NATIONAL WATER RESEARCH INSTITUTE

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NWRI Contribution No. 93-06

# BENTHIC MACROINVERTEBRATE COMMUNITY STRUCTURES IN HAMILTON HARBOUR FROM JUNE TO AUGUST 1989

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## ABSTRACT

The benthic invertebrate communities from 13 sites along a nearshore-offshore transect on the northern shore of Hamilton Harbour were sampled 4 times between June and August 1989. Despite the significant improvement in the abundance and species composition, the benthic community still reflects eutrophic conditions in the Harbour. Low oxygen tolerant oligochaetes dominated by far in 96% of the sites, except for the occasional presence of Crustacea, oligochaetes were the only class present at sites deeper than 12 meters, from June to August. These consisted mainly of immatures without hair setae followed by *Limnodrilus hoffmeisteri*, immatures with hair setae, and *Limnodrilus cervix* which are typically found in highly eutrophic habitats. Both oligochaete densities and distribution decreased throughout the season. Oligochaetes were dominant to a greater extent in June and July and to a much lesser extent in August, when the Crustacea and Insecta increased in density. Arachnid, pelecypod and gastropod densities also increased throughout the season, but to a much lesser extent.

While faunal diversity decreased, population densities increased with increasing depth, for all dates sampled, with the most pronounced increase occurring at around 8 meters. Species diversity increased throughout the season at the expense of oligochaete densities, especially at the shallowest sites. The seasonal and spatial variability of total benthic invertebrate densities were of a much lesser magnitude above 8 meters.

According to the various diversity and biotic indices computed, at least 65% of the sites sampled were diagnosed as moderately to heavily polluted. Since 1964, biomass in the Harbour has increased between 5 and 10 fold, but the most noticeable sign of improvement is the significantly greater diversity. The number of species rose from 13 to over 31, while the number of oligochaete species decreased from 9 to 5 (excluding immatures). Similarly, community composition has shifted away from pollution-tolerant species towards slightly more pollution sensitive species. *Quistodrilus multisetosus* and *Tubifex tubifex* were found at lower densities and represented a smaller percentage of the population in this survey than in 1984. *L. profundicola*, largely restricted to oligotrophic situations, was found in this survey although it was not reported in the 1988 nor in the 1984 surveys. An additional 6 genera of chironomids were found in 1989, as opposed to 1964, two of which: *Dicrotendipes* and *Parachironomus* were never reported prior to 1989. While 7 crustacean and 2 pelecypod genera were collected in 1989, not a single representative of these two classes had been reported in 1964. Five arachnid and 5 gastropod genera were reported for the first time in 1989.

## INTRODUCTION

Since Hamilton Harbour's designation in the early 1970s by the International Joint Commission as one of the 42 Areas of Concern in the Great Lakes, an estimated $600 million has been spent by industry and regional municipalities to reduce the discharge of nutrients and contaminants to the Harbour (OMOE 1991). Furthermore in 1986, OMOE joined with Environment Canada in a full consultative process to develop a plan to complete restoration of the Harbour in accordance with the Great Lakes Water Quality Agreement. Incorporation of biological assessment techniques into management policies is essential for the adequate protection of these resources. The composition of benthic fauna has long been considered a good indicator of water quality. Because these sedentary organisms form relatively stable communities in the sediments, they integrate changes over long time intervals that reflect characteristics of both the sediments and the water column (Wiederholm 1980). Unfortunately, sediments are still designated as contaminated almost exclusively on the basis of bulk chemical analysis, even though the ultimate concern is whether or not the contaminants are exerting biological stress. Biological impact assessment should include benthic invertebrate community structure since it is a good indicator of stress.

In view of these facts, research was undertaken to study species composition and relative abundance of benthic invertebrate communities in Hamilton Harbour through a nearshore-offshore transect, in order to evaluate the benthic invertebrate community's response to the remedial actions implemented. Documentation of species distributions will not only enable comparison with historical data but also future assessments of changes in the benthic invertebrate community. The goal of this study was not only to provide a record of the benthic invertebrate community structure, but also, to give insight into the spatial (depth related) as well as temporal variability.

## MATERIALS AND METHODS

A sampling program of benthic invertebrate communities was carried out along the northern shore of Hamilton Harbour, just west of LaSalle Park Marina. Thirteen sites along a nearshore-offshore transect (depths ranging from 2 to 24m) were sampled (Fig. 1). This transect was selected to avoid steep depth gradients and interference from discharges and other point sources. Seiche activity in the northern shore is also much milder than in the southern shore. At least 5 Ponar dredges (23 x 23cm) were taken at each site. These sites were sampled 4 times at approximately 3 week intervals from June to August 1989.

The benthic invertebrates were sorted, enumerated and identified. Each sample was washed over a 500$\mu$m copper sieve to separate the invertebrates which were then preserved in 10% formalin solution. The invertebrates from each collection were subsequently sorted using fine forceps under a low power binocular dissecting stereoscope (Wild M4A, 12 to 80X), identified and enumerated into major taxonomic groups according to Pennak (1953) and Merritt and Cummins (1984). Identifications were made to the lowest taxonomic levels (species whenever possible, genus otherwise) with the aid of the relevant taxonomic keys: Baker (1972) for Mollusca, Burch (1982) for Gastropoda, Stimpson et al. (1982) for Tubificidae, and Wiederholm (1986) for Chironomidae. Chironomids were first separated using the stereoscope then wet mounted on microscope slides to allow further identification using a microscope (Leitz, 40 to 400X). Oligochaete samples were initially enumerated with the aid of the stereoscope. A subsample of fifty (or all specimens in the sample if less than fifty worms were available) were mounted (Polyvinyl lactophenol, Gurr Microscopy Materials, BDH Chemicals Ltd.) on microscope slides and keyed. Identification of oligochaetes to species, and often to generic level, is based mainly on characters of the sexual organs found in mature specimens. Immature specimens normally lack these diagnostic features thus limiting their identification to the level of the Tubificidae with or without hair setae. The total number for each oligochaete taxa in a sample was calculated from the relative abundance in the subsample multiplied by the total count of the sample. All mollusc identifications were confirmed by Dr. G.L. Mackie, University of Guelph. Arachnids were identified by Dr. Ian Smith, Biosystematics Research Division, Agriculture Canada. The invertebrates were preserved separately within the different taxonomic groups in 70% ethanol.

## RESEARCH RESULTS

The benthic invertebrate enumerations revealed that the fauna from our sites was composed of over 31 species belonging to 18 families, 11 orders and 6 classes. A total of 38,813 invertebrate specimens (including immatures and egg cases) were enumerated from all the sampled sites. The major taxa and total numbers of benthic invertebrates in the various samples are listed in Table 1. The percentage composition of these invertebrates are summarized in Table 2. The two most dominant classes in Hamilton Harbour were oligochaetes and crustaceans.

All the Annelida were tubificid oligochaetes, and these dominated by far, accounting for 97.69% of the total number of individuals. Most of the 97.69% of oligochaetes, were immatures (74.94%) and egg cases (3.42%), only 19.33% were adults. The most dominant oligochaetes were the immatures without hair setae (70.44%), followed by *L. hoffmeisteri* (16.89%), immatures with hair setae (4.50%), egg cases (3.42%), *L. cervix* (1.07%), *Tubifex tubifex* (0.82%), *L. profundicola* (0.37%), and *Quistodrilus multisetosus* (0.18%). The figures between parentheses are the percentages each species represents relative to the total benthic invertebrate population found in all the sites and for all the dates sampled. Mature oligochaete densities ranged from: 1 to 5,662/m$^2$ (mean=1314/m$^2$) while total oligochaete densities ranged from: 315 to 24,018/m$^2$ (mean=6073/m$^2$). Site 11C was not included in these ranges because its extremely low diversity and density reflect exceptional conditions.

Only the immature tubificids without hair setae were found at all sites and for all sampling dates; *L. hoffmeisteri* was the only species also found at all sites and dates except for 11C, where the benthic invertebrate population was restricted to a mere 28 specimens/m$^2$ of immature tubificids without hair setae.

Oligochaete densities decreased throughout the season, the highest total oligochaete as well as mature oligochaete densities occurred in early July, then decreased from mid-June, early August to late August respectively; this was particularly noticeable for sites deeper than 11m, and is due to the occurrence of the highest densities of *L. hoffmeisteri* and *L. cervix* in early July while the other less common species experienced their maximum densities in mid-June.

The second dominant class was the Crustacea (1.76% or 5573 ind.), represented in this transect by 4 orders. The most dominant order was Copepoda (1.72% or 5419 ind.), which was found at all dates sampled, but at far greater densities and with a more extended distribution in early August. These were followed by the Amphipoda (0.02% or 74 ind.), with only 1 species, *Gammarus fasciatus*, found at shallow sites in early July and at the end of August exclusively, with densities ranging from: 3 to 52/m$^2$. Podocopida (0.02% or 57 ind.) occurred mostly between 10 and 18m in early August, but also at the end of August, with the occasional appearance of Cladocera (<0.01% or 11 ind.).

Crustacea were found at 62% of the sites, with densities ranging from 3 to 1853/m$^2$, and averaging 107/m$^2$. They were present in greater numbers and with a more extensive distribution in early August, when the water was at its warmest, then in decreasing numbers by the end of August, mid-June, and early July, respectively. In mid-June, the Crustacea were restricted to the shallowest sites, less than 11m, while in early July and August they extended to 20m, and to 22m, respectively, while being absent from many intermediate sites (between 18 and 20 m).

The next dominant class was the Insecta (0.43% or 1350 ind.) most of which were Diptera chironomids (0.42% or 1341 ind.), only one species of Lepidoptera, *Acentria* sp., was found at one site at approximately 11m in early August. Insecta densities increased throughout the season, reaching a maxima by the end of August. They were restricted to depths, shallower than 12m. Ten chironomid genera were surveyed, the most dominant ones were: *Chironomus* sp. (0.12% or 393 ind.), *Cladopelma* sp. (0.12% or 367 ind.), *Cryptochironomus* sp. (0.10% or 321 ind.), *Procladius* sp. (0.03% or 88 ind.), *Polypedilum* sp. (0.02% or 77 ind.), *Endochironomus* sp. (0.01% or 38 ind.). Each of the other four genera represented less than 0.01% of the total population: *Glyptotendipes* sp. (15 ind.), *Paratanytarsus* sp. (14 ind.), *Parachironomus* sp. (10 ind.) and *Dicrotendipes* sp. (5 ind.).

Chironomids occurred at low densities ranging in number from 3 to 312 individuals/m$^2$ in sediments shallower than 10m from June to August, being totally absent from deeper sediments. Chironomids were found at 48% of the sites but only 8% of the sites had over 100 individuals/m$^2$. Where found, chironomid communities comprised from 1 to 9 taxa per site, the greatest number of genera being found in the shallower sites.

All the Arachnida (0.05% or 172 ind.) belonged to the Prostigmata order. The most numerous family was Limnesiidae (0.04% or 133 ind.), followed by Pionidae (<0.01% or 18 ind.) Hygrobatidae (<0.01% or 9 ind.), Unionicolidae (<0.01% or 8 ind.) and finally Mideopsidae (<0.01% or 3 ind.). Arachnida distribution was sparse and similar to that of the Insecta but limited to depths shallower than 10m and with much lower densities, ranging from 3 to 99/m$^2$ with an average of 3/m$^2$. They were found in 17% of the sites. Arachnida were rare in mid-June and totally absent from early July, but had more representatives in early August and were most frequent by the end of August in sites shallower than 10m.

Pelecypoda (0.05% or 158 ind.) were represented in Hamilton Harbour by 2 genera of sphaeriid Eulamellibranchia. *Pisidium compressum* (0.03% or 99 ind.) outnumbered *Pisidium casertanum* (<0.01% or 9 ind.). *Musculium* sp. (Newborn) (0.01% or 42 ind.) outnumbered *Musculium partumeium* (<0.01% or 8 ind.) and were most numerous at the end of August. Pelecypods were present at 31% of the sites where they ranged from 2 to 27/m$^2$ with an average of 3/m$^2$.

Pelecypoda were found at about the same frequency as the Arachnida and with a similar though more limited distribution to that of the Insecta, they were restricted to sites shallower than 12m. Their densities increased while their distribution extended to deeper sites throughout the season, from 8m in early June to 11m by late August.

The rarest class was the Gastropoda (0.01% or 28 ind.) with only a few representatives from 2 orders. Mesogastropoda (0.01% or 24 ind.) were more numerous and were found in the early July and late August sampling. The second order, Basomatophora (<0.01% or 4 ind.) was only found in one site around 5m in mid-June, and consisted essentially of: a few representatives of *Physella* sp. and of the Lymnaeidae family (both with <0.01% or 2 ind.). Gastropods were only found at 12% of the sites, where they ranged from 1 to 13/m$^2$ and averaged 1/m$^2$. They were most numerous at the end of August and at sites shallower than 8m. The most numerous species were *Valvata sincera* (0.01%), then *Bithynia tentaculata* and *Amnicola limosa*, both with <0.01% or 3 ind./m$^2$ at approximately 6m in late August. Gastropod densities increased very slightly throughout the season from 4 in early June to 13/m$^2$ by the end of August, but were completely absent from the early August sampling.

Broken shells of *Elliptio complanata* were found at the shallower sites, more particularly between 5 and 8m. This was also observed in Lake Ontario by Cook and Johnson (1974).

**Community composition in a given site.**

Oligochaetes dominated by far, for all dates sampled and for all except 2 sites at approximately 6 and 8m, in early August, where Crustacea dominated (Table 2). The ratio of oligochaete density to total density varied from 41.85 to 100% of the community, at any given site, averaging 90.26% (Fig. 2). The oligochaetes represented more than 90% of the individuals at a given site for 75% of the sites. This occurred for all but 2 of the sites sampled in mid-June and early July, whereas this was only the case for sediments deeper than 8m in August. There was greater diversity for the shallower sites in August, after stable stratification.

From 28.37 to 100% (mean=74.04%) of the oligochaetes present in a given site were immatures. The percentages that mature oligochaetes, immatures without hair setae, immatures with hair setae and oligochaete egg cases represented relative to the total oligochaete population in a given site are summarized in Table 3. Immatures without hair setae ranged from 20.74 to 100.00% of the oligochaete population (in a given site), averaging 68.41%. The percentages that each oligochaete species represented relative to the total mature oligochaete population in a given site are summarized in Table 4.

Tubificid immatures (with and without hair setae) represented more than 50% of the individuals at a given site for 88% of the sites. The tubificid immatures without hair setae were present at all sites and for all dates. They represented over 50% of the individuals in a given site for 85% of the sites, except for a few of the shallower sites. They represented 100% of the individuals for site 11C, suggesting that they are possibly, the only group capable of withstanding the harsh conditions in that site.

*L. hoffmeisteri* represented more than 50% of the total mature oligochaete and total mature population in a given site for 85 and 67% of the sites, respectively. The percentages that mature oligochaete species represented relative to the total and total mature population in a given site are summarized in Table 5.

Crustacea dominated for 4% of the sites between 6 and 8m in early August, accounting for 49.26 to 55.37% of the community in these sites. They were absent from 38% of the sites. On average they represented 6.53% of the population at a given site, and exceeded this percentage for 19% of the sites.

Insecta represented up to 22.37% of the community in one site, at approximately 2 meters at the end of August, but with an average of only 2.5%. They exceeded this percentage for 33% of the sites. Insecta were present at the shallower depths being absent from 50% of the sites, generally those deeper than 11m.

Arachnida represented between 0.28 and 7.12% (mean=0.31%) of the population in a given site. They represented over 1% for 6 sites (12% of the sites), 5 of which were sampled in late August at depths shallower than 10m, the 6th site being the shallowest site (2m) in early August. Pelecypoda represented between 0.15 and 5.65% (mean=0.35%) of the population at a given site, exceeding 1% for 12% of the sites. Gastropoda represented between 0.28 and 1.74% (mean=0.08%) of the population at a given site and exceeded 1% for only 2% of the sites.

**Spatial variability along the depth gradient**

For all the dates sampled, population densities increased with depth, by one order of magnitude from the shallowest site (2m: 878 ind/m$^2$) to the deepest site (24m: 15,868 ind./m$^2$)

(Table 1). Population density was positively correlated to sediment depth, for all dates sampled, but to a greater extent for mid-June and late August (Fig. 3). Both the slopes and intercepts of these regressions are significantly different from 1 and 0 respectively, for all dates. All these regressions underestimate population densities at the shallowest depths, but the regressions for early July and early August also underestimate density at the deepest depths, while the regressions for mid-June and late August overestimate them. The lower slopes for the two August samplings confirm the lower population densities observed on these dates compared to those of mid-June and early July.

At the shallower depths, population densities were more stable, the increase in densities being much more pronounced below 8 meters (Fig. 4). Population densities were also more variable from one date to the other below 8 meters.

Total macroinvertebrate populations averaged 6,073 ind./$m^2$ (for all dates and depths), ranging from 0 to 24,018 ind./$m^2$. The average total benthic macroinvertebrate density is 906 ind./$m^2$ for shallow sites (sites 1 to 5: $\leq$8m) and 9,302 individuals/$m^2$ for deep sites (sites 6 to 13: >8m).

Since oligochaetes dominated the benthic invertebrate community, it is not surprising that the total number of oligochaetes also increased dramatically with depth (Fig. 5), especially below 8 meters, where Crustacea and Insecta become scarce and Arachnida, Pelecypoda and Gastropoda were totally absent (Fig. 6a, b, c, d). The abundance of total oligochaetes ranged from 287/$m^2$ (site 1B, 2m) to a maximum of 23,167/$m^2$ (site 13B, 24m). The average oligochaete density was 682 oligochaetes/$m^2$ for shallow sites and 9,214 oligochaetes/$m^2$ for deep sites. The abundance of adult oligochaetes ranged from (absent at one exceptional site 11C): 107/$m^2$ (1B, 2m) to 4310/$m^2$ (13A, 24m), averaging 215/$m^2$ for shallow sites and 1774/$m^2$ for deep sites.

Except for the oligochaetes, whose densities peaked, between 14 and 24m, the densities for all other classes increased with depth until reaching their maxima at shallower depths. Insecta and Arachnida exhibited the shallowest density peaks at depths shallower than 6m, followed by Gastropoda and Pelecypoda at depths shallower than 8m. The density peaks for Crustacea were observed between 4 and 10m.

Even though most oligochaete species were found in great numbers at the deepest sites, *L. cervix* was limited to 11m and *Q. multisetosus* to 18m. Most Crustacea were found to a depth of 22m, except for *Gammarus fasciatus* and *Ilyocryptus* sp. (it only appeared in late August), which were limited to 6m, *Musculium* sp. to 8m and *Musculium partumeium* to 11m. All other classes were restricted to much shallower depths. Gastropods had the most limited distribution, being restricted to depths shallower than 8m, arachnids extended to 10m while pelecypods and insects both extended to 12m.

Depth, however is only an indirect factor involved in determining population distribution and densities, a complex of other factors such as: thermal stratification, oxygen depletion, sediment type and extent of contamination, are intimately related to it. More detailed analysis of the variables will allow us to establish the relationships between benthic invertebrate community structures and contaminants and how these relationships are affected by oxygen levels, and other physico-chemical variables. These variables will be studied in relation to benthic invertebrate distribution in Hanna (in prep.).

**Benthic invertebrate seasonal variation**

There was greater diversity at the shallower sites for all sampling dates, but the increase in diversity was more pronounced for the late August sampling (Fig. 7). There was less diversity at the earlier dates (mid-June and early July: 20 species) but greater numbers of individuals from these fewer species. The diversity was greater in early August (22 species) and greatest by the end of August (35 species), when the lower tubificid densities (Fig. 5) were offset by the appearance of 1 crustacean, 5 chironomid, 2 gastropod and 3 arachnid species.

The highest total benthic invertebrate densities were observed in early July, then mid-June, late August and finally early August. The latter ranking also coincides with the ranking of tubificid densities. The seasonal variation of total benthic invertebrate densities appears to be of a much lesser magnitude above and including 8 meters, where the coarse sandy substrate limits the populations to low densities (Fig. 4), and much more important at the deeper sites. The highest total oligochaete densities occurred in early July, more particularly for sites deeper than 11m, while the highest Crustacea densities occurred in early August. For all the other classes, the highest densities occurred at the end of August. Oligochaetes were dominant to a greater extent in June and July and to a much lesser extent in August when mostly the Crustacea, but also species belonging to all other classes increased in density. The end of August was, therefore, characterized by the greatest number of species and the highest densities of organisms not belonging to the oligochaetes and crustaceans.

Along with the density increases throughout the season, the distribution of two classes: Crustacea and Pelecypoda also extended to deeper sites throughout the season, from 10m to 22m and from 8m to 11m, respectively from mid-June to the end of August.

**Species Diversity**

Species diversity has a recognised potential for describing the trophic status of a community (Johnson and Brinkhurst 1971). The most common method of achieving this goal is through the use of diversity indices (Wilhm and Doris 1968, Zand 1976) that summarize information on the numbers and kinds of organisms in a community. These indices were computed because of their common use, apparent differential sensitivity, and ability to detect community change. A critical review of the many diversity and biotic indices that have been applied to aquatic ecosystems is given in Washington (1984).

The number of species (S) is believed to be the only truly objective measure of diversity (Poole 1974). Margalef (1958) popularized the concept of species richness using the following equation:

$$d = (S-1)/\ln N \tag{1}$$

where N is the number of individuals of all species, and S is the number of species. This index measures the distribution of individuals among the species present, but does not contain an evenness component (Metcalfe 1989). Low values of d denote a community in which most of the individuals belong to a few species, while high values indicate that the community is made up of a wide range of species.

By far the most widely used diversity index is the Shannon-Weaver index because it is stable in any spatial distribution and insensitive to rare species (Cairns and Pratt 1986):

$$H' = -\Sigma\, p_j \,\mathrm{Log}\, p_j \tag{2}$$

where $p_j$ is the proportion of the population belonging to the jth species (Shannon-Weaver 1949). This index is a measure of species richness and of the equitability of distribution (evenness) of individuals among species. The higher the value of H', the greater the diversity and, supposedly, the cleaner the environment (Metcalfe-Smith 1991).

In a "healthy" benthic community, the densities of organisms are normally determined by interspecific competition for available food resources and by predators. Such a community is characterized by high diversity or richness, an even distribution of individuals among the species, and moderate to high counts of individuals. In organically polluted areas, a very reduced fauna, comprised of few species able to tolerate low oxygen levels, can significantly increase in density and become the dominant, and often only, fauna present (reduced evenness). This is due to an abundant food source in the organic nutrient-rich sediment and to the absence of competition from other groups of organisms (Jaagumagi et al. 1989). Characteristic of these types of communities are oligochaetes, usually *Tubifex tubifex* and *Limnodrilus hoffmeisteri*. Both of these species thrive in these areas simply because of their tolerance of low oxygen levels. In oligo or mesotrophic areas, they form a smaller part of the fauna, mainly because they are poor competitors in natural situations (Jaagumagi 1988). In contrast, low diversity and low abundance are indicative of toxic or acidic pollution (Chapman et al. 1982).

While the number of organisms per meter$^2$ increased, greatly due to the increasing numbers of immature oligochaetes and more particularly immature oligochaetes without hair setae and to a much lesser extent to *L. hoffmeisteri* (Fig. 8a, b, c, d), the number of species clearly decreased with depth.

The number of species per site ranged from 1 to 17 and averaged 10.0 at shallow sites and 5.5 at deep sites. This is confirmed by Margalef's (1958) index, ranging from 0 to 2.6 and averaging 1.4 at the shallow sites and 0.5 at the deep sites (Fig. 9), as well as by Shannon-Weaver's (1949) index, ranging from 0 to 2.7, and averaging 2.0 at the shallow sites and 1.2 at the deep sites (Fig. 10). Wilhm (1968) using aquatic macroinvertebrates, assigned values of H': 3-5 as clean, 1.0-3.0 as moderately polluted and below 1.0 as substantially polluted. Consequently, 42 out of the 52 sites (81%) were considered moderately polluted, the remaining 10 sites (19%) were substantially polluted.

The highest species diversities were found above 10m for all dates, but diversity increased throughout the season reaching its peak by the end of August (Fig. 7). This marked temporal variation was confirmed by Margalef's index which jumped from 1.7 in early June to 3.1 in late August, but was not as obvious for H' even though Murphy (1978) had noted a marked temporal variation in both H' and Margalef's index. This variation partially reflects not only changes in community life cycles, but also the effects of temperature and other physico-chemical conditions. Low temperature apparently inhibited diversity in Lake Ontario, although depth, sediment type and pressure may have been significant (Johnson and Brinkhurst 1971). The number of species reached its maximum at a depth of approximately 6m (Fig. 7), for all sampling dates. The number of species was more variable above 10m both from one date to the other and from one depth to the other. Below this depth oligochaetes were found almost exclusively, with the occasional appearance of crustaceans.

Only one site (11C at approximately 20m in early August) had both low diversity (S=1, d=0, H'=0) and extremely low total benthic invertebrate density comprised exclusively of 28 immature tubificid oligochaetes without hair setae. This is probably an unusual situation due to high contaminant levels (Hanna, in prep.).

When species diversities are desired for comparative purposes, simple indices such as S and d are biologically meaningful measures which are less ambiguous than, and often as informative as, more complex indices such as H' (Hurlbert 1971). However, low diversity (H' <2) makes species diversity a poor choice as an index of the severity of any particular type of environmental impact (Howmiller and Scott 1977). It will be found in any similarly extreme environment but is not at all a specific characteristic of any particular kind of stress, whether naturally-occurring or resulting from cultural environmental impact (Howmiller and Scott 1977). Furthermore, these indices do not reflect knowledge of the physiological attributes or ecological affinities of the organisms comprising the community. It is therefore advisable to consider the composition of the assemblage of organisms and their ecological attributes.

**Biotic indices**

The biotic approach incorporates desirable features of the saprobic and diversity approaches, combining a quantitative measure of species diversity with qualitative information on the ecological sensitivities of individual taxa into a single numerical expression (Metcalfe 1989). In view of the limitations of diversity indices, several approaches were used to evaluate trophic conditions along this transect of the Harbour: the indicator species approach (Howmiller and Scott 1977), the oligochaete-density index (Wright and Tidd 1933, Howmiller and Beeton 1971), the oligochaete relative abundance index (Goodnight-Whitley 1960), and the *%L. hoffmeisteri* index (Brinkhurst 1967).

Of the 5 oligochaete species found in this survey, only *L. profundicola* is considered restricted to oligotrophic situations, according to Howmiller and Scott's (1977) classification of oligochaete species. The other 4 being classified as tolerant to extreme enrichment or organic pollution. Since *L. profundicola* was only found in 27% of the sites, the remaining 73% of the sites would be considered organically polluted according to this classification.

Total oligochaete density has often been used to assess pollution (Wright and Tidd 1933, Howmiller and Beeton 1971, Mozley and Alley 1973). Wright and Tidd (1933) suggested that an oligochaete density of less than $1000/m^2$ indicates negligible pollution, a density between 1000 and $5000/m^2$ indicates mild pollution and more than $5000/m^2$ severe pollution. Consequently, 40% of our sites are severely polluted and 25% are mildly polluted, thus 65% of our sites are mildly to severely polluted (Fig. 5).

Working on a midwestern stream, Goodnight and Whitley (1960) suggested that the relative abundance of oligochaetes to other benthic invertebrates can be used as an index of pollution. Areas with greater than 80% oligochaetes are highly polluted sites, either from organic enrichment or industrial pollution, areas with between 60% and 80% are considered "doubtful", and areas with less than 60% are considered in good condition. According to their definition, 83% of our sites are highly polluted, 10% are doubtful, therefore 93% of the sites are doubtful to highly polluted (Fig. 2).

The percentage of *L. hoffmeisteri* to other oligochaetes was used by Brinkhurst (1967) as an index of organic pollution. The greater the relative abundance of *L. hoffmeisteri* the more enriched the area; a percentage of at least 50% is indicative of perturbed conditions. According to this index (numbers of immature *Limnodrilus* sp. were prorated and included), 81% of the sites have perturbed conditions (Fig. 11). Many studies have verified that high relative abundances of *L. hoffmeisteri* are characteristic of grossly polluted areas, but low abundances occur over a considerable range of environmental conditions (Howmiller and Scott 1977). This explains the greater sensitivity of this index to temporal variability since a given site may oscillate from good to perturbed conditions depending on the sampling date. Both the Goodnight and Whitley (1960) and the Brinkhurst (1967) indices may not be appropriate for this segment of Hamilton Harbour since the inhospitable coarse sandy substrate at the shallow depths might be responsible for the high oligochaete percentage relative to other invertebrates by combining low densities and low diversities.

These indices were generally in agreement in categorizing the extent of pollution at the various stations, but the fact that some discrepancies did arise illustrates that they must be applied cautiously (Nalepa and Thomas 1976). Howmiller and Scott (1977) suggested that single or multiple-species indices may be more sensitive than indices based on higher taxonomic categories. On the other hand, indices based on absolute and relative abundances of oligochaetes suffer from their inability to detect subtle changes in pollution which may not affect overall oligochaete abundance but which may cause changes in species composition brought about by the different physiological responses of the individual species (Krieger 1984).

**Historical comparison:**

In 1964, forty six sites in Hamilton Harbour were sampled during August to Early September (Johnson and Matheson 1968). Since then the Harbour has been resampled by a few other researchers. A summary of the sampling protocols and data from these different benthic invertebrate surveys is given in Table 6. The differences in site locations, sample timing and sampling protocols not only make direct comparisons difficult, but preclude quantitative comparisons. It should be noted that the 1989 survey included a more extensive sampling of shallower sites than previous surveys, but this has been taken into account during the comparison. A major obstacle to the comparative study of benthic faunas is the variety of factors which contribute to the variability among samples (Barton and Hynes 1978). Our data confirms Barton and Hynes' (1978) observation that benthic fauna changes markedly, mostly in composition (Fig. 7), but also in abundance (Fig. 4) over short periods of time, especially in summer, as adult insects emerge and other groups migrate or reproduce. Therefore, only differences in the abundance of organisms in terms of magnitude were considered meaningful while the presence or absence of the various species in the contiguous samples permitted a realistic appraisal of their distribution.

The most pronounced improvement is reflected by the significant increase in population diversity from 13 species reported in 1964 to over 31 observed in 1989. This was accompanied by a reduction in the number of oligochaete species from 9 in 1964 to 5 (not including immatures) in 1989. From Johnson and Matheson's (1968) 1964 survey, Johnson and Brinkhurst (1971) computed an H' of 0.89 for intermediate depths and temperatures and 1.80 in warm shallow inshore waters. Diversity approached and even attained zero in local areas, such as the $2km^2$ area where Johnson and Matheson (1968) were unable to obtain any macroinvertebrates (Johnson and Brinkhurst 1971). Computed values of H' from the 1989 survey (Fig. 10) also confirm an improvement of the conditions in the Harbour translated by greater species diversity (Fig. 7 & 9).

Some improvement does appear to have taken place also with regard to macroinvertebrate density. The total number of individuals has increased by one order of magnitude from 1964 ($max=15,998/m^2$) to 1984 ($max>100,000/m^2$) but seems to have decreased by one order of magnitude since then to a maximum of $24,018/m^2$ in 1989. The benthic invertebrate fauna from our sites was found to be dominated by oligochaetes, as expected from previous studies on

Hamilton Harbour (Johnson and Matheson 1968, OMOE 1989, Krantzberg and Boyd 1992, T. Reynoldson, pers. comm.). In 1964, the oligochaete densities varied between 70 and 22,600/m$^2$, and 62 to 97% of these oligochaetes were immatures (mean=84%) (Johnson and Matheson 1968). A dramatic increase was observed in 1984, with oligochaete densities ranging from 10,000 to 100,000/m$^2$ (OMOE 1989). A subsequent decrease was noted in 1989 when the oligochaetes varied from 28 to 24,018/m$^2$ (including immatures and egg cases), being least abundant in the shallow, sandy sediments, particularly at the end of August. From 28 to 96% of these oligochaetes were immatures and egg cases (mean=74.04%).

In 1984, the immature individuals without hair setae, presumed to be *Limnodrilus* sp. accounted for 48 to 78% (mean=69%) of the oligochaetes present, while those with hair setae accounted for 6 to 40% (mean=20%) (Portt et al. 1989). In our 1989 survey, immature individuals without hair setae, accounted for 20.74 to 93.33% (mean=68.41%) of the oligochaetes present, while those with hair setae accounted for 0 to 30.57% (mean=5.63%).

A shift in the oligochaete species composition has also taken place. The oligochaetes *L. hoffmeisteri*, *T. tubifex* and *L. cervix* comprised 92% of the total number of specimens collected from the Harbour in 1964 (when numbers of immature *Limnodrilus* sp. were prorated and added to the totals of the several species) (Johnson and Matheson 1968). In this study, *L. hoffmeisteri* (16.89%), immatures without hair setae (70.44%), *T. tubifex* (0.82%), and *L. cervix* (1.07%) comprised 89.22% of the total number of specimens collected from the Harbour. During the 1964 survey, *L. hoffmeisteri* occurred at all sites sampled and represented 50% of the total mature population of oligochaetes. *Tubifex tubifex* was found at 85% of the sites and contributed 30% of the population. More sensitive species such as *Quistodrilus multisetosus* made up less than 5% of the population and occurred at less than 30% of the sites. In 1984, on the other hand, *Q. multisetosus*, a pollution-sensitive oligochaete represented 42% of the total benthic invertebrate population, while *L. hoffmeisteri* and *T. tubifex*, pollution-tolerant oligochaetes, represented 32 and 10% of the population, respectively (OMOE 1989). *L. hoffmeisteri* was only dominant at some sites, accounting for 77 to 92% of the oligochaetes present (Portt et al. 1989). At most of the sites examined in 1984, *T. tubifex* accounted for less than 10% of the mature oligochaetes. All Hamilton Harbour stations sampled in November 1988 were dominated by low oxygen tolerant oligochaetes, primarily *L. hoffmeisteri*, *L. cervix*, *Tubifex tubifex*, and *Quistodrilus multisetosus* (Krantzberg and Boyd 1992). During this 1989 survey, *Limnodrilus hoffmeisteri* occurred at all sites except site 11C and accounted for a greater percentage (87.37%) of the total mature population of oligochaetes. This species was clearly dominant, accounting for up to 100% of the mature oligochaetes present; it represented at least 50% of the total mature population of oligochaetes for 85% of the sites and over 50% of the total mature population for 67% of the sites. In comparison with 1964, both *Tubifex tubifex* and *Quistodrilus multisetosus* were found less frequently, at only 17 and 8% of the sites, respectively, and contributed significantly lower percentages 4.22 and 0.95% of the mature oligochaete population, respectively, and 0.82 and 0.18% of the total benthic invertebrate population, respectively. Despite the improvement, species composition of the oligochaete community still reflects the eutrophic conditions in the Harbour. *L. hoffmeisteri* and *T. tubifex* were the dominant species in 1964, *Q. multisetosus* and *L. hoffmeisteri* the dominant ones in 1984 and *L. hoffmeisteri* and *L. cervix* the dominant ones during this study. *L. hoffmeisteri*, *Q. multisetosus* and *T. tubifex* are typically found in highly eutrophic habitats as is *L. cervix* (Spencer 1980, Brinkhurst 1980, Howmiller and Scott 1977).

The community of the central depression of the Harbour at depths in excess of 15m was composed of *L. hoffmeisteri* (at every station with macroinvertebrates) and *T. tubifex*. The latter composed of 20 to 57% of the oligochaete population in the central depression and was of greatest relative abundance at the greatest depth (Johnson and Matheson 1968). In this survey, *T. tubifex* only represented 0 to 27.14% (mean=2.33%) of the mature oligochaete population. In sediments shallower than 12m along the northern shore: it comprised less than 10% of the total number (Johnson and Matheson 1968). In this study, *T. Tubifex* was absent from depths shallower than 8 to 20m, depending on the sampling date. The overall decline in the relative abundance of *L. hoffmeisteri* and *T. tubifex* combined with the increase in the relative abundance in *Q. multisetosus* from 1964 to 1984 (OMOE 1989) reflects an improvement in habitat quality. Until 1964, all sewage from the city of Hamilton was discharged untreated into the Harbour until a new primary treatment plant was put into operation. *L. hoffmeisteri* is much more tolerant of sewage sludge than *T. tubifex* which, in turn, is more tolerant than *Q. multisetosus* (Chapman et al. 1982). In the 1989 survey there was a decrease in *Q. multisetosus*, combined with an increase in *L. hoffmeisteri*, the same phenomenon was observed in the Bay of Quinte (R. Dermott, pers. comm.).

Two oligochaete species, characteristic of mesotrophic or only slightly enriched conditions (Howmiller and Scott 1977), have not been reported in the Harbour since 1964, not only were they not found in the 1989 survey but they were also not found in 1984, these were: *Peloscolex ferox* and *Euilyodrilus moldaviensis*. Two other species: *L. udekemianus*, and *L. claparedeanus* collected in 1964 and frequently present, particularly in the nearshore areas shallower than 12m, in 1984 (Portt et al. 1989) were not found in the 1989 survey. This might be a sign of improvement since these two species tolerate extreme enrichment or organic pollution (Howmiller and Scott 1977). No naidids were found in 1989 (they were probably lost through the 500$\mu$m sieve used), nor in 1964, although they were present in 11 of 25 sites, mainly at the nearshore sites in 1984 (OMOE 1989). Members of this family are considered indicative of mesotrophic conditions (Howmiller and Scott 1977), their presence reflects an improvement in habitat conditions. *L. profundicola*, considered to be largely restricted to oligotrophic situations (Howmiller and Scott 1977) was not reported in the 1984 (Portt et al. 1989) nor in the 1988 (Krantzberg and Boyd 1992) surveys, yet was found in 27% of the sites in this survey at densities of up to 265/m$^2$.

Even though four chironomid genera: *Chironomus attenuatus, Glyptotendipes polytomus, Procladius sp.* and *Tanypus stellatus* were reported in 1964 (Johnson and Matheson 1968), in actual fact, for sites close to those of this study, only 1 chironomid species, *C. attenuatus* was reported at a density of 8/m$^2$ at site 10 (Johnson and Matheson 1968). Chironomids, notably *C. attenuatus* were more numerous at depths shallower than 10m in 1964 (Johnson and Matheson 1968). *Tanypus* was only found in one site (Windermere Basin) in 1964 but not in 1984 nor in 1989. Eight chironomid genera occurred at all of the littoral sites sampled in 1984 with a mean abundance of 302/m$^2$ (OMOE 1989). In 1989, an additional 2 genera: *Dicrotendipes* and *Parachironomus*, were found for a total of 10 chironomid genera. At least four of the 10 chironomid genera: *Dicrotendipes, Parachironomus, Polypedilum* and *Cladopelma* thrive in shallow waters with relatively good oxygen conditions. During this survey, from 1 to 9 chironomid genera were found at a given site, with more genera at the shallowest sites, and the most genera per site occurring in late August. Chironomid populations ranged from 3/m$^2$ (4B) to 312/m$^2$ (1D) and their distribution extended to 12m.

No sphaeriids were captured in the 1964 survey but 9 species were present in low numbers at 24% of the sites in 1984. Only 4 species were collected in 31% of the sites in 1989. The presence of sphaeriids is a further indication of improved habitat conditions.

A single amphipod, *Gammarus fasciatus*, was collected from site 13 in 1984, none had been reported in 1964. *Gammarus fasciatus* was also the only amphipod found in our survey, but it was found at 3 shallow sites (<6m), at a density of 3 to 52/m$^2$, mostly at the end of August. The presence of this organism is indicative of oxic conditions at the sediment-water interface.

Arachnida and Gastropoda have not been previously reported in the Harbour. Even though they represented small percentages of the total benthic invertebrate population, 0.05% for the Arachnida and 0.01% for the Gastropoda, the 5 arachnid genera occurred at 17% of the sites and the 5 gastropod genera occurred at 12% of the sites.

In spite of these documented improvements, conditions in the Harbour have still not met the 3 proposed Hamilton Harbour delisting objectives indicative of reduced degradation impairment for benthic invertebrates (OMOE 1991). These 3 delisting objectives are:

1) Shift in oligochaete assemblages (benthic sludge worms) from *Limnodrilus hoffmeisteri* and *Tubifex tubifex*, indicators of eutrophic environments, to mesotrophic indicators such as *Spirosperma ferox*, *Stylodrilus heringianus*, and *Ilyodrilus templetoni*.

2) An increase in the contribution of other species in Hamilton Harbour sediment indicative of mesotrophic conditions such as midges (*Tanypus* and *Strictochironomus*), fingernail clams (*Pisidium*), mayflies (*Hexagenia*) and the amphipod (*Pontoporeia hoyi*).

3) Reduction in oligochaete (sludge worm) density from an average 10,000 animals per $m^2$ found in 1984 to between 2,000 and 3,000 per $m^2$ in profundal sediments.

## CONCLUSION

The Hamilton Harbour benthic invertebrate fauna was composed of over 31 species:

. most of the sampled sites were dominated by low oxygen tolerant oligochaetes; in decreasing order of dominance, these were: immatures without hair setae, *Limnodrilus hoffmeisteri*, immatures with hair setae, *L. cervix*, *Tubifex tubifex*, *L. profundicola* and *Quistodrilus multisetosus*. Only the tubificid immatures without hair setae and *L. hoffmeisteri* were present at all sites.

. oligochaete densities as well as the extent of their depth distribution decreased throughout the season: oligochaetes were dominant to a greater extent, and at more sites in June and July and to a much lesser extent in August when they became more limited to the deeper sites while the Crustacea and Insecta increased in numbers at the shallower sites.

. arachnid, pelecypod and gastropod densities also increased throughout the season, but to a much lesser extent.

. for all the dates sampled, faunal diversity decreased while population densities increased with increasing depth, with the most marked increase in both of these variables occurring around 8m. Species diversity increased throughout the season at the expense of oligochaete densities, especially in the shallower sites.

. spatial and seasonal variability of population density were more pronounced for sites deeper than 8m, from June to August.

. according to the various diversity and biotic indices computed, at least 65% of the sites sampled were diagnosed as moderately to heavily polluted.

Although the benthic invertebrate community in Hamilton Harbour is still indicative of a highly eutrophic environment, substantial improvements have occurred in the abundance and community composition since 1964:

. the number of species rose from 13 to over 31 while the number of oligochaete species decreased from 9 to 5.

. 6 more genera of chironomids were found in 1989, among these: *Dicrotendipes* and *Parachironomus* had never been reported prior to 1989.

. an additional 7 crustacean, 2 pelecypod, 5 arachnid and 5 gastropod genera were found in 1989.

. community composition has shifted away from pollution-tolerant species towards slightly more pollution sensitive ones.

Because of the importance of the spatial and temporal variabilities, it is recommended that sampling protocol as well as sample timing be standardized, and protocol and sampling details be documented. If sampling is limited to a single date, then it should preferably be carried out at the time of maximum heat content of the Harbour (mid to end of August), since this coincides with the period of maximum species diversity.

## ACKNOWLEDGEMENTS

I would like to thank M. Baker for the benthic invertebrate identification and enumeration and W. Morton and Dr. G.L. Mackie (University of Guelph) for confirmation, and Dr. Ian Smith (Biosystematics Division, Agriculture Canada) for Arachnid identification. I am also indebted to M.N. Charlton (NWRI) and R. Dermott (DOE, Burlington, Ontario) for their valuable comments on this manuscript and to H. Don and the Technical Operations team for collecting the sediments.

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**FIGURE LEGENDS**

Figure 1. Map of Hamilton Harbour indicating the nearshore-offshore transect along which the thirteen sampling sites were selected.

Figure 2. Percent composition of oligochaetes relative to the total benthic invertebrate population (including immatures, excluding eggs cases) in relation to depth, for the different sampling dates.

Figure 3. Relationship between population density for the different sampling dates as well as the average population density for all the dates sampled and sediment depth.

Figure 4. Depth distribution of benthic invertebrates from the Hamilton Harbour nearshore-offshore transect sampled at approximately 3 week intervals between June and August, 1989.

Figure 5. Depth distribution of oligochaetes for the different sampling dates.

Figure 6. Depth distribution of the various classes of benthic invertebrates: a) June 22, 1989, b) July 5, 1989, c) August 2, 1989, d) August 30, 1989.

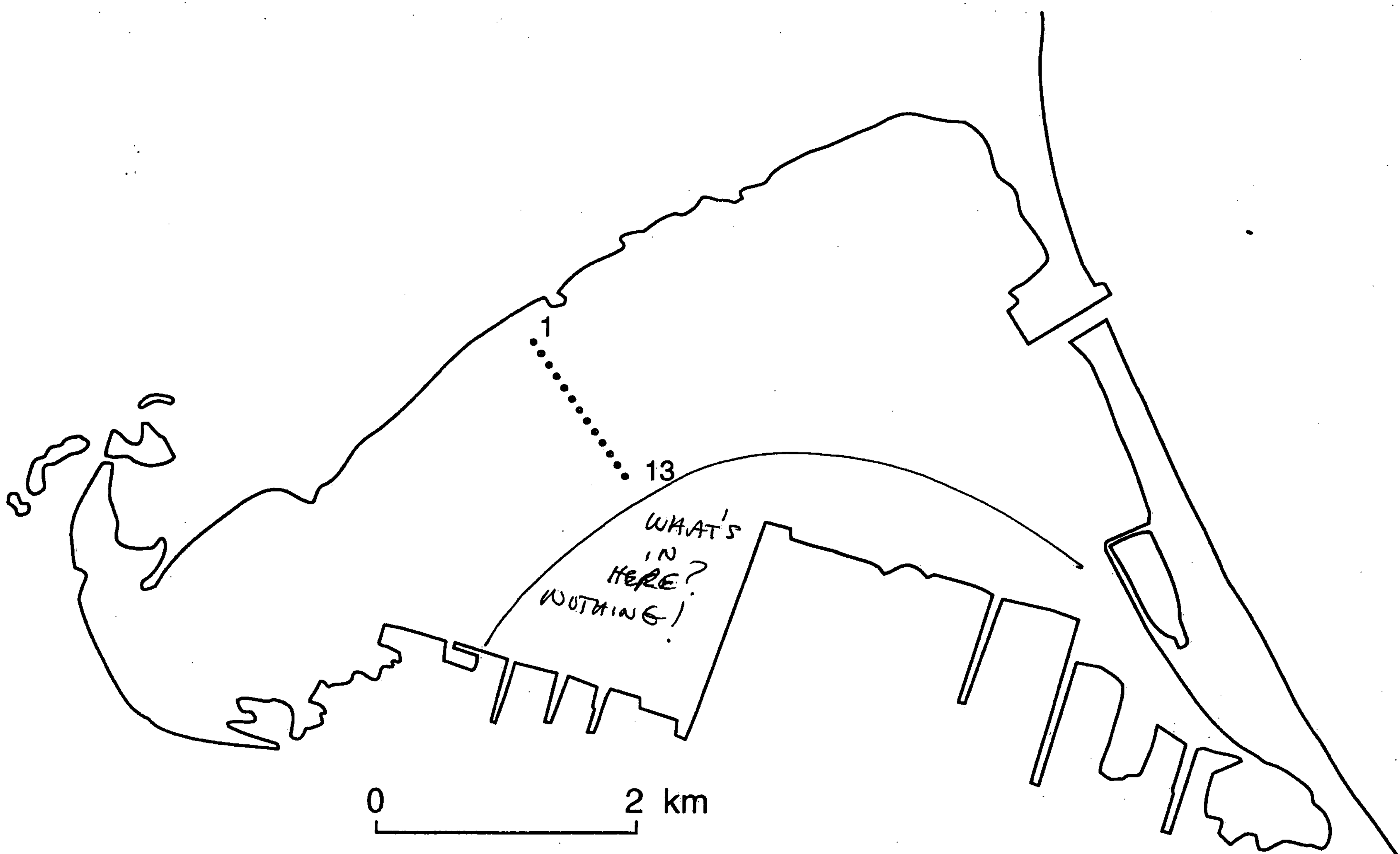
Figure 7. Species Diversity in relation to depth at each site for the different sampling dates.

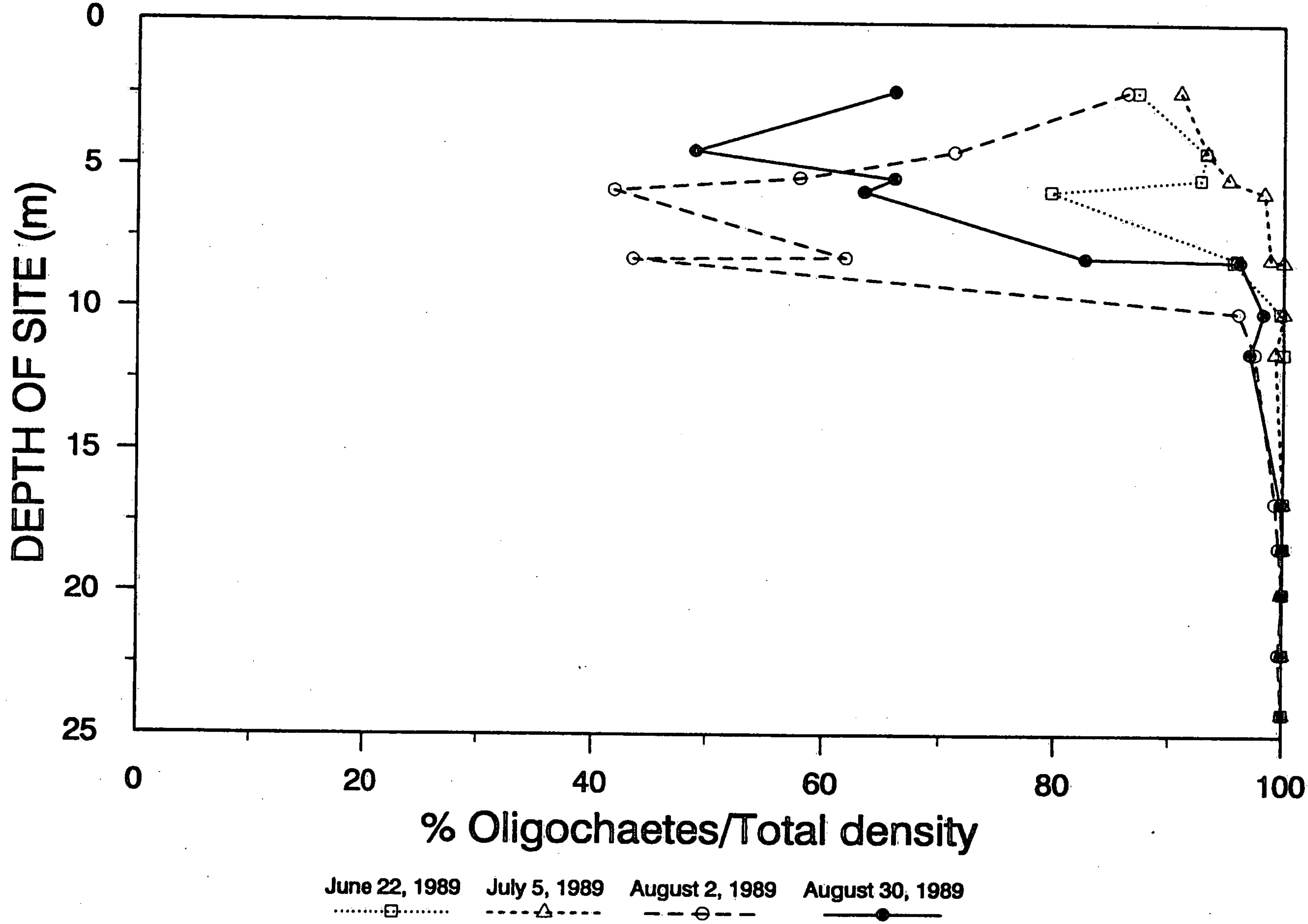
Figure 8. Depth distribution of the various oligochaete species for the different sampling dates: a) June 22, 1989, b) July 5, 1989, c) August 2, 1989, d) August 30, 1989.

Figure 9. Species richness index (Margalef 1958) in relation to depth for the different sampling dates.

Figure 10. Diversity index (Shannon-Weaver 1949) in relation to depth for the different sampling dates.

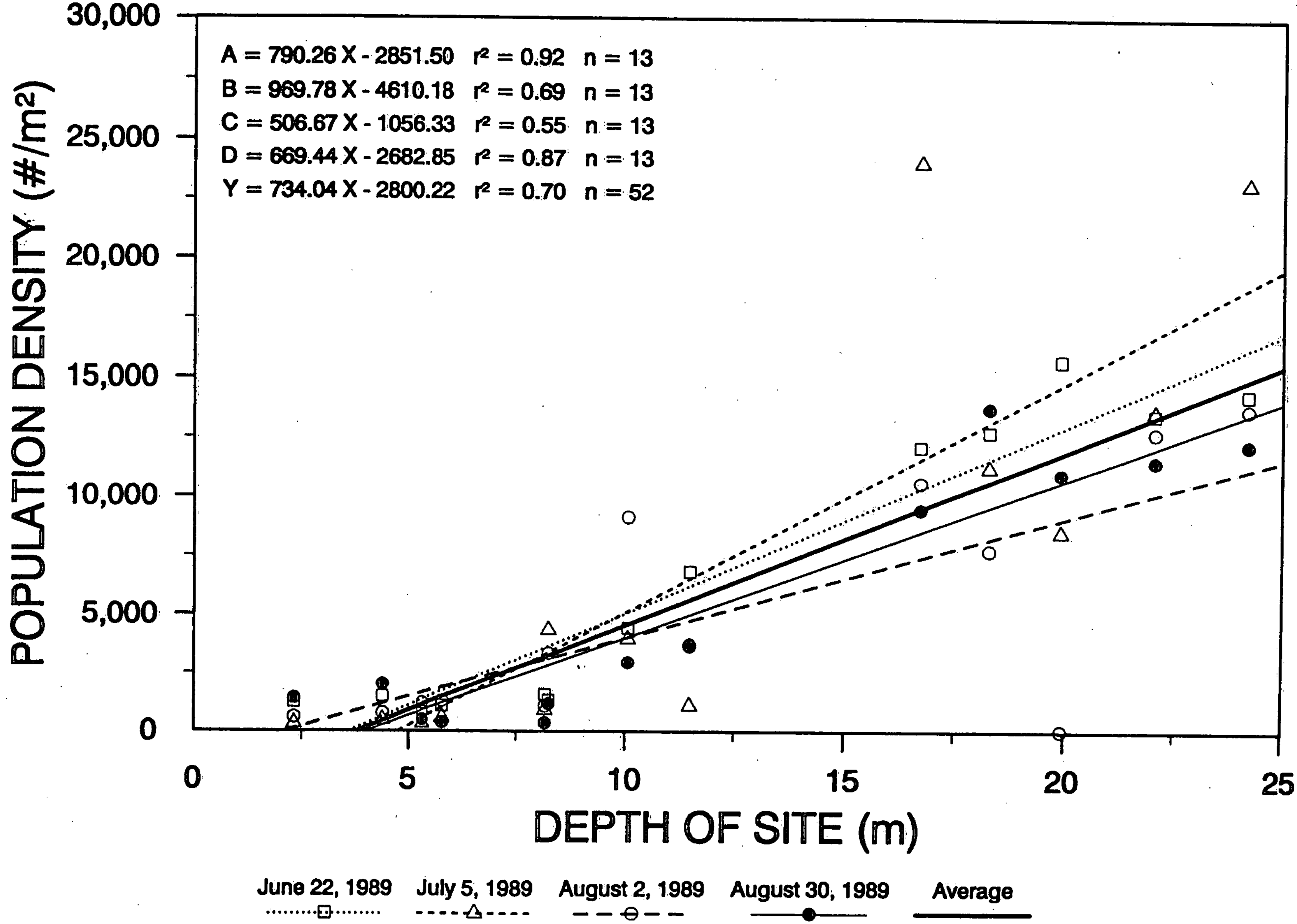
Figure 11. Percent composition of *L. hoffmeisteri* relative to the total oligochaete density in relation to depth for the different sampling dates.


1
13
WHAT'S IN HERE?
NOTHING!
0
2 km



DEPTH OF SITE (m)
0
5
10
15
20
25
0
20
40
60
80
100
% Oligochaetes/Total density
June 22, 1989
July 5, 1989
August 2, 1989
August 30, 1989


Figure 2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B = 969.78 X - 4610.18   r² = 0.69   n = 13
C = 506.67 X - 1056.33   r² = 0.55   n = 13
D = 669.44 X - 2682.85   r² = 0.87   n = 13
Y = 734.04 X - 2800.22   r² = 0.70   n = 52
POPULATION DENSITY (#/m²)
30,000
25,000
20,000
15,000
10,000
5,000
0
0
5
10
15
20
25
DEPTH OF SITE (m)
June 22, 1989
July 5, 1989
August 2, 1989
August 30, 1989
Average

Figure 3

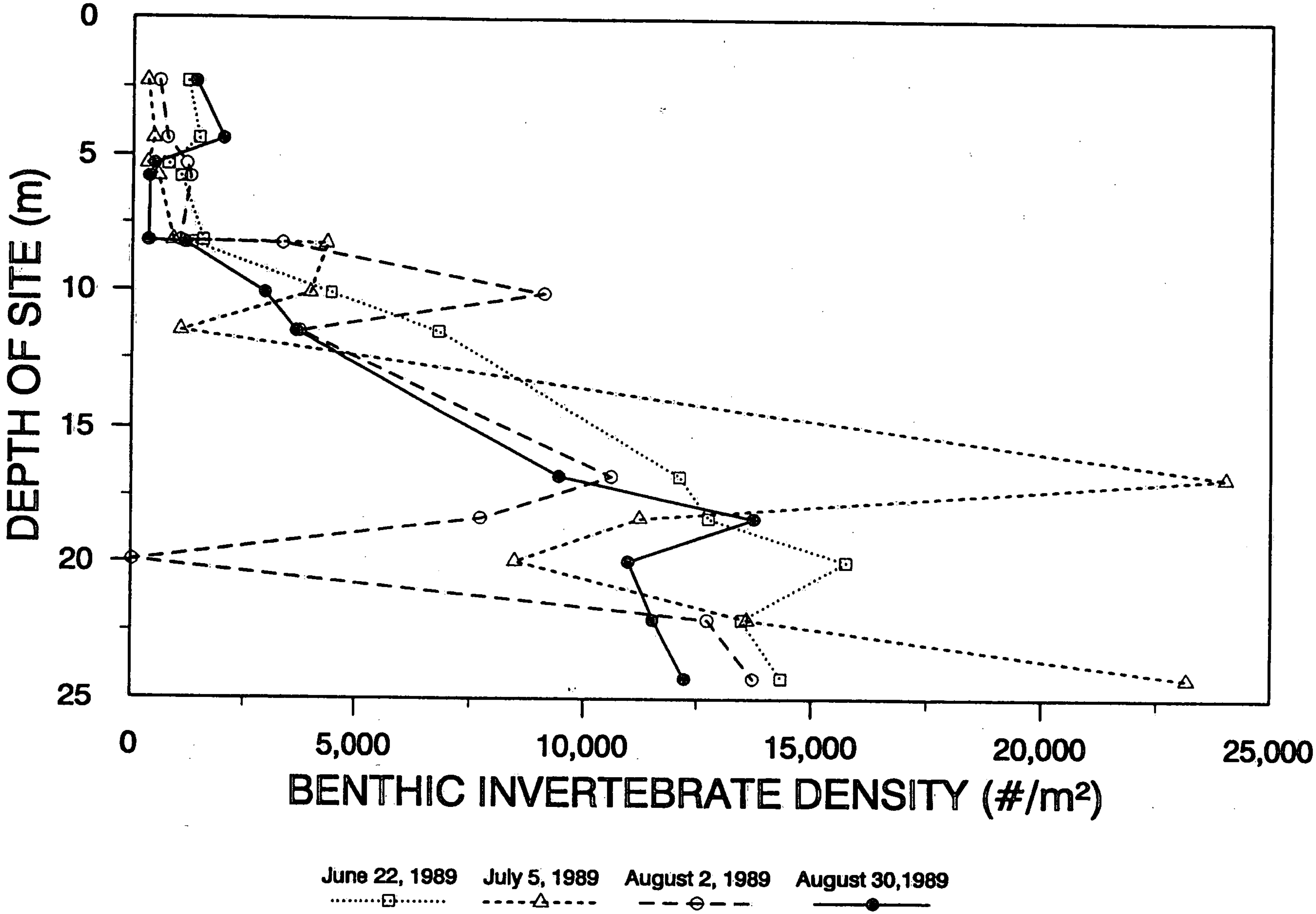

DEPTH OF SITE (m)
0
5
10
15
20
25
0
5,000
10,000
15,000
20,000
25,000
BENTHIC INVERTEBRATE DENSITY (#/m²)
June 22, 1989
July 5, 1989
August 2, 1989
August 30,1989

Figure 4

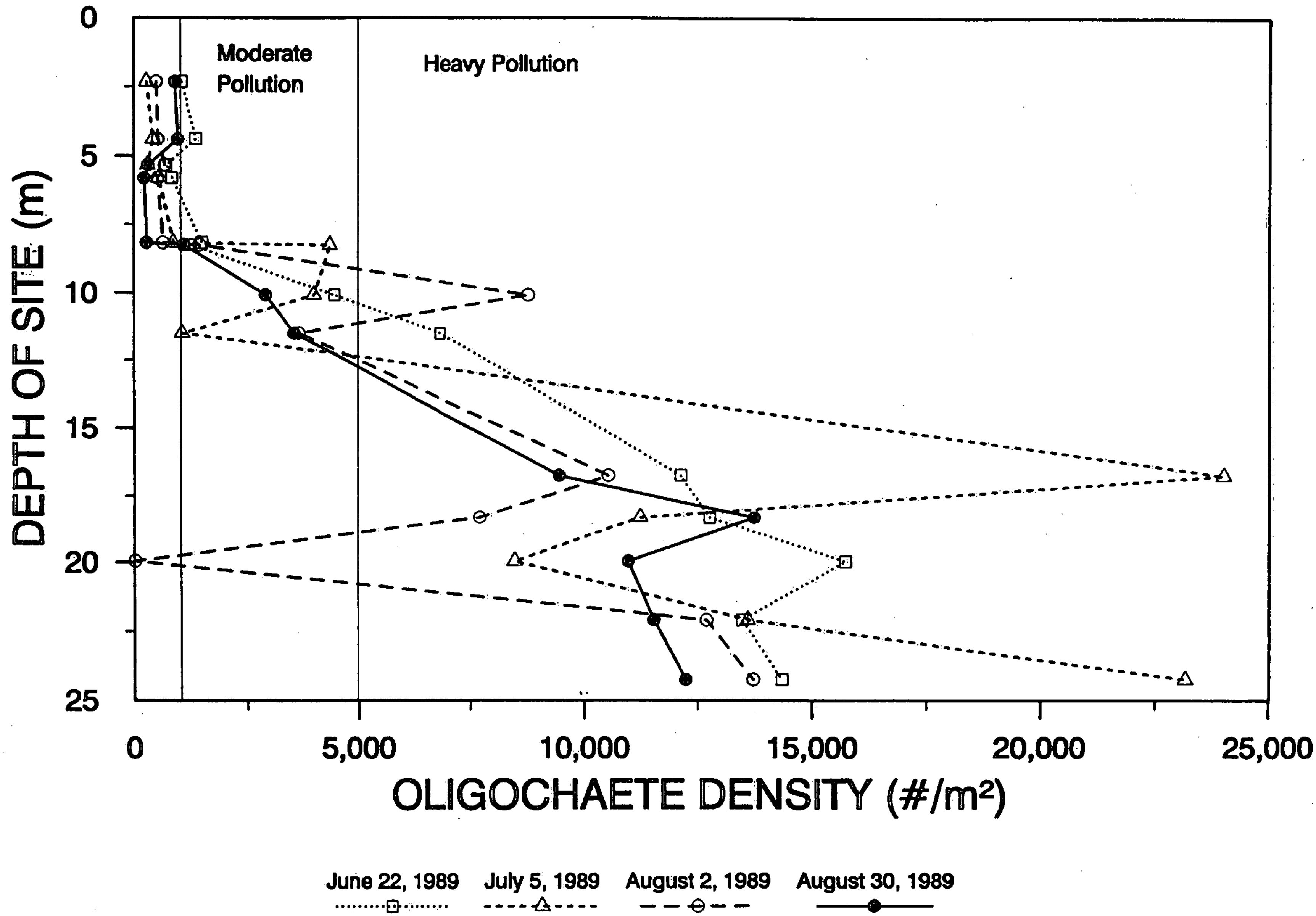

0
5
10
15
20
25
DEPTH OF SITE (m)
Moderate
Pollution
Heavy Pollution
0
5,000
10,000
15,000
20,000
25,000
OLIGOCHAETE DENSITY (#/m²)
June 22, 1989
July 5, 1989
August 2, 1989
August 30, 1989

Figure 5

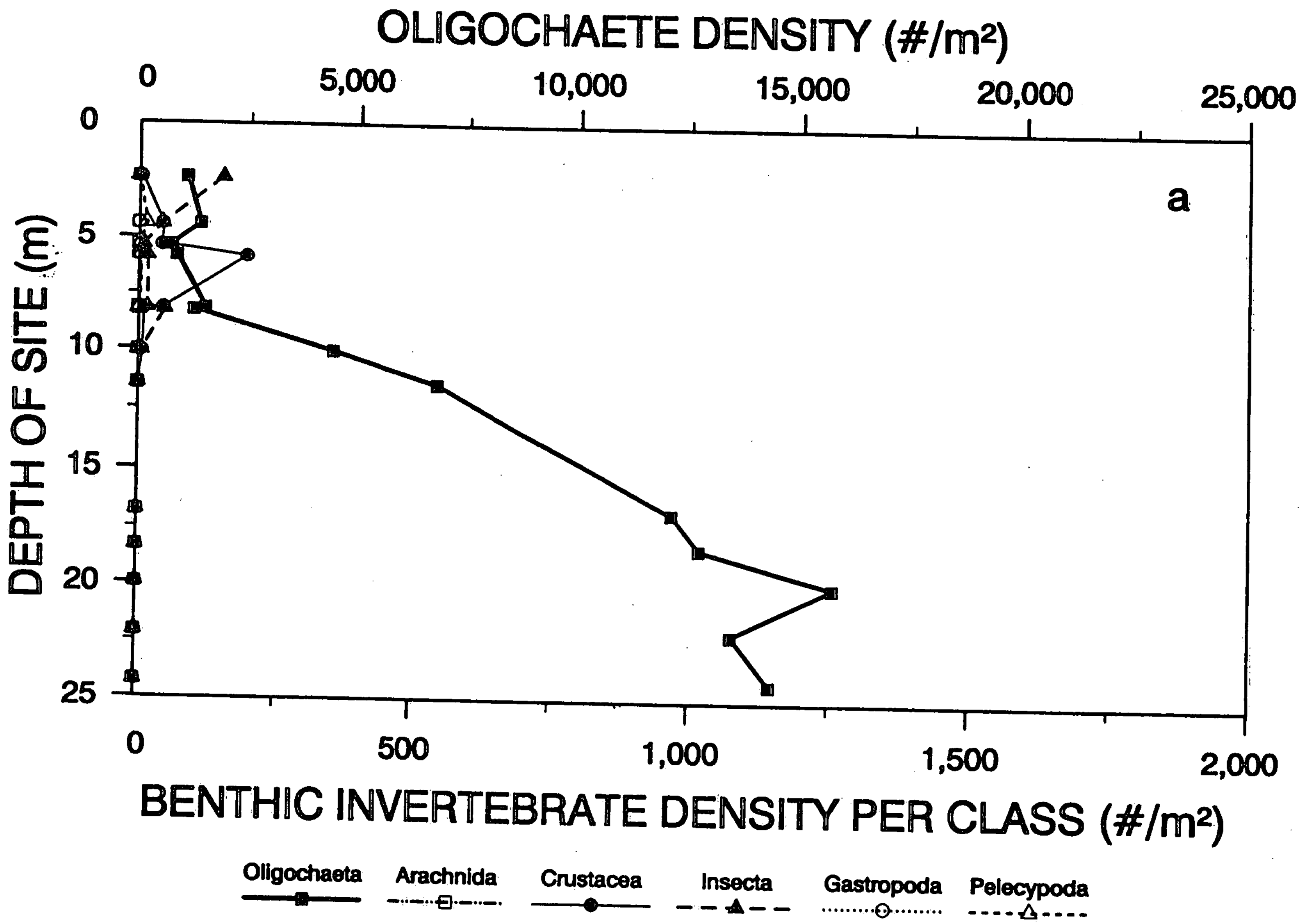

OLIGOCHAETE DENSITY (#/m²)
0
5,000
10,000
15,000
20,000
25,000
a
DEPTH OF SITE (m)
0
5
10
15
20
25
0
500
1,000
1,500
2,000
BENTHIC INVERTEBRATE DENSITY PER CLASS (#/m²)
Oligochaeta
Arachnida
Crustacea
Insecta
Gastropoda
Pelecypoda

*Figure 6a*

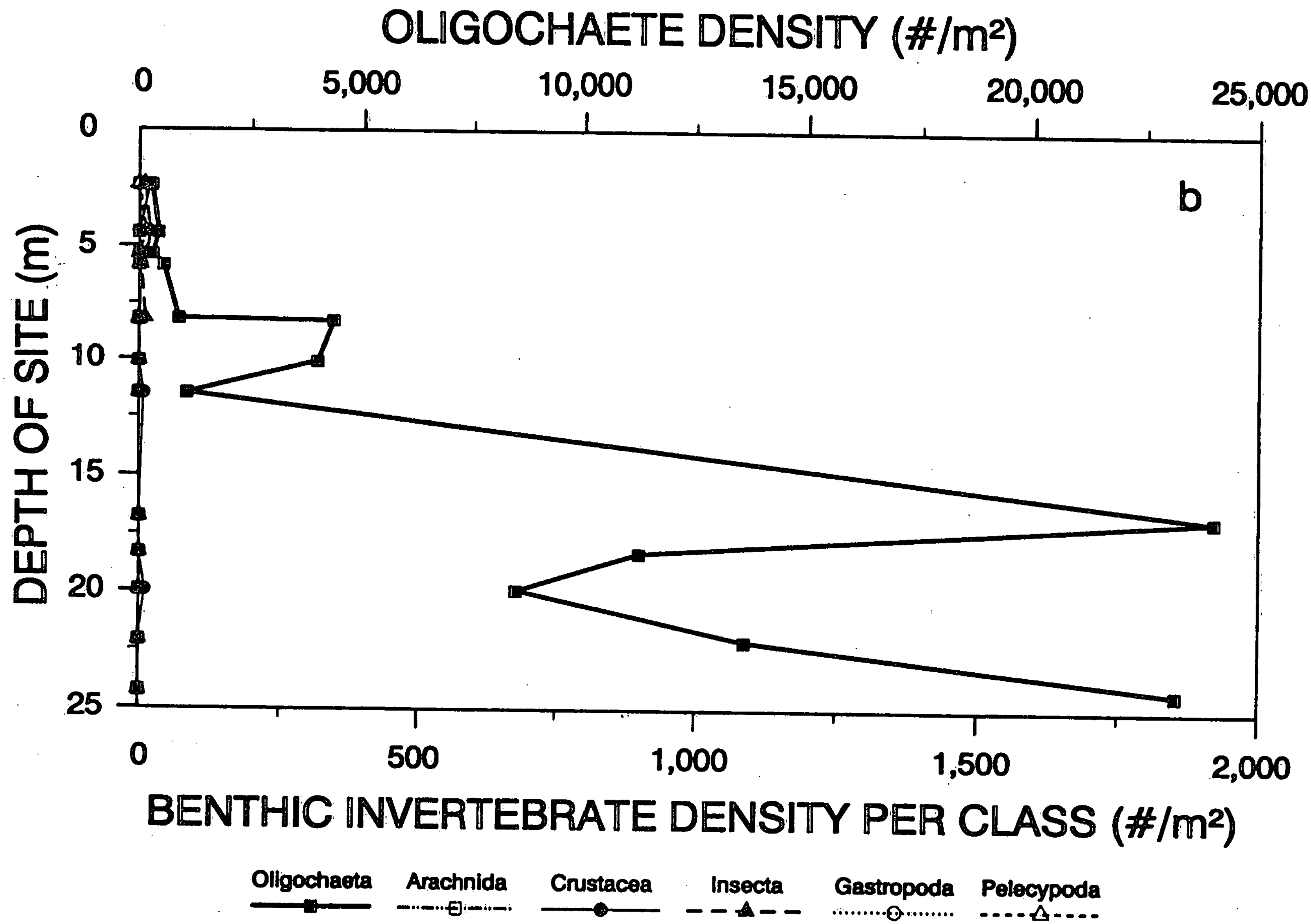

OLIGOCHAETE DENSITY (#/m²)
0
5,000
10,000
15,000
20,000
25,000
b
DEPTH OF SITE (m)
0
5
10
15
20
25
0
500
1,000
1,500
2,000
BENTHIC INVERTEBRATE DENSITY PER CLASS (#/m²)
Oligochaeta
Arachnida
Crustacea
Insecta
Gastropoda
Pelecypoda

Figure 6b

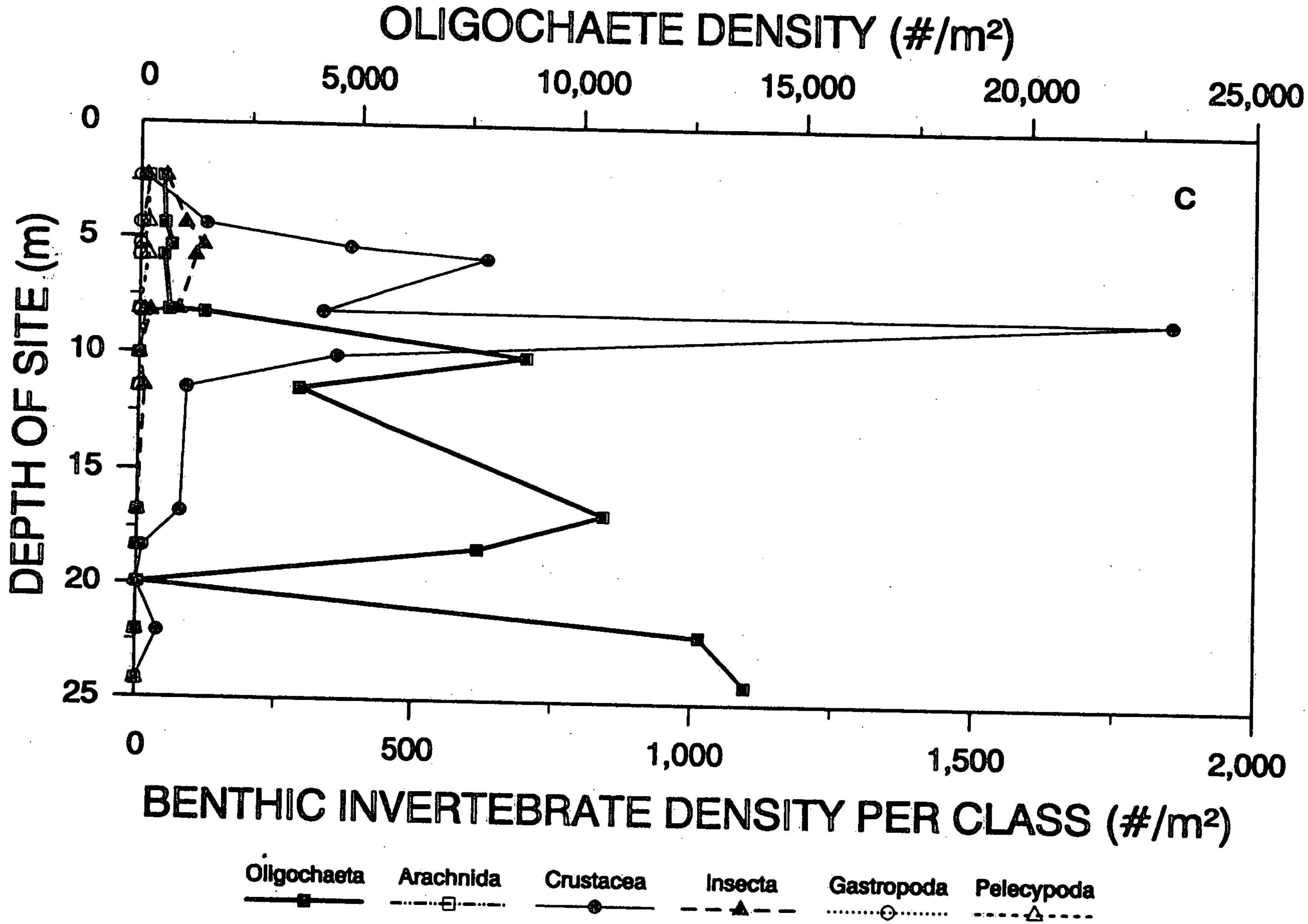
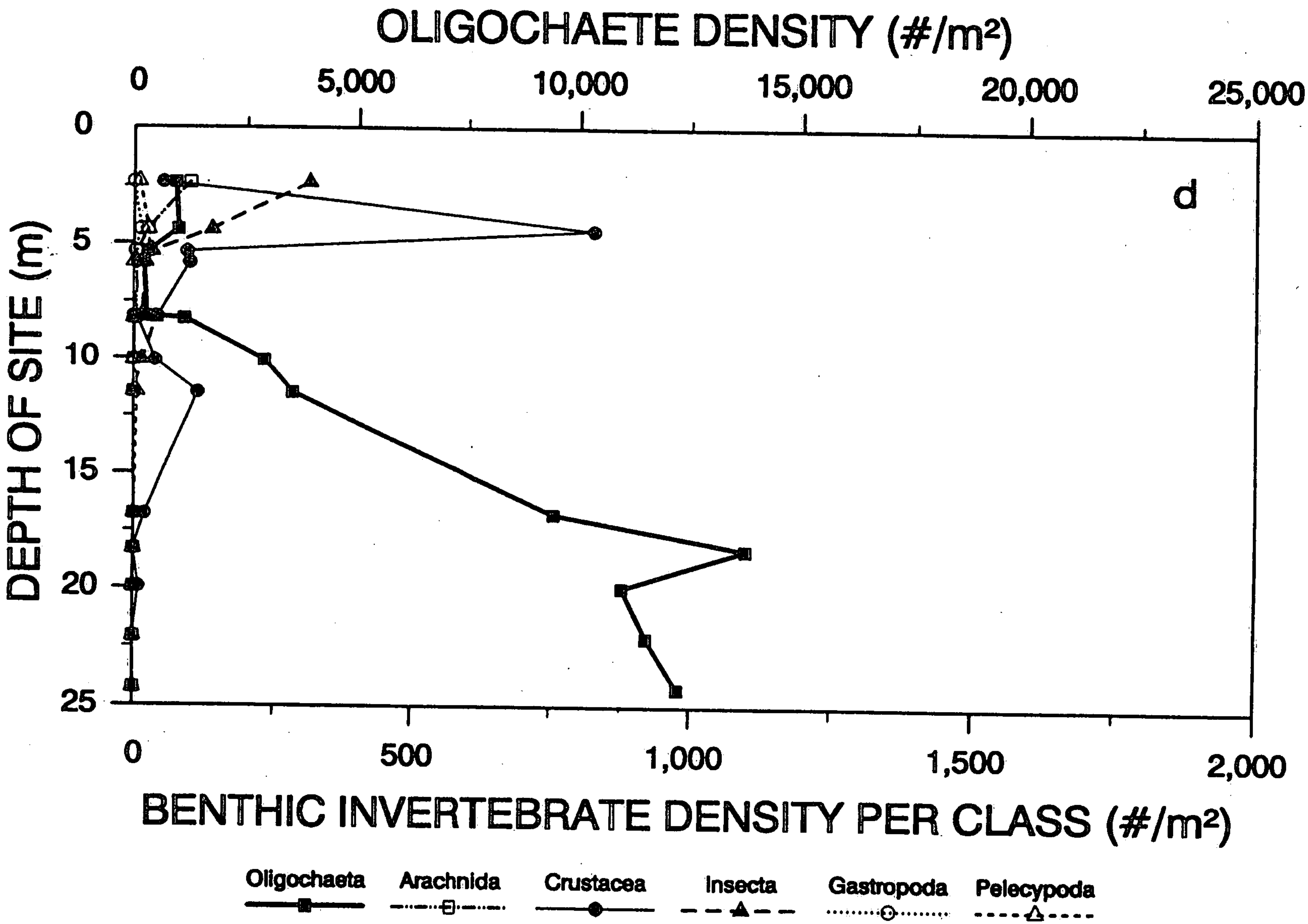
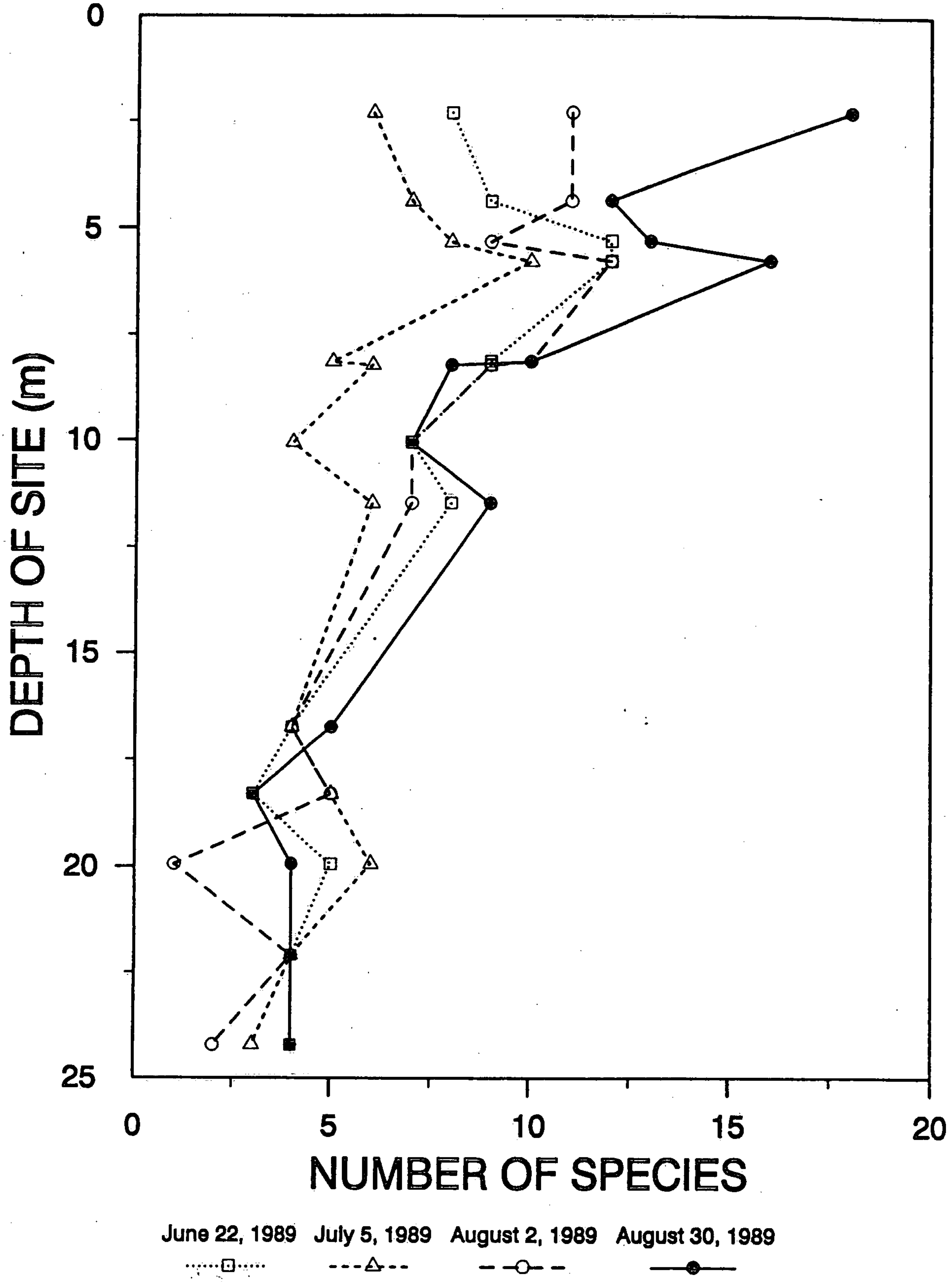

OLIGOCHAETE DENSITY (#/m²)
0
5,000
10,000
15,000
20,000
25,000
C
DEPTH OF SITE (m)
0
5
10
15
20
25
BENTHIC INVERTEBRATE DENSITY PER CLASS (#/m²)
0
500
1,000
1,500
2,000
Oligochaeta
Arachnida
Crustacea
Insecta
Gastropoda
Pelecypoda

Figure 6c



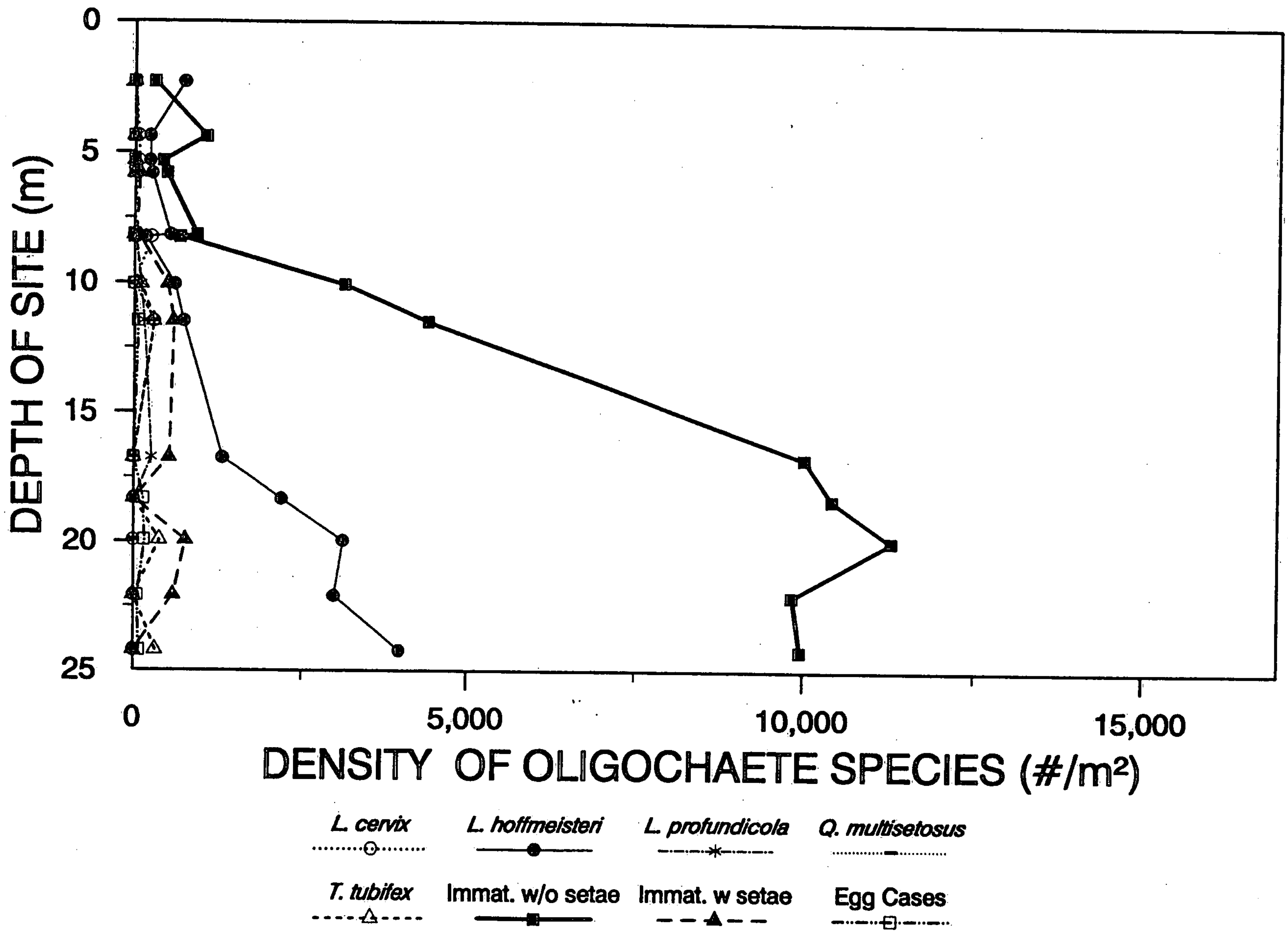
OLIGOCHAETE DENSITY (#/m²)
0
5,000
10,000
15,000
20,000
25,000
d
DEPTH OF SITE (m)
0
5
10
15
20
25
0
500
1,000
1,500
2,000
BENTHIC INVERTEBRATE DENSITY PER CLASS (#/m²)
Oligochaeta
Arachnida
Crustacea
Insecta
Gastropoda
Pelecypoda


Figure 6d



DEPTH OF SITE (m)
0
5
10
15
20
25
0
5
10
15
20
NUMBER OF SPECIES
June 22, 1989
July 5, 1989
August 2, 1989
August 30, 1989


*Figure 7*



0
5
10
15
20
25
DEPTH OF SITE (m)
0
5,000
10,000
15,000
DENSITY OF OLIGOCHAETE SPECIES (#/m²)
L. cervix
L. hoffmeisteri
L. profundicola
Q. multisetosus
T. tubifex
Immat. w/o setae
Immat. w setae
Egg Cases


Figure 8a

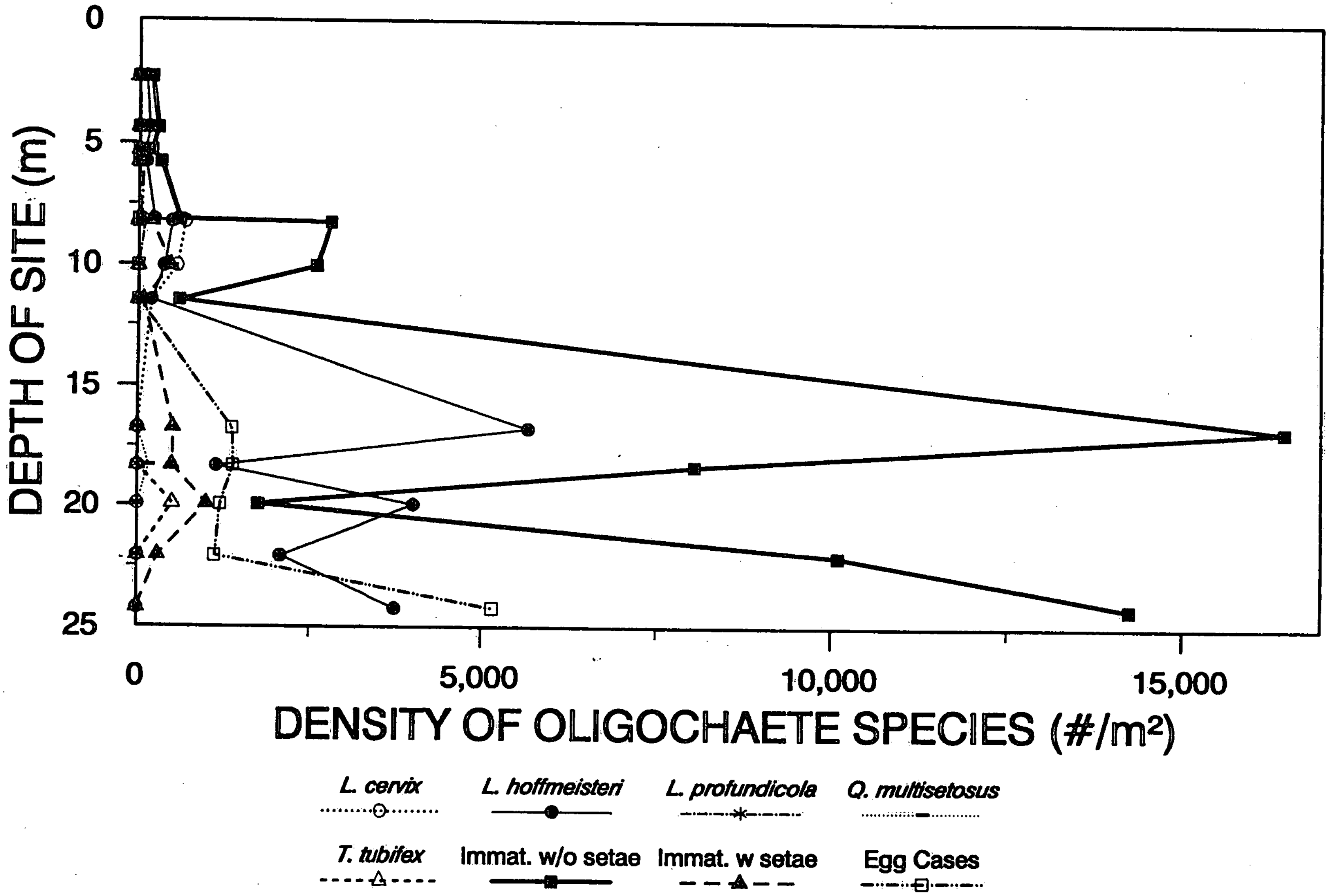

DEPTH OF SITE (m)
0
5
10
15
20
25
0
5,000
10,000
15,000
DENSITY OF OLIGOCHAETE SPECIES (#/m²)
L. cervix
L. hoffmeisteri
L. profundicola
Q. multisetosus
T. tubifex
Immat. w/o setae
Immat. w setae
Egg Cases

Figure 8b

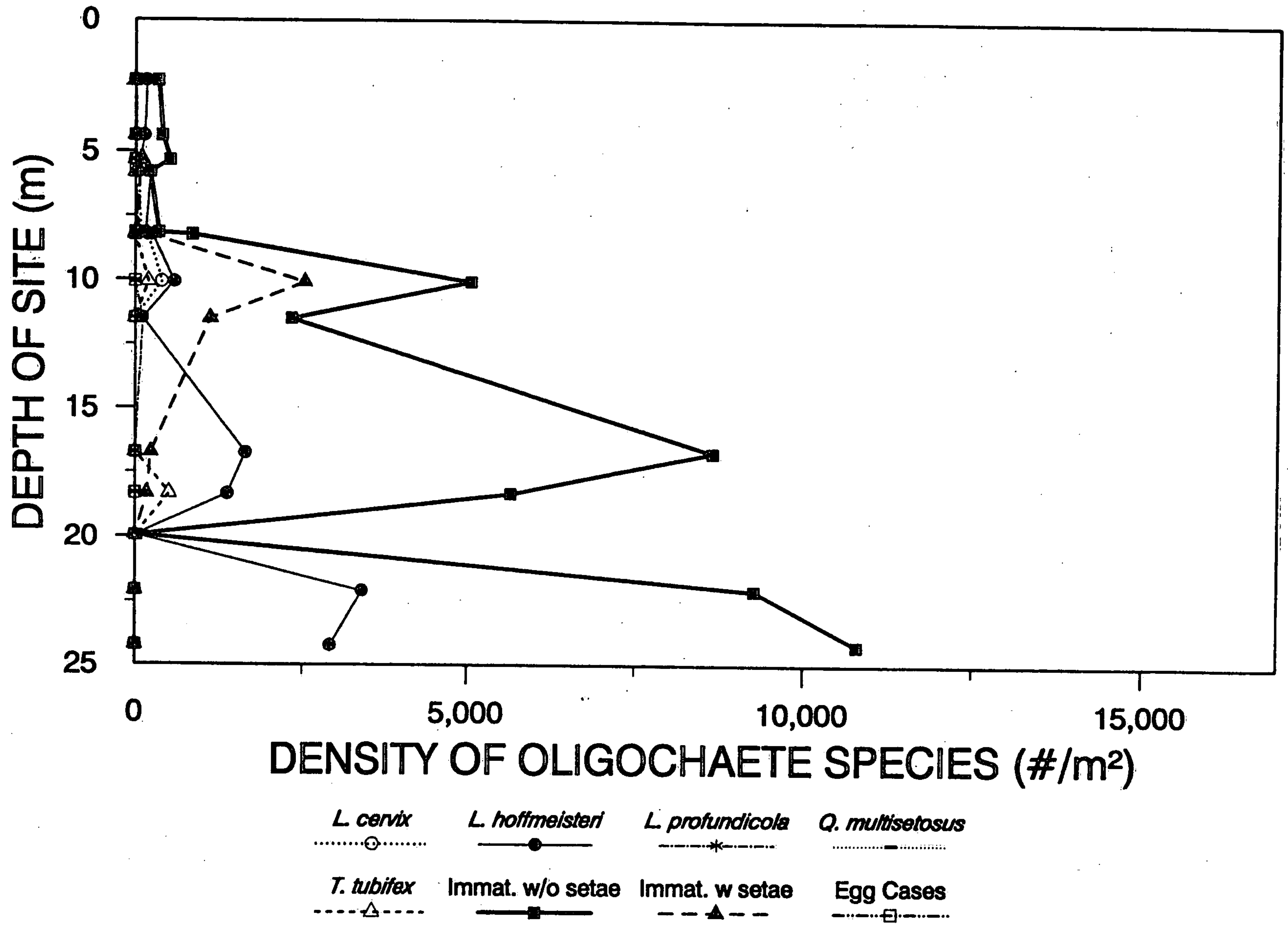
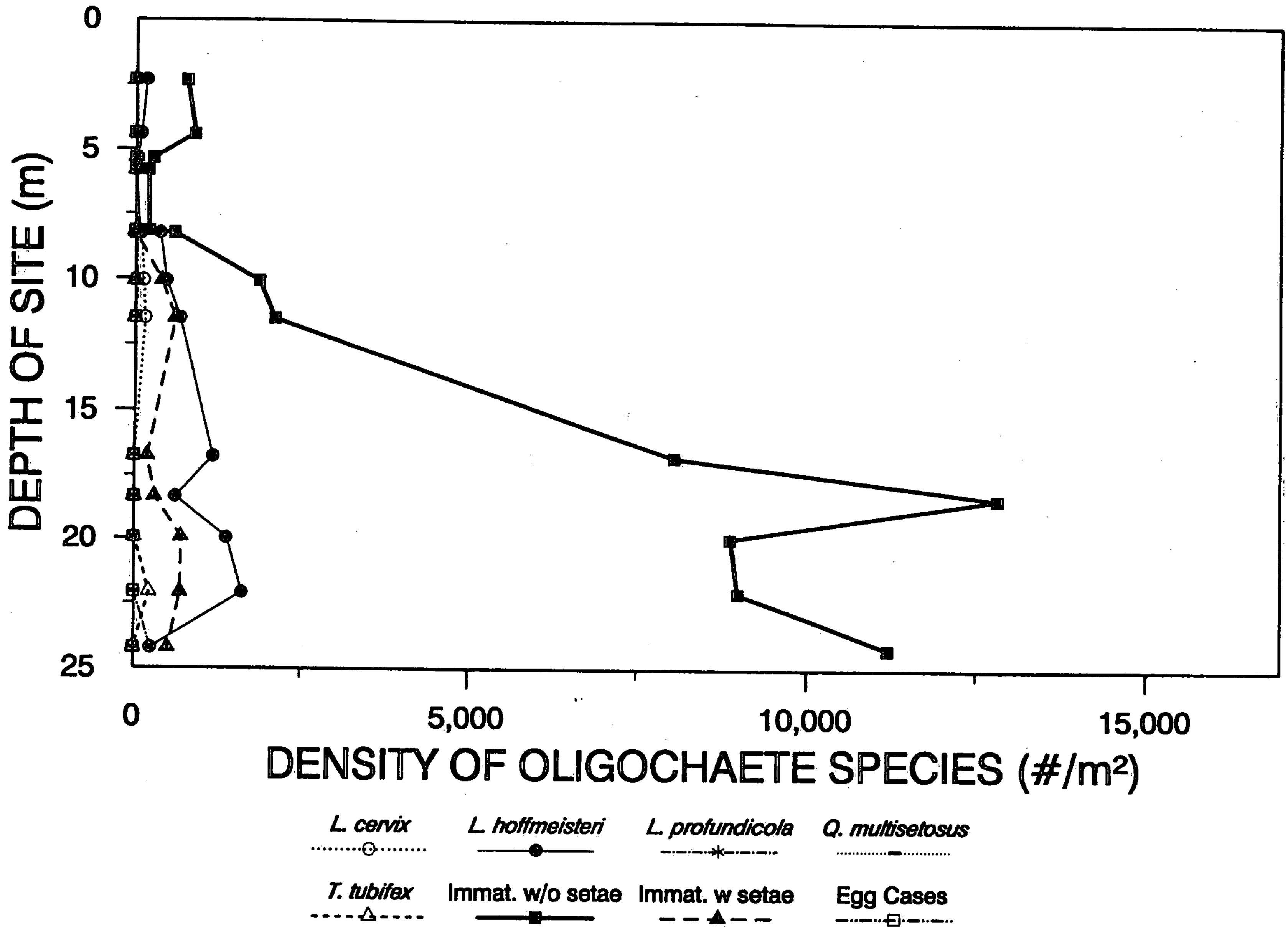

0
5
10
15
20
25
DEPTH OF SITE (m)
0
5,000
10,000
15,000
DENSITY OF OLIGOCHAETE SPECIES (#/m²)
L. cervix
L. hoffmeisteri
L. profundicola
Q. multisetosus
T. tubifex
Immat. w/o setae
Immat. w setae
Egg Cases

Figure 8c



DEPTH OF SITE (m)
0
5
10
15
20
25
0
5,000
10,000
15,000
DENSITY OF OLIGOCHAETE SPECIES (#/m²)
L. cervix
L. hoffmeisteri
L. profundicola
Q. multisetosus
T. tubifex
Immat. w/o setae
Immat. w setae
Egg Cases


Figure 8d

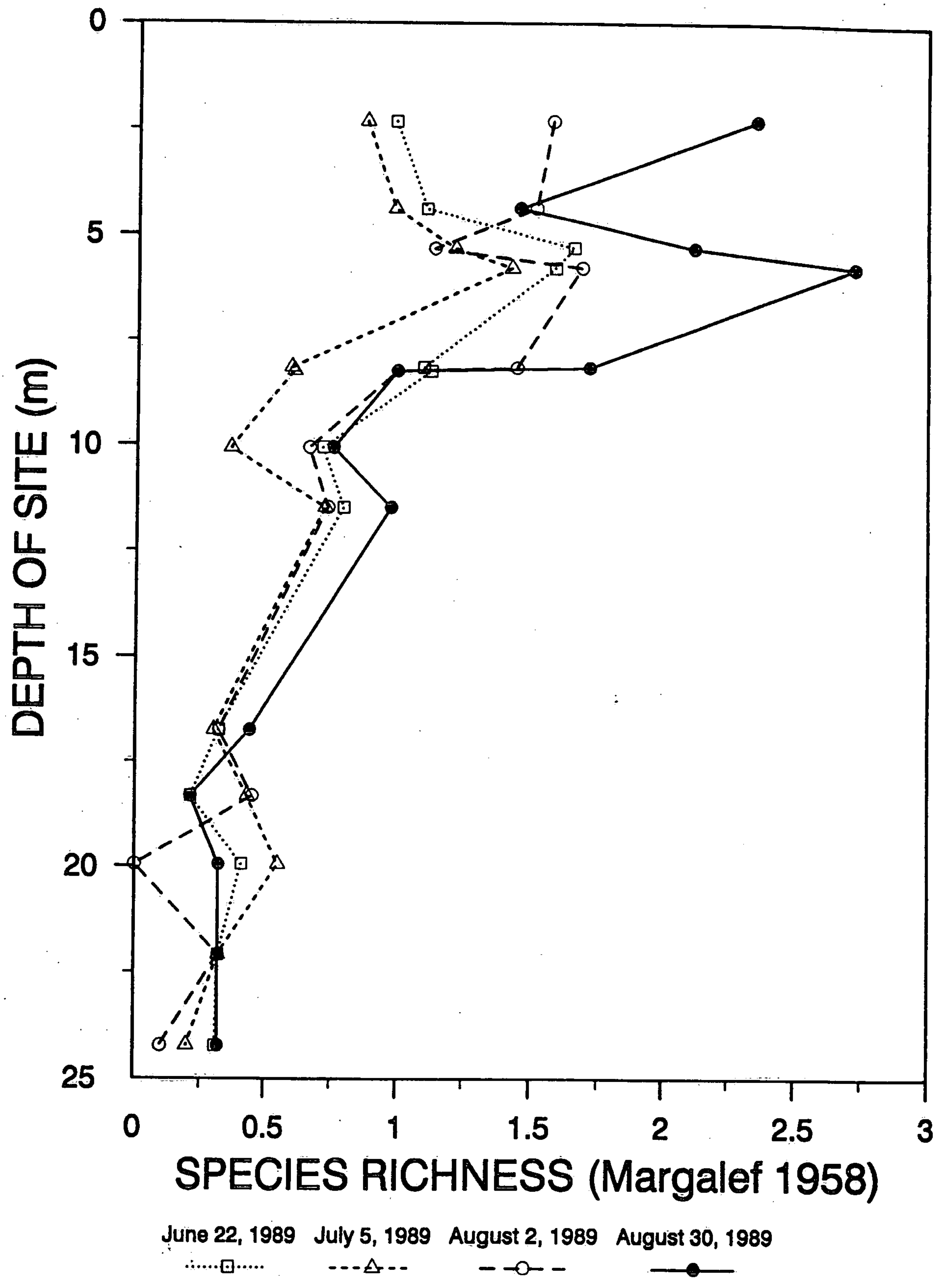

0
5
10
15
20
25
DEPTH OF SITE (m)
0
0.5
1
1.5
2
2.5
3
SPECIES RICHNESS (Margalef 1958)
June 22, 1989
July 5, 1989
August 2, 1989
August 30, 1989

Figure 9

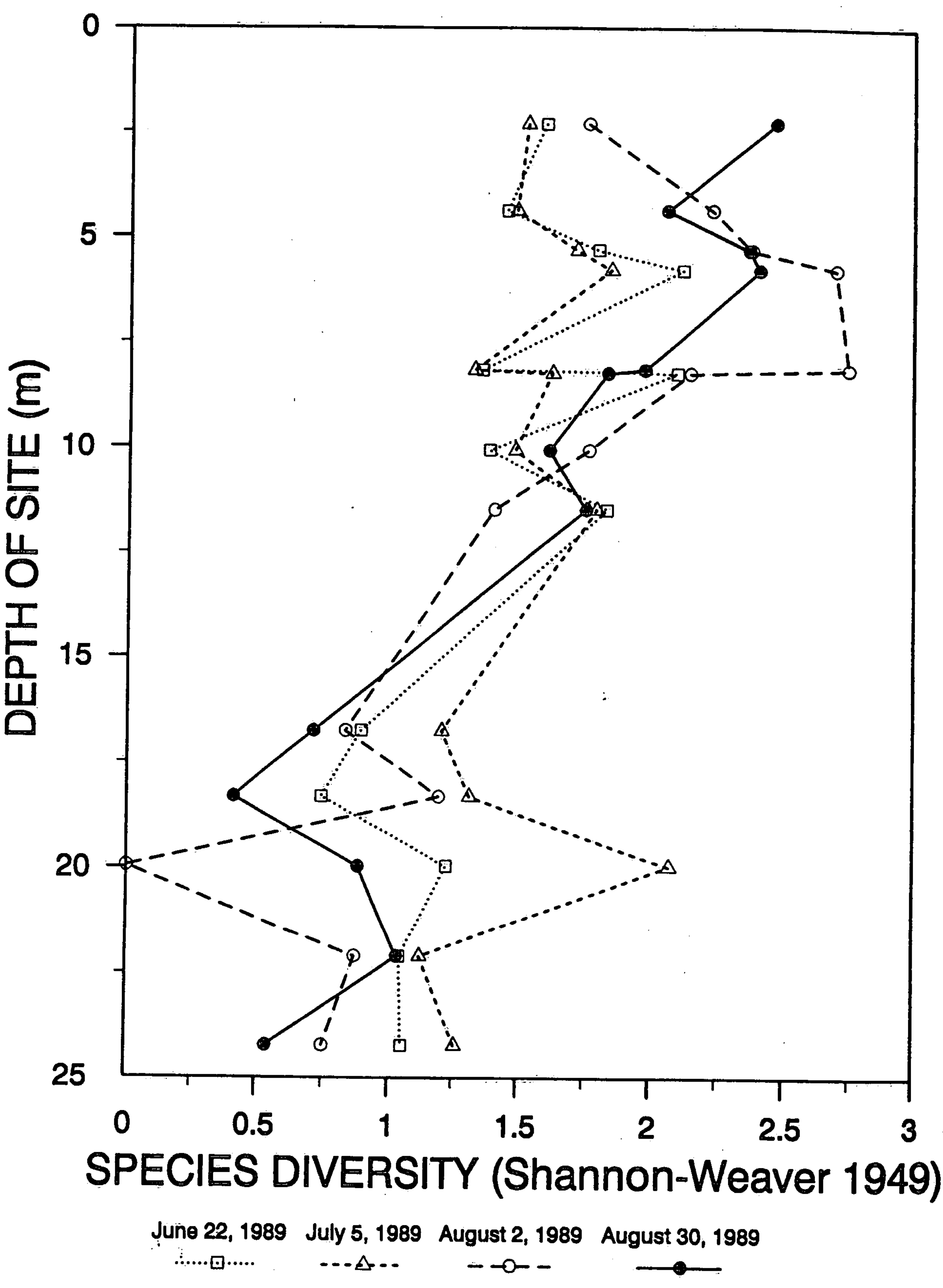
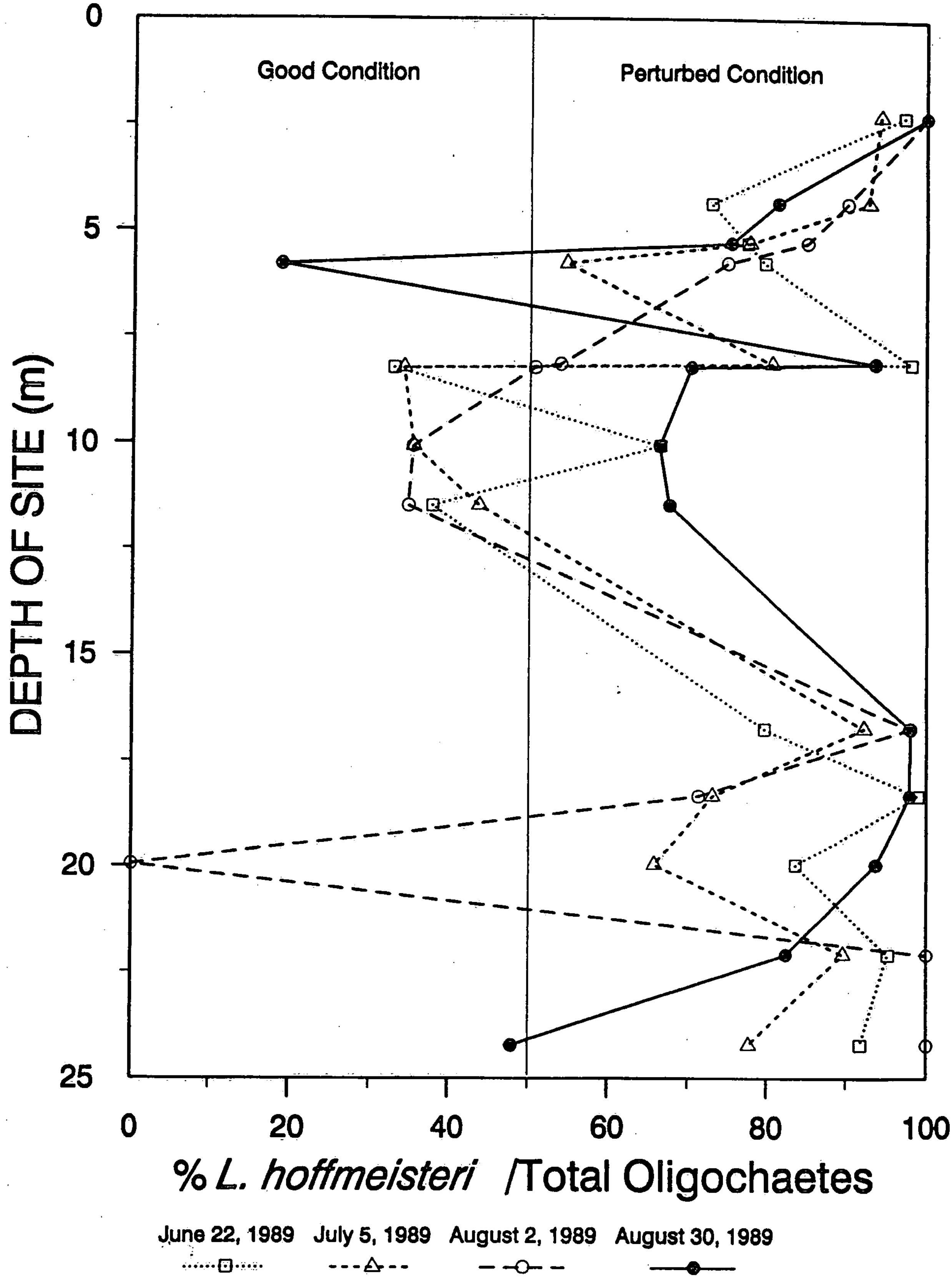

DEPTH OF SITE (m)
0
5
10
15
20
25
0
0.5
1
1.5
2
2.5
3
SPECIES DIVERSITY (Shannon-Weaver 1949)
June 22, 1989
July 5, 1989
August 2, 1989
August 30, 1989

*Figure 10*



Good Condition
Perturbed Condition
DEPTH OF SITE (m)
0
5
10
15
20
25
0
20
40
60
80
100
% L. hoffmeisteri /Total Oligochaetes
June 22, 1989
July 5, 1989
August 2, 1989
August 30, 1989


Figure 11.

TABLE 1. Major taxa and total numbers of benthic invertebrates on the various dates sampled: A) June 22, 1989, B) July 5, 1989, C) August 2, 1989, D) August 30, 1989. The total for each date represents the sum of the number of individuals per square meter from all 13 sites on a given date.

| SPECIES | A | B | C | D | MINIMUM #/m2 | MAXIMUM #/m2 | MEAN #/m2 | TOTAL |
|---|---|---|---|---|---|---|---|---|
| Annelida | | | | | | | | |
| Oligochaeta | | | | | | | | |
| Tubificida | | | | | | | | |
| Limnodrilus cervix | 703 | 1551 | 709 | 424 | | 681 | 65 | 3388 |
| Limnodrilus hoffmeisteri | 17099 | 18352 | 10995 | 6904 | | 5662 | 1026 | 53349 |
| Limnodrilus profundicola | 596 | 135 | 142 | 287 | | 265 | 22 | 1160 |
| Quistadrilus multisetosus | 293 | 255 | | 32 | | 293 | 11 | 580 |
| Tubifex tubifex | 1141 | 501 | 709 | 227 | | 510 | 50 | 2577 |
| Immatures without hair setae | 62922 | 58177 | 44480 | 56858 | 28 | 16475 | 4278 | 222436 |
| Immatures with hair setae | 3197 | 3130 | 4424 | 3448 | | 2524 | 273 | 14198 |
| Egg cases | 501 | 10246 | | 41 | | 5161 | 207 | 10788 |
| Arthropoda | | | | | | | | |
| Arachnida | | | | | | | | |
| Prostigmata | | | | | | | | |
| Atractides sp. | | | 9 | | | 9 | | 9 |
| Limnesia sp. | 3 | | 8 | 123 | | 85 | 3 | 133 |
| Mideopsis sp. | | | | 3 | | 3 | | 3 |
| Piona sp. | | | | 9 | | 9 | | 9 |
| Unidentified Pionidae | | | 5 | 5 | | 5 | | 9 |
| Unionicola sp. | | | 8 | | | 8 | | 8 |
| Crustacea | | | | | | | | |
| Amphipoda | | | | | | | | |
| Gammarus fasciatus | | 19 | | 55 | | 52 | 1 | 74 |
| Cladocera | | | | | | | | |
| Ilyocryptus sp. | | | | 2 | | 2 | | 2 |
| Egg cases-Ephippium | | | | 13 | | 13 | | 13 |
| Unidentified Cladocera | | 9 | | | | 9 | | 9 |
| Copepoda | | | | | | | | |
| Unidentified Cyclopoida | 15 | | 2591 | 1035 | | 1569 | 70 | 3641 |
| Unidentified Harpacticoida | 329 | 11 | 1252 | 185 | | 435 | 34 | 1777 |
| Podocopida | | | | | | | | |
| Unidentified Podocopida | | | 47 | 9 | | 47 | 1 | 57 |
| Insecta | | | | | | | | |
| Diptera | | | | | | | | |
| Chironomus sp. | 164 | 21 | 163 | 46 | | 110 | 8 | 393 |
| Cladopelma sp. | 39 | 9 | 163 | 156 | | 76 | 7 | 366 |
| Cryptochironomus sp. | 52 | 18 | 46 | 205 | | 104 | 6 | 320 |
| Dicrotendipes sp. | | | | 5 | | 5 | | 5 |
| Endochironomus sp. | | | | 38 | | 38 | 1 | 38 |
| Glyptotendipes sp. | 4 | 3 | | 8 | | 5 | | 15 |
| Parachironomus sp. | | | | 9 | | 9 | | 9 |
| Paratanytarsus sp. | | | | 14 | | 14 | | 14 |
| Polypedilum sp. | | 4 | 15 | 58 | | 43 | 1 | 77 |
| Procladius sp. | 31 | 3 | 39 | 16 | | 19 | 2 | 88 |
| Unidentified Chironominae | | | | 14 | | 14 | | 14 |
| Lepidoptera | | | | | | | | |
| Acentria sp. | | | 9 | | | 9 | | 9 |
| Mollusca | | | | | | | | |
| Gastropoda | | | | | | | | |
| Basommatophora | | | | | | | | |
| Physella sp. | 2 | | | | | 2 | | 2 |
| Unidentified Lymnaeidae | 2 | | | | | 2 | | 2 |
| Mesogastropoda | | | | | | | | |
| Amnicola limosa | | | | 3 | | 3 | | 3 |
| Bithynia tentaculata | | | | 3 | | 3 | | 3 |
| Valvata sincera | | 3 | | 15 | | 13 | | 18 |
| Pelecypoda | | | | | | | | |
| Eulamellibranchia | | | | | | | | |
| Musculium partumeium | 2 | | | 6 | | 6 | | 8 |
| Musculium sp. | | 2 | 9 | 31 | | 22 | 1 | 42 |
| Pisidium casertanum | | | 9 | | | 5 | | 9 |
| Pisidium compressum | 20 | 11 | 36 | 32 | | 25 | 2 | 99 |

TABLE 2. Percentage composition of the benthic invertebrates on the various dates sampled: A) June 22, 1989, B) July 5, 1989, C) August 2, 1989, D) August 30, 1989. The percentages each date was computed on the basis of the sum of individuals per square meter from all 13 on a given date.

| SPECIES | A | B | C | D | MINIMUM | MAXIMUM | MEAN |
|---|---|---|---|---|---|---|---|
| Annelida | | | | | | | |
| Oligochaeta | | | | | | | |
| Tubificida | | | | | | | |
| Limnodrilus cervix | 0.22 | 0.49 | 0.22 | 0.13 | | 19.57 | 3.00 |
| Limnodrilus hoffmeisteri | 5.41 | 5.81 | 3.48 | 2.19 | | 60.68 | 17.99 |
| Limnodrilus profundicola | 0.19 | 0.04 | 0.04 | 0.09 | | 3.57 | 0.62 |
| Quistadrilus multisetosus | 0.09 | 0.08 | | 0.01 | | 4.34 | 0.21 |
| Tubifex tubifex | 0.36 | 0.16 | 0.22 | 0.07 | | 6.87 | 0.60 |
| Immatures without hair setae | 19.93 | 18.42 | 14.09 | 18.01 | 17.04 | 100.00 | 62.78 |
| Immatures with hair setae | 1.01 | 0.99 | 1.40 | 1.09 | | 29.80 | 5.07 |
| Egg cases | 0.16 | 3.24 | | 0.01 | | 28.66 | 1.53 |
| Arthropoda | | | | | | | |
| Arachnida | | | | | | | |
| Prostigmata | | | | | | | |
| Atractides sp. | | | | | | 0.28 | 0.01 |
| Limnesia sp. | | | | 0.04 | | 6.10 | 0.23 |
| Mideopsis sp. | | | | | | 0.87 | 0.02 |
| Piona sp. | | | | | | 0.68 | 0.01 |
| Unidentified Pionidae | | | | | | 0.63 | 0.02 |
| Unionicola sp. | | | | | | 1.30 | 0.02 |
| Crustacea | | | | | | | |
| Amphipoda | | | | | | | |
| Gammarus fasciatus | | 0.01 | | 0.02 | | 6.00 | 0.20 |
| Cladocera | | | | | | | |
| Ilyocryptus sp. | | | | | | 0.43 | 0.01 |
| Egg cases-Ephippium | | | | | | 0.35 | 0.01 |
| Unidentified Cladocera | | | | | | 0.13 | |
| Copepoda | | | | | | | |
| Unidentified Cyclopoida | | | 0.82 | 0.33 | | 46.89 | 3.46 |
| Unidentified Harpacticoida | 0.10 | | 0.40 | 0.06 | | 34.07 | 2.83 |
| Podocopida | | | | | | | |
| Unidentified Podocopida | | | 0.01 | | | 1.26 | 0.03 |
| Insecta | | | | | | | |
| Diptera | | | | | | | |
| Chironomus sp. | 0.05 | 0.01 | 0.05 | 0.01 | | 8.98 | 0.70 |
| Cladopelma sp. | 0.01 | | 0.05 | 0.05 | | 7.50 | 0.68 |
| Cryptochironomus sp. | 0.02 | 0.01 | 0.01 | 0.06 | | 7.46 | 0.60 |
| Dicrotendipes sp. | | | | | | 0.34 | 0.01 |
| Endochironomus sp. | | | | 0.01 | | 2.71 | 0.05 |
| Glyptotendipes sp. | | | | | | 1.00 | 0.05 |
| Parachironomus sp. | | | | | | 0.68 | 0.01 |
| Paratanytarsus sp. | | | | | | 1.02 | 0.02 |
| Polypedilum sp. | | | | 0.02 | | 3.05 | 0.14 |
| Procladius sp. | 0.01 | | 0.01 | | | 1.48 | 0.14 |
| Unidentified Chironominae | | | | | | 1.02 | 0.02 |
| Lepidoptera | | | | | | | |
| Acentria sp. | | | | | | 0.25 | |
| Mollusca | | | | | | | |
| Gastropoda | | | | | | | |
| Basommatophora | | | | | | | |
| Physella sp. | | | | | | 0.24 | |
| Unidentified Lymnaeidae | | | | | | 0.24 | |
| Mesogastropoda | | | | | | | |
| Amnicola limosa | | | | | | 0.87 | 0.02 |
| Bithynia tentaculata | | | | | | 0.87 | 0.02 |
| Valvata sincera | | | | | | 0.63 | 0.03 |
| Pelecypoda | | | | | | | |
| Eulamellibranchia | | | | | | | |
| Musculium partumeium | | | | | | 0.24 | 0.01 |
| Musculium sp. | | | | 0.01 | | 4.52 | 0.11 |
| Pisidium casertanum | | | | | | 0.65 | 0.02 |
| Pisidium compressum | 0.01 | | 0.01 | 0.01 | | 2.48 | 0.21 |

Table 3. Percentage composition of the different oligochaete life stages relative to the total oligochaete population in a given site, to the total oligochaete population from all samples and dates, as well as the percentage of sites where each group was found.

| OLIGOCHAETE GROUP | % OF TOTAL OLIGOCHAETE POPULATION | | | | % SITES |
|---|---|---|---|---|---|
| | IN A GIVEN SITE AND DATE | | | ALL SITES AND DATES | |
| | MIN. | MAX. | MEAN | | |
| Mature Oligochaetes | 0 | 71.63 | 24.65 | 19.79 | 98.08 |
| Immatures without hair setae | 20.74 | 100.00 | 68.41 | 72.11 | 100.00 |
| Immatures with hair setae | 0 | 30.57 | 5.63 | 4.60 | 71.15 |
| Egg Cases | 0 | 22.28 | 1.31 | 3.50 | 23.08 |

Table 4. Percentage composition of the different oligochaete species relative to the total mature oligochaete population in a given site, to the total mature oligochaete population from all samples and dates, as well as the percentage of sites where each species was found.

| SPECIES | % OF MATURE OLIGOCHAETE POPULATION | | | | % SITES |
|---|---|---|---|---|---|
| | IN A GIVEN SITE AND DATE | | | ALL SITES AND DATES | |
| | MIN. | MAX. | MEAN | | |
| *L. hoffmeisteri* | 0 | 100.00 | 78.33 | 87.38 | 98.08 |
| *L. cervix* | 0 | 80.00 | 12.73 | 5.55 | 44.23 |
| *T. tubifex* | 0 | 27.14 | 2.33 | 4.22 | 17.31 |
| *L. profundicola* | 0 | 50.00 | 3.88 | 1.90 | 26.92 |
| *Q. multisetosus* | 0 | 16.58 | 0.80 | 0.95 | 7.69 |

Table 5. Percentage composition of the different oligochaete species relative to the total population in a given site and to the total mature population in a given site.

| SPECIES | % OF TOTAL POPULATION IN A GIVEN SITE AND DATE | | | % OF TOTAL MATURE POPULATION IN A GIVEN SITE AND DATE | | |
|---|---|---|---|---|---|---|
| | MIN. | MAX. | MEAN | MIN. | MAX. | MEAN |
| *L. hoffmeisteri* | 0 | 60.68 | 17.99 | 0 | 100.00 | 62.87 |
| *L. cervix* | 0 | 19.57 | 3.00 | 0 | 60.00 | 8.68 |
| *T. tubifex* | 0 | 6.87 | 0.60 | 0 | 26.73 | 2.23 |
| *L. profundicola* | 0 | 3.57 | 0.62 | 0 | 50.00 | 3.31 |
| *Q. multisetosus* | 0 | 4.34 | 0.21 | 0 | 16.58 | 0.80 |

Table 6. Summary of the sampling protocols and data from different benthic invertebrate surveys.

| REFERENCE | SAMPLING DATE D M Y | SITE | DEPTH m | SAMPLER TYPE | TOTAL NUMBER INDIVIDUALS Ind/m2 | TOTAL NUMBER MATURE INDIVIDUALS Ind/m2 | TOTAL NUMBER OLIGOCHAETES Ind/m2 | TOTAL NUMBER MATURE OLIGOCHAETES Ind/m2 | TOTAL NUMBER SPECIES | NUMBER OLIGOCHAETE SPECIES | NUMBER CHIRONOMID SPECIES | NUMBER OTHER SPECIES |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Johnson & Matheson 1968 | 8&9 1964 | 10 | 6 | Ekman | 4582 | | 4543 | | | | 1 | 0 |
| | | 12 | 19 | | 4543 | | 4543 | | | | 0 | 0 |
| | | 13 | 12 | | 2765 | | 2765 | | 3I | 3I | 0 | 0 |
| | | 15 | 19 | | 7110 | | 7110 | | 4I | 4I | 0 | 0 |
| | 7 1965 | 16 | 21 | | 4345 | | 4345 | | | | 0 | 0 |
| | | 17 | 19 | | 15998 | | 15998 | | | | 0 | 0 |
| | | 19 | 23.5 | | 1501 | | 1501 | | 3I | 3I | 0 | 0 |
| | | 20 | 21 | | 12245 | | 12245 | | | | 0 | 0 |
| | | 24 | 20 | | 5530 | | 5530 | | 3I | 3I | 0 | 0 |
| | | Harbourwide | | | | | 70 - 22600 | | 13 | 9 | 4 | 0 |
| Golini 1979 | 1 1978 | 1 | | mini-Shipek | 1150 | | 800 | | | | | |
| | | 2 | | | 450 | | 450 | | | | | |
| | | 3 | | | 800 | | 500 | | 3 | 2 | 1 | 0 |
| | | 4 | | | 1000 | | 250 | | | | | |
| | | 5 | | | 2750 | | 2200 | | 6 | 5 | 0 | 1 |
| | | 7 | | | 10900 | | 10350 | | 6 | 5 | 0 | 1 |
| | | 8 | | | 7350 | | 6850 | | 7 | 6 | 0 | 1 |
| | 5 1978 | 1 | | | 15200 | | 850 | | | | | |
| | | 2 | | | 2250 | | 600 | | | | | |
| | | 3 | | | 800 | | 300 | | | | | |
| | | 4 | | | 7650 | | 1100 | | | | | |
| | | D*(Disposal area) | | | 350 | | 350 | | | | | |
| Portt et al. 1989 | 10 1984 | 13 | 12 | Ekman | 26663 | 5372 | 26663 | | 6I | 6I | 0 | 0 |
| | | 16 | 21 | | 60830 | | 60830 | | | | 0 | 0 |
| | | 19 | 23.5 | | 29289 | 3162 | 29230 | | 6I | 4I | 0 | 2 |
| | | Harbourwide | | | 49375 | | | | | | 8 | 10 |
| Krantzberg & Boyd 1992 | 11 1988 | 258-1 | 24 | Ekman & Ponar | 7455 | | | | 6 | 5 | 0 | 1 |
| | | 258-2 | 24 | | 6912 | | | | 6 | 5 | 0 | 0 |
| This study | 11 6 1989 | 1-13 | 2-24 | Ponar | 783 - 15738 | 344 - 4310 | 726 - 15738 | 287 - 4310 | 3 - 12 | 5I,E | 5 | 7 |
| | 22 7 1989 | 1-13 | 2-24 | | 315 - 24018 | 127 - 5662 | 287 - 24018 | 107 - 5662 | 3 - 10 | 5I,E | 6 | 6 |
| | 2 8 1989 | 1-13 | 2-24 | | 28 - 13724 | 0 - 3441 | 28 - 13724 | 71 - 3403 | 1 - 13 | 4I | 5 | 11 |
| | 30 8 1989 | 1-13 | 2-24 | | 350 - 13743 | 127 - 1843 | 230 - 13743 | 24 - 1843 | 3 - 18 | 5I,E | 11 | 16 |
| | 6-8 1989 | Samplewide | 2-24 | | 28 - 24018 | 0 - 5662 | 28 - 24018 | 24 - 5662 | >31 species** | 5 | 10 | 16 |

** Unidentified species were not taken into account here, only identified species were included in this count for conservative purposes.
I: Immature Tubificids with and/or without hair setae
E: Tubificid egg cases

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