. nitidum	-	-	-	-	-	-	1	-	-	-
Musculium partumeium	-	-	-	-	1	-	-	-	-	-
M. transversum	-	-	-	-	-	-	-	-	-	-
Amphipoda:										
Gammarus fasciatus	-	-	-	-	-	-	-	-	-	-
Isopoda: *Caecidotea*	-	-	-	-	-	-	-	-	-	-
Chironomini:										
Chironomus anthracinus	-	-	-	-	-	-	-	-	-	-
Cryptochironomus	-	-	-	-	-	-	-	-	-	-
Glyptotendipes	-	-	-	-	-	-	-	-	-	-
Tanytarsini:										
Cladotanytarsus	-	-	-	-	-	-	-	-	-	-
Orthocladiinae:										
Cricotopus	-	-	-	-	-	-	-	-	-	-
Tanypodinae:										
Procladius	-	-	-	-	-	-	-	-	-	-
Clinotanypus	-	-	-	-	-	-	-	-	-	-
Zavrelimyia	-	-	-	-	-	-	-	-	-	-
Insecta: Odonata *Argia*	-	-	-	-	-	-	-	-	-	-
Totals	2630	470	2600	4820	1261	2460	2261	560	870	1490
Number taxa	5	8	6	6	8	6	n.a	n.a	n.a	5
Diversity **D**	0.508	1.138	0.636	0.590	0.980	0.640	n.a	n.a	n.a	0.547
Oligochaete biomass mg	3392	721	3653	3957	1617	1046	2722	1775	712	1471

Appendix 2d. Hamilton Harbour benthos per Ekman (Oct.1984), cont. .

Site ID	**31**	**32**	**33**	**34**	**35**	**36**	**37**	**38**	**39**	**40**
Depth (m)	16	10	6	12	14	12	3	9	13	15
Oligochaeta	2310	0	1640	1590	2340	2040	0	16	1620	4240
Tubificidae:										
Immature with hairs	-	-	258	-	-	281	-	-	481	1693
Immatures without hairs	-	-	990	-	-	986	-	-	1019	2383
Limnodrilus cervix	-	-	45	-	-	8	-	-	-	-
L. claparendianus	-	-		-	-	-	-	-	-	-
L. hoffmeisteri	-	-	33	-	-	-	-	-	19	33
L. maumeensis	-	-	12	-	-	-	-	-	-	-
Tubifex tubifex	-	-	32	-	-	-	-	-	9	82
Ilyodrilus templetoni	-	-		-	-	-	-	-	-	-
Quistadrilus multisetosus	-	-	58	-	-	633	-	-	83	49
Aulodrilus pluriseta	-	-		-	-	106	-	-	9	-
Naididae:	-	-	212	-	-	26	-	-	0	0
Mollusca										
Gastropoda:	-	-	-	-	-	-	-	-	-	-
Sphaeriidae:										
Pisidium casertanum	-	-	-	-	-	-	-	-	-	-
P. compressum	-	-	-	-	-	-	-	-	-	-
P. fallax	-	-	-	-	-	-	-	-	-	-
P. subtruncatum	-	-	-	-	-	-	-	-	-	-
P. variable	-	-	-	-	1	-	-	-	-	-
Sphaerium corneum	-	-	-	-		-	-	-	-	-
S. nitidum	1	-	-	-		-	-	-	-	-
Musculium partumeium	1	-	-	1	1	-	-	-	-	-
M. transversum	-	-	-	-	-	-	-	-	-	-
Amphipoda:										
Gammarus fasciatus	-	-	-	-	-	-	-	-	-	-
Isopoda: *Caecidotea*	-	-	1	-	-	-	-	1	-	-
Chironomini:										
Chironomus anthracinus	-	-	16	-	-	-	-	-	-	-
Cryptochironomus	-	-	-	-	-	-	-	-	-	-
Glyptotendipes	-	-	-	-	-	-	-	-	-	-
Tanytarsini:										
Cladotanytarsus	-	-	-	-	-	-	-	-	-	-
Orthocladiinae:										
Cricotopus	-	-	-	-	-	-	-	-	-	-
Tanypodinae:										
Procladius	-	-	-	-	-	-	-	-	-	-
Clinotanypus	-	-	-	-	-	-	-	-	-	-
Zavrelimyia	-	-	1	-	-	-	-	-	-	-
Insecta: Odonata *Argia*	-	-	-	-	-	-	-	-	-	-
Totals	2312	0	1658	1591	2342	2040	0	17	1620	4240
Number taxa	n.a.	0	11	n.a	n.a	6	0	n.a	6	5
Diversity **D**	n.a.	0	1.349	n.a	n.a	0.656	0	n.a	0.677	0.479
Oligochaete biomass mg	2209	0	1006	2378	2790	978	0	23	1228	4184

Appendix 2e. Hamilton Harbour benthos per Ekman (Oct.1984), cont.

Site ID	41	42	43	44	45	46	47
Depth (m)	9	20	7	8	8	1	1
Oligochaeta	500	2730	2510	2480	2170	7370	23650
Tubificidae:							
Immature with hairs	-	-	317	-	-	1027	8960
Immatures without hairs	-	-	1224	-	-	5122	14065
Limnodrilus cervix	-	-	118	-	-	35	-
L. claparendianus	-	-	31	-	-	-	-
L. hoffmeisteri	-	-	79	-	-	1134	521
L. maumeensis	-	-	47	-	-		
Tubifex tubifex	-	-	39	-	-	35	104
Ilyodrilus templetoni	-	-	-	-	-	-	-
Quistadrilus multisetosus	-	-	490	-	-	-	-
Aulodrilus pluriseta	-	-	118	-	-	-	-
Naididae:	-	-	47	-	-	17	-
Mollusca							
Gastropoda:	-	-	-	-	-	-	-
Sphaeriidae:							
Pisidium casertanum	-	-	-	-	-	-	-
P. compressum	-	-	-	-	-	-	-
P. fallax	-	-	-	-	-	-	-
P. subtruncatum	-	-	-	-	-	-	-
P. variable	-	-	-	-	-	-	-
Sphaerium corneum	-	-	-	-	-	-	-
S. nitidum	-	-	-	-	-	-	-
Musculium partumeium	-	-	1	-	-	-	-
M. transversum	-	-	-	2	-	-	-
Amphipoda:							
Gammarus fasciatus	-	-	-	-	-	-	-
Isopoda: *Caecidotea*	-	-	-	-	-	-	--
Chironomini:							
Chironomus anthracinus	-	-	-	-	-	4	1
Cryptochironomus	-	-	-	-	-	-	-
Glyptotendipes	-	-	-	-	-	24	-
Tanytarsini:							
Cladotanytarsus	-	-	-	-	-	1	-
Orthocladiinae:							
Cricotopus	-	-	-	-	-	1	-
Tanypodinae:							
Procladius	-	-	-	8	-	12	4
Clinotanypus	-	-			-		
Zavrelimyia	-	-	-	-	-	-	-
Insecta: Odonata *Argia*	-	-	-	-	-	1	-
Totals	500	2730	2511	2490	2170	7413	23655
Number species	n.a	n.a	11	n.a	n.a	12	6
Diversity **D**	n.a	n.a	1.277	n.a	n.a	1.234	0.496
Oligochaete biomass mg	691	2776	2184	2627	1959	8806	16021