STUDIES ON THE MACROINVERTEBRATE BOTTOM FAUNA OF THE IRWELL, A POLLUTED RIVER.

Jeremy Peter Eyres, B.Sc. (Southampton), M.Sc. (Salford).

THESIS

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This work is dedicated to the memory of my father.

CONTENTS.

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ABSTRACT.

The Irwell is polluted along its entire length. The headwaters are contaminated by drainage from a disused colliery and the rest of the river suffers from organic pollution of domestic and industrial origin. The degree of contamination is particularly great in the lower reaches of the river, downstream of the confluence with the River Roch. Despite this, the physical nature of the watercourse tends to ensure the maintainance of relatively high dissolved oxygen concentrations under all but the worst conditions.

Contamination of substrate materials by copper, lead and zinc has been demonstrated at all sites studied except one located near the source of the river. Contamination by copper is particularly severe in Radcliffe; lead reaches highest concentrations at Agecroft. Zinc has peaks of concentration at both these sites. Copper is the most toxic of the metals studied to both Erpobdella octoculata and Asellus aquaticus; zinc is the least toxic.

Data obtained from analysis of bi-monthly samples of riffle benthos from ten sites on the river show the fauna to be dominated by Oligochaeta, notably Limnodrilus hoffmeisteri. Using simple association analysis the fauna is divisible into three 'ecological assemblages'. One assemblage, association B, dominates the fauna at all sites and is fairly evenly distributed along the river. This association comprises Tubifex tubifex, Limnodrilus hoffmeisteri, Nais elinguis, Asellus aquaticus and Orthocladiinae larvae. Association A is restricted to the upstream reaches of the river, association C to the downstream sites. The lack of success of association C, which includes Limnodrilus udekemianus and Chironominae larvae, may be related to an inability of its members to compete with association A animals which in turn cannot tolerate downstream conditions. A major factor influencing the nature of the riffle benthos of the Irwell is the modification of substrate by suspended material and sewage fungus. Toxic metals also clearly exert a deleterious effect.

AIMS.

To survey the macroinvertebrate bottom fauna of eroding substrata in the River Irwell and to examine the complex of physical, chemical and biotic factors controlling the distribution of taxa.

INTRODUCTION

The history of the pollution of the River Irwell has been discussed by Eyres (1973), along with the geography of the river's catchment area. This former study described the distribution and seasonal abundance of the oligochaete fauna of depositing substrates, and included data on the population structures of the predominant species. While oligochaetes form a major part of the macroinvertebrate fauna of the Irwell, other groups are well represented under certain conditions; areas with stony substrates in the more swiftly flowing reaches support a particularly diverse fauna. The present study was devised to survey quantitatively the macroinvertebrate benthos of a series of stony bottomed sites along the length of the river. The earlier study by the author included data relating to environmental parameters. An omission was some evaluation of the type of substrate at each of the sites sampled. This led to difficulties of interpretation when attempting to decide whether observed differences in fauna between sites were wholly due to pollution or were influenced by the nature of the substrate. Substrates have been examined quantitatively in the present study. Routine chemical analyses of river water, the results of which have kindly been made available to the author by the North West Water Authority, do not give a complete picture of the pollution of the Irwell. Data on heavy metal levels, for example, are sparse. During the course of the present survey, determinations of three metals have been made, on samples of water, substrate material and fauna. In order to assess the relative importance of these metals in limiting the distributions of certain species, some simple toxicity tests have been carried out.

The survey provides a practical description of the biological

status of the river as it existed over the period during which the samples were taken, providing a base line for comparison against which future changes in the condition of the river may be placed in context; the work also furnishes information on the nature of stream communities under polluted conditions, allowing the evaluation of various schemes devised for the biological assessment of pollution.

SURVEY OF LITERATURE.

1. The effects of pollution upon stream fauna.

No survey of a polluted environment can be evaluated satisfactorily without some knowledge of the situation as it prevails in similar, but unpolluted or less polluted habitats. The bulk of the literature relating to the ecology of stream macroinvertebrate communities has been reviewed by Hynes (1970). This work provides an account of the factors influencing the distribution of benthic macroinvertebrates, and allows certain assumptions to be made concerning the expected nature of the fauna in a given type of habitat. Macan (1974) has reviewed the studies made on running water since the publication of Hynes' book.

An early study of a river fauna which took into account the nature of the prevailing environmental conditions was that of Percival and Whitehead (1929). These authors made a qualitative study of the fauna of various types of stream bed.

Cummins (1974) has attempted a synthesis of knowledge on the structure and function of stream ecosystems. He questions the assumption that species recognition is the fundamental prerequisite of ecological insight, preferring the identification of functional groups of organisms in order to address "process-oriented ecological questions". He cites the work of Lindemann (1942) on trophic levels as an example of an approach at a level other than the taxonomic.

The most comprehensive review of literature concerned with the effects of pollution on stream macroinvertebrate communities is provided by Hynes (1971a). Hynes considers that the physical and chemical effects of pollution can, from an ecological point of view, be divided into five catagories,

namely; addition of poisonous substances, additions of suspended solids, de-oxygenation, addition of non-toxic salts and heating of the water. It is stressed that one, several or all of these may be present in any one effluent. The best documented effect is that of de-oxygenation, but the classic, 'text-book' effect of an oxygen depleting discharge seldom describes an actual field condition.

Bartsch (1948) provides an early discussion of the effects of pollution upon the aquatic environment, and also of the effects of organisms upon pollutants in the purification process. Some important effects of pollution are, he feels, changes in the stream bottom, in the physical and chemical properties of the water and in the competitive relations of organisms. Brinley (1942), having considered biological zones in a polluted stream, reiterates the fact that the introduction of putrescible organic matter into a stream has downstream effects which tend to be a logarithmic function of time and which are influenced by the kind of organic matter and the physical nature of the stream. Brinley (1942) divides a polluted stream into five zones, depending on the nature of the plankton and fish populations. The system, of course, applies to the simple situation with a single point of pollutant discharge.

Paterson and Nursall (1975) studied the effects of domestic and industrial discharges upon a large, turbulent river. Their study showed that, even in the presence of large amounts of waste substances and a high biochemical oxygen demand load, considerable levels of dissolved oxygen can be maintained. Despite this, they found that significant changes in biota did occur. It is suggested that these changes are not necessarily related to the chemical parameters measured, but instead to more

subtle influences of pollution such as slight increases in nutrients, modification of the substrate, sub-lethal effects on organisms or lethal effects on a particularly vulnerable stage of the life-cycle of a species.

Learner et al. (1971) examined the effects of domestic and industrial wastes on the macroinvertebrate fauna of a stream in South Wales. They found that coal particles changed the nature of the substrate at some sites, bringing about changes in bottom communities. Nais barbata (Oligochaeta) and chironomid species dominated the fauna in such situations. Substantial organic discharges encouraged a community dominated by tubificids and an enchytraeid species.

Other studies documenting the effects of largely organic pollution on stream communities include those of Gaufin (1958), Gaufin and Tarzwell (1955) and Pickavance (1971). The effects of the highly polluting discharges of some agricultural operations have been studied by Prophet and Edwards (1973). Nuttall (1972) has investigated the effect of sand deposition upon macroinvertebrate communities. He found that the poor incidence of plants and animals inthe affected area was associated with the unstable shifting nature of the substrate rather than with turbidity or abrasion caused by sand particles in suspension. Diversity was lessened by the sand, although the Tubificidae thrived. The same author (Nuttall, 1973) has also studied the effects of refuse tip liquor, a complex pollutant, upon stream biology. The liquor caused massive growths of sewage fungus and encouraged a community dominated by Nais elinguis (Oligochaeta). He suggests that the deleterious effects of the pollution are not a direct result of toxins or de-oxygenation but of changes in the substratum and smothering caused by sewage fungus. Modification of the substrate is also a major factor in streams

polluted by china clay wastes (Nuttall and Bielby, 1973).

Koryak et al. (1972) have studied the effects of acid mine drainage upon riffle faunas. They found that the immediate effect, with low pH and high acidity, was similar to that produced by organic pollution. The later stage, involving iron hydroxide precipitation, however, resulted in slightly increased diversity but a substantially reduced biomass.

The problem of heat as a pollutant has been considered by several authors, including Coutant (1962). A marked elevation in river temperature (20 to 25^{o}F above normal) led to a drastic reduction in both the number of individuals and the number of macroinvertebrate taxa present. Such effects were less readily discernable where temperatures were nearer the ambient. The reaches studied by Langford and Aston (1972) showed far less elevation of temperature and they found the effects on the fauna to be far less subtle. Influences on the hatching of insect nymphs possibly attributable to temperature were not nearly as marked as the natural annual variations.

The range of studies on macroinvertebrate stream communities affected by pollution is great. The effects of one simple organic discharge are well documented and fairly predictable. The literature serve to emphasise, however, that the situation is seldom simple. Stream ecologists are still far from being able to predict the effects of an additional discharge upon an already polluted situation, and the ways in which pollutants interact are still not well understood.

2. The assessment of pollution using biological criteria.

Historically, the water quality of a stream has been assessed by chemists, using well established standard methods. In recent years, however, serious limitations of the purely chemical approach have become apparent. A water sample taken for chemical analysis reflects the condition of the river when the sample was taken, and no more. If the pollution situation is a fluctuating one, large numbers of samples or expensive continuous monitoring techniques are necessary to provide a true picture of the stream's status. Chemical methods may be appropriate where the pollution is fairly constant and simple in nature, and the investigator knows what he is looking for. In complex situations, such as that presented by the effluents from a chemical works engaged in batch production of a variety of products, many pollutants may exist with no practical chance of determination.

The flora and fauna of a water course are exposed to the prevailing environment at all times; thus every facet of a continually changing and very complex pollution situation will reflect itself in the stream's biology. A toxic effluent released only sporadically will nevertheless exert an influence on the flora and fauna. This overall reflection in a stream's ecology of the degree of pollution is of value in a water quality study. Some components of the ecosystem are more useful than others for such work. Fish are very motile; to a certain extent they can move about in order to escape locally or temporarily undesirable situations. The macroinvertebrate benthos, on the other hand, is relatively static; it cannot escape pollution and must therefore reflect it.

The principle of the use of macroinvertebrates in environmental quality work is well established. Hellawell (1974) has made a brief, unpublished, literature review to discover which groups of organisms are preferred for biological surveillance, and has found that most published work recommended the use of macroinvertebrates.

Once a decision has been reached to carry out a survey of the macroinvertebrate benthos of a water course, and data have been collected, the question arises as to how the data are to be dealt with to produce a meaningful set of results. Earlier work, such as that of Kolkwitz and Marsson (1909), developed the concept of indicator species. This led to classifications based on the simple presence or absence of selected species. It may be argued that the presence or absence of a single species is of little significance; so called sensitive species may be washed into a polluted reach, and species common in polluted must clearly be found in unpolluted situations.The Saprobien System, as the scheme devised by Kolkwitz and Marsson is named, is however based upon many species of widely different habits, and is in fact of considerable value; it has been used much on the continent of Europe, although less in Great Britain or North America.

Now that applied biologist are working to a greater extent with chemists and engineers, they find that they are asked to put a figure to the 'biological health' of a stream, in the same way that the biological oxygen demand of its water or its rate of discharge are described. It is to this end that numerous schemes have been proposed to allow the results of a survey of macroinvertebrates to be expressed in a simple but reproducable way, rather than by the traditional (and still vital) listing of species with abundance data or by descriptive schemes such

that of Kolkwitz and Marsson (1909). Reviews are given by Hellawell (1974), Wilhm (1972), Hynes (1971a), Klein (1962) and Bick (1963).

A simple, but well respected system is that of Woodiwiss (1964), much used by Water Authority biologists. Taxa are classified according to their tolerance of organic pollution, and a table is used to give a sample a score, or 'biotic index', based on presence criteria. A chance presence in polluted water of a clean water form can bias the results, but a certain amount of common sense can be applied in such cases, and the index has been found to be very useful in practice.

Chandler (1970) considers the biological approach to pollution assessment. He starts with a short discussion of the Saprobien System, and emphasises its contribution, but he points out that the system was devised for large, slow moving rivers suffering from organic pollution. He feels that it is less applicable to the turbulent streams so common on many parts of the British Isles, and in situations involving toxic pollution. Chandler (1970) makes the point that no species should be looked at in isolation and feels that the only valid ecological unit is the community. He feels that Woodiwiss' scheme overcomes many of these objections, but that by assuming that all species within a group react in the same way to pollution, the system can produce anomalous results which may be intensified by sampling errors. He cites the example of the plecopteran Amphinemoura sulcicollis which is found in polluted circumstances where a high dissolved oxygen concentration is maintained. He continues, to describe a similar scheme which also takes into account simple abundance data.

Hawkes (1956), in a paper on the biological assessment of pollution in Birmingham streams, also emphasises that before

applying any method, it is necessary to appreciate both the complexity of stream life and the nature of pollution. He then discusses the analysis of results, using a system based on the Saprobien System. He feels that this system is more readily interpreted than techniques devised to give numerical indices. Beck (1954) has produced an ecological classification of organisms, again similar to the Saprobien System, but being modified to suit local conditions (Florida, U.S.A.).

The simple method of King and Ball (1964) requires only that benthic invertebrates be separated into two groups, the aquatic insects and the tubificid worms. It is assumed that the former are sensitive to, and the latter tolerant of, pollution. This appears to be a gross oversimplification, and is described be Hellawell (1974) as "both crude and naive", as indeed is the index of Goodnight and Whitley (1960)where the ratio of tubificids to other macroinvertebrates is calculated.

Patrick (1950) feels that the ecology of a stream is much too complex to rely on a few species to indicate conditions. Describing the cycle of events in the stream ecosystem as the "biodynamic cycle", she suggests that pollution may be assessed by examining the stream community and dividing its constituents into seven groups represented by columns on a histogram. Species grouped together are said to react in the same way under the influence of pollution. Algae, protozoa, rotifers, macroinvertebrates and fish are included in the scheme, which provides a useful, visual and readily understood assessment, although the assumptions made are probably only valid for organic pollution. Gaufin and Tarzwell (1955) made bacteriological studies in a polluted catchment but placed emphasis on the role of macroinvertebrates as indicators of pollution. The authors feel that schemes relying on lists of species typifying certain situations are a

gross oversimplification, and they point out that several environmental factors other than the presence of a pollutant may affect or limit the distribution of certain species. Gaufin and Tarzwell (1956) believe that organisms should be considered in groups according to their morphological adaptations and physiological requirements.

All the schemes described thus far rely upon some sort of ecological classification of organisms, whether ecological, morphological or in terms of tolerance to pollution. Clearly this can lead to arguments of a somewhat circular nature; a habitat is said to be polluted because it supports a community that we expect to find in a polluted habitat, but all the species making up such a community obviously also occur in 'clean' conditions. In recent years, the tendency has been towards methods of analysis which take into account the actual abundance of all the taxa making up the community in order to produce a measure of the diversity of the fauna. These methods are not just applicable to the study of pollution; they have been developed and much used in the study of the nature of communities, and in this respect reference may be made to Fisher et al. (1943), Hairston (1959), Menhinick (1964) and McIntosh (1967). McIntosh (1967), for example, has developed an index of diversity and has considered the concepts of richness, diversity, homogeneity and similarity in the context of studies on plant and animal communities.

The indices of diversity used in water quality studies have been reviewed by various authors, including Warren (1971) and Wilhm (1972). Wilhm (1967) has compared some diversity indices by applying them to a set of data. He finds that in most cases maximum diversity exists if each individual belongs to a different species and minimum diversity exists if each individual

and Dorris

belongs to the same species. Wilhm (1968) emphasise that an index selected for use must be independent of sample size, since as this increases the number of individuals increases faster than the number of species. One index considered is that of Margalef (1951):

s = number of species

N = number of individuals

d = diversity

(ln refers to natural logarithm)

$$d = \frac{s - 1}{\ln N}$$

This index has been found by Menhinick (1964) to show wide variation with sample size, and in fact can give the same value using data drawn from widely differing hypothetical communities (Wilhm and Dorris, 1968). The same criticism must apply to the index of Menhinick (1964), where $d = s/\sqrt{N}$.

Many expressions devised as a measure of community structure do not take into account the abundance of each species or taxon in the community, merely the total number of individuals and the number of species. The above mentioned indices are examples. Clearly full use is not being made of the data available. One exception is the index of Simpson (1949), where

$$d = \frac{\sum n_i(n_i - 1)}{N(N - 1)}$$

(n_i is the number of individuals in the i^{th} species and N is the total number of individuals.)

A powerful mathematical tool has become available to ecologists with the development of 'Information Theory'. The application of this concept to ecology has been discussed in

detail by Margalef (1958). Warren (1971) summarises by equating diversity, as derived from Information Theory, with the uncertainty that exists as to the identity of a species selected at random from a community. The greater the number of species in a community, and the more equal their abundance, the greater the uncertainty as to the identity of a randomly selected individual. Clearly this measure of uncertainty, or information content, may be used as a measure of diversity. It is clear that before applying formulae derived from information theory it is necessary to consider the rationale behind such applications. Pielou (1966a) has considered in detail the measurement of diversity in different types of biological collections. She points out that although information content as defined by Shannon and Weaver (1949) and Brillouin (1962) provides a convenient measure of diversity in all situations encountered by the ecologist, the method of application must be adapted to the type of collection in hand. Pielou (1966a) classifies ecological collections into five types, for each of which a different method is appropriate. The key given defining the five types may usefully be reproduced here:

(A) Collections small enough for all members to be identified and counted. (Type A)

(B) Larger collections:

(a) Collections from which a random sample can be drawn:

(i) Number of species known (Type B).

(ii) Number of species unknown;

(A) Sample gives a smooth species-abundance curve (Type C).

(B) Otherwise (Type D).

(b) Collections from which a random sample cannot be drawn (Type E).

In type A collections, diversity per individual, H, is given by Brillouin (1962) as:

$$H = \frac{1}{N} \log \frac{N!}{N_1!\, N_2! \cdots N_s!}$$

where N = the total number of individuals

and s = the number of species.

(In this account, diversity may be taken as diversity per individual (Pielou, 1966a) unless otherwise stated.

In Pielou's (1966a) type B collections the diversity must be estimated by taking a sample from the collection (community). Average diversity (H') is given by Shannon and Weaver's (1963) formula $H' = -\sum p_i \log p_i$, where p_i is the proportion of the i^{th} species in the community. Shannon and Weaver's population (community) H' may be estimated by the sample $\hat{H}'$ using $\frac{n_i}{n} = \hat{p}_i$, where n is the number of individuals in the sample and n_i is the number in the i^{th} species. Pielou (1966b) emphasises that the use of Shannon and Weaver's formula with type A collections is inappropriate. Type B collections are those in which the number of species is known; in most cases the ecologist is unable to collect all the rarer species in his study area, but Pielou (1966a) considers that if the number of species falls slightly short of the true value, no appreciable error will arise if a large sample from a type C collection is treated as if it were from type B.

(A certain amount of ambiguity exists in the above account with regard to the term "collection" as used by Pielou (1966a). The term "population" is used in the same context by Pielou (1966b). The substitution of "community" would clarify the matter. The point to emphasise is that "community" does not appear to mean "sample".)

So far in this account, the base of logarithms in the formulae has not been specified. The choice is in fact an arbitrary one and only affects the units in which the results are expressed (Pielou, 1969). If logarithms to the base 2 are taken, as is the normal practice, the information unit is a 'binary digit' or 'bit', while with $\log_{10}$ the unit is a 'bel', 'decimal digit' or 'decit'. Natural logarithms give us 'natural bels'.

The decision as to which formula to apply (Brillouin's or Shannon and Weaver's) is one that seldom confronts stream invertebrate ecologists. Shannon and Weaver's is either appropriate or reasonably so in most situations encountered. If, however, the entire fish fauna of a pond is removed by electrofishing, Brillouin's formula is clearly the one to use. Lloyd et al. (1968) give examples of the application of both formulae.

Shannon and Weaver's (1963) H', where $H' = -\sum(N_i/N) \log_2 (N_i/N)$, and N_i/N is the population ratio, is estimated from sample values (n_i/n) to give diversity per individual, $\bar{d}$, as follows:

$$\bar{d} = -\sum(n_i/n) \log_2 (n_i/n).$$

Wilhm and Dorris (1968), discussing the above formula, continue, to explain how a theoretical ($\bar{d}_{max}$) and minimum ($\bar{d}_{min}$) diversity can be calculated. Redundancy, r, is an expression of the dominance of one or more species, and is inversely proportional to the wealth of species. It is given by:

$$r = (\bar{d}_{max} - \bar{d})/(\bar{d}_{max} - \bar{d}_{min}).$$

The formula of Shannon and Weaver (1963) has been widely used by stream ecologists, especially in pollution studies. Ransom and Dorris (1972) found the calculation of $\bar{d}$ to be a useful method of determining the long term effects of waters of different qualities on the benthos of a reservoir. Hocutt et al. (1974) applied the formula to data on the fish communities in

a large river system, although it is arguable that Brillouin's formula would have been more appropriate here, since their collections with the fish poison rotenone may well have sampled the entire fish community in a given area. Ransom and Prophet (1974) found $\bar{d}$ values in excess of 3 (bits) in streams with excellent water quality. Archibald (1972) has applied various indices in a study of South African diatom associations in relation to water quality; he found that diversity in such associations did not consistently follow water quality, and he considers it a dubious and sometimes misleading parameter in this respect. Species composition and autecological considerations are regarded by him as being more important. Patten (1962) has considered the species diversity in net phytoplankton, and finds that such formulae are useful in relation to successional studies as well as in pollution studies. McErlean and Mihursky (1968) have considered the application of diversity indices to fishery work. Nuttall and Purves (1974) found the formula of Shannon and Weaver the most consistent and sensitive of several methods used in assessing the biological state of a river.

Despite the vast amount of work put into studies of diversity, Hurlbert (1971) criticises the whole concept, feeling indeed that it has become a "non-concept". He suggests that ecologists take more direct approaches to the study of species : number relationships. To this end, Hurlbert (1971) develops species composition parameters, based on the probability of interspecific encounter between species.

An alternative to considering the structure of the community at a particular point by the calculation of various indices of diversity is to compare communities at different sites, by the calculation of some form of similarity index. Ghent (1963)

has discussed the use of Kendall's 'Tau' coefficient as an index of similarity in community comparisons. Kaesler et al. (1971) and Crossman and Cairns (1974) have based measurements of similarity on Jaccard's coefficient (Jaccard, 1908) and used cluster analysis to express their results. Sorensen's 'K' (Glime and Clemons, 1972) is another measure of the degree of similarity between communities, as is Czekanowski's coefficient (Prentice and Kain, 1976; Field, 1971).

In a recent paper, Edwards (1975) has reconsidered the whole problem of the biological detection of the effects of pollution on natural communities. He points out the danger of adopting the indicator species approach too rigidly since these species have obviously been identified retrospectively as being sensitive to a pollutant the effects of which we are already aware. There is no guarantee that such an indicator species will be sensitive to pollutants with different modes of action. The various numerical descriptions of community structure are felt by Edwards (1975) to be of limited value in that they do not differentiate between components at any level. He suggests that qualitative aspects of community structure, such as those stressed by Kolkwitz and Marsson (1909) might prove more valuable. Edwards (1975) also considers the methods which make comparisons between communities. He found it useful to obtain ordinary correlation coefficients (r) from comparisons of the abundance of each pair of species at all the sampling stations that he studied. Edwards (1975) concludes that some international standardisation of methods is clearly required if the full benefits of biological and other surveillance programmes are to be realised.

3. Methods for sampling benthos inhabiting stony substrates.

Macan (1958) divides sampling methods into several catagories, the simplest of which involves lifting stones by hand, enclosing them in a net for removal from the stream and scraping the animals into a vessel. The method may be quantified by sampling for a set period, but Cummins (1962) does not regard it as quantitative in any strict sense. Clearly there are many obstacles to reproducability in such a method, not least in the intensity of effort applied by the collector. A similar drawback applies to the technique of Frost et al.. (1971), where the substrate is disturbed with the feet and the fauna collected in an appropriately held net. The method gives an insight into the relative abundance of the taxa present, although it might be expected that species attached to the substrate in some way might be underestimated or overlooked altogether. The method cannot furnish data on the absolute abundance of species, but it has the advantage that it can be used in deep water where other methods are inappropriate.

Several of the samplers described by Macan (1958) consist of boxes or cylinders designed to enclose an area of substrate while the animals are removed. A problem is that such devices seldom fit snugly over a rocky substrate, and animals will be scoured out by the resulting alteration of currents. A seal may be obtained by fitting the device with a foam rubber skirt, but this does not work well in practice (Hynes, 1971b). Better results may be obtained if the device is actually driven into the substrate; the samplers of Wilding and others (Macan, 1958) and Hess (Lattin, 1968) fall into this catagory. Such samplers are invariably cumbersome, considerable mechanical strength being required to resist the rigours of being driven into the substrate.

Macan (1958), Hynes (1971b), Lattin (1968) and Cummins (1962) all include descriptions of nets and dredges that are pushed forward

through the substratum. Such methods are difficult to quantify, valid comparisons between sites having different substrates, with different resisances to the progress of the dredge, being unobtainable. Except in gravel, such samplers are difficult to operate as they ride over large stones, and they do not collect active animals which can escape by swimming (Hynes, 1971b).

The most widely used sampling methods, in the present context, involve the transfer of fauna from a delineated area of substrate into a fixed net. The best known sampler of this type is that of Surber (1937), which consists of two frames, each enclosing 1 ft^2. One frame is held on the stream bed to enclose the sampling area. The second frame, hinged to the first, has a large net attached to it, and is held at right angles to the stream bed, downstream of the quadrat frame, with the net streaming in the current. All stones enclosed by the first frame are picked up and washed in the mouth of the net, and the finer sediments are stirred up with the fingers to dislodge any remainaing invertebrates. A disadvantage of the sampler is that back pressure from the net, especially when this is fine meshed, causes some of the fauna to be swept around the side of the net opening (Lattin, 1968). Leonard (1939) found the sampler difficult to seat in rough gravel, leading to escape of fauna under the net frame. He also emphasises that the sampler is useless in regions of sluggish flow. Hynes (1971b) regards the method as a useful one, but prefers box samplers for work involving production estimates. He states that the efficiency of the sampler varies with the water level, mesh size of the net, current speed and the amount of organic matter present, this latter tending to clog the meshes. Kroger (1972) has estimated the extent to which the Surber sampler underestimated standing crop. He found that, with a mesh size of 0.5mm, the method collected about a quarter of the species present, losses

being due to backwash and escape through the meshes of the net. He also feels that Surber sample collections misrepresent the abundance of groups of invertebrates relative to one another, the extent of this depending upon the mesh size used. Hughes (1975), however, has investigated the efficiency of various samplers and found that a Surber sampler and a box sampler (Neill, described in Macan, 1958) gave similar results. He states that even though the sample area with the Surber sampler is exposed, providing an opportunity for escapes, such escapes are not significant. Mundie (1971) describes a more elaborate device for sampling a given area of bottom; this sampler is appropriate for sampling both benthos and substrate materials. The sampler of Hess (Lattin, 1968) is perhaps more comparible with the devices of Surber and Mundie than with the cylinder and box samplers with which it has been grouped by Macan (1958) and Cummins (1962), since the former samplers rely upon current for the actual collection of animals whereas with the latter, fauna is removed by the operator.

The sampling methods described thus far have involved removing fauna from the natural substrate of the stream bed. Problems can arise due to the irregular nature of the substrate at a location, and to the range of substrates encountered in a stream. This leads to problems in the interpretation of data; it may be unclear whether differences in fauna are due to differences in the substrate sampled or other factors. To eliminate the variability in the substrate, and also to control more accurately the area sampled, many authors have installed some form of artificial substrate in the stream and removed the sampler after colonization. Usually, a constant type of substrate has been employed, but some authors have used the substrate available on site to fill their containers. Macan (1958) describes a method used by Moon (1935); material similar to that of the substrate of the lake under

investigation was placed into a tray, which was lowered to the bottom to allow colonization. The method worked well in a lake, but material is washed out of the tray in a stream. A sampler used a good deal in America consists of a 'barbeque basket', as described by Anderson and Mason (1968). The basket is 28cm long and 18cm in diameter and is filled with limestone rocks (2.5 - 5cm diameter). Anderson and Mason (1968) compared such baskets with a Petersen dredge for collection macroinvertebrates. Their baskets were suspended 1.5m below the surface of a large river for 6 weeks. They concluded that the basket sampler is a practical device for collecting benthic macroinvertebrates in large rivers. Their baskets collected more aquatic insects but fewer oligochaetes and molluscs than the Petersen dredge. Colonization presumably takes place from the invertebrate drift. Fullner (1971) compared a 'barbeque basket' sampler with a device consisting of a series of hardboard sheets (7.6 x 7.6cm) spaced at intervals on a bolt (a modified Hester and Dendy (1962) sampler). The multiple plate sampler compared favourably with the basket sampler. The advantages of the former were its small size and light weight. Arthur and Horning (1968) have evaluated similar multiple plate samplers. Dickson et al. (1971) used baskets made of ½ inch (1.3cm) mesh formed into a 30.5cm cube filled with 5cm limestone chips interspersed with grass. Radford and Hartland-Rowe (1971) used local substrate material to fill their samplers which consisted of perforated cans buried in the stream bed.

Mason et al. (1973) have evaluated the factors affecting the performance of basket and multiple plate samplers, working on a deep river. The maximum number and diversity of macroinvertebrates from limestone filled baskets were obtained by placing the samplers 30.5cm below the surface for 8 weeks, and the length of exposure had a greater effect on the number of organisms than placement depth.

Baskets resting on the streambed tended to accumulate debris and gave more variable results. Comparing porcelain and limestone filled baskets, they found similar abundance and diversity figures, but taxonomic groups occured in different proportions on the two types of substrate. Their baskets and multiple plate samplers gave different figures for abundance and diversity, but standardizing the surface area available for colonization leads to equivalent performance. Mason et al. (1973) emphasize that consistent practices in sampler installation and analysis are required for comparisons of collections in water quality studies. Crossman and Cairns (1974) have compared two different artificial substrate samplers and more traditional sampling techniques. One of their artificial substrate samplers consisted of a floating device made of styrofoam and a webbing material. The other was a 30.5cm square wire mesh basket filled with rocks and leaf litter. The basket samplers were placed on the river bottom, and all samplers were left in place for 32 days. For comparison, samples were taken using a Surber sampler and the technique of Frost et al. (1970). Comparing their results for the artificial substrates with those from the conventional sampling, they conclude that the bottom basket samplers are more reliable than the floating type, the latter being selectively colonized by beetles, mayflies and caddisflies. The authors feel that artificial substrate samplers may be very useful tools in pollution assessment as long as their limitations are understood. Benfield et al. (1974) come to similar conclusions regarding the limitations and bias of floating webbing structures. The rocks usually used to fill baskets make the samplers heavy and unwieldy; Bergersen and Galat (1975) find that pieces of coniferous tree bark make a lightweight, effective

alternative.

Whatever the sampling method employed, a problem arises in deciding how many samples should be taken. Different numbers of samples may be necessary to estimate biomass, total number of organisms and number of species. Elliott (1971), Gaufin et al. (1956) and Southwood (1966) all provide formulae, to be applied after a preliminary survey, for the calculation of the number of samples necessary for an accurate estimation of the quantity one wishes to measure. A sampling technique which has been closely investigated in this respect, because of its popularity, is the Surber sampler.

Needham and Usinger (1956) studied the variability in the macrofauna of a single riffle, taking 100 Surber samples from the streambed. They found that 194 samples would be necessary to estimate the total wet weight of organisms with 95 percent confidence, 73 samples being necessary for the estimation of total numbers. Two or three samples would be necessary to collect at least one representative of the Plecoptera, Trichoptera, and Diptera. The authors point out that this latter finding is important in connection with stream pollution surveys, where the total spectrum of groups present is more significant than total weights or numbers. Chutter and Noble (1966), discussing the reliability of the Surber sampler, point out the difficulty of sampling equivalent areas of stream bed at a site, parameters such as particle size, water depth and rate of flow varying over small areas. Even so, they conclude that three 1 ft^2 Surber samples furnish satisfactory data in general river surveys. Chutter (1972) has reappraised the data of Needham and Usinger (1956), questioning the validity of their estimate of the number of samples necessary for 95 percent confidence in the determination of total numbers of invertebrates.

Chutter (1972), however, feels that the sampler should not be used where the depth of water is such that the apparatus is submerged, loss of fauna being excessive in such situations. Hughes (1975), in his work on benthic sampling methods, took four Surber samples per site and found the technique to be a reliable one.

Simple methods for sampling benthic macroinvertebrates only sample the surface and top few centimetres of the substrate. Clearly, animals living deeper in the substrate will be missed. Williams and Hynes (1974) have developed a method for sampling this hyporheic fauna, and have demonstrated that large numbers of animals occur in interstitial spaces deep in the streambed.

No entirely satisfactory method of sampling standing crop, species abundance or species 'richness' has yet been devised for use in the stony bottomed lotic environment. Problems arise as a result of the patchy distribution of many species, and of irregularities in the substrate presenting a variety of microhabitats to the fauna. Very large numbers of samples at a location can overcome the problem, but furnish unworkably large amounts of data. Cleary a sampling programme will be a compromise between the desirable and the feasable.

4. Heavy metals in the aquatic environment.

Heavy metals are amongst the most insidious and persistent pollutants of the aquatic environment. These elements originate from a variety of natural, industrial and mining sources, and a variety of analytical procedures are available for their determination. Until recently, all such work was done using colorimetric techniques; details of various methods are given in Klein (1959), American Public Health Association (1971) and Allen (1974). The techniques of flame spectroscopy, using both emission and absorption spectra, have recently allowed analysts to determine metals quickly, sensitively and accurately. Atomic absorption spectrophotometry, especially, has been widely used in pollution studies. Full application details are given in Allen (1974), A.P.H.A. (1971) and Parker (1972). An alternative, simple method is that of anodic stripping voltametry, which has been applied and assessed by Gardiner and Stiff (1975). Neutron activation techniques have been used by Rehwoldt et al. (1975). Despite the existence of these latter two techniques, the vast majority of analysts at present use atomic absorption spectrophotometry.

The work of Rehwoldt et al. (1975) on the Danube river system near Vienna provide data on what might be regarded as the 'normal' levels of cobalt, chromium, iron, zinc and scandium and they feel that the levels that they recorded are of geological, rather than industrial origin.

The chief pollutants studied by Tyler and Buckney (1973) in a Tasmanian river polluted by mine effluents were lead, zinc, copper, cadmium, iron and sulphuric acid, and the effects of these extended far beyond the mining areas causing severe damage to farming interests. Sprague and Ramsay (1965) have studied sub-lethal pollution of a salmon river by copper and zinc; they

found copper to be over twelve times more toxic than zinc to young salmon in soft water. Aquatic invertebrates, especially mayflies, were good indicators of the copper/zinc pollution.

Kronfeld and Navrot (1974) studied the heavy metal contamination of the Quishon River system (Israel). They observed no life at all in one grossly polluted tributary, and the discharge of the system has been blamed for a serious decline in the commercial fishing industry of Haifa Bay. The authors found high levels of various metals in sediments, but a paucity in the waters. They emphasise an interesting situation; the pH of the water is kept artificially high through pollution, and this lowers the solubility of the metals, keeping them in the sediments. If the dumping of high pH wastes is stopped, there is a danger that the more acidic conditions will lead to a huge mobilisation of metals with potentially damaging consequences for Haifa Bay.

Chung and Jeng (1974) examined the effect of heavy metal pollution in a river in Taiwan. The river was polluted by waste from a number of paper manufacturers and chemical companies. The authors measured levels of mercury, cadmium, copper, nickel, lead and zinc in crustaceans and fish, and found evidence of pollution by mercury. They suggest that "shrimp" , which move within a very restricted area, may provide the best indication of local contamination of the water.

More work on toxic metals seems to have been carried out in relation to the marine environment that to the freshwater habitat. This is partly due to the greater importance of marine species as food resources; it is important to know whether maximum recommended level of pollutants in food, as laid down by such bodies as the World Health Organisation, are being exceeded. Examples of this

include work on the accumulation of metals by oysters carried out by Shuster and Pringle (1969), Thrower and Eustace (1973), Mackay and Williams (1975) and Ratkowsky et al. (1974). Trace metals in a variety of coastal organisms have been determined by Leatherland and Burton (1974); Ireland (1974) has studied levels of zinc, copper, manganese and lead in the barnacle Balanus balanoides in Cardigan Bay (Wales), while Navrot et al. (1974) suggest that the limpet Patella vulgata might well be a useful organism with which to monitor the pollution of coastal waters. Bryan (1971) has examined the effects of toxic metals upon marine and estuarine organisms, while Bryan and Hummerstone (1971 and 1974) have made a study of the adaptation of two polychaete species to high sediment concentrations of metals. Raymont and Shields (1963) concentrated upon the toxic effects of copper and chromium in the marine environment.

The levels of metals in the environment of marine organisms, rather than in the organisms themselves, have been studied from a variety of points of view. Cooper and Harris (1974) have determined metals in the organic phases of river and estuarine sediments. They found that quite high concentrations can accumulate even in lightly polluted situations. The authors reiterate the ability of organisms to concentrate elements, and the well known association of heavy metals with the organic portions of sediments. They assume that the availability of an element in a sediment to a food chain will depend upon its partition between the various organic and inorganic phases. Cooper and Harris (1974) conclude that the distribution of metals as organic complexes in sediments is very sensitive to the

prevailing environmental conditions, but that even in lightly polluted habitats high levels can build up.

Ramamoorthy and Kushner (1975) studied heavy metal binding components in water from the Ottawa River (Canada) and a canal; in the latter HCO_3^- and CO_3^{2-} ions accounted for a substantial part of the binding activity, but in the river, low molecular weight (<1400) organic compounds were implicated.

Metal levels, both dissolved and suspended sediment bound, have been examined in the Bristol Channel by Abdullah and Royle (1974), who point out that the fate of metals added to the marine environment may be controlled by removal onto particulate material by adsorption, chelation, coprecipitation or biological concentration. Helz et al. (1975) found that they could not explain the falloff in metal concentration with distance from a point of input in terms of dilution alone; they suggest that active immobilisation processes must be removing these metals to the sediments. The authors speculate as to the various processes that might be involved.

A number of studies have been concerned with the actual mechanism of the toxicity of the heavy metals. D'Amelio et al. (1974), for example, have studied the action of lead on protein synthesis, more particularly on haemoglobin synthesis in a fish and on polyribosomal structures in a crustacean.

Measurement of levels of heavy metals, in various facets of the biological and physical environments, is a valuable part of the study of man's impact upon his environment, but a sound knowledge of the chemical processes involved is essential is valid conclusions are to be drawn from such work.

5. The use of toxicity tests in the study of the effects of poisonous substances upon aquatic organisms.

The object of a toxicity test, or bioassay, is to determine the effect of an element, compound or mixture of substances upon a given species. A practical application of such determinations is in deciding upon levels of toxins or wastes which may be desirable, or at least permissable, in a given situation. Methods used for conducting toxicity tests have been developed using fish as test animals; methods for invertebrates have evolved from these.

The usual basis of a toxicity test is the subjection of organisms to a range of concentrations of toxin under controlled conditions, with records being kept of the survival of the animals over a set length of time. An alternative is to expose organisms to a given concentration, and record survival times. Details of the former type of test are given in Doudoroff et al. (1951), summarised in A.P.H.A. (1971). Results of such tests may be expressed in various ways; American workers express their results in terms of tolerance limits (TL), together with the time over which the tests were conducted and the percentage of organisms surviving at the TL. For example, the 96 hour TL_{50} of a poison is the concentration at which 50 percent of the test animals survive for 96 hours. TL_{50} is usually in fact designated the median tolerance limit, or TL_m. British workers prefer the term 'lethal concentration', the LC_{50} of a poison being equivalent to its TL_m.

As well as the methods designed to measure the LC_{50} of a poison, much use is also made of techniques designed to determine median survival times in a given concentration or range of concentrations (Brown et al., 1969; Bengtsson, 1974; LLoyd, 1960; Tovell et al., 1975).

Methods for exposing the test organisms to the toxins may be divided into two catagories (A.P.H.A., 1971). Static bioassays are the simplest to perform; problems may arise due to oxygen depletion or reduction in the toxicity of the test solution due either to chemical changes or physical absorption onto surfaces. More reliable control of the nature of the test solution, as well as better conditions for the test animals, may result from the use of continuous flow bioassays, where the test medium is constantly replaced and which have the added advantage that the may be continued for long periods. Such bioassays are, however, more complex and expensive than static toxicity tests.

Many environmental parameters exert considerable influence upon the toxicity of deleterious substances; the effect of hardness is particularly well documented in this respect (Tovell et al., 1975; Lloyd, 1960). Other parameters commonly determined in bioassay work are bicarbonate alkalinity (as $CaCO_3$), total dissolved solids, dissolved oxygen concentration, pH and temperature (Brown, 1968). Bengtsson (1974) also measured conductivity.

A large number of toxic substances may be found in polluted rivers, but the five most common and abundant are ammonia, copper, cyanide, phenol and zinc (Brown et al., 1970). These authors have studied the toxicity of some polluted river waters to several fish species; the toxicities were greater than expected from chemical analyses of the river waters concerned. The calculation of the acute toxicity to trout of mixtures of poisons, under laboratory conditions has been described by Brown (1968). The method he uses assumes that all toxins contribute similarly to the toxicity of the mixture, and while appreciating that this assumption is

illogical, he emphasises that it works in practice. Brown (1968) mentions that one limitation of his technique is that polluted rivers may contain a variety of poisons other than the ones that he considers, and that this will of course affect the toxicity. It is possible that the discrepencies in the results of Brown et al. (1970) might be due to the influence of toxic substances not determined by them.

As an extension of the work on the toxicity of mixtures of poisons, Brown et al. (1974) have considered the effects of fluctuating mixtures of poisons, namely ammonia, phenol and zinc. They found that toxic concentrations were similar whether test concentrations were constant or fluctuating by + or - 50 percent around the LC_{50} (for trout) as long as the period of the fluctuations was less than the time required to irreversibly damage the fish (the resistance time).

The work discussed thus far has been concerned with determinations of acute toxicity; when one considers that the ultimate aim of such bioassay work is the setting of standards for natural waters, the limitations of such an approach are obvious. Dubious extrapolations are necessary when one is required to specify a concentration of toxicant that a species can tolerate indefinately when the only data available are from short term acute bioassays. Mortality is not the only factor of importance; fecundity and fertility are equally important population attributes. Susceptibility to toxins may vary throughout the life-cycle of an organism. Bengtsson (1974), for example, found that newly hatched minnow fry (Phoxinus phoxinus) were more susceptible to poisoning by zinc than other stages of the species' life-history. The sub-lethal, or chronic, influence of a toxin upon a population is obviously difficult to determine; such work is necessary to

allow the validation of extrapolations based on the vast amount of literature relating to acute toxicity .

A portion of the vast literature relating to bioassays with fish has been considered; far less work has been done using invertebrates as test animals. Klein (1959) summarises the work of Jones (1937, 1941), who studied the toxicity of a range of metallic salts to Polycelis nigra and Gammarus pulex. He was especially interested in the relative toxicities of cations and anions. Anderson (1946) studied the toxicity of various sodium salts to Daphnia magna, finding that while the effects of some could be explained in terms of osmotic influences alone, others exert truly toxic effects. This toxicity was in some cases a result of pH adjustment.

Wurtz and Bridges (1961) were interested in the toxicity of common pollutants to a range of freshwater animals influenced by estuarine conditions; they discuss problems that they encountered during their work. For example, the midge Tendipes decorus, showed a very wide range of tolerance to toxins, being extremely vulnerable at pupation. Limnodrilus hoffmeisteri tolerated a zinc concentration of $10mg.l^{-1}$ for ten days, and the authors feel that sudden losses on the eleventh day could have been due to starvation.

Surber and Thatcher (1963) made continuous flow bioassays on a range of invertebrates using a detergent (alkyl benzine sulphonate). Three species of mayfly were killed by ten days exposure to 16 $mg.l^{-1}$; Hydropsychidae larvae were more tolerant.

The oligochaete Nais is a pest in that in that it has been known to clog filters at water treatment works. The toxicity of various substances to Nais has been investigated by Learner and Edwards (1963) with a view to controlling the animal. Whitten and Goognight (1966) examined the toxicity of three common insecticides to tubificids; they found no apparent difference between the two

genera tested, and found the worms to be more tolerant to the insecticides than either fish or aquatic insects. Whitley (1968) also found identical responses in Tubifex and Limnodrilus (the genera studied by Whitten and Goodnight) in his investigation into the toxicity of various salts to the worms. The toxicity of lead was found to vary with pH, from 27.5 to 49.0 $mg.l^{-1}$ (96 hour LC_{50}). This figure is higher than those found by various workers for other aquatic organisms, and a similar situation was found by Whitley (1968) for zinc.

Warnick and Bell (1969) have determined the acute toxicity of the salts of copper, zinc, cadmium, lead, iron, nickel, cobalt, chromium and mercury to three species of aquatic insects. They found the insects to be less sensitive to these metals than are fish. The huge differences in tolerance exhibited by different species are emphasised by the work of McIntosh and Kevern (1974); they found that the TL_m (96 hour), using copper sulphate, was 0.096 $mg.l^{-1}$ for Daphnia pulex and 225.0 $mg.l^{-1}$ for Cyclops sp.

Thorp and Lake (1974) have studied the toxicity of cadmium to selected invertebrates, and in addition have studied the effects of the interaction of cadmium and zinc in studies using the shrimp Paratya tasmaniensis Riek. They found a huge range of toxicities of cadmium, from 0.04 $mg.l^{-1}$ (96 hour LC_{50}) for an amphipod to well over 2000 $mg.l^{-1}$ for a trichopteran. They found some evidence of seasonal differences in sensitivity to cadmium in Paratya. Zinc and cadmium acted less than additively at certain concentrations; at higher concentrations the interaction was strictly additive.

A pollutant not normally the subject of toxicity tests is hydrogen sulphide; Oseid and Smith (1974) have studied some factors influencing the acute toxicity of this substance to freshwater invertebrates. Their results, which show that factors

not normally controlled can exert an important influence, led them to emphasise that test conditions should approximate natural habitat conditions as closely as possible. The chronic exposure tests of these authors led them to suggest that 'no-effect' levels are 8 to 12 percent of the 96 hour LC_{50}. These concentrations, it is postulated, will permit satisfactory completion of all stages of the life-histories of three species studied. Abel (1974), who has studied the toxicity of synthetic detergents to fish and aquatic invertebrates, has also considered low-level as well as acute toxic effects, and he also points out that although the effects of low levels of pollutants are usually studied over long exposure periods, it is incorrect to assume that such effects can only be detected in this way. Abel (1974) suggests that factors causing death in acute toxicity tests may not necessarily be operative at low concentrations of toxin.

Tarzwell (1971) has discussed the use of bioassays to determine allowable waste concentrations in the aquatic environment. He feels that long term studies are essential for determining safe levels of potential poisons under continuous exposure, but appreciates that such work is expensive and time consuming. Tarzwell (1971) emphasises that short term methods are needed for determining long term effects, and feels that histopathological, histochemical and other methods will be useful in this respect.

Lloyd (1972) regards acute toxicity tests as being of limited value; he emphasises that results from sub-lethal tests can give an insight into the mechanisms of toxic action and feels that toxicity tests should be designed to show levels at which poisons exert no adverse effect. It is pertinent to quote from Lloyd (1972), whose remarks in relation to fisheries apply also to other facets of the biota: "It seems certain that there is no single concentration of a poison above which fisheries will be absent and below which

they will flourish. Rather, there is a range of increasing concentration within which fisheries will show a progressive deterioration, either in quality or numbers."

Plate 1. Site 1, Irwell Springs, viewed from downstream.

Plate 2. Site 2, Townsend Fold, viewed from downstream

Plate 3. Site 3, Irwell Vale, viewed from downstream.

Plate 4. Site 4, Summerseat, viewed from downstream.

Plate 5. Site 5, Chestwheel Bridge, viewed from downstream.

Plate 6. Site 6, Warth Bridge, viewed from downstream.
Note the large weir upstream of the bridge.

Plate 7. Site 7, Radcliffe, viewed from downstream.

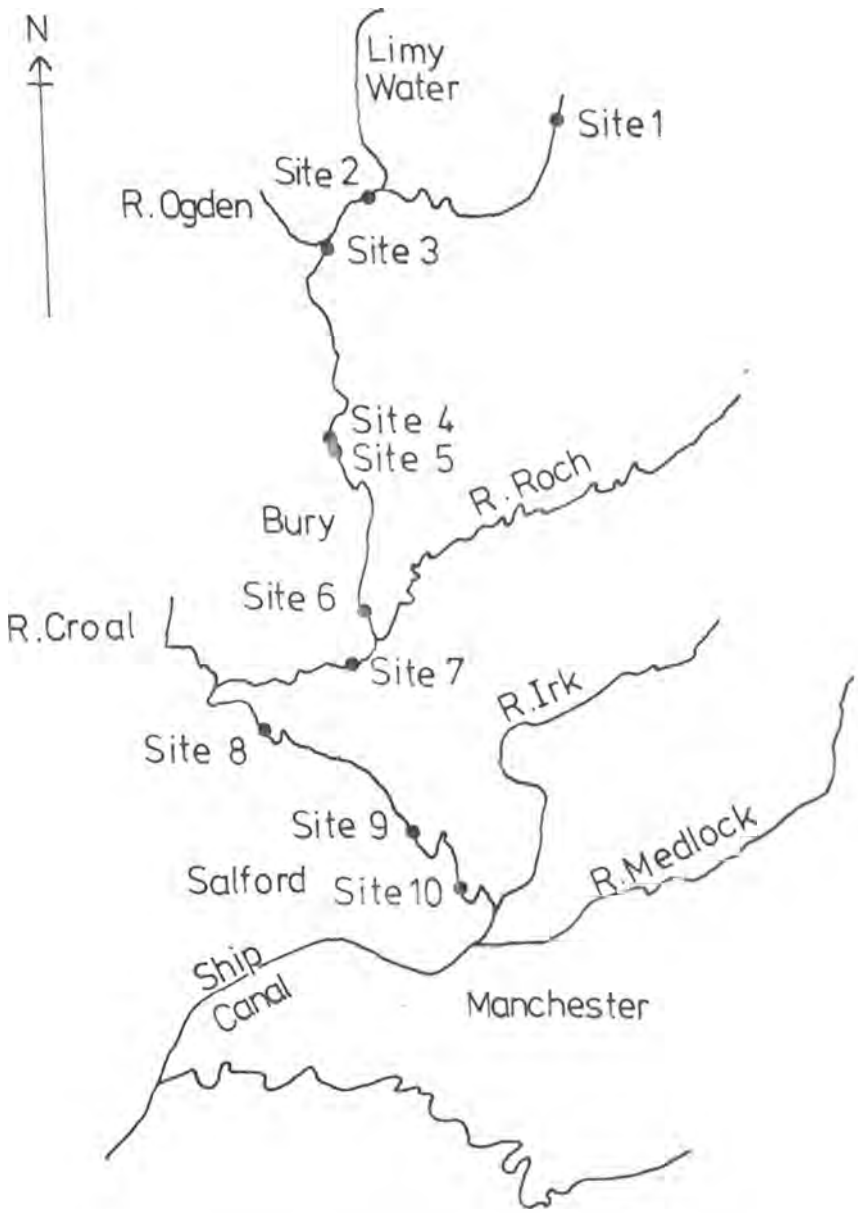
Plate 8. Site 8, Ringly, viewed from downstream.

Plate 9. Site 9, Agecroft, viewed from downstream.

Plate 10. Site 10, Salford, viewed from downstream.

Figure 1.

Sketch map of the River Irwell, showing sampling sites.



Scale 1 : 250 000 — 5 miles / 8 km

METHODS.

1. The sampling sites.

The ten sites sampled in the present survey were chosen to correspond as closely as possible with those used in previous work on depositing substrates (Eyres, 1973); their positions are shown on figure 1. Samples were taken from areas of river bed with stony substrate and swift current velocity. These habitats are often described as riffles or stickles. The North West Water Authority collects water samples monthly from the Irwell for routine chemical analyses. The author's sampling sites corresponded as closely as possible with those visited by the Authority's chemists. Detailed descriptions of the sampling sites follow.

Site 1. Irwell Springs. Grid reference SD874258.

The Irwell at this site, which is close to the source of the river, is polluted by acid mine drainage from disused colliery workings and the bed is covered with a characteristic deposit of ferric hydroxide. The water is usually clear, and flows swiftly over a stony bed. The stream is about 1 m wide and 15 cm deep in dry weather (see plate 1).

Site 2. Townsend Fold. Grid reference 801220.

The river here is about 17 m wide and 30 cm deep in dry weather. The ferric hydroxide precipitate so apparent at site 1 is no longer evident. Samples were taken upstream of the bridge shown in plate 2.

Site 3. Irwell Vale. Grid reference 792202.

Samples were taken just upstream of the confluence with the heavily polluted River Ogden, downstream of a small weir (plate 3). The river at site 3 has similar characteristics to those of site 2.

Site 4. Summerseat. Grid reference 794146.

The river flows over a large riffle bounded upstream and downstream by pools (see plate 4). The current is swift; the stream is about 20 m wide. Water samples are not collected from this site by the Water Authority; their nearest collection point is 250 m downstream at site 5.

Site 5. Chestwheel Bridge. Grid reference 795144.

Site 5 is about 250 m downstream from site 4; between the two a small sewage outfall enters the river. The riffle at site 5 is not as extensive as at site 4, and the water flowing over it is deeper. The channel in which the riffle is formed is quite narrow (plate 5).

Site 6. Warth Bridge. Grid reference 797090.

Samples were taken downstream of the roadbridge, about 50 m downstream of a large weir (plate 6). The river is about 20 m wide, and the substrate is rather more uniform than at previous sites. The stones are often covered with substantial deposits of Cladophora, with some sewage fungus. Water Authority chemists collect their samples upstream of the weir.

Site 7. Radcliffe. Grid reference 786069.

This site is about 50 m downstream of the A668 road bridge in Radcliffe (plate 7). The river is about 25 m wide. The bed of the river is invariably covered with sewage fungus. The substrate, which contains much rubble and some glass, is black and anaerobic beneath the surface even in reaches with swift flow.

Water analyses for this site in fact refer to a point about half a mile downstream of the author's sampling site.

Site 8. Ringly. Grid reference 763053.

The river at Ringly is about 22 m wide, and is generally slow moving and deep with a muddy bed not suitable for the sampling method employed. A small island has developed at one point, and

between this and the west bank, a small riffle has built up. This area (plate 8) was suitable for the purposes of the present survey.

Site 9. Agecroft. Grid reference 807020.

Samples were taken downstream of Agecroft power station and the A6044 road bridge. The river is about 34 m wide. The riffle sampled is about two miles downstream of the point where the Water Authority collects water samples for chemical analysis.

Site 10. Salford. Grid reference 823993.

This site is about a mile downstream of the Cromwell Road bridge, where the Water Authority collects samples for analysis, at a point where a footbridge links Salford University to Lower Broughton. The river, about 30 m wide, is partly canalised, and the substrate sampled consists largely of bricks and pieces of concrete, with much broken glass.

2. The sampling technique.

Samples were taken using the apparatus described by Surber (1937) and since known as the Surber sampler. The sampler enclosed a substrate area of 1 ft^2 (929 cm^2) and was used with a net with mesh aperture 1 x 0.25 mm.

Ten sites along the length of the river were sampled, and three Surber samples were collected from each of these on a monthly basis from October 1972 until October 1973. Samples were thus collected on thirteen occasions; in practice, it proved impossible to examine all of these samples due to the excessive work load involved. Faunal analysis was thus carried out on a bi-monthly basis, seven sets of samples being examined.

The sampler was used in the standard way, the net frame being gripped between the knees while the hands were used to scrub the fauna from stones in the area delineated by the quadrat frame and then to stir up the finer substrate to a depth of about 5 cm. After taking the sample, fauna and debris were washed to the foot of the net by sweeping it through the water. The material collected was transferred to a jar, and 40 percent formalin was added to give a strength of about 5 percent. Formalin had previously been buffered with calcium carbonate to prevent damage to mollusc shells. The stony substrates of the Irwell harbour large amounts of organic detritus, even in areas where the current is quite swift. Accumulation of this debris in the sampler net occasionally caused clogging, impeding the flow of water and reducing the efficiency of the sampling technique. This is an inevitable problem when nets are used to sample heavily polluted streams. Larger mesh sizes alleviate the problem, but of course allow the escape of relatively larger numbers of animals. The three samples at each site were usually taken in a row at right angles to the

current, about 2 m apart. Where this was not possible, for example at site 1, the samples were taken working upstream.

Samples were not collected from site 3 (Irwell Vale) between October and December 1972, as dredging work was being carried out at this time. No samples were collected from site 8 (Ringly) prior to April 1973, since the nature of the substrate was not suitable for Surber sampling until that month. The blocking of an access point prevented the collection of samples from site 10 (Salford) in October 1973.

3. Determinations made at the sampling sites during the survey.

Determinations of various physical parameters were made at each site on a monthly basis during the survey period. Dissolved oxygen concentration was measured with an E.I.L. meter fitted with a Mackereth type electrode. The instrument was calibrated in the laboratory prior to use, using water aerated to saturation. The assumption that such water was 100 percent saturated was verified using the Winkler technique. Current speed was measured at the point from which each Surber sample had been taken, using an 'Ott' propellor driven flow meter (type "10.152"). The determination was made as close as possible to the bed of the river. Water temperature was measured using a mercury thermometer accurate to $\pm$ 0.5°C.

4. Treatment of samples in the laboratory.

Samples were returned from the field and stored in half-pound honey jars preserved in 5 percent formalin buffered with calcium carbonate. When required for analysis, a sample was tipped into a 1 litre beaker; water was added under pressure and when the beaker was full its contents were tipped directly into a sieve with a mesh aperture of 0.125 mm. It was determined by preliminary work that this aperture allowed no fauna to pass. The sieving action was not severe enough to transfer all material to the sieve; grit and pebbles were retained. This process, repeated ten times, served to separate all the fauna, except the occasional large gastropod, from the grit and stones; after examination for any remaining fauna this material was discarded. Where sub-sampling was necessary prior to faunal analysis, this was carried out as described in the following section; if not, the sample was transferred to a series of petri dishes and thinly spread in water prior to examination. Dishes were scanned under the dissecting microscope; Oligochaeta and Chironomidae were prepared for microscopy as described in a subsequent section while all other taxa were identified where possible, counted, and transferred to a specimen tube for storage. Each dish was scanned a second time. If animals were found on the second examination, a third was made, and so on until one entire run yielded no further animals. This leads to confidence that virtually all animals were counted.

5. Sub-sampling.

The sub-sampling technique used was that devised by Allanson and Kerrich (1961), used by Eyres (1973). The sample is placed in an octagonal vessel (600 ml) and made up to a known volume with water. A property of the shape of the vessel, is that the use of a magnetic stirrer distributes the sample randomly, and it is assumed that an aliquot of the sample will represent the sample as a whole (Allanson and Kerrich, 1961; verified by Eyres, 1973). A pipette with a bore of 7 mm was used to withdraw 10 ml aliquots of the suspended sample; depending on the number of animals to be sub-sampled the water in the octagonal vessel was made up to the appropriate volume. 500 ml led to a sub-sample 1/50th of the original sample, and so on.

A problem that arises when one wishes to reduce the amount of time spent sorting samples of benthic invertebrates by sub-sampling is that although certain species may be very numerous, if one sub-samples the entire sample, rarer species may well be missed or inaccurately estimated. Allanson and Kerrich (1961) surmount this problem by initially examining the entire sample, identifying and counting the rarer species, removing these and then sub-sampling the more numerous taxa. The present author found it more convenient to initially sub-sample the entire sample, ignoring at this stage the rarer species and counting only the taxa which merited sub-sampling. The entire sample was 'reconstituted', apart from the sub-sampled forms, for determination of the rarer taxa. In this way, the decision as to which taxa to sub-sample was a more informed one. Using the procedure of Allanson and Kerrich (1961), one is sometimes unclear which taxa to count on the first examination of the sample and which to leave for sub-sampling. If one leaves a species which is not in fact abundant enough to justify sub-sampling,

one is faced with the prospect of counting all the animals on their own when this could have been done along with the rest of the unsub-sampled fauna. If, on the other hand, one counts all the individuals of a species which could well have been sub-sampled, one has clearly wasted much time. To tackle the problem in the order preferred by the author reduces these problems. In the present study, the sub-sampled taxa were usually the Oligochaeta and Chironomidae; often Asellus aquaticus. Sufficient sub-samples were taken to furnish at least 30 individuals of each sub-sampled taxon. Often it was necessary to take more sub-samples for some groups than for others; sometimes 1/50 th. part sub-samples were appropriate for some groups, 1/20 th. for others.

Before microscopic preparations have been made, it is not possible to make accurate identifications of oligochaete worms or chironomid larvae. As has been indicated above, the sub-sampling technique is not suitable for the rare forms of these groups, and it is likely that such taxa will be inaccurately estimated or missed altogether. Since the alternative is the examination of all worms and chironomid larvae, an impossible task, the defficiency must be accepted and acknowledged.

6. Microscopic preparations.

Satisfactory identification of oligochaete worms and chironomid larvae depends upon the preparation of specimens for microscopic examination. The technique for clearing oligochaetes has been fully described by Eyres (1973). Suffice to say that the animals were picked out of the petri-dishes with forceps and placed in rows on glass slides. The animals were then covered with "Gurr's" polyvinyl lactophenol; number 1 or 1½ 20 x 40 mm coverslips were added. After the preparations had dried for six to twelve hours, they were ringed with "Gurr's glyceel", which is well suited to ringing fluid mounts. The permanent preparations were stored in slide trays for at least a fortnight prior to microscopy, during which time satisfactory clearing had taken place.

Chironomid larvae were treated using the method given by Bryce and Hobart (1972). To identify larvae to sub-family, only the head capsules need be mounted, but for specific identifications all parts must be available for examination. Initially, only head capsules were mounted; latterly some bodies were included to verify the identity of some larvae. Specific identifications were not made, however, except for one readily identified species. Larvae were picked out of the petri-dishes with fine forceps and transferred to a small beaker containing 10 percent aqueous potassium hydroxide. When all the larvae from a sample or sub-sample had been placed in a beaker, this was boiled for about a minute. After cooling, larvae were picked out and placed in water in a petri-dish. Head capsules, now cleared of soft tissue, were easy to remove with fine forceps while holding the body of the animal with a mounted needle. Capsules were mounted in rows on slides. The mountant was again polyvinyl lactophenol. Ringing with "glyceel" was sometimes necessary, but only for the larger larvae.

7. Identification of fauna.

Apart from oligochaete worms and chironomid larvae, all animals were identified with the aid of a dissecting microscope. Occassional microscopic preparations were necessary, for example of the gills or legs of Ephemeroptera, in order to identify certain species.

The following works were consulted for the identification of fauna:

Oligochaeta; Sperber (1950)
Brinkhurst (1971)
Brinkhurst and Jamieson (1971)

Hirudinea; Mann (1964)

Crustacea; (Malacostraca) Hynes et al. (1960)

Ephemeroptera; Macan (1970)

Plecoptera; Hynes (1967)

Trichoptera; Hickin (1967)

Coleoptera; Leech and Chandler (1968), Macan (1959)

Hemiptera; Macan (1965)

Mollusca; Macan (1969)

Diptera; Wirth and Stone (1968)

Chironomidae; Bryce and Hobart (1972), Mason (1968).

Most determinations were made to the species level. The larvae and pupae of the Diptera present a notoriously difficult taxonomic problem. In the present study, the majority of dipteran larvae, except the Chironomidae, were identified to the generic level. The chironomid larvae were identified to sub-family after examination of desclerotised head capsules. Problems encountered in the identification of Oligochaeta have been discussed by Eyres (1973). The juveniles of some species are difficult to assign correctly, identification sometimes relying on sexual features present only in mature worms. Setal characteristics allow reasonably confident

identification in such cases, but juveniles of the genus Limnodrilus are exceptionally difficult to determine. Juveniles of Limnodrilus sp. with the setal characteristics of Limnodrilus hoffmeisteri were identified as L. hoffmeisteri, this worm comprising the bulk of the adult worms with this setal form.

Table 1.

Sieve mesh apertures used in the analysis of substrate samples (to BS 1337).

Sieve number.	Mesh aperture (mm).
1	76.2
2	63.5
3	50.8
4	38.1
5	25.4
6	19.05
7	12.7
8	6.35
9	4.76
10	2.0
11	1.18
12	0.60
13	0.42
14	0.30
15	0.21
16	0.15
17	0.075
(18	collecting pan)

8. Examination of the particle size distribution of substrate materials.

To furnish data on the nature of the prevailing physical environment in the river, samples of substrate material were collected from each of the sampling sites in February 1975. These samples were subjected to particle size analysis. Three samples were collected from each site. The sampling technique involved pushing a metal cylinder with a diameter of 35.5 cm and a height of 45 cm into the bed of the river to a depth of approximately 20 cm. The substrate thus enclosed was scooped out with the hands and place in a bucket (5 litre capacity), scooping continuing until the bucket was full. Each bucket held about 5 kg of substrate material. Substrate samples were taken from the riffles whence the Surber samples were taken in the main survey, material generally being collected from points about 2 m apart. Current speed was determined at each collection point, using the method already described. The sampling method tended to result in the loss of some of the finer sediments as material was scooped out of the cylinder through the water. Despite this, the technique leads to samples which are perfectly suitable for comparative purposes; it was used by Edwards (1975) in a detailed study of the particle size distribution of sediments from the River Lune.

In the laboratory, samples were air dried, being spread out on stainless steel trays over a source of gentle heat. The sediments were quite dry after about 24 hours, and were returned to their respective buckets prior to sieving.

The particle size distribution of each sample was determined by passing the material through a series of sieves with mesh sizes as specified in British Standard number 1337. The mesh apertures are listed in table 1.

Material was first passed through sieves 1 to 5, these having a diameter of 45 cm. Sediment passing this series was transferred to the nest of sieves 6 to 9, which had a diameter of 30 cm. Sieves 1 to 9 were shaken by hand, shaking continuing until no further material passed the meshes. The nest of sieves 10 to 18, 20 cm in diameter, was skaken on an electrically driven sieve shaker (Endecotts) for 5 minutes, this period having been shown by experiment to be adequate.

The contents of each sieve, and of the collecting pan, were transferred in turn to a tared weighing box and weighed on a top pan balance (Mettler) to an accuracy of +/- 0.01 g. Sieves with fine meshes were scrubbed with a nylon bristled brush to transfer all traces of substrate to the weighing box. It was sometimes necessary to weigh the contents of a sieve in batches; the largest stones were broken with a hammer and cold chisel for weighing in pieces.

As well as the collection of substrate samples and the determination of current speeds in February 1975, a set of Surber samples was collected in the usual way; this was done in order to furnish data on species distribution and abundance more strictly comparible with the substrate samples than would that drawn from the main survey. This set of samples also provides information on the status of the invertebrate fauna at a time removed from that of the main survey. Dissolved oxygen concentration and water temperature were determined in the usual way.

9. Determination of lead, zinc and copper.

The merits of the methods available for the determination of heavy metals have been discussed in a previous section (literature review). Atomic absorption spectrophotometry was used in the present work, the appropriate apparatus being available in the Department of Chemistry and Applied Chemistry of the University of Salford. The machine used required that samples be prepared in aqueous solution; methods involving chelation into organic solvents would have led to damage to P.V.C. tubing.

All reagents were of a grade suitable for the work in hand (Hopkin and Williams reagents for atomic absorption). Water was glass distilled and deionised. Glassware, previously unused, was grade 'A' for volumetric work, and was cleaned in "DECON 90" prior to use. During use, glassware was rinsed with 50 percent nitric acid followed by deionised distilled water.

Two water samples were collected from each of four sites on 9/3/75, the sites being numbers 2 (Townsend Fold), 6 (Warth Bridge), 7 (Radcliffe) and 9 (Agecroft). The containers used were polyethylene bottles with polyethylene lids, and were of 1 litre capacity. They were cleaned prior to use in "DECON 90" followed by 50 percent nitric acid and five rinses of deioised distilled water. The bottles were rinsed twice in the field with river water prior to collection of the sample. At the start of the sampling trip, two control bottles were filled with deionised distilled water. On returning to the laboratory, 500 ml of each sample was filtered through a "Millipore" filter with a pore diameter of 45μm, using all glass filtration apparatus (Millipore) and a vacuum pump. A 45 μm filter is arbitrarily regarded as removing suspended material from a liquid, dissolved substances remaining with the filtrate (Parker, 1972). Filtrate was transferred to a 1 litre beaker. 5 ml of concentrated hydrochloric acid was

added, acidification of samples reducing absorption of metals onto glass surfaces. In order to concentrate metals for analysis, the samples were placed in a drying oven, in the beakers, at a temperature of 95 - 100°C until almost dry. The contents of each beaker were then washed, with deionised distilled water, into a 25 ml volumetric flask and made up to volume. A portion of each sample (about 12 ml) was transferred from the volumetric flasks to glass vials with polyethylene lids and stored in a refrigerator (4°C) prior to atomic absorption spectrophotometry.

The collection of representative samples of substrate material from streams for metal analysis can present problems. If mud samples are taken, problems of interpretation arise, since the organic content of the substrate of the substrate, which may vary greatly, has a considerable influence of the level of metal accumulated. This problem can be surmounted by determining organic content; however, in the present survey it was felt to be more useful to collect scrapings of the film coating the stones on the stream bed. This material was quite thick in places, comprising, among other things, algae and sewage fungus. It is felt that this material provided a more representative sample of that portion of the stream's substrate available to riffle dwelling animals as food than other substrate materials. Since the material is almost wholly organic in nature, it can be completely digested in appropriate solutions, dispensing with problems of interpretation arising from the presence of varying amounts of insoluble organic material.

Samples of substrate material ('stone slime') were collected by scraping stones with a flexible nylon spatula, care being taken to exclude animals as far as possible. Samples were returned to the laboratory in rinsed plastic urine cups (250 ml) with

plastic lids, and deep frozen prior to digestion and analysis.

It was not possible in the time available to collect adequate numbers of all invertebrate species present in the Irwell for the determination of heavy metal levels. For this reason, two readily identifiable species were chosen which occured at a number of the sampling sites, were numerous enough to collect in sufficient quantities for analysis, and which did not require laborious separation from substrate materials. These species were Asellus aquaticus and Erpobdella octoculata. Samples were collected with a simple pond net, the feet being used to dislodge animals from the substrate. The catch was tipped into a white enamelled dish, and was sometimes supplemented with leeches collected by hand from stones picked up from the streambed. The contents of the dish were searched, and animals were picked out with plastic forceps and placed in plastic urine cups. If possible, three samples of each species were collected from each site at which they occured; where feasable, a sample of Asellus comprised about 100 animals, a sample of Erpobdella about 10 animals. Scarcity at some sites made these targets unattainable. Samples were frozen in the laboratory prior to analysis.

Samples of substrate and fauna were treated in a similar fashion prior to atomic absorption spectrophotometry. The sediment samples (stone slime) were thawed, drained and transferred to tared 100 ml conical flasks, using plastic forceps. Fauna samples were thawed, drained, tipped onto a double thickness of filter paper, blotted with further filter paper and counted into tared 100 ml conical flasks. After wet weight determination, flasks were transferred to a drying oven at 105°C, to constant weight. After cooling in a dessicator, weighing gave the dry weight of the sample.

The digestion procedure used was based on that of Bryan and Hummerstone (1971). To the dried samples in the conical flasks was added 10 ml of concentrated nitric acid. Each flask was covered with a watch glass (convex face down) and placed on a thermostatically controlled hotplate set to give a temperature in the flasks of 80 - 90°C. Digestion was carried out in a fume cupboard. The convex surface of the watch glass resulted in a simple refluxing system, vapours condensing on the watch glass and dripping from its centre back into the flask. The effect was similar to that of the glass ball used by Bryan and Hummerstone (1971). This refluxing digestion was allowed to proceed overnight, after which time the watch glass was removed to allow evaporation of the acid. The dry sample was redissolved in 50 percent hydrochloric acid; Bryan and Hummerstone (1971) used 2 ml of acid, but considerably more was found to be necessary in the present work. The hydrochloric acid was evaporated off, on the hotplate, and sufficient hydrochloric acid was added to give a 0.1 M solution when the sample was washed with deionised distilled water into a 25ml volumetric flask. After making up to volume, about 12 ml of each sample was transferred to a glass vial and stored in a refrigerator (4°C), prior to analysis. In addition to the sample digestions, blank digestions were carried out in order to check for contamination of reagents or glassware.

Atomic absorption spectrophotometry does not give direct readings of concentration. It is necessary to compare sample data with data drawn from readings using a series of standards of known concentration. These were made up from accurately prepared solutions with metal concentrations of 1000 $mg.l^{-1}$, supplied by Hopkin and Williams Ltd. The standards are supplied made up in 0.1 M perchloric acid. Appropriate concentrations were made up by dilution, and were kept in plastic topped glass vials under

refrigeration prior to atomic absorption spectrophotometry.

Metal concentrations were determined using a Pye Unicam SP900 atomic absorption spectrophotometer. The hollow cathode lamps were manufactured by Activon Glass Ltd., the pen recorder by Perkin Elmer Ltd. In all cases, the flame was produced by a mixture of air (approximately 28 $lb.in^{-2}$) and acetylene (10 to 12 $lb.in^{-2}$), gases being fed from cylinders (British Oxygen Company Limited). The various instrument parameters, such as slit width and lamp current, were set initially according to the manufacturers instructions, but in practice use of the machine was somewhat empirical, a certain amount of unpredictable drift being encountered.

Normally, the instrument was set such that zero absorption and 100 percent absorption gave traces on the pen recorder at the bottom and top of the paper respectively. Absorption is assumed to be proportional to the concentration of absorbing (metal) ions. A plot of concentration versus absorption is slightly curved, giving lower sensitivities at higher concentrations. Absorbance, A, is given by;

$$A = \log((X - Y)/d)$$

where X = chart reading with shutter closed ('100 percent absorption')

Y = chart reading for unabsorbed lamp output ('zero absorption')

d = chart reading for sample

For low levels of metals, which cannot be detected using the apparatus set as described above, scale expansion was used. This was achieved by increasing slit width, lamp current or amplifier gain. The zero control is adjusted so that the 'unabsorbed' reading still remains at the base of the paper trace. Over a short concentration range, especially near the sensitivity limit of the apparatus for the element under analysis, concentration

is an almost linear function of percent absorption. Under such circumstances, $(d - X)$ was plotted against concentration.

With atomic absorption spectrophotometry, it is essential that sufficient standards be run at intervals, interspersed with the samples, to allow an accurate calibration curve to be plotted. In the present work, at least five standards were always used, and were run after each set of ten samples.

10. Toxicity tests.

The rationale for conducting toxicity tests has been discussed in a previous section (literature review). In the present context, the aim was to discover the toxicities of lead, zinc, copper and ammonia to Erpobdella octoculata and Asellus aquaticus.

The tests carried out were of the acute, static type; the methods used were based on standard methods given in A.P.H.A. (1971). Tests were run in water from the River Hodder (Lancashire), a trout stream flowing into the River Ribble. No unpolluted water was available from the Irwell or its larger tributaries. Chemical analysis of Hodder water showed it to have total hardness of 119 $mg.l^{-1}$, calcium hardness of 105 $mg.l^{-1}$ and bicarbonate alkalinity of 110 $mg.l^{-1}$. Tests were carried out in a cold room, with a light / dark cycle of 12h/12h. Light was provided by fluorescent tubes. The test vessels were 1 litre, 'squat' form, glass beakers.

Animals for bioassay were collected from site 9 (Agecroft) and were acclimatised for at least one week prior to testing. Erpobdella were acclimatised in the test beakers, ten per vessel, in about 500 ml of Hodder water. Asellus were acclimatised in pneumatic troughs, in about 1 litre of water, and it was found that about 60 animals per trough gave a good survival rate. Both troughs and beakers were covered with sheets of glass to exclude dust, but aeration was not found to be necessary.

After acclimatisation, 10 Asellus were transferred, using very fine, light forceps, to each test beaker containing 490 ml of Hodder water. The leeches, already in the beakers, were found to remain attached to the glass sides of the vessel as the acclimatisation water was poured off; this was quickly replaced by 490 ml of test water. Animals were left in the final

batch of test water overnight; toxicants were added the following morning, dissolved in 10 ml deionised distilled water to make the total test volume up to 500 ml. Concentrations of toxicant are expressed as $mg.l^{-1}$ metal or ammonium radical, but the following salts were used to make up the test solutions: zinc chloride ($ZnCl_2$), copper chloride ($CuCl_2$), lead chloride ($PbCl_2$) and ammonium chloride (NH_3Cl_2). The range of poisons was designed to follow the logarithmic progression recommended by A.P.H.A. (1971). Five concentrations and a control were run for each test; the object was to determine 96 hour LC_{50}, but observations were made throughout the tests. Dead animals were removed as soon as possible. Lack of response with fine forceps was taken as an indication of death. The pH of test solutions was recorded and ambient temperatures were noted.

11. Artificial substrate sampling.

When the sites sampled in a pollution survey have different substrate characteristics, it is often difficult to decide how much of an observed difference in fauna between sites is attributable to pollution and how much to the substrate and other variables. For this reason many workers (see literature review) have used various devices designed to present a uniform, standardized substrate to the fauna. For the purposes of the present work, a device was necessary which would be cheap, robust and 'child proof' (this latter requirement proved impossible to satisfy, as will be mentioned subsequently).

It was decided that baskets, of the type used for autoclaving glassware, constructed from ½ inch (1.27 cm) plastic coated steel mesh, would be suitable in that they would contain the substrate while allowing free access for colonizing invertebrates. Such baskets are available in a range of sizes. Two sizes were tested in the first instance, 20 x 20 x 20 cm and 14 x 14 x 14 cm. Two baskets of each size were installed at site 4 (Summerseat) on 4/12/74. The baskets were filled with stream bed material, on site, and were dug into the substrate so that as far as possible their tops were flush with the river bottom. This was not easy, and in some cases it was necessary to build up material around a basket to a certain extent. The rationale for using on-site substrate materials, when the main object of the technique is to standardize substrate, may seem obscure. It was felt that it might have been possible to install samplers at a number of sites using substrate obtained from just one site. The baskets were placed in a square, approximately one metre

apart, in about 15 cm of water. They were left in place for a month (until 4/1/75, and then removed using the following procedure. The current speed over each basket was measured, using an 'Ott' propellor driven flow meter (type '10.152'); then, working on downstream baskets first, each basket was pulled out of the streambed and transferred to a plastic bowl gripped between the knees, using one swift movement. On returning to the river bank, the baskets were emptied into plastic buckets. The debris collected in the bowl upon removal of a basket was added to the appropriate bucket.

The basket samplers collected on 4/1/75 yielded enormous numbers of animals; for example, the two smaller baskets each contained ca. 30 000 specimens of the oligochaete Nais elinguis. It was decided that nothing would be gained by examining the larger baskets, the vast amount of accumulated organic material making analysis very laborious, even with sub-sampling. Clearly the substrate presented was more attractive to the worms than the surrounding substrate. This might be due to the looser packing of material in the baskets, allowing dense colonisation to a greater depth than normal, and also due to the accumulation of excessive amounts of detritus. It was decided not to proceed using baskets filled with 'natural' substrate materials. Instead, a technique was applied using pebbles of similar shape and size to fill 15.2 x 15.2 x 15.2 cm baskets made of plastic coated ½ inch (1.27 cm) steel mesh. The material was obtained from a beach; it was sieved using two mesh sizes, 63.5 and 38.1 mm. Pebbles passing the larger mesh and retained by the smaller were kept for use in the baskets. Three batches of these pebbles were subsequently analysed for their particle size distribution.

Plate 11. Artificial substrate samplers prior to installation.

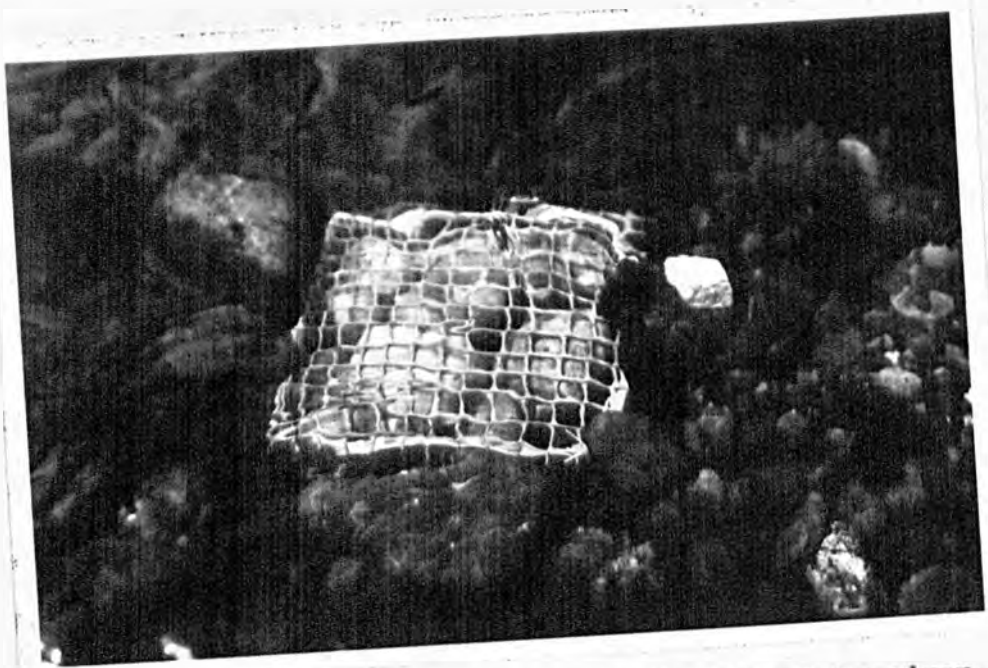


Plate 12. Basket sampler installed in the bed of the river.

The results of these analyses were as follows:-

Sieve aperture (mm).	Weight of pebbles retained (g).		
	I	II	III
50.8 mm	474 (4.7%)	2931 (30.2%)	2110 (21.8%)
38.1 mm	8826 (88.3%)	6570 (67.8%)	8055 (83.1%)
25.4 mm	692 (6.9%)	195 (2.0%)	345 (3.6%)

It will be noted that some stones which were retained by the 38.1 mm aperture in the field were not retained by it in the laboratory. This is due partly to the irregular shape of some of the pebbles and partly to the more vigourous shaking carried out in the laboratory.

Baskets were packed with stones selected as randomly as possible from the pile of pebbles. Care was taken not to use force to fill spaces. After all the baskets (20) had been filled, five were emptied again and the stones contained therein weighed and counted, yielding the following information:-

	Basket number				
	1	2	3	4	5
Weight of contents (g).	5126	5250	5185	5331	5277
Number of stones.	35	36	32	34	35

The tops of the baskets were covered with squares of ½ inch (1.27 cm) plastic mesh held in place with nylon twine. The resulting sampling cubes were easily stacked (see plate 11) and handled, although rather heavy to carry in any numbers over distances. Two surveys were made using the pebble filled baskets.

On 24/2/75 ten baskets were installed at site 2 (Townsend Fold) and ten at site 6 (Warth Bridge). At both

sites the baskets were installed about 1 m apart in two rows of five across the stream, one row about 1 m upstream of the other. The depth of water over the samplers was 10 to 20 cm at site 6, slightly more at site 2. Plate 12 shows samplers installed in the stream bed. The baskets were left in place for a month, and on 24/3/75 were removed using the technique already described. On the same day, five Surber samples were collected from each of the two sites.

Although ten baskets were used at each site, it was only necessary to examine the fauna collected by five of these to obtain useful data. To have examined the rest would have taken an excessive amount of time.

Once it had been established that the method described above was a useful one (statistical procedure given in 'results') when applied with five samplers per site, it was decided to extend the number of sites covered, although the number of baskets available (20) was a limiting factor. On 1/7/75 five baskets were installed at each of the following sites:- site 2 (Townsend Fold), site 6 (Warth Bridge), site 7 (Radcliffe) and site 9 (Agecroft). They were removed on 1/8/75. Unfortunately, a considerable amount of disruption of the baskets had occurred in the intervening month, apparently caused by children. Only two baskets were recovered from site 2. One, and that displaced, remained at site 6. All five baskets were recovered intact from site 7, but four had disappeared from site 9. This vandalism emphasises a problem facing any worker who wishes to leave equipment in the field; one is seldom justified in putting expensive apparatus at risk, so all such apparatus must be as robust and cheap as possible. After removal of the baskets, five Surber samples were collected, for comparitive purposes.

Table 2 .

Water temperatures, as measured by the author, over the course of the survey period and in February 1975. Results as ^{o}C.

Site.	1	2	3	4	5	6	7	8	9	10	MEAN
Month.											
Oct. 1972	4.9	7.6	-	8.1	8.8	10.0	13.0	11.5	11.5	11.5	9.7
November	3.5	4.0	-	4.1	4.1	4.5	5.1	4.9	5.9	5.5	4.6
December	6.5	7.0	-	7.0	7.0	6.5	8.5	7.5	8.0	7.5	7.3
January	0.5	0.5	1.5	1.5	2.0	2.0	2.0	5.0	5.0	4.5	2.5
February	5.5	6.5	6.5	7.5	7.5	7.5	8.5	9.0	8.5	9.0	7.6
March	6.2	7.0	7.5	7.5	8.0	8.0	9.0	-	9.5	9.5	8.0
April	6.5	7.5	9.5	10.5	10.5	11.5	11.5	-	11.0	11.5	11.5
May	8.3	9.7	10.6	11.7	11.7	12.8	14.4	14.4	14.7	15.0	12.3
June	13.0	16.0	17.0	19.0	19.0	20.0	21.0	22.0	22.0	22.0	19.1
July	11.0	13.0	14.0	14.0	15.0	16.0	18.0	19.0	19.0	18.0	15.0
August	11.0	13.0	15.0	16.0	16.0	17.0	19.0	18.0	18.0	18.0	16.1
September	6.0	6.5	7.0	7.5	8.0	8.0	10.0	10.0	13.5	-	8.5
October 73	6.5	7.5	8.0	7.5	8.0	8.0	10.0	9.5	9.5	-	8.3
February 75	3.5	4.5	4.5	5.0	5.0	5.0	5.0	5.0	5.5	5.5	4.9

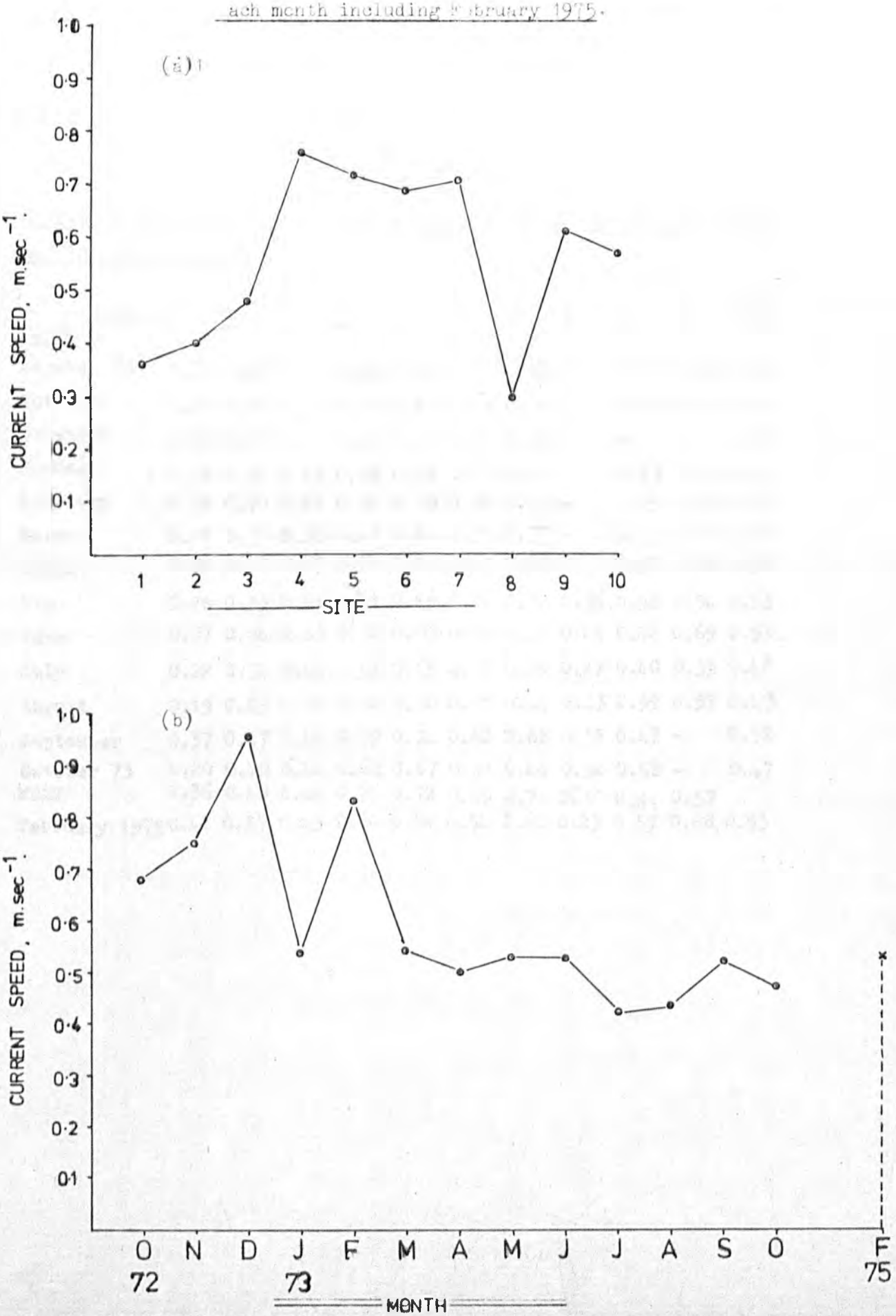
Table 3 .

Current speed ($m.s^{-1}$) recorded over the course of the survey period and in February 1975.

Month. \ Site.	1	2	3	4	5	6	7	8	9	10	MEAN
October 72	0.31	0.37	-	0.94	0.86	0.80	0,82	-	0.65	0.70	0.68
November	0.35	0.36	-	1.10	0.88	0.78	0.89	-	0.79	0.83	0.75
December	0.83	0.68	-	1.03	1.11	0.79	1.34	-	-	-	0.96
January	0.26	0.32	0.45	0.98	0.59	0.63	0.65	-	0.53	0.48	0.54
February	0.78	0.50	0.92	0.96	0.78	0.76	0.93	-	0.95	0.92	0.83
March	0.19	0.38	0.38	0.67	0.66	0.75	0.77	-	0.72	0.30	0.54
April	0.38	0.41	0.47	0.61	0.46	0.69	0.63	-	0.59	0.30	0.50
May	0.26	0.33	0.41	0.61	0.69	0.79	0.78	0.36	0.58	0.50	0.53
June	0.37	0.34	0.53	0.72	0.83	0.69	0.50	0.25	0.42	0.69	0.53
July	0.22	0.34	0.42	0.55	0.65	0.57	0.39	0.27	0.40	0.35	0.42
August	0.19	0.29	0.34	0.52	0.50	0.61	0.44	0.23	0.59	0.59	0.43
September	0.37	0.47	0.50	0.49	0.74	0.62	0.68	0.35	0.47	-	0.52
October 73	0.20	0.40	0.40	0.67	0.67	0.51	0.44	0.32	0.58	-	0.47
MEAN	0.36	0.40	0.48	0.76	0.72	0.69	0.71	0.30	0.61	0.57	
February 1975	0.42	0.57	0.45	0.60	0.64	0.54	0.62	0.23	0.59	0.68	0.53

Figure 2.

Mean current speeds recorded during the survey period showing (a) the mean values for each site and (b) the mean values for each month including February 1975.



RESULTS.

1. Water temperature.

Table 2 shows the water temperature recorded monthly at each site. Highest temperatures were recorded in June 1973; lowest in January 1973. Variations in temperature between sampling sites are largely a result of determinations being made at different times of day, although altitude is obviously an influential factor.

2. Current speed.

Table 3 shows the current velocities recorded monthly at each site, together with the mean values for each site over the survey period and each month over the river as a whole. These means are shown graphically in figure 2.

In common with many streams in the north of England, the Irwell is prone to spates which can result in dramatic increases in discharge over very short periods. For obvious reasons, sampling was not carried out when the river was high, and the recorded current speeds do not give a true picture of the range of current speeds actually prevailing in the river. Another factor influencing the interpretation of the data is the concept of the boundary layer, Hynes (1970) revieving the work of Schmitz (1961), Hubault (1927) and Ambühl (1959, 1961, 1962) on the subject. The velocity of flow at a point in a channel is inversely proportional to the logarithm of the depth; the rate of flow thus decreases rapidly towards the bottom and there is a boundary layer right on the bottom where it declines very rapidly to zero. Turbulence leads to a thicker boundary layer. The experimental work of Ambühl (1959, 1961, 1962) has demonstrated the presence of a boundary layer 1 - 3 mm thick on the tops of stones,

higher flow rates leading to a thinner boundary layer. Clearly the measurement of current velocity with the type of meter used in the present survey yields figures of dubious biological significance with regard to the benthos. The data, however, do provide useful comparisons between sites in that they may be expected to reflect the rigour of the environment in terms of the thickness of the boundary layer. Seasonal observations are not really valid, since the days for field work were selected with a view to low water levels; however, there is an indication of higher mean current velocities in the winter months (figure 2), January 1973 being an exception.

Figure 3.

Particle size distributions of substrate samples.

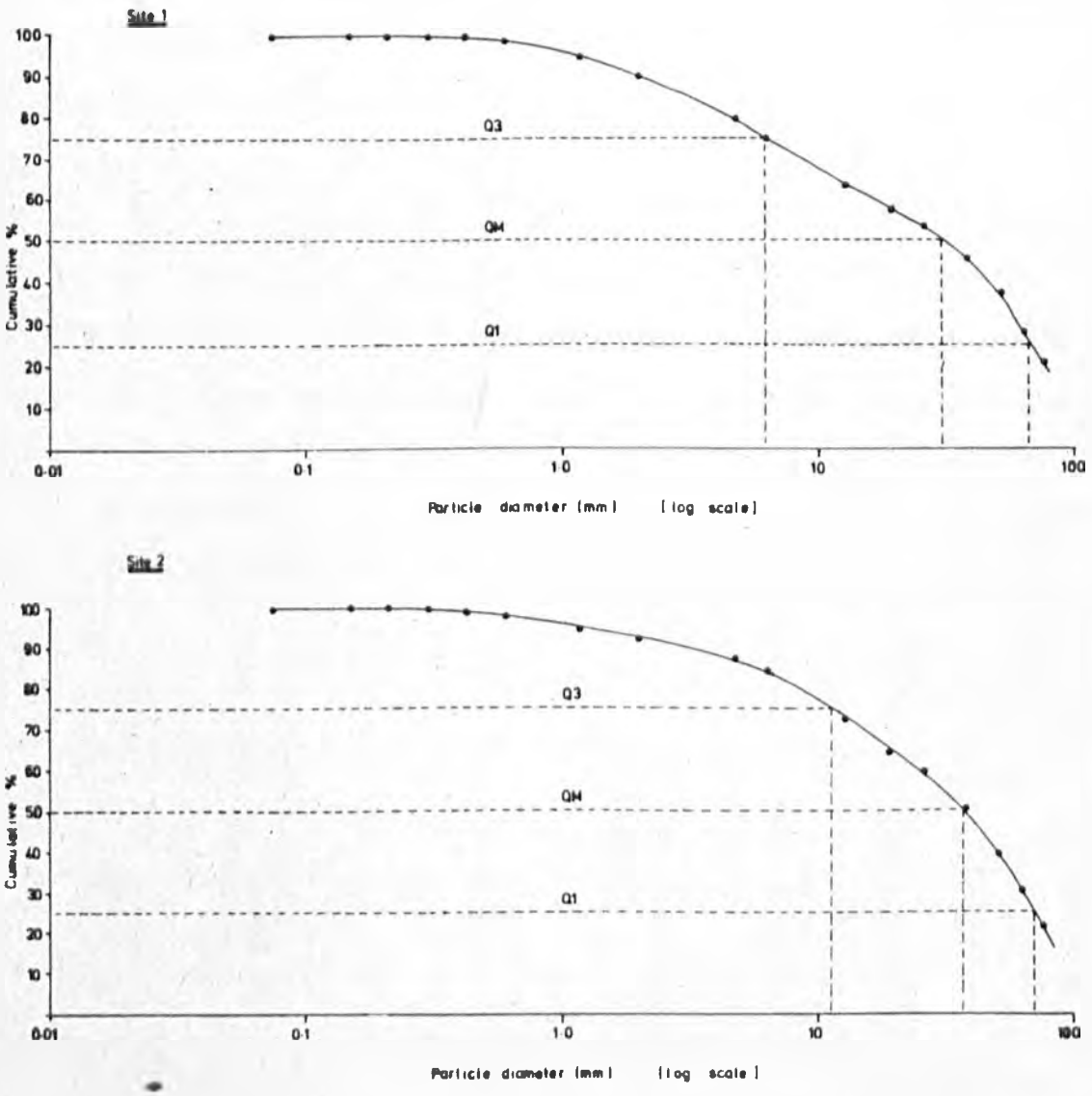


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Figure 3 (cont.)

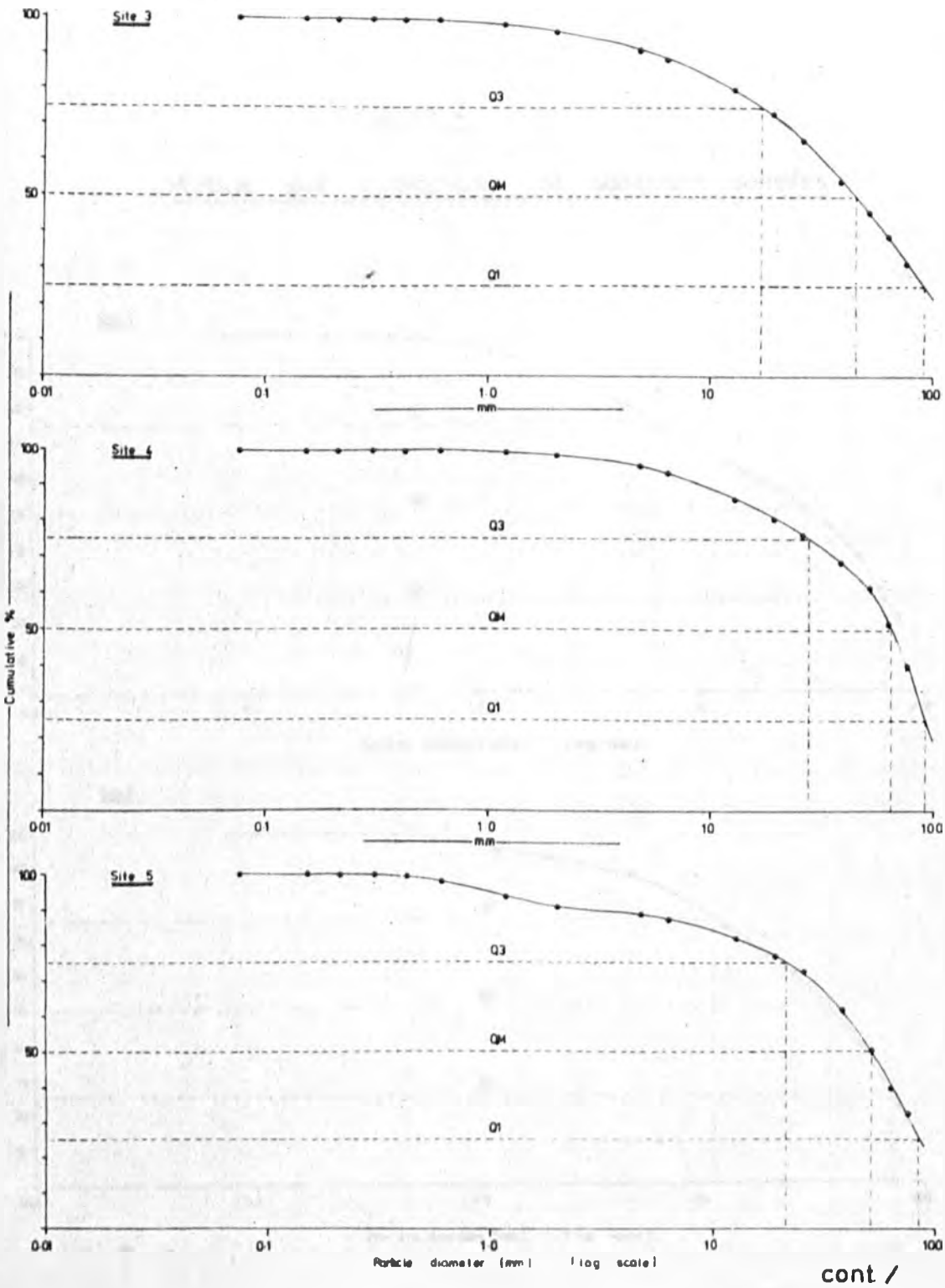

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Figure 3 (cont.)

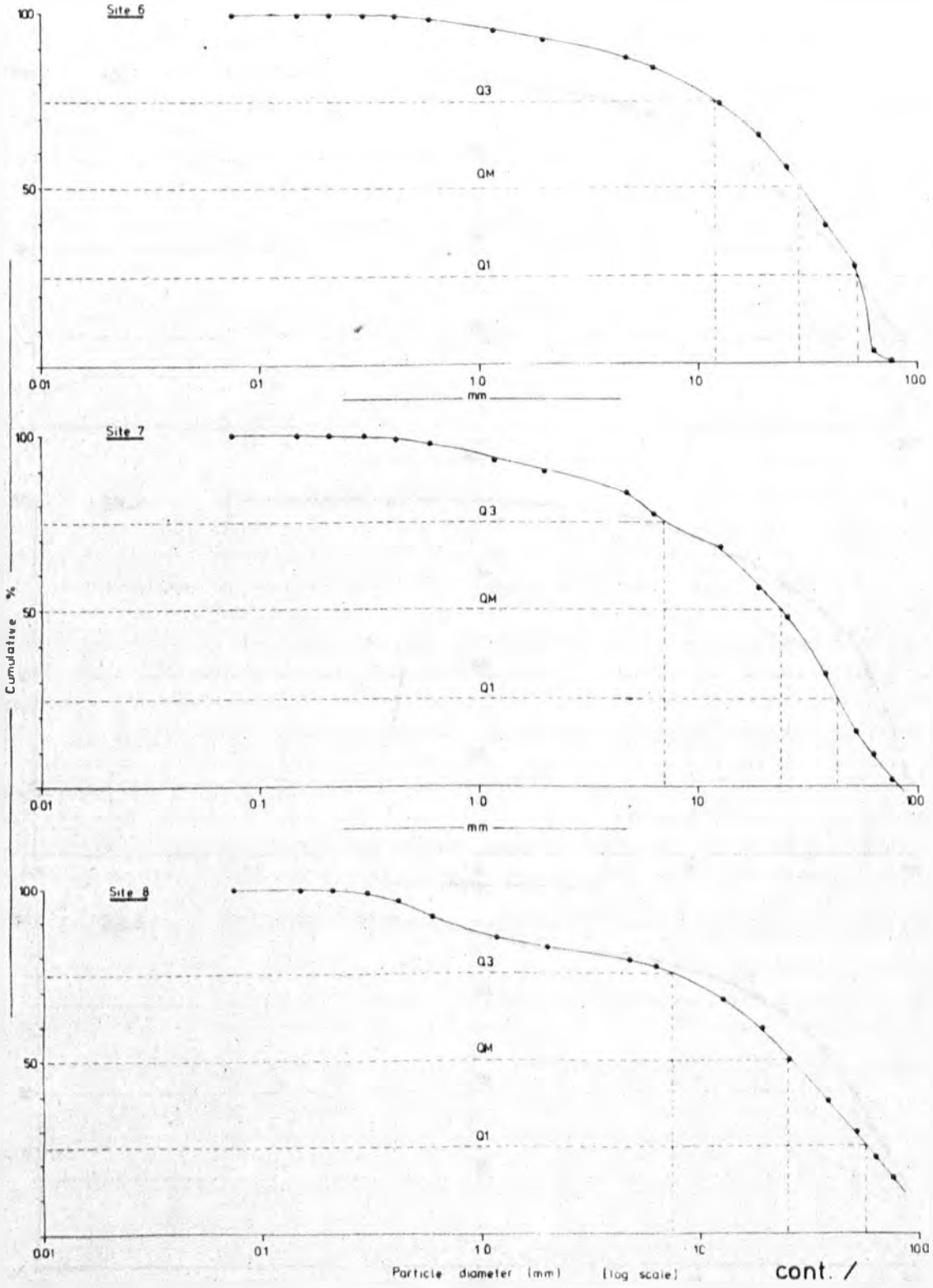

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Figure 3 (cont.)

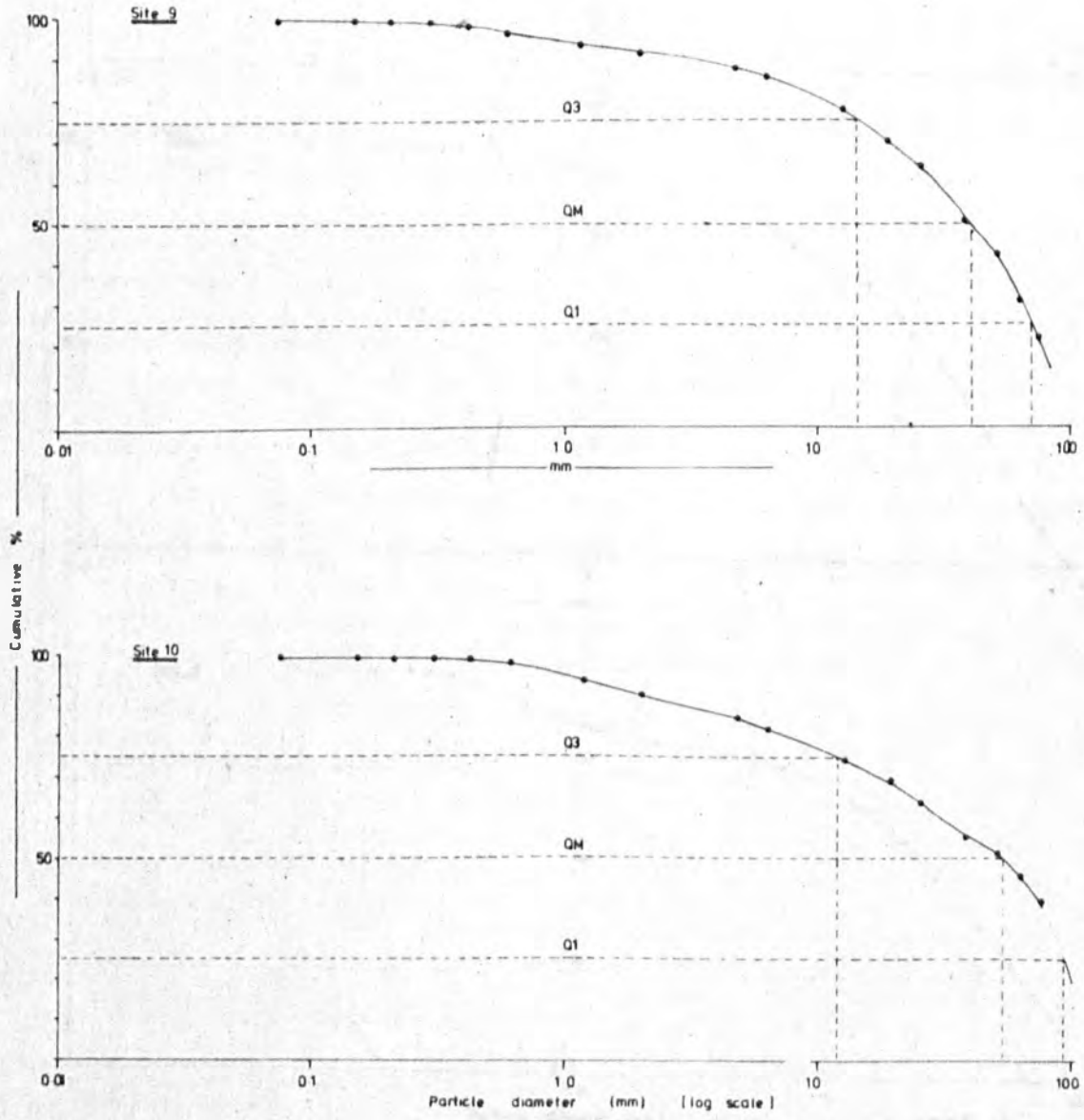


Table 16.

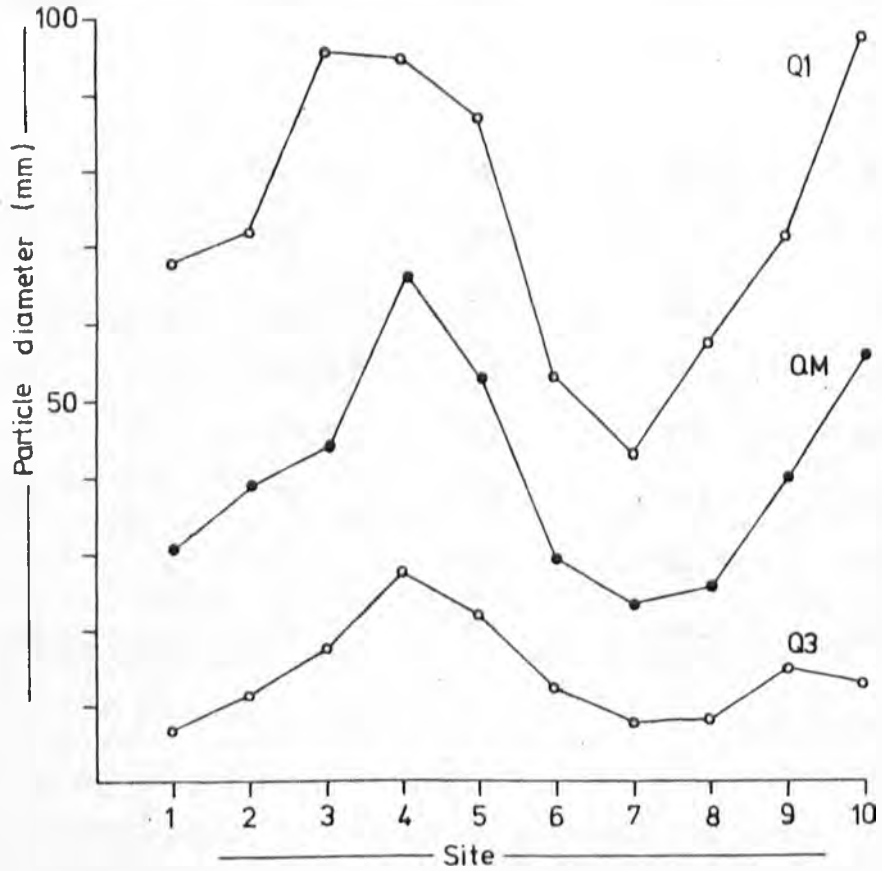
Parameters derived from analysis of particle size distributions of substrate samples collected in February 1975.

Median particle diameter (QM), mesh size retaining 25 percent of sample (Q1) and 75 percent of sample (Q3), and quartile deviation (QD) (QD =(Q1 - Q3)/2). Figures as mm.

Site.	QM	Q1	Q3	QD
1	31	68	6.4	30.8
2	39	72	11.3	30.35
3	44	96	17.5	39.25
4	66	95	27.5	33.75
5	53	87	22	32.5
6	29.5	53	12.2	20.4
7	23.5	43	7.5	17.75
8	26	57	7.7	24.65
9	40	71	14.7	28.15
10	56	97	12.7	42.15

Figure 4.

Median particle diameter (QM), mesh size retaining 25 percent of sample (Q1) and 75 percent of sample (Q3), for each site.



3. Analysis of substrate samples.

The results of the particle size analysis of substrate samples are given in tables 4 to 13 of Appendix I. Data are expressed on a cumulative percentage basis (Buchanan and Kain, 1971), and these figures are graphed in figure 3. It is usual for particle sizes to be expressed on the 'phi scale'; when sieves conforming to the Wentworth scale are used this transformation results in an arithmetic scale of integers. This is not the case with the sieve grade scale (B.S.) used in the present work, and the conversion was not considered appropriate. Instead, logarithmic graph axes have been used. Conventially, a number of parameters are used to characterise the size frequency curve (Buchanan and Kain, 1971). The median particle diameter (QM) measures the central tendency and is read by taking the point on the curve crossed by the 50 percent line. The Q1 and Q3 are sieve apertures which would retain 25 and 75 percent respectively of the sample. Quartile deviation (QD) measures the spread between the first (Q1) and the third (Q3) quartile diameters. It is given by (Q3 - Q1)/2. A small QD is said to signify a well sorted sediment. The parameters describing the particle size distributions of the substrate samples are given in table 16, and shown graphically in figure 4. The results of these particle size anlyses demonstrate that merely to select a number of 'riffles' on the assumption that such areas will provide comparible substrates can be misleading. The substrates of some sites, for example sites 3, 4, 5, and 10, clearly contain a far higher proportion of coarse particles than do others, for example site 7. The graph for QM (figure 4) shows the median particle diameter of the substrate at site 4 to be over twice those measured for sites 1, 6, 7 and 8. The best sorted sediment was that collected from site 7.

Figure 5 .

Relationship between current speed (m.sec^{-1}) and QM (mm), using QM data for February 1975 and current speed data (a) as a mean for the period Oct.'72 to Oct.'73 and (b) for February 1975.

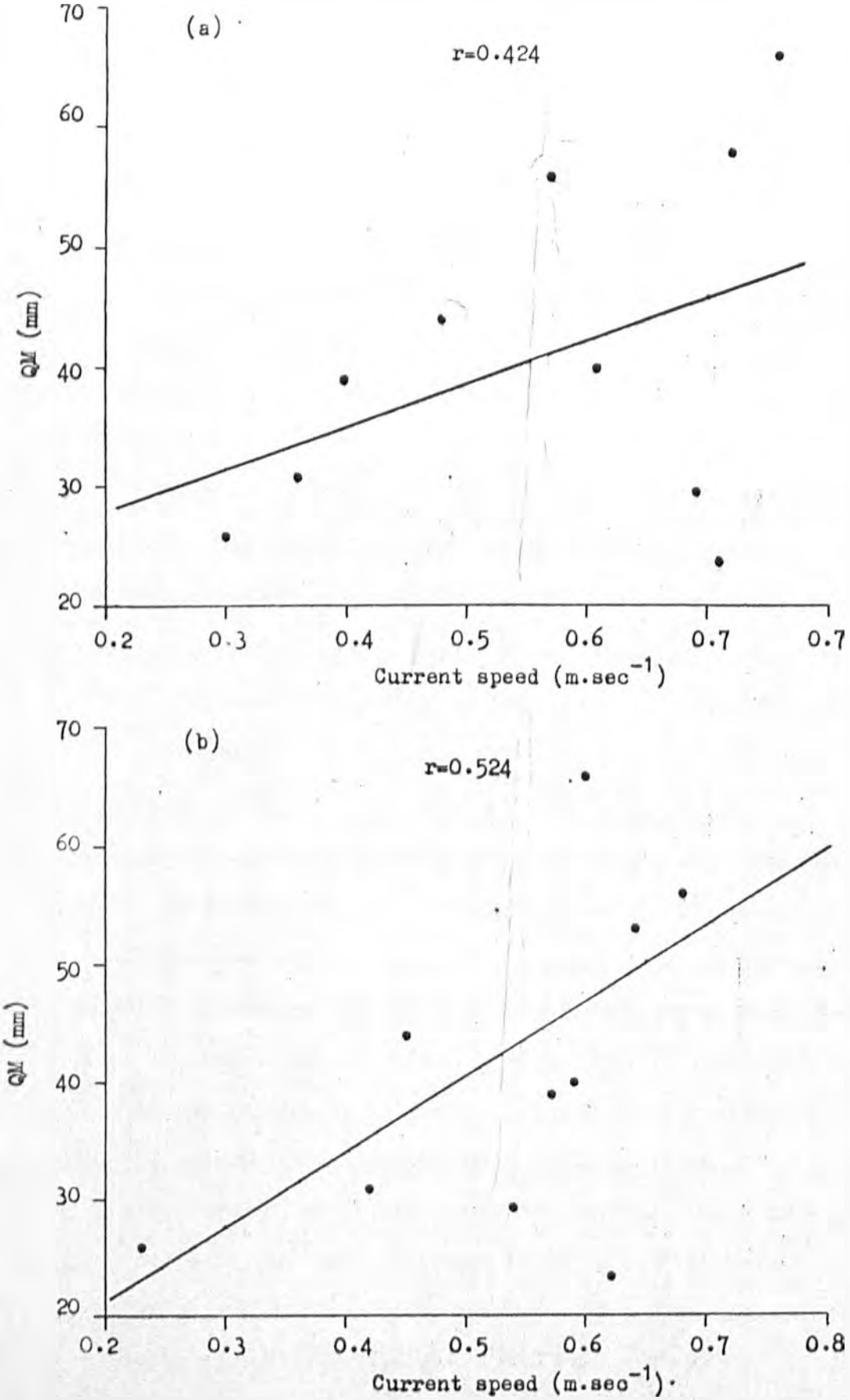


Figure 5 shows plots of QM against current speed, using flow data (a) as a mean for the period October 1972 to October 1973 and (b) for February 1975. Both plots show a trend of increasing QM with increasing current speed, although neither gives a significant regression line.

The data on substrate particle size distributions are based on samples collected in February 1975, while the main survey period ended in October 1973. However, it is clear from observations made by the author that little change took place in the substrate characteristics of the sampling sites during the course of the work on the river.

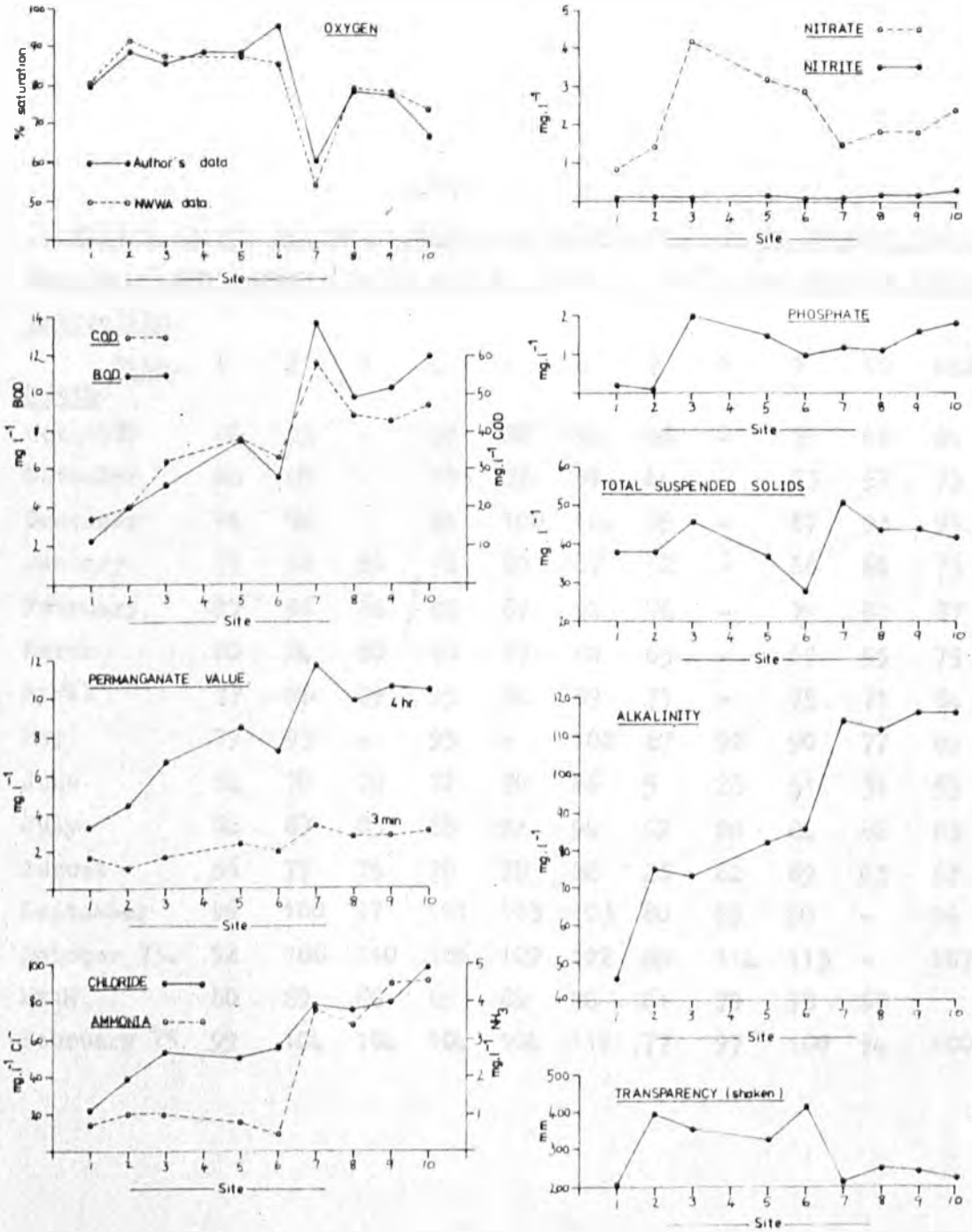
Table 17.

Dissolved oxygen concentrations, as determined by the author, over the course of the survey period and in February 1975. Results as percentage saturation.

Site. / Month.	1	2	3	4	5	6	7	8	9	10	MEAN
Oct.1972	86	93	-	90	88	99	46	-	80	68	81
November	60	88	-	87	83	99	44	-	63	58	73
December	96	98	-	94	100	104	89	-	87	93	95
January	75	80	80	79	80	87	52	-	68	60	73
February	97	91	86	90	89	92	76	-	79	80	87
March	80	84	80	80	77	82	65	-	69	55	75
April	77	90	89	95	94	89	75	-	75	71	84
May	79	93	-	95	-	102	87	92	90	77	89
June	64	70	70	72	70	86	5	28	51	31	55
July	82	87	83	88	92	94	62	80	84	82	83
August	56	77	75	78	78	88	26	62	69	63	67
September	96	100	97	101	103	103	80	95	90	-	96
October 73.	92	108	110	106	109	122	85	114	113	-	107
MEAN	80	89	86	89	89	96	61	79	78	67	
February 75	99	104	104	104	104	112	77	97	100	94	100

Figure 6.

Mean values of selected chemical parameters.



4. Chemical analysis of water samples.

Table 17 shows the results of the dissolved oxygen determinations made over the course of the study period by the author. Tables 18 to 39 in Appendix II give the results of the routine chemical analyses of water samples carried out by the North West Water Authority. Mean values for selected chemical parameters for the period October 1972 to October 1973 are shown for each site in figure 6.

Determinations of dissolved oxygen concentration made by the author and those made by the N.W.W.A. show close agreement (see figure 6). Discrepancies reflect fluctuations in the degree of pollution and in other factors influencing oxygen concentration such as temperature and discharge rate. Oxygen levels remain remarkably high over much of the river. This is due to the turbulent nature of the Irwell; there are many areas where the water flows swiftly over a stony bed, and there is a considerable number of weirs, legacies of the Industrial Revolution. A similar maintainance of high dissolved oxygen concentrations under organically polluted conditions was recorded in a turbulent river in Wales by Edwards et al. (1972). The effect of a weir on dissolved oxygen concentrations in the Irwell is emphasised at site 6. The author's dissolved oxygen determinations were made downstream of the weir, while those of the N.W.W.A. were made on samples collected upstream. The discrepancies between the two sets of measurements are greatest at this site (see figure 6), and it is clear that the oxygenating effect of the weir is considerable.

Figures for biochemical oxygen demand (B.O.D.), chemical oxygen demand (C.O.D.) and permanganate value (P.V.) all reflect the degree of pollution by oxidisable material in that they measure the oxygen demand of the sample in terms of 'oxygen absorbed'. The B.O.D. test is in widespread use as a measure of

organic pollution; it is of great significance in biological work since it can be regarded as reflecting the situation as it exists in the river. Klein (1959) reproduces a table classifying rivers according to their B.O.D.; this table is given below:-

B.O.D. ($mg.l^{-1}$).	Classification.
1	Very clean
2	Clean
3	Fairly clean
5	Doubtful
10	Bad

The three minute permanganate value of a sample measures the immediate oxygen demand due to oxidizable inorganic matter and to very easily oxidizable organic material (Klein, 1959). The relatively high mean 3 minute P.V. of water at site 1, for example, is due to the oxygen demand of ferrous salts in the mine drainage. There is no evidence of organic pollution at this site. It appears from figure 6 (for 3 min. P.V.) that inorganic and quickly oxidized organic material exerts a considerable oxygen demand. Apart from site 1, the trend follows that of organic pollution reflected in figures for B.O.D.

The four hour permanganate value is a comprehensive measure of the amount of oxidizable material in a sample; the test can involve the oxidation of some material not degraded by the B.O.D. Even more complete oxidation may be obtained using the C.O.D. test.

For samples collected from the Irwell, there is clearly a good deal of similarity between the results for the 4 h P.V., B.O.D., and C.O.D. tests. In fact, as will be shown subsequently, the parameters are highly significantly statistically correlated. This is despite the usual observation that B.O.D. and 4 h P.V. show little general correlation. Klein (1959) discusses the significance of the ratio B.O.D./4 h P.V.. It is suggested that while the 4 h P.V. reflects the actual amount of organic material present, the B.O.D. indicates the ease with which biochemical oxidation takes place. Trade wastes with bacteriocidal properties can reduce the ratio, and it appears that some such influence in at work in water samples from the Irwell. It is clear that the ratio is of the order of 1 over much of the river, figure 6 showing both parameters to have similar values. A ratio in the region of 1 is extremely low in heavily organically polluted conditions (Klein, 1959).

The most ubiquitous organic pollutant of rivers is domestic sewage, and this is responsible for much of the load of organic pollution in the upper reaches of the river, between sites 2 and 6. Industrial discharges can also, of course, exert considerable oxygen demands. Among the more important of these on the Irwell are those from textile manufacture and processing and paper manufacture; the latter, together with the confluence of the grossly polluted River Roch, is largely responsible for the dramatic rise in B.O.D. at site 7 (Radcliffe). Figure 6, showing a fall in B.O.D., C.O.D. and P.V. between sites 7 and 8, demonstrates the beneficial effect of the relatively unpolluted River Croal on the degree of pollution of the Irwell's water. This influence is recent; it dates from the demise of the Bolton

Table 40.

Criteria for fresh, brackish and salt waters (after Klein, 1962).

Description of water.	Content of salt expressed as $mg.l^{-1}$ Cl^-.
Fresh water.	up to 100
Brackish water.	100 - 1000
Salt water.	over 1000

Table 41.

Average chloride content of various waters (after Klein, 1959).

Description of water.	Content of salt expressed as $mg.l^{-1}$ Cl^-.
Rain water.	2
Upland surface water.	12
Unpolluted river water.	up to 15
Spring water.	25
Deep well water.	50
Drinking water.	10-20, but variable
Weak sewage.	70
Medium sewage.	100
Strong sewage.	up to 500
Urine.	4500 to 5000
Sea water.	20 000

textile industry. After site 8, water quality in terms of organic pollution declines again.

The concentrations of chloride recorded in the Irwell are inordinately high, Klein (1959) points out that chloride (from sodium chloride) is present in urine to about 1 percent, and since chloride is unaltered in sewage treatment processes levels in the river will reflect the strength and volume of sewage discharged, the presence of chloride bearing trade wastes and the 'natural' level of the catchment in question. Two tables from Klein (1959) and Klein (1962) are reproduced here as tables 40 and 41. Table 40 shows a classification of fresh, brackish and salt water according to their chloride content. Table 41 shows the average chloride content of various waters. Clearly, at times (see table 29 for February 1973, for example) the chloride content of the water of the Irwell could lead to the river being described as brackish, having a content of the ion similar to that of medium/strong sewage. Although table 29 emphasizes the variable nature of the pollution, it is clear (figure 6) that concentrations increase with distance downstream.

Levels of ammonia greater than 0.2 $mg.l^{-1}$ are unlikely to be of natural origin, and are probably a result of pollution by domestic sewage and a variety of industrial wastes (Klein, 1959). Levels in the Irwell, although erratic, are greater than this (see table 26), mean levels (figure 6) rising dramatically at site 7. The range and magnitude of ammonia concentrations are similar to those recorded in the River Trent and its tributaries by Lester (1975).

Fully oxidized sewage will contain a high proportion of nitrogen as nitrate, since this is the final oxidation product of ammonia. Nitrite is the intermediate product;

oxygen defficiency leads to an increase in the nitrite/nitrate ratio. A trace of nitrite in a river indicates pollution by improperly treated sewage, especially when accompanied by an increase in ammonia and chloride, as is the case in the Irwell, where an increase in nitrite with a corresponding decrease in nitrate at downstream sites is evident from figure 6.

Phosphates are indicative of pollution by sewage, but they do not exert any documented toxic effect; they play an important part in the well known process of eutrophication associated with organic pollution.

Streams receiving sewage effluents undergo alkalinity changes due to utilization of carbon dioxide and associated processes; this is reflected in figure 6.

A high suspended solid load will lead to some modification of substrate, even in the swiftest of streams. This can have deleterious effect on benthos, resulting from simple smothering and from damage to delicate respiratory mechanisms. The lowest mean figure for suspended solids was recorded for site 6 (see figure 6). This partly reflects the slow moving nature of the river at the point sampled by the N.W.W.A., which allows settlement of sediments behind the weir, and partly the improvement in water quality that occurs at this site as demonstrated by figures for B.O.D. Transparency (mm seen through) reflects suspended solid levels, as might be expected. Site 1 presents an anomoly, with extremely low transparency, but the material in suspension at this site is quite different in nature from that occurring elsewhere in the river, being of mineral rather than organic origin. This material clearly exerts a very high effect per unit weight

Table 42.

Table showing relationships between chemical parameters, based on Pearson Correlation Coefficients (r values).

	Temp.	Conduct.	Hardness	B.O.D.	Phosphate	Nitrate	Nitrite	NH_3	P.V.(4 h)	P.V.(3 min)	Susp. sols.	Total sols.	Transpar.	C.O.D.	Alkalin.	O_2	Cl^-
Cl^-	0	+++	+++	+++	+	0	+	+++	++	++	0	+++	0	++	+++	0	x
O_2	---	---	---	---	---	0	---	---	---	---	0	---	0	---	---	x	
Alkalin.	++	+++	+++	+++	+++	0	+++	+++	+++	+++	-	+++	+	+++	x		
C.O.D.	+	++	+	+++	+++	0	+++	+++	+++	+++	+++	+++	---	x			
Transpar.	0	0	0	---	0	+++	0	0	---	---	---	-	x				
Total sols.	0	+++	+++	+++	++	0	+++	+++	+++	+++	0	x					
Susp. sols.	0	-	+++	+++	-	0	0	0	+++	+	x						
P.V.(3 min)	++	+++	+++	+++	+++	0	+++	+++	+++	x							
P.V.(4 h)	+	++	+	+++	+++	0	+++	+++	x								
NH_3	+	+++	+++	+++	+++	0	+++	x									
Nitrite	+++	+++	+++	+++	+++	+	x										
Nitrate	0	0	+	0	++	x											
Phosphate	+++	+++	+++	++	x												
B.O.D.	0	++	+	x													
Hardness	0	+++	x														
Conduct.	0	x															
Temp.	x																

Key

0 no significant correlation
\+ positive correlation (p = 0.05)
++ positive correlation (p = 0.01)
+++ positive correlation (p = 0.001)
\- negative correlation (p = 0.05)
— negative correlation (p = 0.01)
--- negative correlation (p = 0.001)

on transparency.

The degree of statistical correlation between values of the various chemical parameters has been examined by calculating correlation coefficients (r) (Pearson correlation coefficients), using data for the period October 1972 to October 1973. Computations were performed using the computer program PEARSON CORR (Nie et al., 1970). Table 42 summarizes the results, showing the degree of correlation as suggested by the probability 'p' values corresponding to the coefficients ('r' values) at the appropriate number of degrees of freedom. There are clearly close relationships between many of the parameters.

Conclusions drawn from consideration of the data presented relating to the chemical analyses of water samples are summarized in the next section.

5. Implications from the results of chemical analyses of water samples.

(a) At site 1 the river is polluted by drainage from disused colliery workings, showing low pH, a high 3 minute permanganate value due to the presence of ferrous salts, and very low transparency.

(b) The degree of organic pollution increases steadily from site 2 to site 5; the situation improves slightly at site 6, but the confluence of the River Roch and the discharge of effluents from paper manufacturing and other concerns bring about a dramatic deterioration in water quality as reflected by 'oxygen absorbed' tests and dissolved oxygen concentrations. This trend is ameliorated at site 8 by the inflow of the River Croal, but the improvement does not continue downstream. Despite heavy contamination, the mean dissolved oxygen concentration (author's data) does not fall below 80 percent of saturation between sites 1 and 6. At site 7 the mean is 61 percent, although a figure of 5 percent was recorded for June 1973. Sites 8 to 10 have mean values greater than 70 percent. The maintainance of relatively high dissolved oxygen levels is a result of the physical characteristics of the water course.

(c) Inorganic materials exert an oxygen demand; this influence, revealed by the 3 minute permanganate value, increases downstream. Site 1 is a special case in this respect.

(d) Contamination by suspended solids leads to a decrease in transparency, especially at sites 7, 8, 9, and 10. Turbidity at site 1 is a result of organic pollution.

(e) While the trends summarized above are clearcut, it is apparent from tables 17 to 39 (all except 17 in Appendix II) that the degree of pollution is extremely variable.

Table 43.

Concentrations of zinc in water samples collected on 10/3/75. Results as $mg.l^{-1}$.

Site.	Zinc ($mg.l^{-1}$).
Townsend Fold (2)	0.002
Warth Bridge (6)	0.002
Radcliffe (7)	0.020
Agecroft (9)	0.026

(Concentrations of lead and copper in the water samples were below the detection limits of the analytical procedure.)

Table 44.

Levels of heavy metals as measured in sediment samples collected 16/4/75. Results expressed as $mg.g^{-1}$ (dry weight basis).

Site.	Sample.	Lead.	Copper.	Zinc.
	I	0.1500	0.1062	0.6423
Summerseat (4)	II	0.1789	0.0950	1.0331
	III	0.1227	0.0510	0.3606
	I	0.2979	0.2013	0.6201
Warth Bridge (6)	II	0.1793	0.0886	0.3721
	III	0.1923	0.0873	0.4119
	I	0.3656	0.2724	1.0086
Radcliffe (7)	II	0.4546	0.8299	0.7625
	III	0.3948	0.2520	1.0730
	I	2.7297	0.1641	0.7703
Agecroft (9)	II	0.9668	0.1094	0.3926
	III	1.9440	0.1431	0.6096
Summerseat (4)	Mean	0.1505	0.0841	0.6787
Warth Bridge (6)	Mean	0.2232	0.1257	0.4680
Radcliffe (7)	Mean	0.4050	0.4514	0.9480
Agecroft (9)	Mean	1.8802	0.1389	0.5908

Table 45.

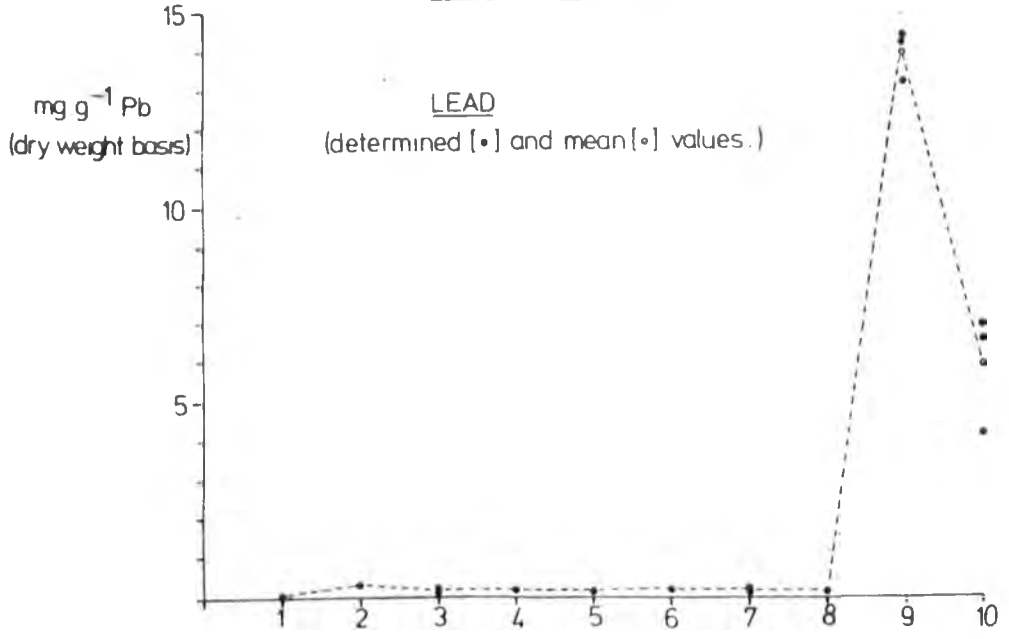
Levels of heavy metals as measured in sediment samples collected 17/5/75.

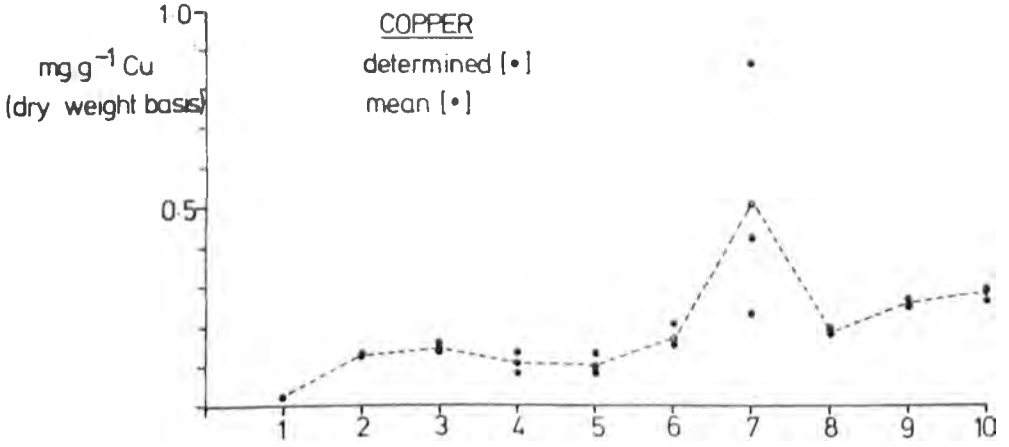
Results expressed as $mg.g^{-1}$ (dry weight basis).

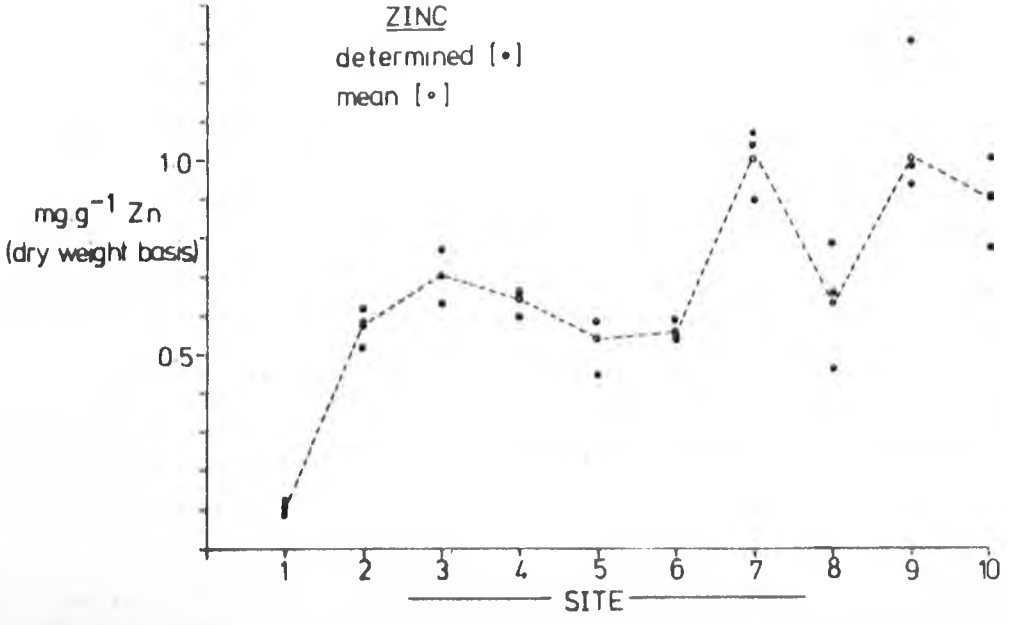
Site.	Sample.	Lead.	Copper.	Zinc.
Irwell Springs (1)	I	0.0364	0.0237	0.1255
	II	0.0328	0.0244	0.0888
	III	0.0402	0.0254	0.1229
	mean	0.0365	0.0245	0.1124
Townsend Fold (2)	I	0.2978	0.1288	0.6212
	II	0.3432	0.1350	0.5874
	III	0.3492	0.1326	0.5281
	mean	0.3301	0.1321	0.5789
Irwell Vale (3)	I	0.2010	0.1366	0.7053
	II	0.2805	0.1583	0.7685
	III	0.1828	0.1387	0.6323
	mean	0.2214	0.1445	0.7020
Summerseat (4)	I	0.1881	0.1068	0.6654
	II	0.2373	0.0832	0.5970
	III	0.2472	0.1338	0.6594
	mean	0.2242	0.1079	0.6406
Chestwheel (5)	I	0.2163	0.1331	0.5863
	II	0.1619	0.1012	0.5924
	III	0.1488	0.0863	0.4514
	mean	0.1757	0.1069	0.5434
Warth Bridge (6)	I	0.2193	0.2034	0.5437
	II	0.2339	0.1608	0.5918
	III	0.1931	0.1510	0.5501
	mean	0.2154	0.1717	0.5619
Radcliffe (7)	I	0.2415	0.8606	1.0330
	I	0.1920	0.2300	1.0868
	III	0.2907	0.4217	0.8999
	mean	0.2414	0.5041	1.0066
Ringly (8)	I	0.2512	0.1856	0.4662
	II	0.2280	0.1956	0.8639
	III	0.2756	0.2024	0.7831
	mean	0.2516	0.1939	0.6377
Agecroft (9)	I	14.3387	0.2594	1.3019
	II	14.1762	0.2462	0.9382
	III	13.1985	0.2669	0.9858
	mean	13.9045	0.2575	1.0746
Salford (10)	I	4.1353	0.2901	0.7757
	II	6.9752	0.2969	1.0255
	III	6.5413	0.2647	0.9088
	mean	5.8839	0.2839	0.9027
Gressingham (Lune) *Cladophora* sample.	I	0.0340	0.0265	0.1003
	II	0.0379	0.0214	0.1246
	III	0.0446	0.0209	0.1045
	mean	0.0388	0.0229	0.1098
Gressingham (Lune) Stone scraping.	I	0.0365	0.0173	0.1300
	II	0.0530	0.0185	0.1278
	III	0.0410	0.0166	0.1226
	mean	0.0435	0.0175	0.1268

Figure 7

Metal concentrations in sediment samples collected 17/5/75







6. Levels of lead, zinc and copper in water and substrate materials.

Table 43 shows zinc concentrations in water samples collected on 10/3/75. Levels at site 7 and 9 are greater, by a factor of ten, than those recorded for samples collected further upstream, but all data are comparable with those for 'normal' situations as suggested by figures in Wilson (1976). Levels of lead and copper in the water were below the detection limits of the apparatus used, despite twenty-fold concentration of samples. Clearly levels of dissolved zinc, copper and lead are low in the Irwell. A different picture emerges from the examination of substrate samples ('stone scrapings'). The results of analyses on samples collected on 16/4/75 are shown in table 44, and on 17/5/75 in table 45. Data from the latter determinations are shown in figure 7. Table 45 includes data from the analyses performed upon comparable samples collected from the River Lune, which for present purposes may be regarded as an unpolluted control.

Levels of lead in sediments, at all sites except site 1, are considerably higher than those recorded for the River Lune, but concentrations remain fairly constant from site 2 to site 8. There is clearly a massive input of lead to the river between sites 8 and 9. The level falls off by site 10, but is still very much higher than those recorded upstream. On 16/4/75 the mean concentration of lead in sediments at site 9 was 1.8802 $mg.g^{-1}$ (dry weight basis) while on 17/5/75 it was 13.9045 $mg.g^{-1}$. Clearly, lead is not discharged to the river at a constant rate, and this leads to considerable fluctuations in sediment bound levels. The low levels of lead in all water samples and the very high sediment levels at sites 9 and 10

is at first sight anomalous, but the situation results largely from the slightly alkaline pH (mean 7.2 at site 9) leading to a very low solubility for the lead salts. A possible source of the lead entering the river between sites 8 and 9 is a battery manufacturing concern. It seems that the lead in the effluent is very rapidly precipitated to the sediments. The observed fluctuations suggest that there is a very rapid turnover of sediment materials, with constant deposition and scouring. This is likely to be the case in any turbulent river.

As with lead, sediment related levels of copper are higher than those recorded for the River Lune at all sites except site 1. Levels in samples collected on 17/5/75 are fairly constant from sites 2 to 6, but rise considerably at site 7, in Radcliffe. Levels are lower at site 8, but high again at sites 9 and 10 (see figure 7). These data reflect trends evident from preliminary samples collected on 16/4/75.

The overall trend of zinc concentration in sediments is similar to that for copper, as shown in figure 7. Only at site 1 do substrate concentrations compare with those prevailing in the River Lune.

The low levels of metals in water samples, and the relatively high levels in sediments, reflect a situation discussed by Helz et al. (1975). They feel that dramatic decreases in metal concentrations in solution, involving immobilisation to sediments, is a result of pH rises occurring after discharge inducing rapid inorganic deposition of trace metal hydroxides, carbonates and phosphates. Deposition of phosphates is felt to be particularly significant in phosphate enriched waters; the Irwell clearly falls into this catagory (see figure 6). The

authors also feel that increased pH may encourage removal of metals by sorption onto organic and inorganic particles, and speculate on a possible biological removal mechanism.

It is useful to compare sediment bound levels of metals recorded in the present survey with those reported in the literature. In a similar study to the present one, Kronfeld and Navrot (1974) found low metal concentrations in river water with relatively much higher levels in sediments. Lead concentrations of between 0.009 and 0.205 m g.g^{-1}, copper concentrations between 0.003 and 0.048 m g.g^{-1} and zinc levels of 0.020 to 1.5 mg.g^{-1} were found, all determinations being made on air dried sediments. The site that the authors regarded as being unpolluted, for comparative purposes, had sediment levels of lead, zinc and copper of 0.009, 0.005 and 0.020 mg.g^{-1} respectively. Levels recorded in the present work for the 'unpolluted' River Lune were somewhat higher than these (table 45). This may well be due to differences in analytical procedure, the drying technique of the present author being the more thorough of the two. As has already been mentioned in connection with the present work, Kronfeld and Navrot (1974) also point out that high pH results in the rapid precipitation of metals from solution. Dean et al. (1972) give the following pH values at which metals precipitate out as pH is raised: 5.3 (Cu^{++}), 6.0 (Pb^{++}) and 7.0 (Zn^{++}). These data may indicate why zinc was the only metal detected in water from the Irwell.

Cooper and Harris (1974) have shown that even in a lightly polluted (estuarine) situation, concentrations of metals in sediments can be quite high; levels of lead, copper and zinc of 0.100, 0.700 and 0.800 mg.g^{-1} respectively were recorded. The data are not, however, strictly comparable with those obtained during the present survey, since Cooper and Harris (1974) employed

rather more vigourous digestion techniques.

A drawback of comparisons between levels of sediment bound metals recorded by different authors is that there is little standardization of sampling methods or analytical procedure. In the present work, scrapings of stones were taken, this being regarded as a substrate material of great significance with respect to the benthos; other authors have collected samples of substrate from beneath the surface layer of sediment (Cooper and Harris, 1974), from the surface of the river bed (Kronfeld and Navrot, 1974), and from alluvial flood plain silt (Tyler and Buckney, 1973). Wilson (1976) points out that metal concentrations in river water vary greatly both spatially and temporally, and emphasises that great care should be taken when planning analyses.

Table 46.

Levels of heavy metals as measured in samples of Erpobdella octoculata collected on 17/5/75. Results expressed as $mg.g^{-1}$ (dry weight basis).

Site.	Sample.	Lead.	Copper.	Zinc.
Irwell Vale (3)	I	0.0084	0.0140	1.5132
	II	0.0449	0.0140	1.6277
	III	0.0352	0.0167	1.5526
	mean	0.0295	0.0149	1.5645
Summerseat (4)	I	0.0380	0.0541	1.3459
Warth Bridge (6)*	1	-	-	1.1724
Agecroft (9)	I	0.1347	0.0267	1.0567
	II	0.0923	0.0230	1.0051
	III	0.1057	0.0277	0.8864
	mean	0.1109	0.0258	0.9827
Salford (10)	I	0.0908	0.0252	1.1183
	II	0.0865	0.0175	0.9937
	III	0.0705	0.0245	1.0790
	mean	0.0826	0.0224	1.0637

(* one specimen only collected)

Table 47.

Levels of heavy metals as measured in samples of Plecoptera and Ephemeroptera collected from Gressingham (River Lune) on 18/5/75. Results expressed as $mg.g^{-1}$ (dry weight basis).

Taxon.	Sample.	Lead.	Copper.	Zinc.
Ephemeroptera	I	0.0482	0.0394	0.2338
	II	0.0439	0.0591	0.2762
	III	0.0594	0.0377	0.2280
	mean	0.0505	0.0454	0.2460
Plecoptera	I	0.0246	0.0395	0.1922
	II	0.0320	0.0333	0.1864
	III	0.0389	0.0423	0.2125
	mean	0.0318	0.0384	0.1970

Table 48.

Levels of heavy metals as measured in samples of Asellus aquaticus collected on 17/5/75. Results expressed as $mg.g^{-1}$ (dry weight basis).

Site.	Sample.	Lead.	Copper.	Zinc.
Irwell Vale (3)	I	0.2361	0.3082	0.2038
Summerseat (4)	I	0.1694	0.2775	0.1825
	II	0.1626	0.2522	0.1731
	III	0.2245	0.3000	0.1939
	mean	0.1855	0.2766	0.1832
Warth Bridge (6)	I	0.1629	0.2379	0.1399
	II	0.1631	0.2224	0.1681
	III	0.1990	0.2543	0.1298
	mean	0.1750	0.2382	0.1459
Ringly (8)	I	0.1425	0.1689	0.1784
	II	0.1644	0.1576	0.1633
	mean	0.1535	0.1633	0.1709
Agecroft (9)	I	0.4993	0.1764	0.1681
	II	0.6036	0.1787	0.1350
	III	0.6930	0.1939	0.1560
	mean	0.5953	0.1830	0.1530
Salford (10)	I	0.5677	0.1635	0.1520
	II	0.4543	0.1620	0.1826
	III	0.4449	0.1541	0.1237
	mean	0.4890	0.1599	0.1528

Table 49.

Levels of heavy metals as measured in samples of Asellus aquaticus collected on 16/4/75. Results expressed as $mg.g^{-1}$ (dry weight basis).

Site.	Sample.	Lead.	Copper.	Zinc.
	I	0.1620	0.3348	0.3024
Summerseat (4)	II	0.1826	0.2890	0.2231
	III	0.1552	0.3017	0.2155
	mean	0.1666	0.3085	0.2470
	I	0.2688	0.1996	0.1711
Agecroft (9)	II	0.2845	0.2086	0.1849
	III	0.3201	0.2086	0.1843
	mean	0.2911	0.2056	0.1801

Table 50.

Levels of heavy metals as measured in samples of Erpobdella octoculata collected on 16/4/75. Results expressed as $mg.g^{-1}$ (dry weight basis).

Site.	Sample.	Lead.	Copper.	Zinc.
	I	0.0863	0.0257*	0.8628
Agecroft (9)	II	0.0752	0.0224*	0.7894
	III	0.1137	0.0263*	0.8404
	mean	0.0917	0.0248	0.8309

(* determinations made at detection limits of analytical procedure.)

Figure 8

Metal concentrations in Erpobdella octoculata collected on 17/5/75

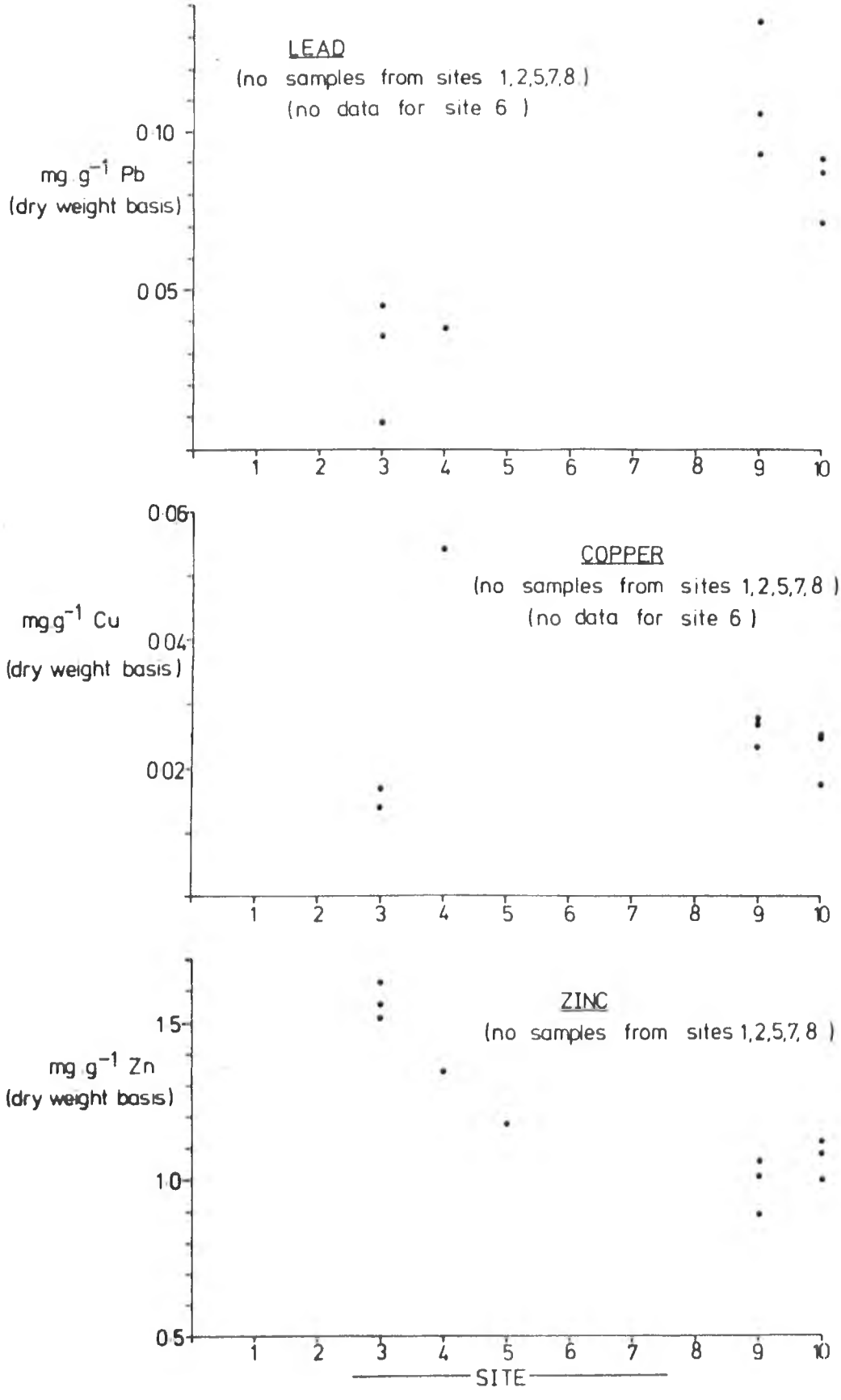


Figure 9

Metal concentrations in Asellus aquaticus collected on 17/5/75

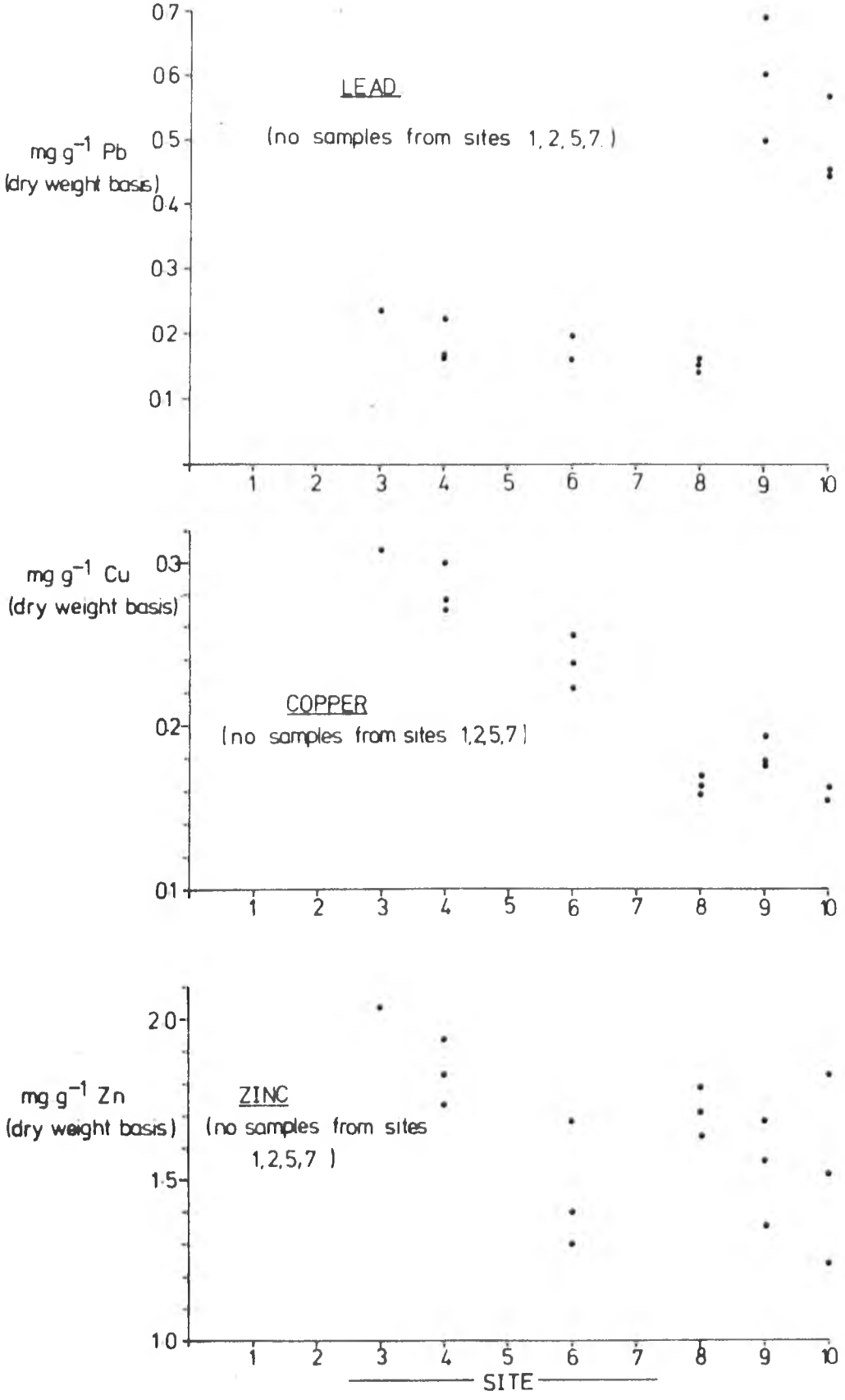


Figure 10.

Substrate vs tissue levels of metals (dry weight basis).

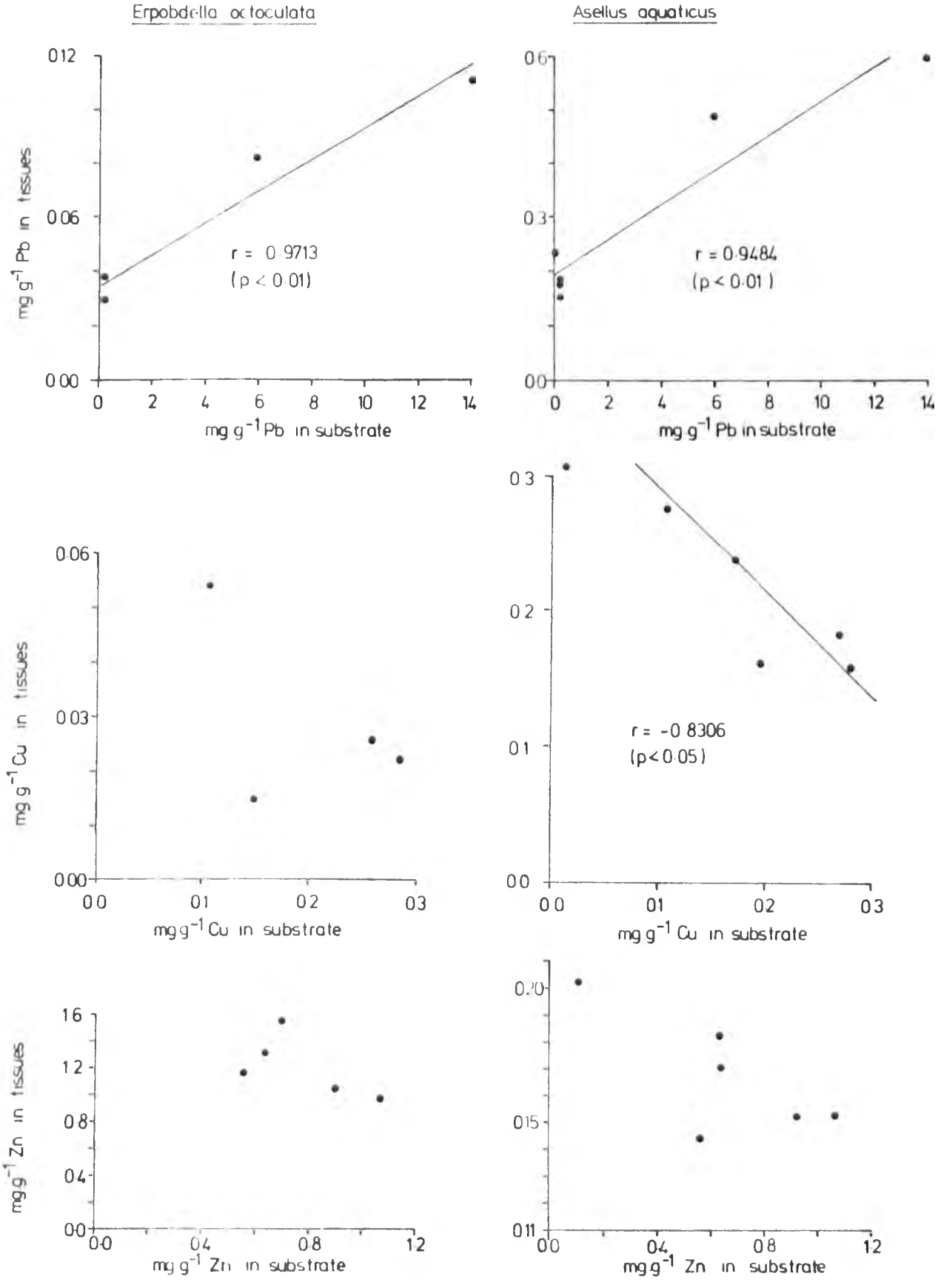


Table 51.

Concentrations of metals in samples of substrate materials and fauna collected on 17/5/75. The ratio (tissue concentration/substrate concentration) has been calculated.

Lead:

Site	Substrate	Asellus	Ratio	Erpobdella	Ratio
1	0.0365	-	-	-	-
2	0.3301	-	-	-	-
3	0.2214	0.2361	1.0664	0.0295	0.1332
4	0.2242	0.1855	0.8274	0.0380	0.1695
5	0.1757	-	-	-	-
6	0.2154	0.1750	0.8124	-	-
7	0.2414	-	-	-	-
8	0.2516	0.1535	0.6101	-	-
9	13.9045	0.5953	0.0428	0.1109	0.0080
10	5.8839	0.4890	0.0831	0.0826	0.0140

Copper:

Site	Substrate	Asellus	Ratio	Erpobdella	Ratio
1	0.0245	-	-	-	-
2	0.1321	-	-	-	-
3	0.1445	0.3082	2.1329	0.0149	0.1031
4	0.1079	0.2766	2.5635	0.0541	0.5014
5	0.1069	-	-	-	-
6	0.1717	0.2382	1.3873	-	-
7	0.5041	-	-	-	-
8	0.1939	0.1633	0.8422	-	-
9	0.2575	0.1830	0.7107	0.0258	0.1002
10	0.2839	0.1599	0.5632	0.0224	0.0789

Zinc:

Site	Substrate	Asellus	Ratio	Erpobdella	Ratio
1	0.1124	-	-	-	-
2	0.5789	-	-	-	-
3	0.7020	0.2038	0.2903	1.5645	2.2286
4	0.6406	0.1832	0.2860	1.3459	2.1010
5	0.5434	-	-	-	-
6	0.5619	0.1459	0.2597	1.1724	2.0865
7	1.0066	-	-	-	-
8	0.6377	0.1709	0.2680	-	-
9	1.0746	0.1530	0.1424	0.9827	0.9145
10	0.9027	0.1528	0.1693	1.0637	1.1784

Metal concentrations expressed as $mg.g^{-1}$

- no data

7. Levels of lead, zinc and copper in fauna.

Table 49 shows the concentrations of metals in samples of Asellus aquaticus collected from sites 4 and 9 on 16/4/75; table 50 shows similar data, for site 9 only, for Erpobdella octoculata. The results of analyses carried out on samples of fauna collected from the Irwell on 17/5/75 and from the River Lune on 18/5/75 are given in tables 46 to 48. Figure 8 shows the 17/5/75 data for Erpobdella , figure 9 for Asellus. Figure 10 shows scatter diagrams of the relationships between the metal concentrations recorded in the tissues and the levels in the substrate materials. The data used are the mean values for each site for the determinations made on samples collected on 17/5/75. Where correlation coefficients are significant, regression lines have been drawn.

The relationship between substrate and tissue concentrations of metals may be examined by calculating the ratio (mean tissue concentration/mean substrate concentration) for each site. This ratio is given in table 51, which summarizes some of the data in previous tables by showing mean values of the metals in substrates as well as in the tissues of both species examined (17/5/75 data).

For lead, both Erpobdella and Asellus show a clear trend of increasing tissue concentration as substrate levels increase ($p < 0.01$). This is clear from figure 10. Examination of table 51, however, makes it clear that the situation is not simple; while the tissue/substrate level for Asellus approximates to unity for lower substrate concentrations, this falls dramatically at higher sediment levels. There are two possible inferences to be drawn from these data; either Asellus does not take up lead from its surroundings at the same rate as do the substrate

materials, implying some form of physical (possibly cuticular) or chemical blocking mechanism, or the animals are able to excrete the metal actively. Erpobdella accumulates far less lead than does Asellus, suggesting that one or both of the above mechanisms may be operating more efficiently in the leech.

For both species the situation as regards copper is more complex. Tissue concentrations for Erpobdella do not approach the substrate levels. There is some indication of an inverse relationship between tissue and substrate tissue concentrations, although this is not significant statistically. The data imply that Erpobdella can actively block the uptake of, or excrete, copper, and that any such mechanism operates more efficiently at higher substrate concentrations. For Asellus, the tissue/substrate ratio at sites 3 and 4, where substrate copper concentrations are relatively low, exceeds two (table 51), implying that the animals are actively taking up copper from their surroundings. There is, however, a clear trend ($p < 0.05$) of decreasing tissue concentration with increasing substrate concentration; at higher substrate levels, the tissue/substrate ratio falls to unity.

Asellus appears to be able to exclude zinc from its tissues to a certain extent (see tissue/substrate ratio, table 51), and as with copper there is an indication of an inverse relationship between tissue and sediment concentrations. Erpobdella seems to actively accumulate zinc at lower substrate concentrations (tissue/substrate ratio greater than two); at the higher sediment levels recorded at sites 9 and 10, the ratio approximates to unity.

Some tentative conclusions may be drawn from the above results. Asellus and Erpobdella accumulate higher concentrations

of lead at sites where substrate concentrations are higher, but both species seem to possess some mechanism limiting the levels of metals that build up in their tissues. This latter ability is most marked in Erpobdella.

Erpobdella can exclude copper from its tissues; Asellus accumulates copper at low substrate concentrations. At higher sediment levels this observation does not apply. There is an inverse relationship between tissue and sediment concentrations of copper for Asellus.

There is also an indication of an inverse relationship between tissue and substrate concentrations of zinc for Asellus. The species can maintain its tissue concentration of the metal below that of the surrounding substrate. Erpobdella accumulates zinc at low substrate concentrations. At higher sediment levels, the tissue/substrate ratio approximates to unity.

Table 52.

Taxa collected during the course of the survey and the percentage contribution of each taxon to the fauna of the river.

Nematoda	0.02 percent
Oligochaeta	83.72
Aeolosomatidae	+
Aeolosoma beddardi Michaelsen	+
Naididae	27.43
Chaetogaster langi Bretscher	0.01
C. diaphanus (Gruithuisen)	1.03
Nais elinguis Müller	17.06
N. variabilis Piguet	1.00
N. alpina Sperber	+
N. barbata (Muller)	6.30
N. communis Piguet	0.50
N. bretscheri Michaelsen	+
N. pseudobtusa Piguet	+
Stylaria lacustris (L)	2.23
Pristina menoni (Aiyer)	0.02
P. aequiseta Bourne	+
P. foreli Piguet	+
Tubificidae	43.55
Tubifex tubifex (Müller)	9.72
Limnodrilus udekemianus Claparede	1.41
L. hoffeisteri Claparede	31.72
L. profundicola (Verrill)	0.54
Monopylephorus rubroniveus (Levinsen)	0.15
M. irroratus (Verrill)	0.03
Lumbriculidae	0.01
Lumbriculus variegatus (Müller)	+
Stylodrilus heringianus Claparede	+
Enchytraeidae	12.67
Lumbricidae	0.05
Hirudinea	0.02
Erpobdella octoculata (L)	0.01
Glossiphonia complanata (L)	+
Helobdella stagnalis (L)	+
Trocheta bykowskii Gedroyc	+
Collembola	0.03
Crustacea	2.35
Cladocera	0.02
Copepoda	0.04
Asellus aquaticus L	2.28
Gammarus pulex (L)	+
Ephemeroptera	0.14
Baetis rhodani (Pict.)	0.13
B. scambus Etn.	+
Rhithrogena semicolorata (Curt.) Esb.-Pet.	+
Ephemerella ignita (Poda)	+
Ecdyonurus dispar (Curt.)	+
Ecdyonurus sp.	+

continued/

/continued

Plecoptera	+
Amphinemura sulcicollis(Stephens)	+
Amphinemura sp.	+
Leuctra sp.	+
Trichoptera	+
Rhyacophila dorsalis (Curt.)	+
Polycentropus kingi McLachlan	+
Plectrocnemia geniculata McLachlan	+
Hydropsyche sp.	+
Rhyacophila sp.	+
Limnephilus sp.	+
Coleoptera	+
Dytiscinae	+
Haliplidae	+
Noterinae	+
Hemiptera	+
Velia caprai Tamamini	+
Mollusca	1.07
Ancylus fluviatilis Müller	0.76
Limnaea peregra (Müller)	0.05
Physa fontinalis (L)	0.24
Hydrobia jenkinsi (Smith)	+
Pisidium sp.	+
Sphaerium sp.	+
Diptera	12.65
Tipulinae larvae	+
Psychodidae larvae	+
Dolochopodidae larvae	+
Stratiomyidae larvae	+
Simulium sp. larvae	+
Pericoma sp. larvae	+
Hemerodromia sp. larvae	+
Atrichopogon sp. larvae	+
Eristalis sp. larvae	+
Dicranota sp. larvae	+
Tipulidae pupae	+
Chironomidae	12.64
Orthocladiinae larvae	11.35
Chironomonae larvae	0.48
Tanypodinae larvae	0.11
Diamesinae larvae	0.03
Corynoneurinae larvae	+
Chironomidae pupae	0.66
Hydracarina	+

(The symbol '+' indicates that a taxon makes up less than 0.01 percent of the fauna.)

Figure 11.

Mean numbers of invertebrates (a) at each site over the survey period and (b) each month for all sites.

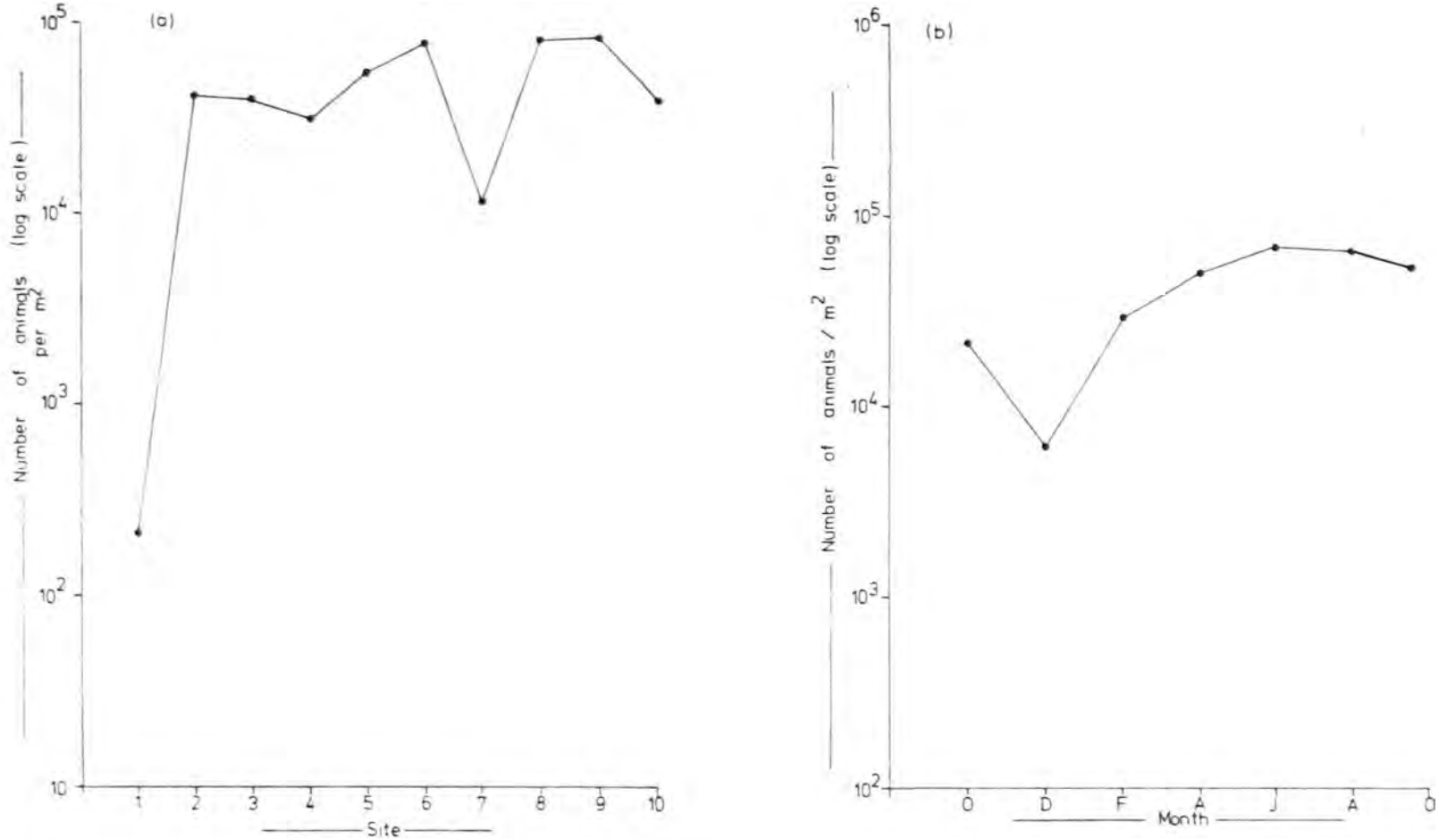


Figure 12

TUBIFEX TUBIFEX collected bi-monthly at each site

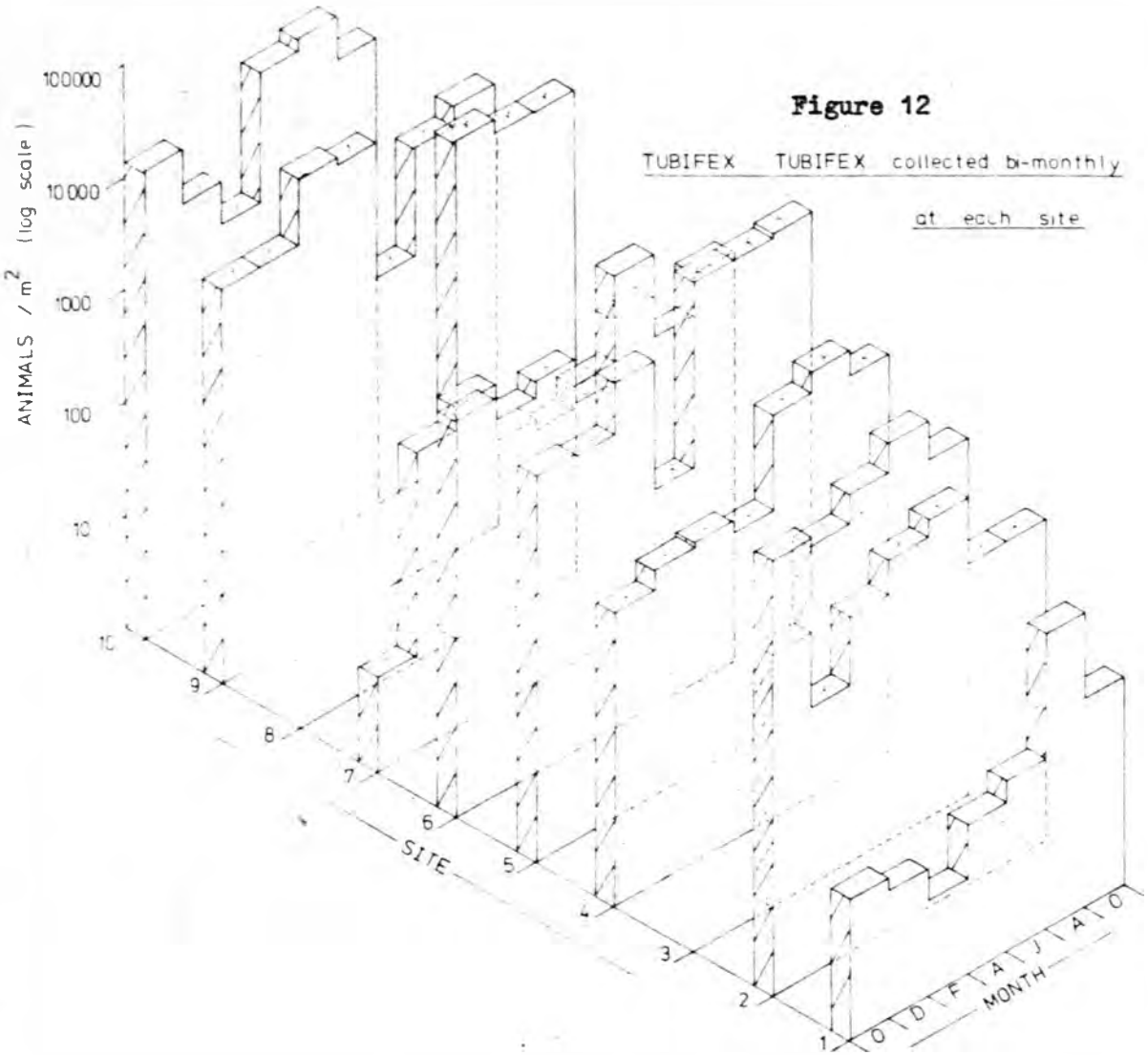


Figure 13

LIMNODRILUS HOFFMEISTERI collected

bi-monthly at each site

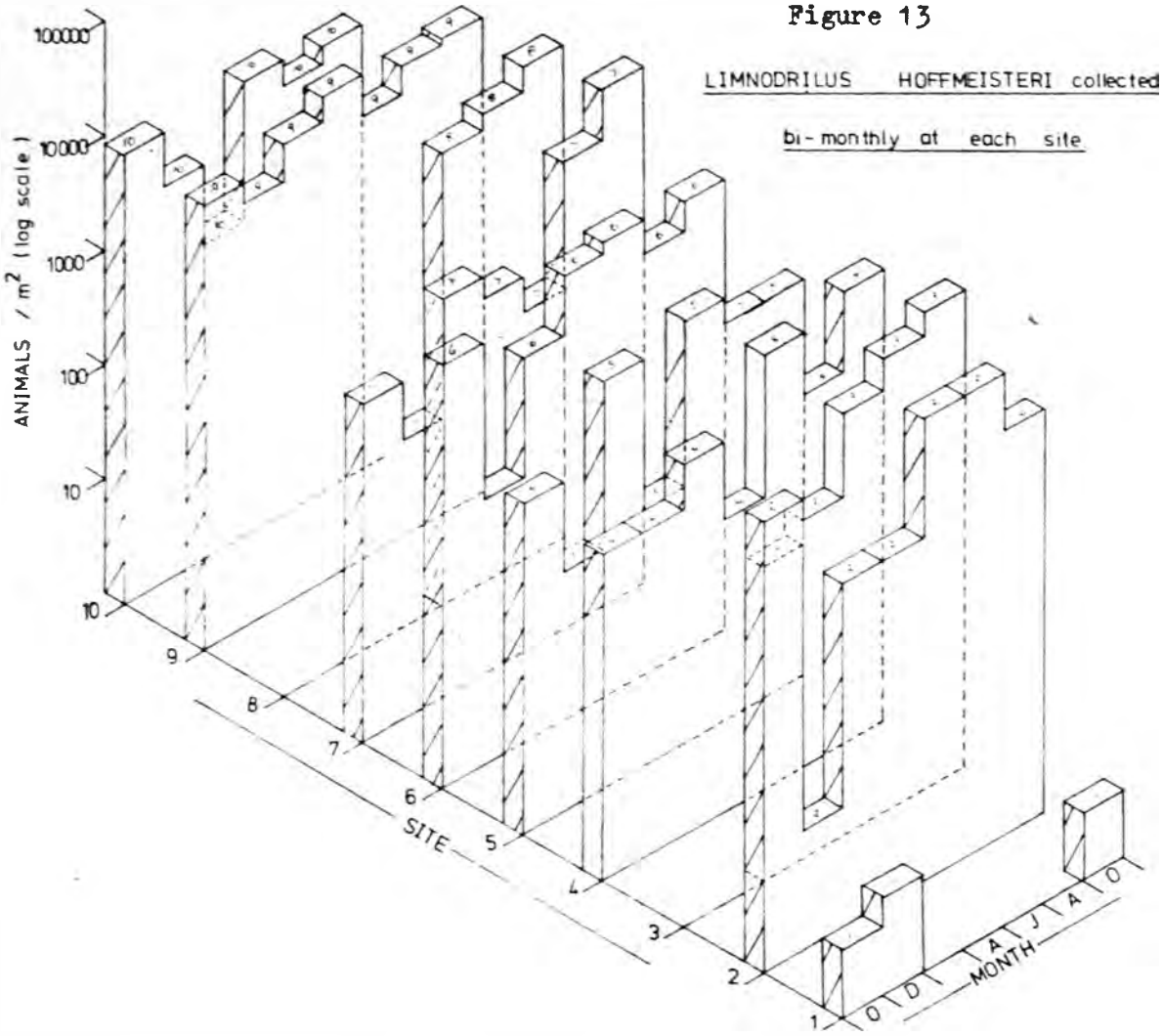


Figure 14

LIMNODRILUS UDEKEMIANUS collected

bi-monthly at each site

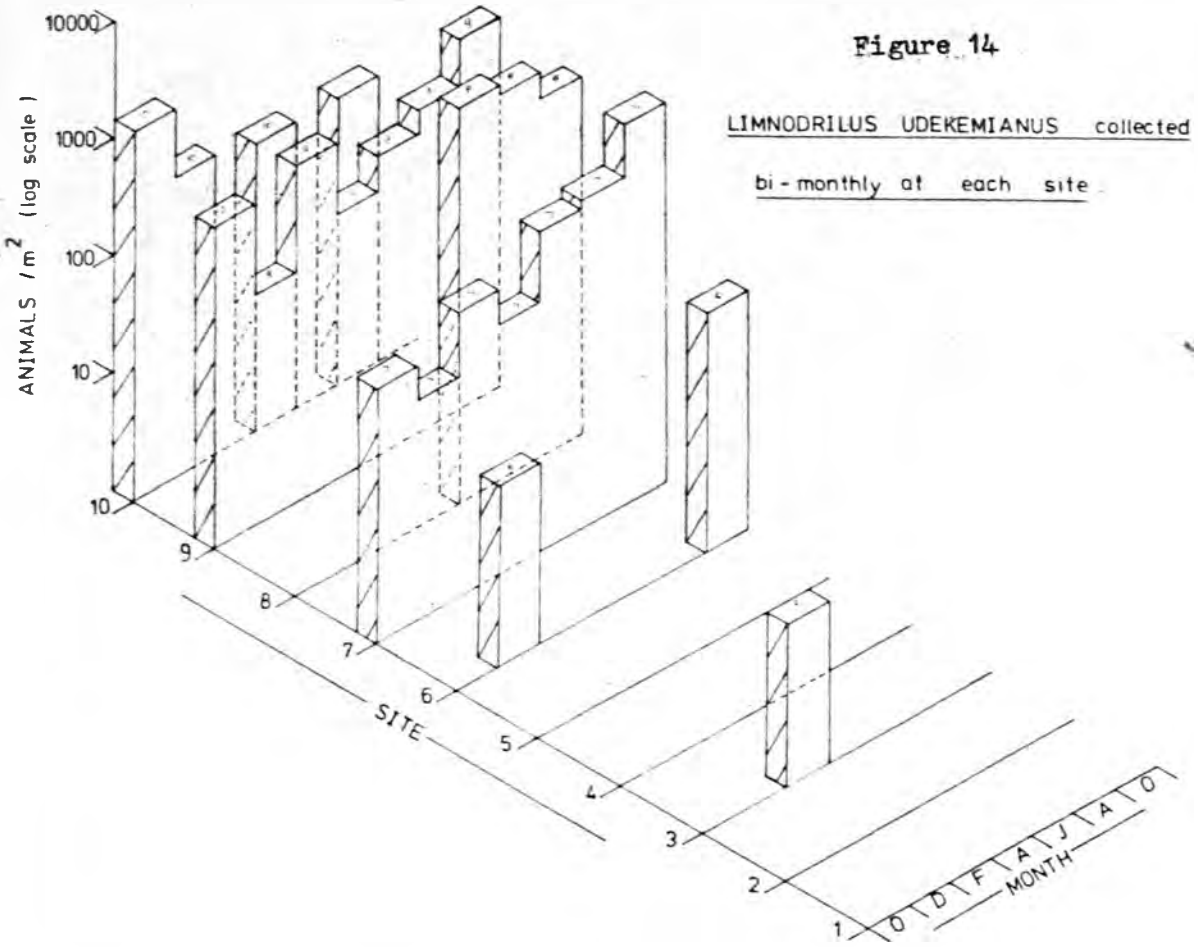


Figure 15

LIMNODRILUS PROFUNDICOLA collected bi-monthly at each site.

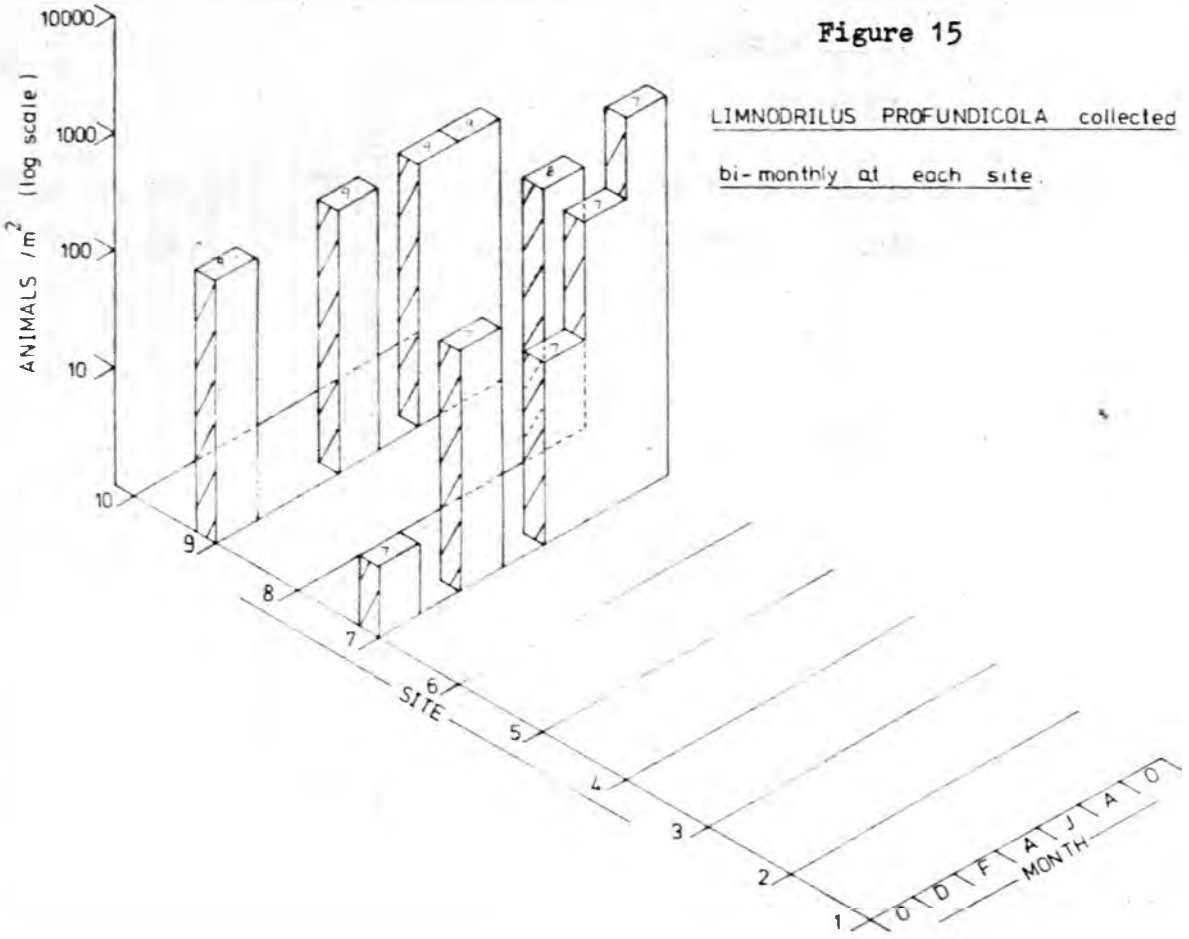
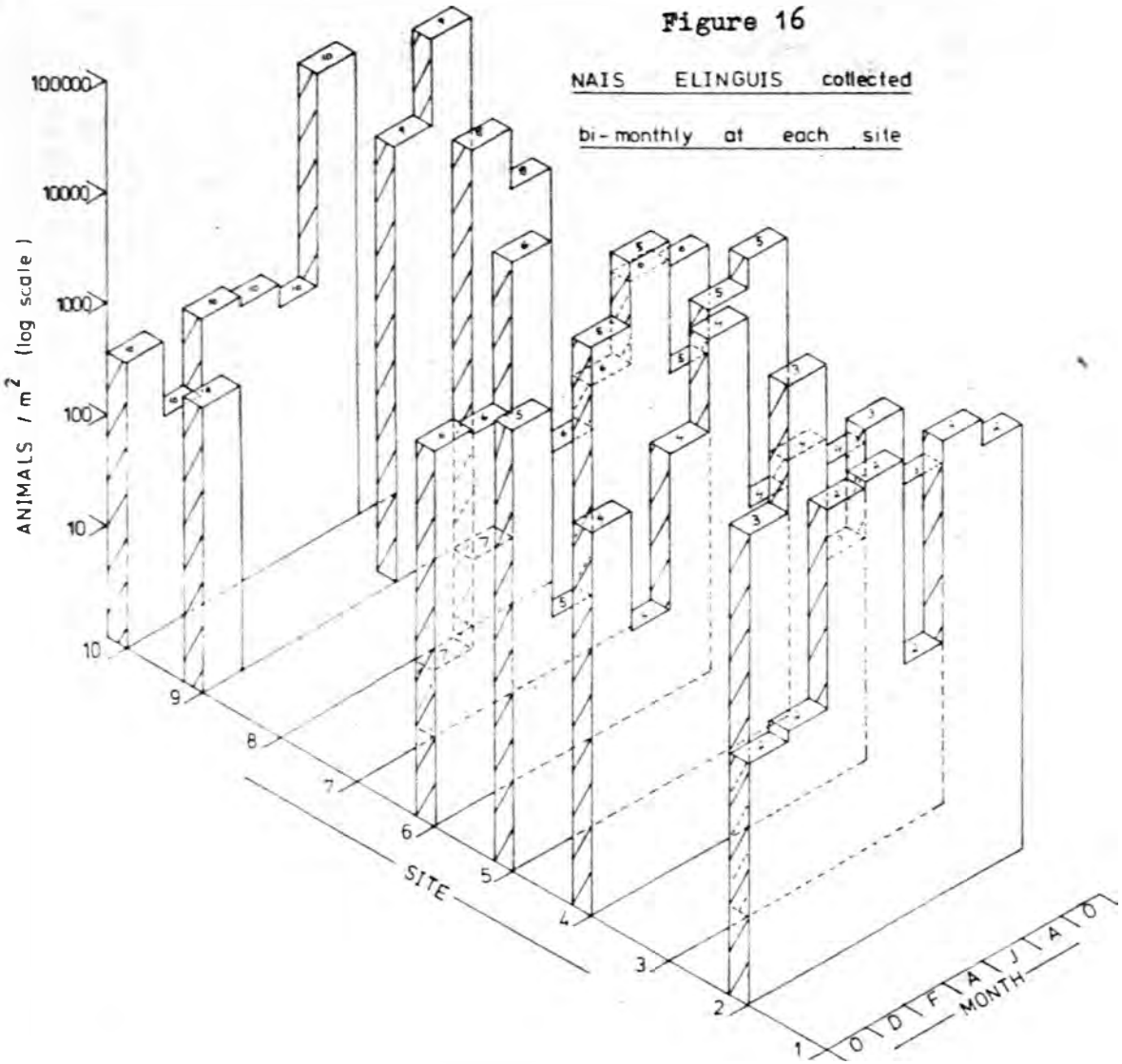


Figure 16


NAIS ELINGUIS collected
bi-monthly at each site
ANIMALS / m² (log scale)
100000
10000
1000
100
10
10
SITE
9
8
7
6
5
4
3
2
1
O
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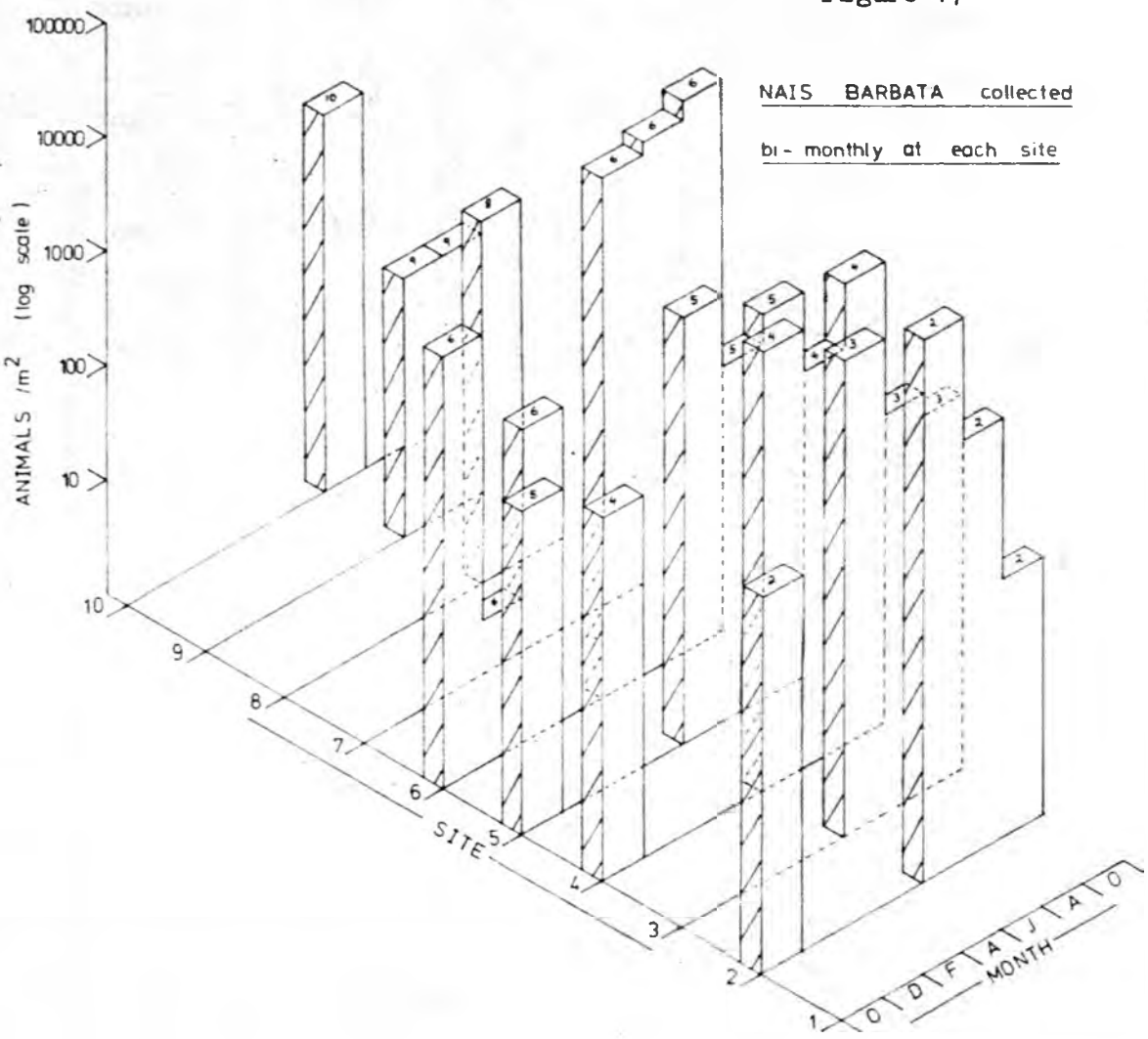
MONTH

Figure 17


NAIS BARBATA collected
bi - monthly at each site
ANIMALS /m² (log scale)
100000
10000
1000
100
10
10
9
8
7
6
5
4
3
2
1
SITE
O
D
F
A
J
A
O
MONTH

8. Basic faunal analysis.

Table 52 lists the taxa collected during the course of the survey; there are 76. The same table lists the abundance of each taxon as a percentage of the total number of invertebrates collected during the period October 1972 to October 1973 and in February 1975. In this way, the table shows the relative abundance in the river of each identified taxon.

Tables 53 to 60 in Appendix III show the mean number per square metre of each taxon collected at each site, for each month. The same data are presented in a different format in tables 61 to 90 in Appendix IV, which treat each numerically important taxon individually.

Figure 11 shows the mean seasonal abundance and mean distribution of total invertebrate numbers, for the river as a whole and for all months respectively. February 1975 data are not included.

For Tubifex tubifex, Limnodrilus hoffmeisteri, L. udekemianus, L. profundicola, Nais elinguis and N. barabata, the data in tables 62, 63, 64, 65, 69 and 70 of Appendix IV are presented in figures 12 to 17, thus showing the abundance of the species concerned each month at each site. These figures are to be interpreted in conjunction with the figures relating to the percentage distribution and percentage seasonal abundance of selected species (figure 18) discussed in the two subsequent sections.

Figure 18.

Percentage mean distribution (left) and percentage mean seasonal abundance of selected species (taxa).

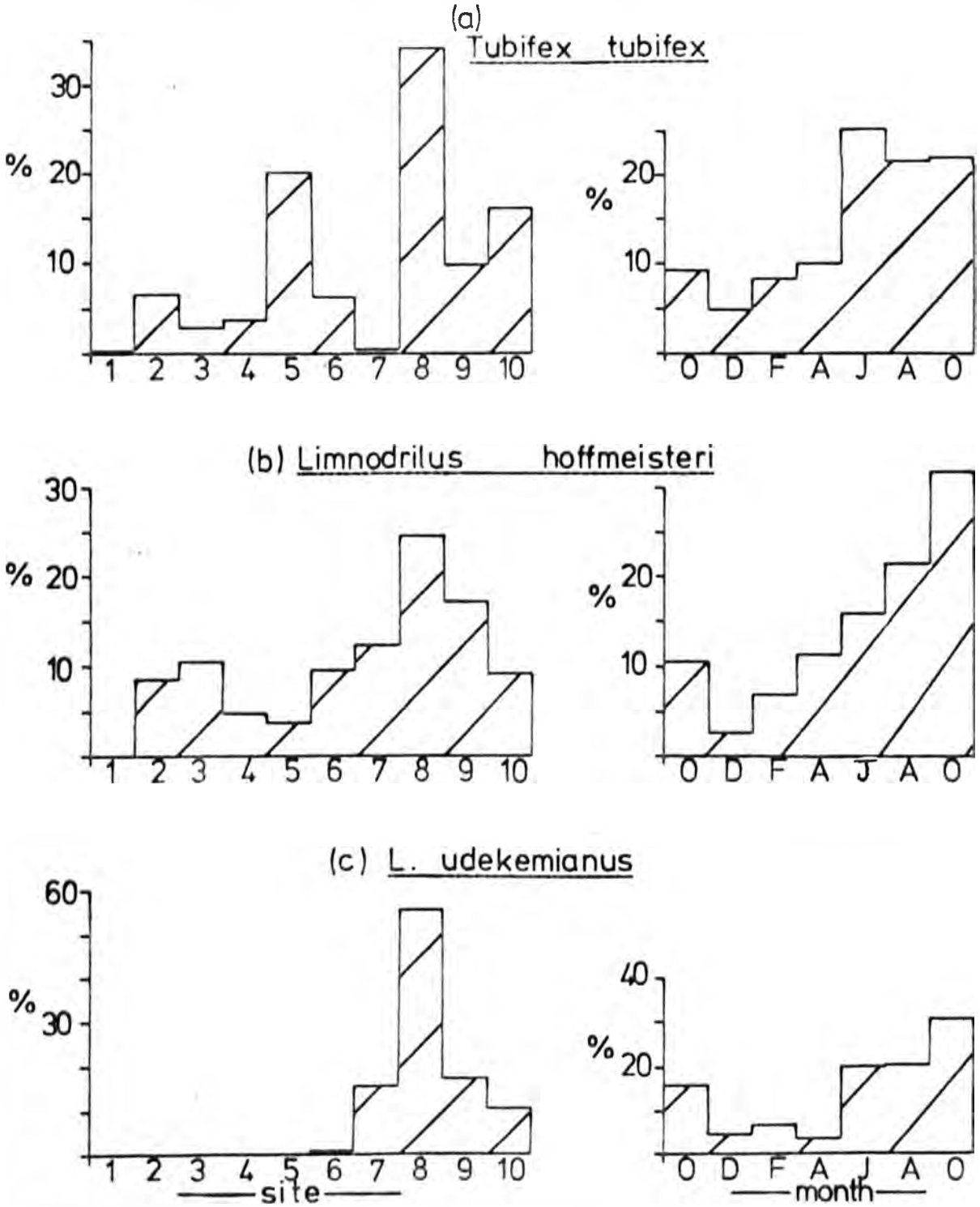


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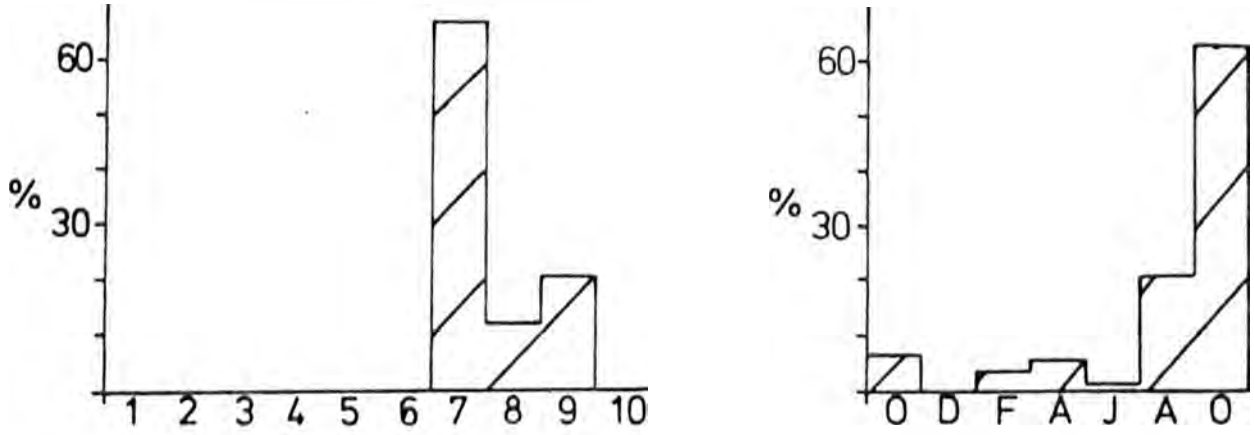
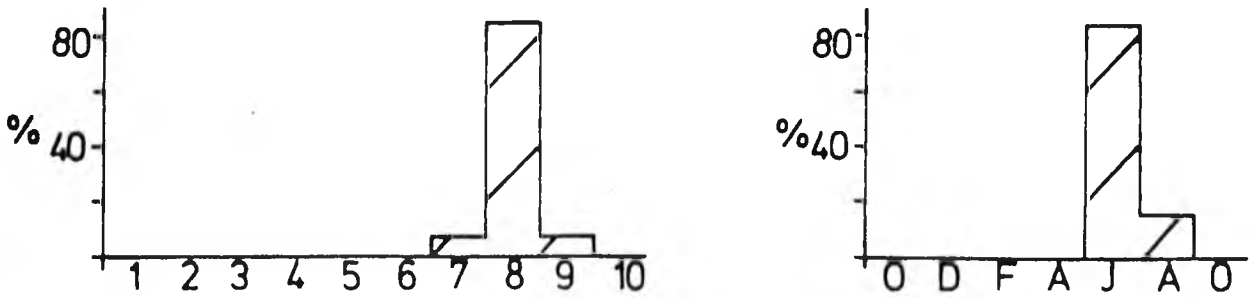
Figure 18 cont.

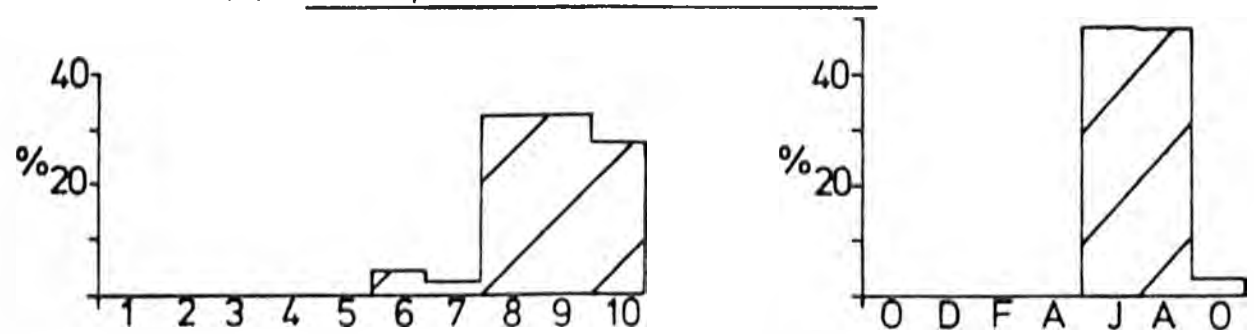
(d) L. profundicola



(e) Monopylephorus irroratus



(f) Monospermathecus rubroniveus



(g) (Enchytraeidae.)

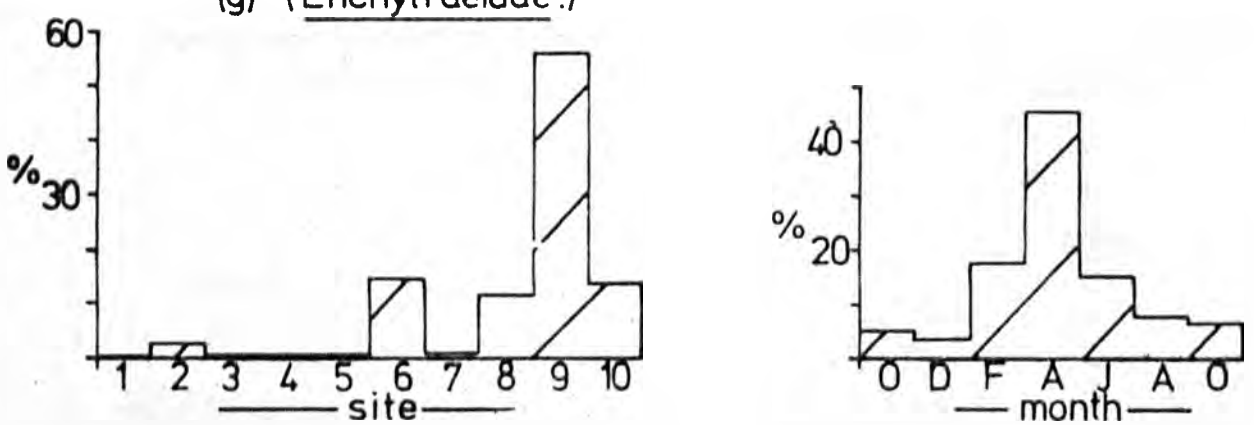


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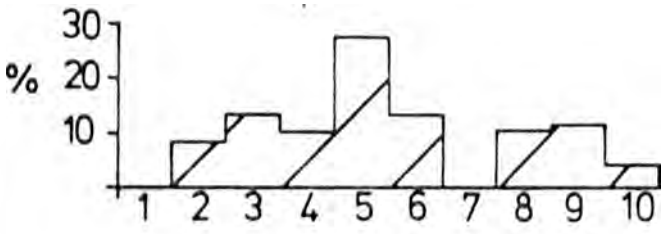
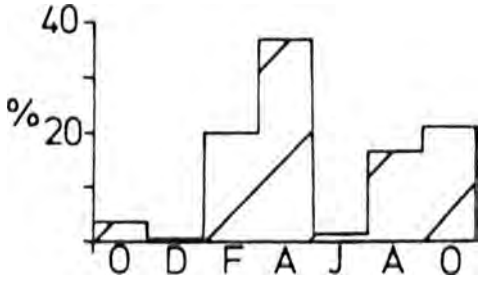
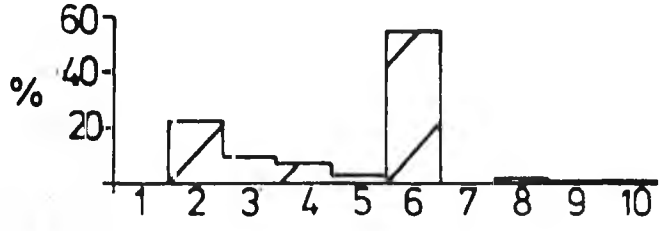
Figure 18 cont.

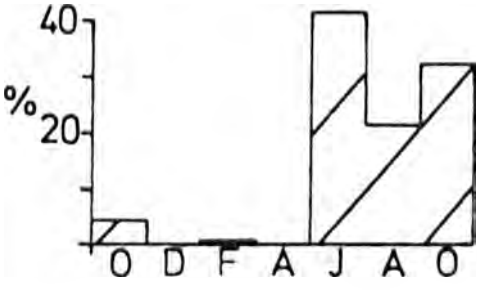
(h) Nais elinguis



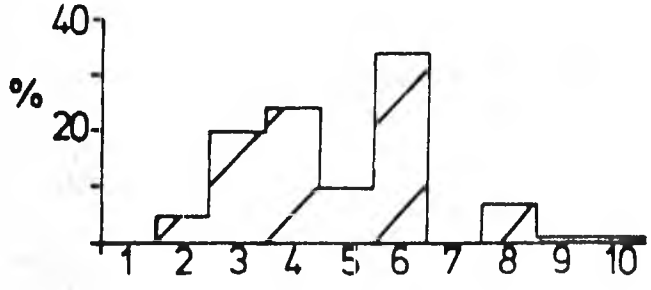


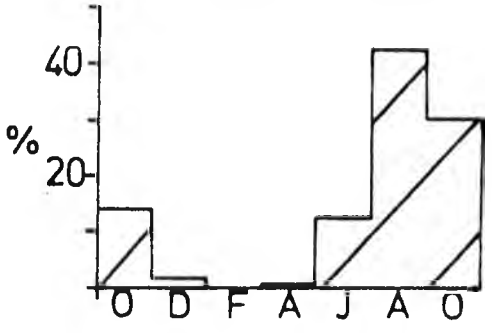
(i) N. barbata



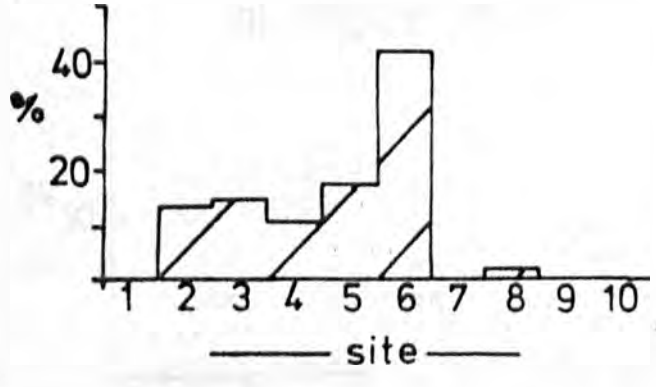


(j) N. variabilis





(k) N. communis



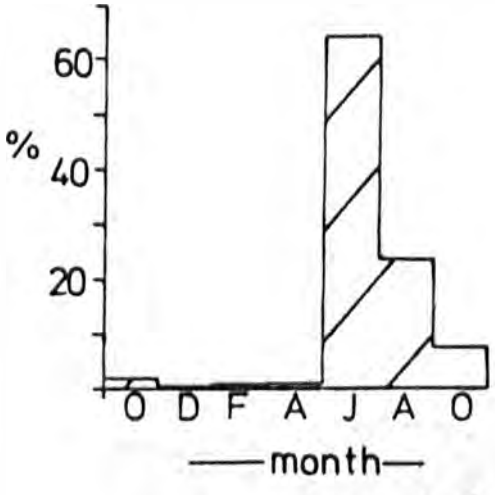


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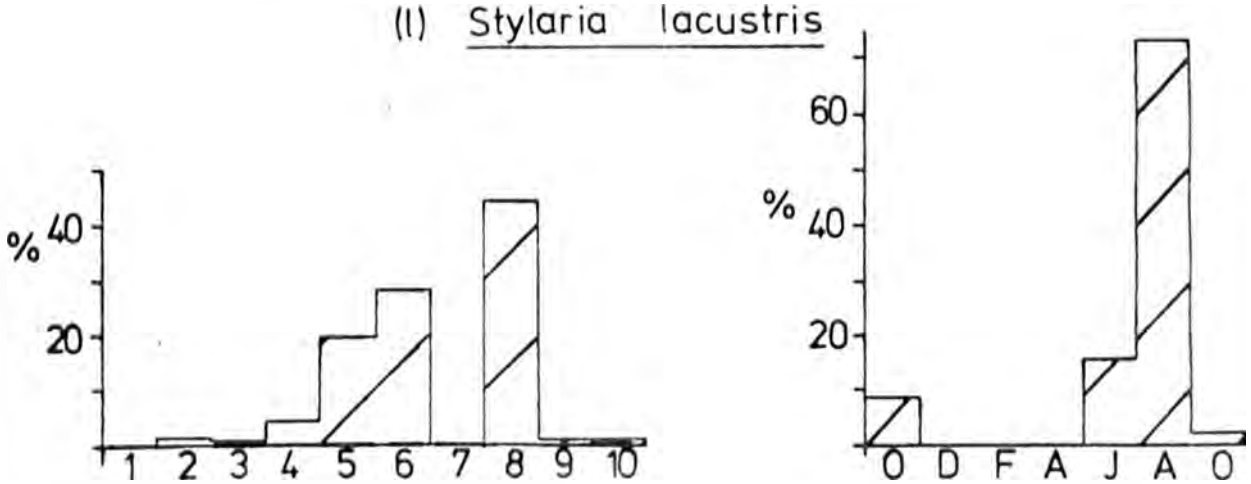
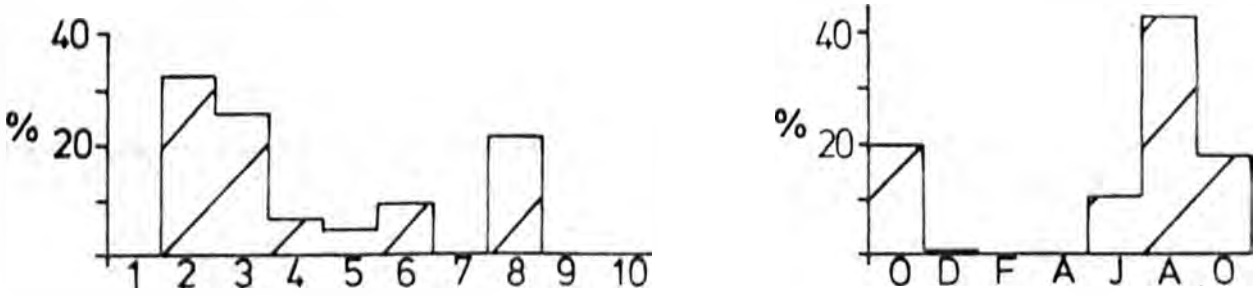
Figure 18 cont.

(l) Stylaria lacustris



(m) Chaetogaster langi



(n) C. diaphanus

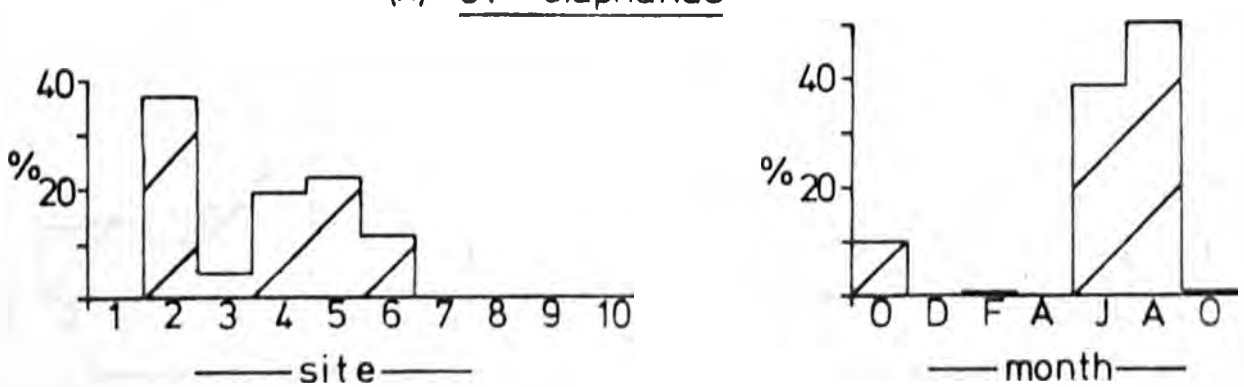


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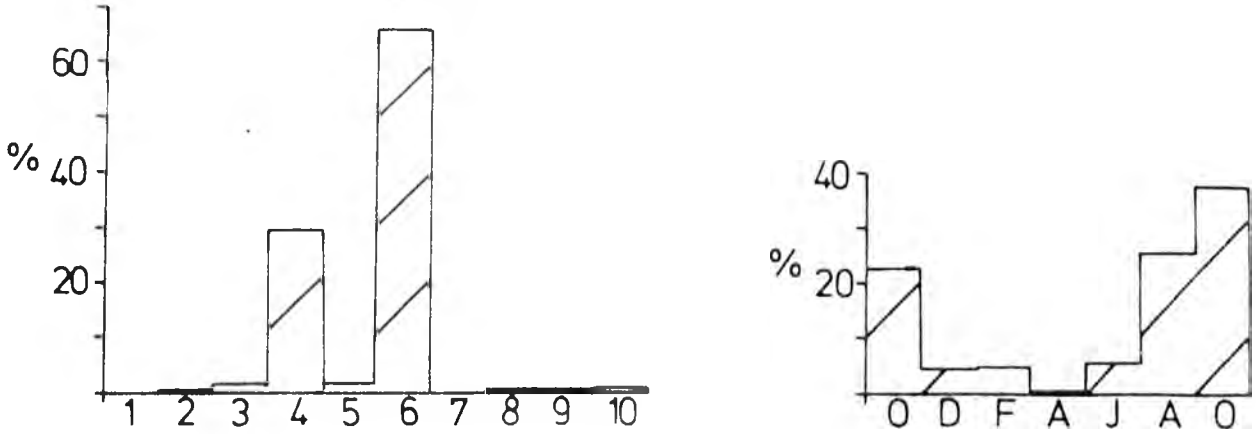
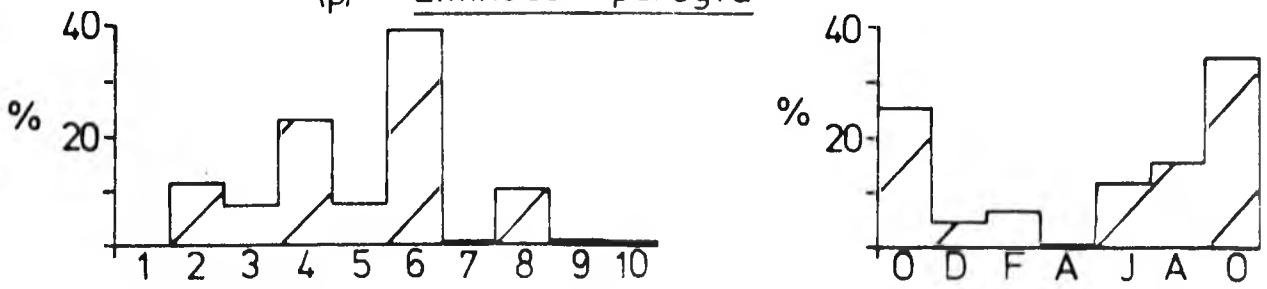
Figure 18 cont

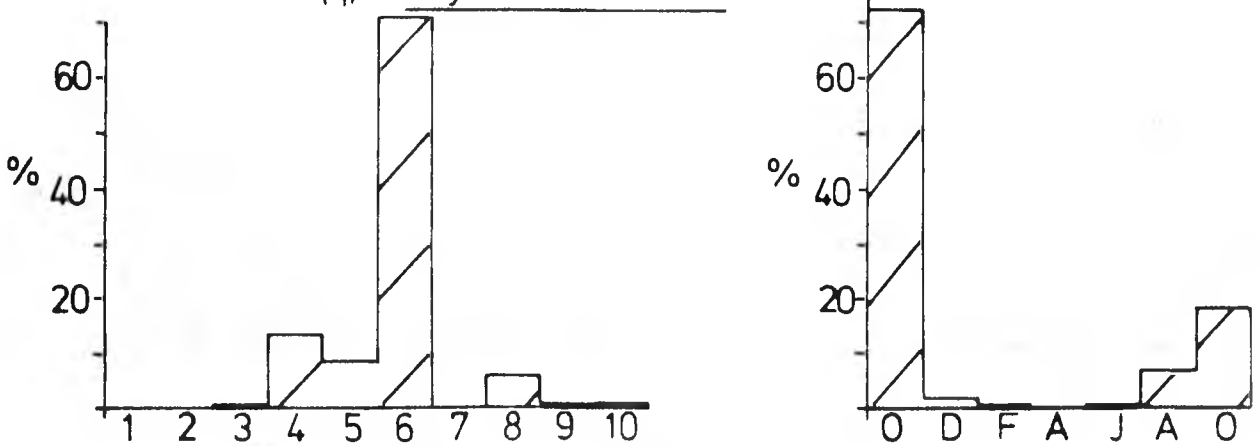
(o) Ancylus fluviatilis



(p) Limnaea peregra



(q) Physa fontinalis



(r) Hydrobia jenkinsi

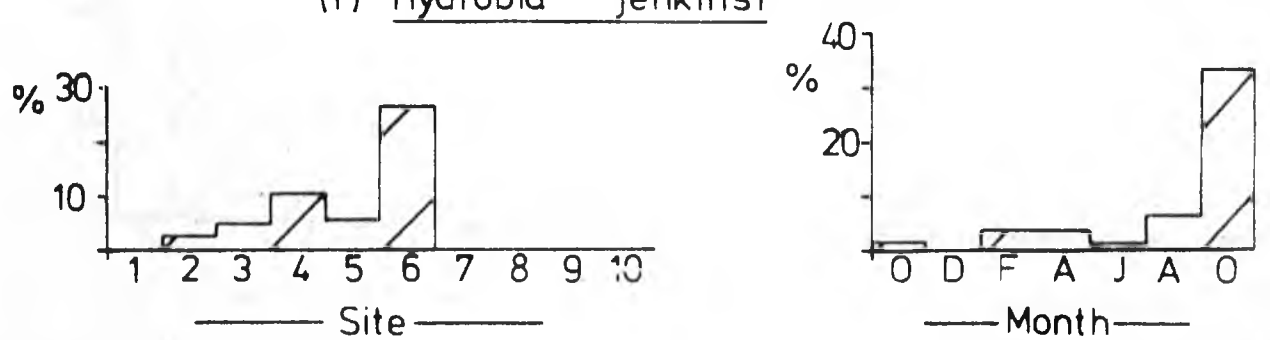


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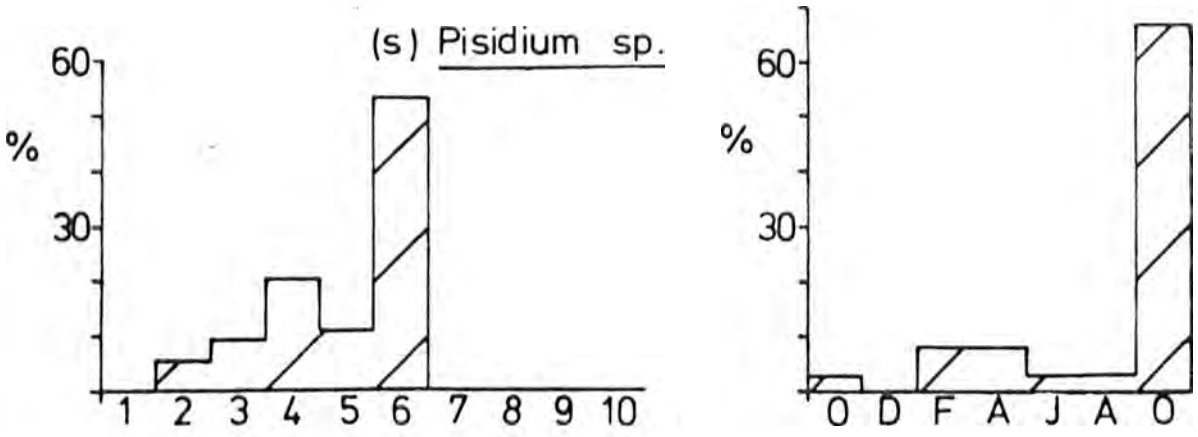
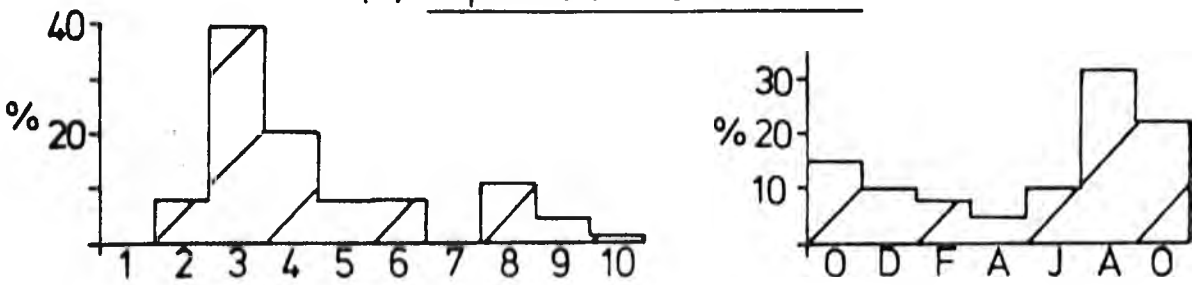
Figure 18 cont.

(s) Pisidium sp.



(t) Erpobdella octoculata



(u) (Chironomidae pupae)

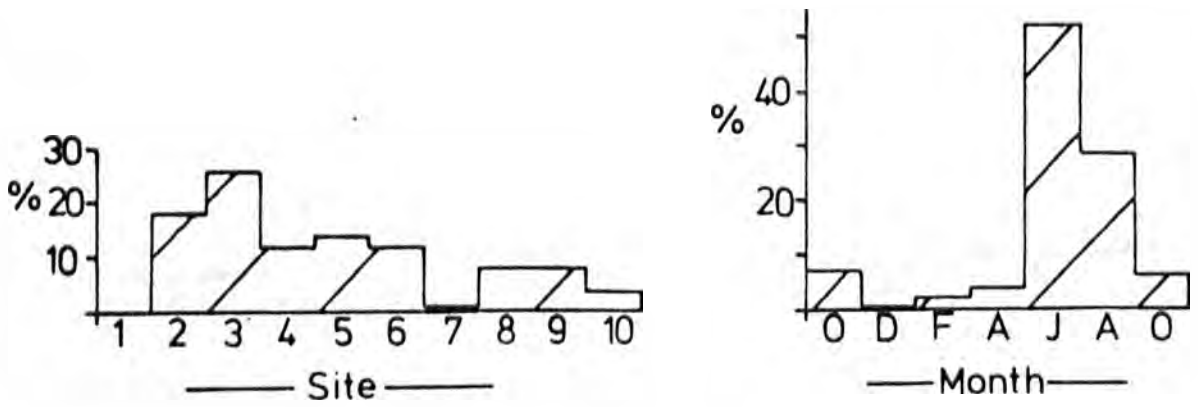


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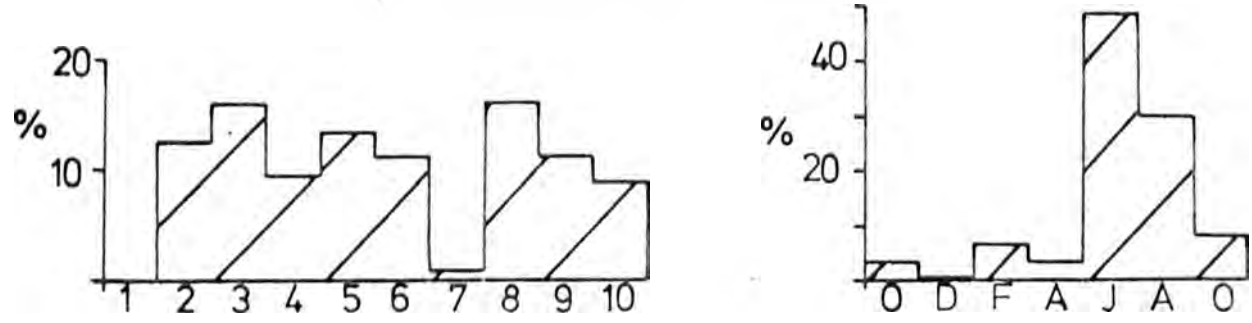
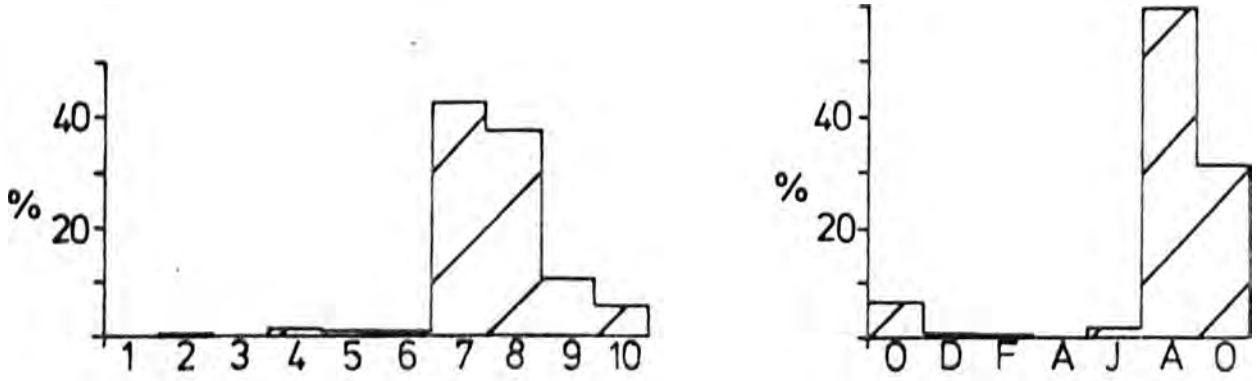
Figure 18 cont.

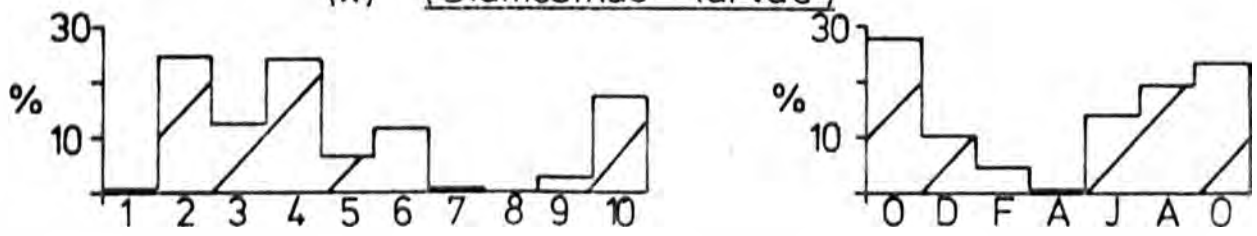
(v) (Orthocladiinae larvae)



(w) (Chironominae larvae)



(x) (Diamesinae larvae)



(y) (Tanypodinae larvae)

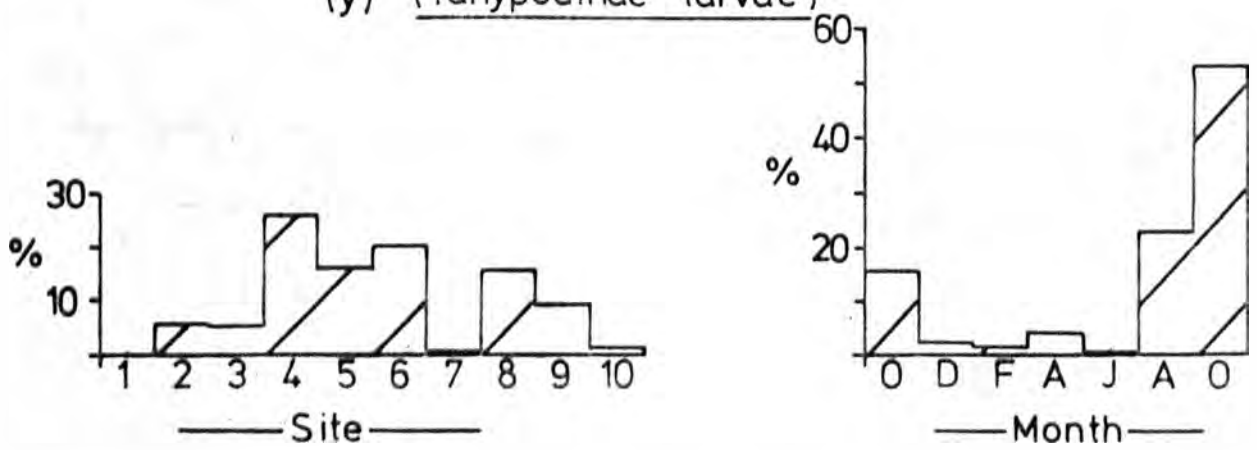


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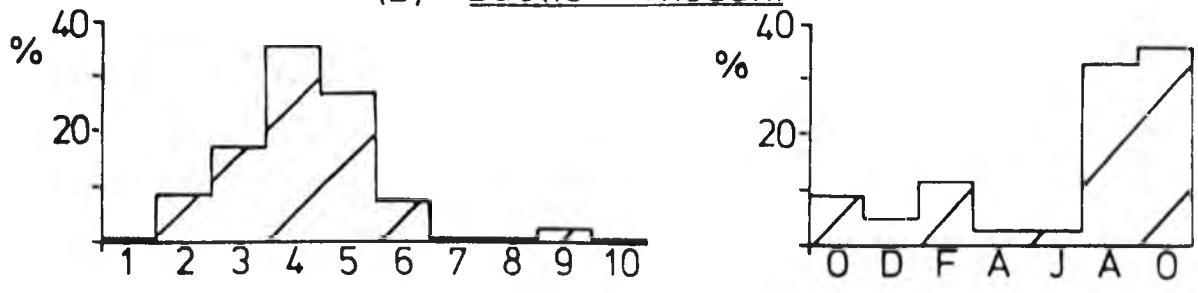
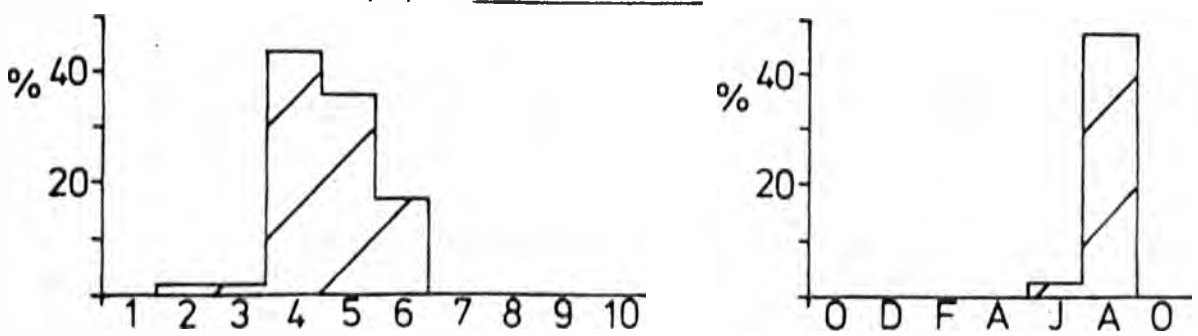
Figure 18 cont.

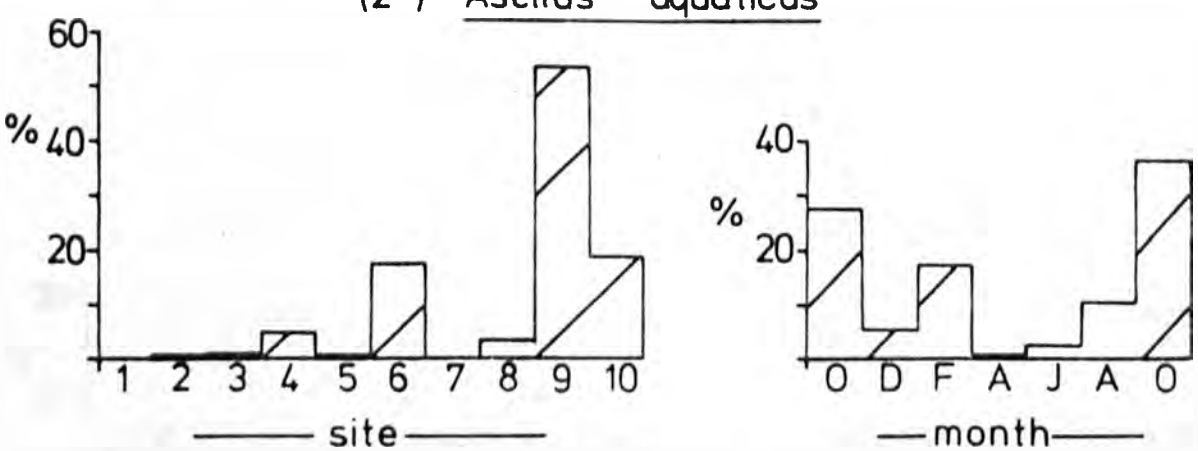
(z) Baetis rhodani



(z') B. scambus.



(z'') Asellus aquaticus



9. Distribution of fauna.

Figure 11 shows most sites to support similar mean numbers of invertebrates; sites 1 and 7 are exceptions. Site 1 is heavily polluted by acid mine drainage, having a mean pH of 4.1, and does not appear to be organically enriched in any way, so it is not surprising that is has low productivity. Site 7, on the other hand is very heavily organically polluted (see figure 6), and might be expected to have a high potential productivity. That this is not the case suggests that pollution of a type other than organic is involved; the sediments at this site have been shown (figure 7) to have the highest sediment-bound copper concentration of any in the river, for example.

The consideration of the distribution of each identified taxon in turn can be a tedious and unrewarding process. In a subsequent section, an attempt has been made to group taxa into 'ecological assemblages', using simple association analysis. The distributions of all taxa within an assemblage can be assumed to be governed by common factors. The analysis of the factors influencing the distribution of the fauna is thus simplified. The ecological requirements of certain taxa are, however, poorly documented in the literature, while for others knowledge is incomplete. It is felt that a more detailed consideration of the distribution of some of these groups in the Irwell is worthwhile.

(a) Oligochaeta; Tubificidae.

Six tubificid species were collected from the Irwell. Tubifex tubifex is well represented at all sites except sites 1 and 7. The peak in percentage mean distribution (figure 18a) at site 8 is to some extent biased in that samples were only collected from this site during months when the species was at

its greatest abundance, the percentage being based on the mean for all months sampled. A clearer picture of the distribution of T. tubifex is presented by figure 12, which shows the number of animals collected each month at each site (figures as mean numbers per square metre). The species clearly thrives in the conditions prevailing at most of the sites sampled, reflecting its well known tolerance of a wide range of environmental conditions. The low number of animals collected at site 1 may reflect the lack of potential productive capacity of this site, as much as the low pH, there being little or no organic enrichment; this is certainly not the case at site 7, where a mean B.O.D. of 13.8 $mg.l^{-1}$ was recorded. It is possible that the species is precluded from colonizing site 7 in large numbers by a combination of periodic low oxygen concentrations and relatively high copper concentrations in sediments (figure 7). There is evidence that tubificids are adversely affected by copper (Butcher, 1946). The reason for the high percentage occurence of T. tubifex at site 5 is unclear.

Limnodrilus hoffmeisteri thrives in the Irwell at all sites except site 1. It is probably scarce at this site for the same reasons as T. tubifex. Conditions at site 7 appear to present no obstacle to colonization by L. hoffmeisteri; it is possible that the greater success of the species, as compared with T. tubifex, at site 7, reflects its ability not only to survive, but to breed, at very low oxygen concentrations (Aston, 1973).

The ecology of Limnodrilus udekemianus is not particularly well documented; in the Irwell, the species is clearly restricted to the lower reaches of the river (see figure 14) where the degree of organic pollution is greatest. Kennedy (1965) reports that, although the species is cosmopolitan, its distribution in

Britain is patchy and that the species never occurs very abundantly. Figure 14 makes it clear that the species is abundant at certain sites sampled during the present work.

The occurrence of Limnodrilus profundicola in the Irwell is spasmodic. The species appears to be established, its occurrence not being limited to one or two isolated collections, but is rare. It is restricted to the lower reaches of the river and can clearly tolerate a high level of organic pollution. The other Tubificidae collected during the course of the survey, Monopylephorus irroratus and M. rubroniveus, also occur in very heavily organically polluted situations (figure 18).

(b) Oligochaeta; Naididae.

Nais elinguis was collected at all sites except sites 1 and 7 (figure 18h) although figure 16 makes it clear that the species occurs more spasmodically at some of the downstream sites than it does in the less polluted upstream reaches. It is interesting to note that more specimens were collected from site 9, where the species only occurred in three months, than from site 10, whence it was taken every month. It is possible that periodic toxic discharges are eliminating the animals at site 9; very high lead concentration were measured in the sediments at this site, and the levels have been shown to fluctuate.

Figure 18i shows Nais barbata to occur at all sites colonized by N. elinguis, but the former species is clearly less well able to tolerate the conditions prevalent in the heavily polluted downstream reaches. For example, while N. elinguis was collected every month from site 10 (figure 16), N. barbata was only collected in one month (figure 17).

Nais variabilis, N. communis, Stylaria lacustris, Chaetogaster langi and C. diaphanus show similar patterns of distribution in the Irwell, as shown by figure 18j-n. None of these species can tolerate conditions at sites 1 or 7; some of them seem quite able to survive at site 8. The species are certainly well able to tolerate conditions in the upstream reaches of the river, even though the water is of 'doubtful' quality when judged by the B.O.D. criteria given by Klein (1959).

(c)Mollusca.

Ancylus fluviatilis, Limnaea peregra, Physa fontinalis, Hydrobia jenkinsi and Pisidium sp., all show remarkably similar patterns of distribution, as shown by figure 18 (o to s). All the molluscs are most abundant at site 6. The water here has the lowest mean suspended solid load (figure 6), and it may be postulated that this is of advantage to the animals, excess suspended solids possibly tending to block respiratory mechanisms. The consistently high dissolved oxygen concentrations resulting from the prodigeous powers of aeration of the weir upstream of the site must also be of influence. Were the degree of contamination of the water by suspended solids the only influential factor, however, the abundance of the molluscs at site 4 would be difficult to explain. Success of the animals here may be related to the abundance of potential food in the form of massive growths of Cladophora observed by the author during the summer months.

The heavily polluted downstream reaches of the Irwell are not favourable to the molluscs; Ancylus fluviatilis, Limnaea peregra and Physa fontinalis are able to survive in small numbers, the latter two species showing considerable success at site 8.

(d). Chironomidae; Orthocladiinae.

The larvae of this sub-family cannot tolerate conditions at

site 1, and are scarce at site 7. The group shows similar abundance at all other sites, making it clear that the animals can thrive in a wide range of the conditions prevailing in the Irwell. It is, of course, by no means clear whether the sub-family is represented by the same or different species at different sites.

(e) Chironomidae; Chironominae.

These larvae are clearly favoured by conditions in the lower reaches of the Irwell, being far less successful in the less polluted upper reaches of the river. The sub-family is well adapted to organically polluted conditions. It is likely that it is represented in the Irwell largely by Chironomum thummi (sometimes called C. riparius) which is a common inhabitant of muds rich in organic matter and tolerant of salt, hydrogen sulphide and ammonia(Hynes, 1971a). Chironomus is regarded by Berg (1948) as being intolerant of swift currents, but this was not found to be the case by Hynes (1971a) who has found the animal in rapid streams where sewage fungus and accumulated solids have filled the spaces between stones to form a suitable microhabitat. This exactly paralells the situation in the lower reaches of the Irwell, where the midge thrives.

(f) Ephemeroptera; Baetis sp.

Baetis rhodani is well known as a species tolerant of organic pollution, Hynes (1971a) feeling that the species is more tolerant of contamination than are the other members of the genus. Baetis scambus shows a pattern of distribution in the Irwell very similar to that of B. rhodani (see figure 18, z and z'), but is very much less abundant. The fact that B.scambus is less abundant than B. rhodani does not necessarily mean, however, that the species is less tolerant of pollution. There are many factors influencing the relative 'commonness' or 'rareness' of species (Andrewartha, 1970).

The above consideration of the distributions of selected taxa make it clear that the heavy degree of pollution in the lower reaches of the Irwell has a profound effect on the fauna. Certain taxa thrive at most sites, and may be described at 'facultatively pollution tolerant' animals, while others only achieve any success in grossly contaminated conditions and may be considered as 'obligatory exploiters' of organic pollution in the Irwell. Another group of animals can tolerate the mild pollution at some sites in the Irwell, but cannot tolerate gross contamination. The distributions of all species will, in any case, be governed by a complex of physical, chemical and biotic factors.

10. Seasonal abundance of fauna.

The seasonal abundance of all invertebrates, grouped together (figure 11b) does not show a clear trend, but as will be discussed subsequently, this is strongly influenced by certain oligochaete species.

Figure 18 shows percentage mean distribution and percentage mean seasonal abundance of selected taxa. The latter will be considered here.

In the study of Eyres (1973) Tubifex tubifex and Limnodrilus hoffmeisteri showed clear peaks of abundance in August, September and October. The situation is less clear in the present study; the species were far less abundant in October 1972 than in October 1973. It is this situation, in these numerically dominant species, that distorts the picture of total invertebrate numbers (figure 11b). Abundance of T.tubifex and L. hoffmeisteri is clearly greater in the summer and autumn months. This situation is similar to that prevailing for the other tubificid species considered in figure 18. It is pertinent to note that the very much higher numbers of, for example, L. hoffmeisteri, in October 1973 as compared with October 1972, do not appear to be a product of sampling errors, since examination of figure 13 shows the trend to occur at all sites studied, except site 2. A certain bias is introduced, however, at site 8, where tubificids occur in great numbers and which was not studied in the early part of the study period.

The Enchytraeidae show a massive peak in abundance in April, clearly reflecting rapid recruitment followed by large scale mortalities, The presence of a single peak may suggest that the family is largely represented by a single species, but this is by no means certain.

Eyres (1973) found that in the depositing substrates of the Irwell, Nais elinguis showed enormous recruitment in April, almost 60 percent of the specimens collected occurring in this month. Although less marked, the same trend is apparent from the present data, although a good deal of recruitment clearly occurs by February. The decline in percentage abundance in June is marked (figure 18h), more so that observed by Eyres (1973). N. elinguis appears to breed at different times in different habitats; Ladle (1971), studying a polluted chalk stream, collected the majority of his specimens in winter while Percival and Whitehead (1930) and Bennike and Berg (1948) found largest numbers in the summer.

It is most interesting to note that the fall in the abundance of N. elinguis is accompanied by a correspondingly great increase in the abundance of N. barbata, a species uncommon in the muddy areas (Eyres, 1973). It is possible that some form of competitive exclusion is involved, although without further studies on the biology of both species, this can only be a tentative suggestion. N. variabilis and N. communis, less abundant members of the genus, show seasonal abundance similar to that of N. barbata, with recruitment taking place between April and June.

No overwintering specimens of Stylaria lacustris were collected in the river, but it is unlikely that the worm is absent since massive recruitment occurs in the summer. Subsequent mortality is severe. A similar situation prevails for Chaetogaster langi and C. diaphanus.

Ancylus fluviatilis, Limnaea peregra and Physa fontinalis show similar trends of seasonal abundance. All three molluscs are scarce in April and commonest in late summer and autumn. The situation is less clear for Hydrobia jenkinsi, abundance of this species showing a marked peak in October 1973 which is not the

case in October 1972. Pisidium sp. shows a similar pattern.

Erpobdella octoculata was collected in all months, being most abundant in August and scarcest in April. This is in keeping with the findings of Mann (1953), who showed that in a stream with moderately hard, organically polluted water, cocoons were laid in June and July with young emerging in August and September.

All the chironomid sub-families show clear trends of seasonal abundance (figure 18, v to y). Orthocladiinae larvae are most numerous in June, numbers declining to a minimum in December. Chironominae larvae are most abundant in August; numbers are very low in winter. Considerable numbers of Diamesinae larvae (principally the easily distinguished species Prodiamesa olivacea were collected in all months except April, although peaks of abundance occur in October 1972 and October 1973. The Tanypodinae larvae are very abundant in October 1973, although less so in October 1972. The data summarized above are remarkably clear cut. It might have been expected that differences in the life-cycles of species within a sub-family would blur the picture, but in fact the least well defined picture is that for the Diamesinae larvae, which appear to be almost wholly represented by a single species, Prodiamesa olivacea. The peak of abundance of Chironomidae pupae (not identified to sub-family) is rather earlier than might be expected from the larval data; in fact the larvae are probably largely dominated by the very numerous Orthocladiinae, which show the earliest larval recruitment.

Baetis rhodani larvae occur in the Irwell throughout the year, highest numbers being collected in August and October 1973. Edwards,L (1975) points out that the multi-voltine life-cycle of this species leads to erratic variations in numbers collected. B. scambus, on the other hand, shows a very marked pattern of seasonal abundance (figure 18z') with over 95 percent of all

specimens being collected in August 1973. Maximum numbers occur in the River Lune in the same month (Edwards,L, 1975). The species seems to have a uni-voltine life-cycle.

Asellus aquaticus is clearly most abundant in October, although a minor peak in February 1973 upsets the trend towards declining numbers in winter. Minimum numbers occurred in April. There is little published work relating to the life-history of A. aquaticus. Ellis (1961) has studied the life-history of A. intermedius, a North American species. He found that the animals bred from May to September, 40 percent or more of the females being pregnant over this period. A similar situation would appear to prevail for Asellus aquaticus in the Irwell.

Many factors influence the weight one can attach to seasonal fluctuations in population density when considering an animal's life-cycle. An important, and often neglected influence in polluted waters is the effect that variations in the nature and degree of contamination can have on animal numbers, blurring and overshadowing natural fluctuations. At its simplest, a highly toxic discharge of a periodic nature, occurring at a time of recruitment to the population, may negate the effects of such recruitment. For example, on one occasion a discharge at site 6 was observed to be killing large numbers of Asellus aquaticus. It is conceivable that such effects may be responsible for the large discrepancies in the numbers of certain species between the months of October 1972 and October 1973.

11. Association analysis.

Without the assistance of some form of numerical technique it is difficult to be other that crudely subjective when discussing similarities between the faunas of sampling sites or grouping species on the basis of similarities in ecological requirements.

The methods of classification used by phytosociologists (for example Williams et al., 1966) have not been fully exploited by animal ecologists. The studies of Field (1971), Hughes et al. (1971) and Prentice and Kain (1976) are exceptions. The basis of an association analysis, in the present context, is the calculation of measures of similarity between the faunas of sites or between the distributions of taxa.

(a) Similarities between sampling sites based on faunal characteristics.

To examine similarities between the faunas of sampling sites, it is necessary to calculate the chosen index of similarity, based on faunal composition and species abundance, for all possible pairs of sites. The Czekanowski coefficient has been shown by Field (1971) to be consistent on both homogenous and heterogenous data sets, i.e. it is not influenced by large numbers of noughts in the data matrix. Field (1971) states that the coefficient is applicable to most types of ecological data including counts of the number of specimens and simple presence/absence data. For present purposes Czekanowski coefficients were calculated using the data in tables 53 to 60. The coefficient, C, is given by:

$$C = (2W/(A+B)) \times 100$$

where A is the total number of individuals collected at site a,

B is the total number of individuals collected at site b,

W is the sum of the smaller counts of each species occurring at both sites a and b.

Table 91.

Matrices of Czekanowski coefficients, for each month.

October 1972

Site	1	2	3	4	5	6	7	8	9	10
10	0.5	67.6	-	17.4	22.9	42.2	9.8	-	71.8	x
9	0.5	45.4	-	21.3	25.4	44.2	8.4	-	x	
8	-	-	-	-	-	-	-	x		
7	7.2	8.9	-	11.7	9.6	4.8	x			
6	0.3	38.6	-	36.1	33.1	x				
5	0.8	36.4	-	61.5	x					
4	1.1	33.7	-	x						
3	-	-	x							
2	0.7	x								
1	x									

December 1972

Site	1	2	3	4	5	6	7	8	9	10
10	2.4	6.5	-	42.9	37.0	34.0	13.8	-	59.3	x
9	1.8	4.2	-	16.1	28.2	24.3	10.3	-	x	
8	-	-	-	-	-	-	-	x		
7	26.4	44.0	-	25.6	36.8	24.7	x			
6	5.2	17.3	-	36.0	60.0	x				
5	10.2	26.5	-	26.3	x					
4	5.4	17.3	-	x						
3	-	-	x							
2	34.6	x								
1	x									

February 1973

Site	1	2	3	4	5	6	7	8	9	10
10	0.8	17.5	14.8	17.4	11.0	8.3	23.1	-	28.6	x
9	0.1	4.9	2.4	16.5	24.0	10.5	9.2	-	x	
8	-	-	-	-	-	-	-	x		
7	2.4	23.9	26.8	27.1	17.3	11.4	x			
6	0.3	38.1	12.8	29.4	56.0	x				
5	0.3	44.8	15.5	47.8	x					
4	0.8	51.4	37.3	x						
3	3.4	43.6	x							
2	1.1	x								
1	x									

continued/

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Table 9/ continued.

April 1973

Site	1	2	3	4	5	6	7	8	9	10
10	0.2	12.7	7.6	4.4	3.3	70.3	12.9	-	41.0	x
9	0.1	4.3	3.1	3.9	1.5	30.8	4.1	-	x	
8	-	-	-	-	-	-	-	x		
7	2.4	24.9	8.0	4.1	3.4	19.5	x			
6	0.4	16.3	10.5	12.0	4.6	x				
5	0.3	31.7	70.5	70.5	x					
4	0.3	45.3	93.0	x						
3	0.6	51.2	x							
2	0.7	x								
1	x									

June 1973

Site	1	2	3	4	5	6	7	8	9	10
10	0.4	37.1	57.2	61.6	71.8	39.9	5.0	80.8	73.0	x
9	0.5	39.6	56.8	68.6	49.4	45.7	7.2	74.8	x	
8	0.3	35.5	44.1	52.8	64.4	42.8	5.4	x		
7	11.6	2.1	5.1	5.8	2.7	1.8	x			
6	1.4	59.3	48.3	41.2	51.1	x				
5	0.2	48.8	62.7	59.6	x					
4	0.6	41.9	74.1	x						
3	0.5	56.0	x							
2	0.2	x								
1	x									

August 1973

Site	1	2	3	4	5	6	7	8	9	10
10	1.7	73.3	59.2	43.7	52.1	41.5	27.6	65.0	70.2	x
9	1.6	70.7	63.0	37.7	42.0	38.0	37.2	61.6	x	
8	1.0	61.0	46.6	37.3	76.3	46.6	27.0	x		
7	2.7	33.1	31.1	17.5	11.6	17.1	x			
6	1.0	45.8	41.7	48.5	50.2	x				
5	1.0	55.1	45.3	52.7	x					
4	2.7	51.2	51.0	x						
3	1.7	76.9	x							
2	1.7	x								
1	x									

continued/

Table 9/ continued.

October 1973

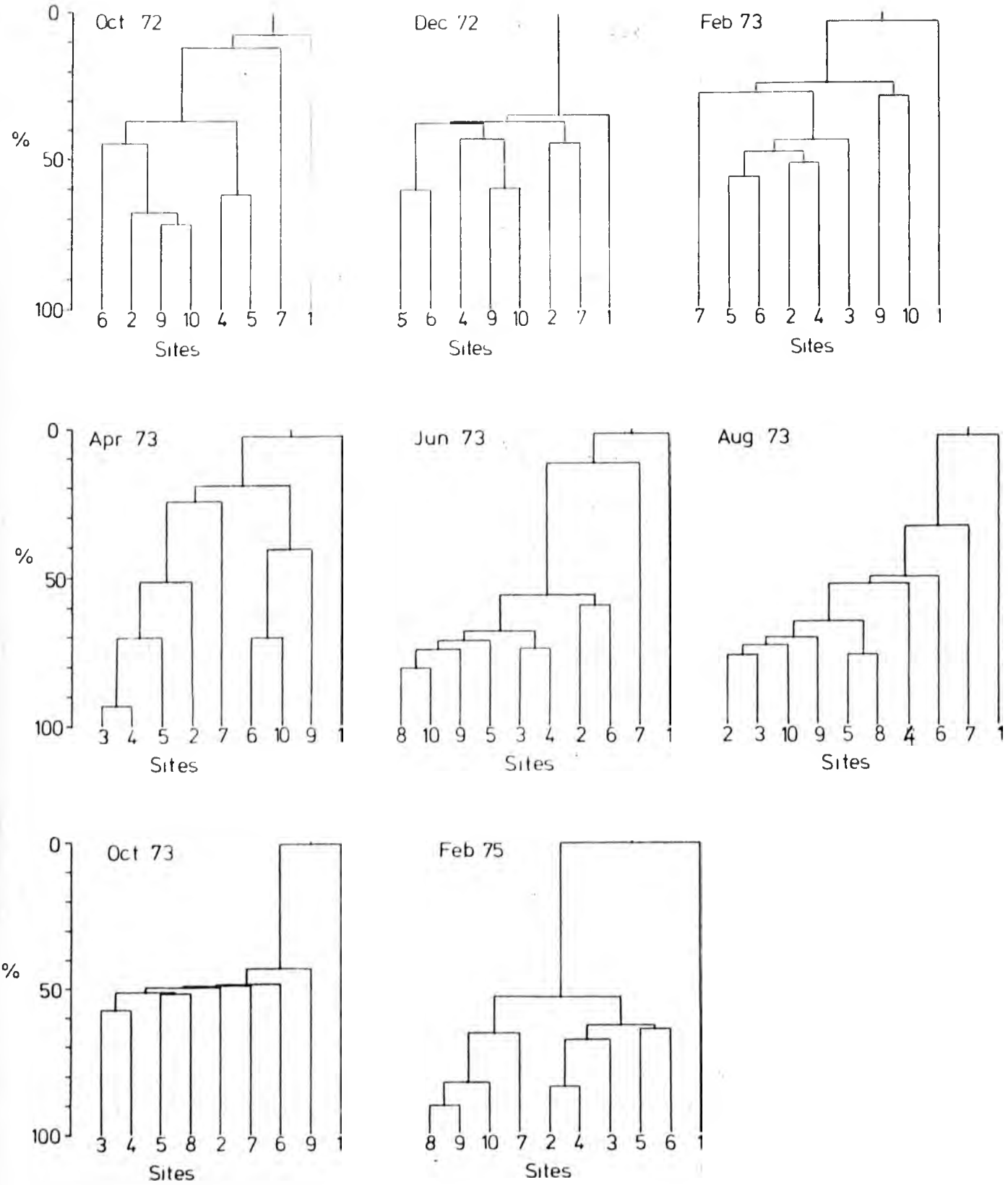
Site	1	2	3	4	5	6	7	8	9	10
10	-	-	-	-	-	-	-	-	-	x
9	0.2	28.9	28.3	25.9	37.7	28.9	21.9	43.4	x	
8	0.5	49.7	51.4	34.9	51.7	28.0	49.0	x		
7	0.6	17.2	49.3	24.4	9.0	13.7	x			
6	0.2	24.3	27.9	49.0	23.7	x				
5	0.5	45.6	25.3	28.8	x					
4	0.7	28.3	57.2	x						
3	1.0	30.1	x							
2	1.3	x								
1	x									

February 1975

Site	1	2	3	4	5	6	7	8	9	10
10	0.1	33.4	39.4	26.6	49.5	53.2	27.4	82.7	48.1	x
9	0.3	46.9	26.8	46.5	30.0	28.9	66.0	90.2	x	
8	0.2	18.4	4.7	14.4	13.1	29.2	47.0	x		
7	0.4	18.4	6.6	16.3	12.0	17.4	x			
6	0.1	30.1	36.1	24.3	64.3	x				
5	0.1	51.8	62.7	44.6	x					
4	0.5	84.1	61.1	x						
3	0.3	68.0	x							
2	0.4	x								
1	x									

Figure 19

Dendrograms of percentage similarity between sites



Matrices of Czekanowski coefficients of similarities between sites, for each month, are given in table 91. The matrices are summarized in the dendrograms in figure 19. These were constructed using the 'single-link' sorting method of Williams et al. (1966). The similarity between sites, based on faunal characteristics, clearly fluctuates, although certain properties of the dendrograms are fairly consistent. Site 1 stands out as being consistently different from the other sites, and the same might be said for site 7 at least for October 1972 and June and August 1973. A word of caution is necessary before interpreting the more subtle implications of the dendrograms. Consider, for example, sites 9 and 10 for February 1973. The fact that these two sites are linked at a'similarity level' need not imply that the sites are similar to each other, merely that taken together they are equally similar to (or different from) the group of sites 7, 5, 6, 2, 4, and 3. Despite this caution, sites 9 and 10 do appear to have certain features in common. In some months (October and December 1972, June and August 1973 and February 1975) the sites' faunas are actually similar; in others (February and April 1973) the faunas are relatively distinct, but the two sites are equally distinct, in turn, from the bulk of the other sites.

The situation as it pertains to sites 1 and, to a lesser extent sites 7, 9, and 10, is clearcut. Site 8 was only studied from June 1973 onward, and for two of these months was markedly similar to sites 9 and 10. The relationships between sites 2, 3, 4, 5 and 6 vary.

The lack of consistency in the dendrograms, implying variations in community structure at the sites studied independent of changes affecting the river as a whole, is possibly a result of local variations in the degree and nature of pollution.

Figure 20

Species associations based on correlation coefficients

a. All months

——— indicates significant correlation ($p < 0.01$)

(see text for key)

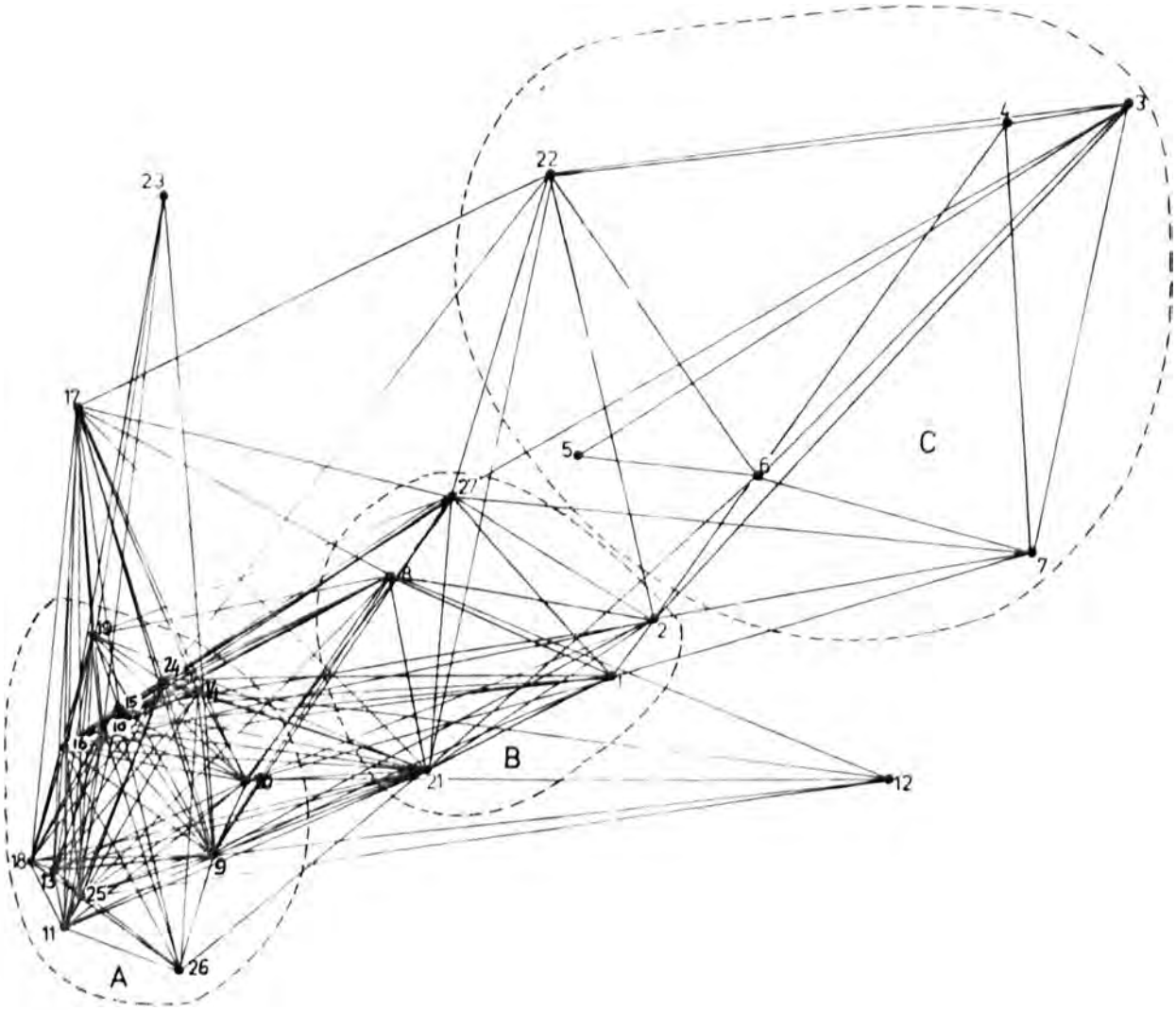


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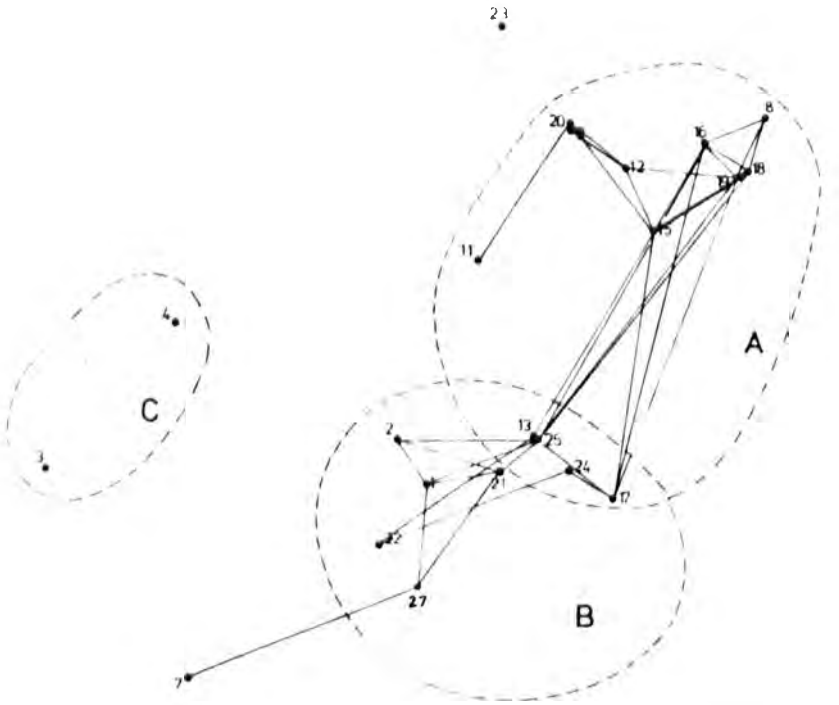
Figure 20 cont.

b. February 1973.

—— indicates significant correlation ($p \leq 0.05$)

(see text for key)



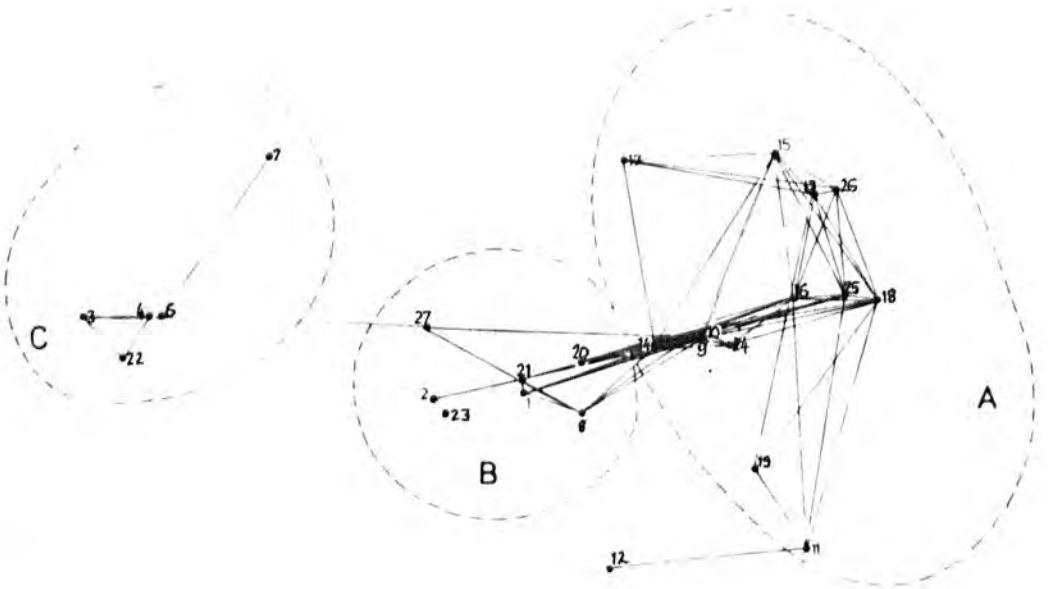
cont./

Figure 2c cont.

c. August 1973

——— indicates significant correlation ($p < 0.05$)

(see text for key)



(b) Species associations.

To examine the data available to find the degree of correlation between counts of the commoner species in the Irwell, Pearson correlation coefficients (r) between all possible pairs of twentyseven species (listed subsequently) were calculated. The coefficients were calculated for each month, and for pooled data for the whole study period. Counts were normalized using the transformation $x = \log_{10}(n-1)$, as suggested in Elliott (1971), and calculations were done using the computer program PEARSON CORR (Nie et al., 1970).

To present the results of the above computations, it was decided that the use of a simple ordination technique would be most appropriate. For this purpose, 'similarities' (r values) need to be converted to 'differences'. Correlation coefficients (r) were treated thus:-

$$(\%\ \text{difference}) = (1 - r) \times 100$$

Negative r values, which were not uncommon, led to percentage differences greater that 100 percent. This did not affect the ordination. The procedure for ordination was as follows. The two species with the greatest 'percentage difference' are used to determine the length of the x axis,'percentage difference' apart. All other species are positioned on the x axis in relation to the first two. The position of species on the x axis gives an indication of their relationships; much more information can be derived by also erecting the y axis, based on two species close together on the x axis but with high 'percentage difference'. Once all species have been positioned on each axis, each species can be characterized by a single point on the ordination.

Figure 20a shows the results of the ordination derived

from the pooled data; 20b and 20c show the same for February 1972 and August 1973 data respectively. These two months were chosen to provide ordinations of winter and summer data to compare with the results of the ordination of the pooled data. Species with significantly positively correlated abundances are linked, the chosen level of significance being $p < 0.01$ for pooled data, and $p < 0.05$ for the other ordinations. These ordinations are intended as aids in picking out associations of species by positioning each species spatially in relation to all other species. It can be assumed that species close together on the ordination, and linked indicating a significant positive correlation of their numbers, are spatially associated in the river in some way. Spatially associated species may be regarded as having certain characteristics in common in terms of their reactions to environmental conditions and of their ecological requirements, and may be termed 'ecological assemblages'. Twenty seven taxa were dealt with in this way, and the numbers by which they are identified on the ordinations are shown below:-

Tubifex tubifex	1
Limnodrilus hoffmeisteri	2
L. udekemianus	3
L. profundicola	4
Monopylephorus irroratus	5
M. rubroniveus	6
Enchytraeidae	7
Nais elinguis	8
N. barbata	9
N. variabilis	10
N. communis	11

Chaetogaster langi	12
C. diaphanus	13
Stylaria lacustris	14
Ancylus fluviatilis	15
Limnaea peregra	16
Physa fontinalis	17
Hydrobia jenkinsi	18
Pisidium sp.	19
Erpobdella octoculata	20
Orthocladiinae larvae	21
Chironominae larvae	22
Diamesinae larvae	23
Tanypodinae larvae	24
Baetis rhodani	25
B. scambus	26
Asellus aquaticus	27

While species are positioned on the ordination by objective means, it is necessary for descriptive purposes to group species in some way, and this must to a certain extent be a subjective process. In figure 20, three groups of species have been delineated. The criteria for drawing the boundaries round the groups are (a) spatial and (b) statistical (i.e. the degree of correlation as indicated by the numbers of significant r values). In figure 20a, for example, association A is fairly 'tight' spatially. Species 17, while 'statistically linked' to many of the species in association A, is excluded from it on grounds of its position. Association C is less well defined spatially and more use was made of degrees of statistical correlation in drawing its boundaries. Association B is intermediate in position between the two other associations

Table 92.

Species present in associations A, B and C in ordinations (fig.) of pooled data and of data for February and August 1973.

Pooled data	February	August	
Nais barbata		N. barbata	A
N. variabilis	N. variabilis	N. variabilis	A
N. communis	N. communis	N. communis	A
	C. langi		
Chaetogaster diaphanus	C. diaphanus	C. diaphanus	A
Stylaria lacustris		S. lacustris	A
Ancylus fluviatilis	A. fluviatilis	A. fluviatilis	A
Limnaea peregra	L. peregra	L. peregra	A
	Physa fontinalis	P. fontinalis	A
Hydrobia jenkinsi	H. jenkinsi	H. jenkinsi	A
Pisidium sp.	Pisidium sp.	Pisidium sp.	A
Erpobdella octoculata	E. octoculata		
Tanypodinae larvae	Tanypodinae larvae	Tanypodinae larvae	A
Baetis rhodani	B. rhodani	B. rhodani	A
B, scambus		B. scambus	A
	Nais elinguis		
Tubifex tubifex	T. tubifex	T. tubifex	B
Limnodrilus hoffmeisteri	L. hoffmeisteri	L. hoffmeisteri	B
Nais elinguis		N. elinguis	B
	C. diaphanus		
	P. fontinalis		
		E. octoculata	B
Orthocladiinae larvae	Orthocladiinae larvae	Orthocladiinae larvae	B
	Chironominae larvae		
		Diamesinae larvae	B
	Tanypodinae larvae		
	B. rhodani		
Asellus aquaticus		Asellus aquaticus	B
Limnodrilus udekemianus	L. udekemianus	L. udekemianus	C
L. profundicola	L. profundicola	L. profundicola	C
Monopylephorus irroratus			
M. rubroniveus		M. rubroniveus	C
Enchytraeidae		Enchytraeidae	C
Chironominae larvae		Chironominae larvae	C

on the ordination, and the abundance of each of its members is significantly correlated with that of species in both the other associations. A potential flaw in pooling the monthly results of a survey for purposes of ordination is that variations in numbers occur seasonally as well as spatially. It was felt, however, that as many species show similar trends of seasonal abundance (figure 18), with maximum numbers occurring in late summer and autumn, spatial influences on the ordination would be far greater than the seasonal ones. It was to validate this assumption that the ordinations for data from February and August 1973 were plotted (figure 20, a and b). Seasonal effects would obviously have no influence here. Species on these ordinations were grouped into the same three associations, on the basis already described. For August, the groups are fairly well defined, although the position of the boundaries between associations B and A is not obvious. For February it will be noted that the boundaries or assiciations A and B overlap. This is because, notwithstanding fairly obvious spatial associations on which basis taxa 13, 25, 26 and 17 are clearly to be included in association B, there are many significant correlations between the abundance of taxa 13, 26, and 17 and the more obvious members of association A. These correlations are responsible for the overlap.

To compare the faunal associations derived from pooled data (figure 20a) with those indicated by the situation prevailing in February and August 1973, the members of the associations in each case are given in table 92. There is a fairly good agreement between the compositions of associations derived from the pooled data and those derived from the data for the individual months, despite the fact that, as has been mentioned, some of the boundaries are by no means clearcut. A number

Table 93.

Faunal associations in the River Irwell, as suggested by ordinations based on correlation coefficients.

Association A.

Nais barbata
N. variabilis
N. communis
Chaetogaster diaphanus
Stylaria lacustris
Ancylus fluviatilis
Limnaea peregra
Hydrobia jenkinsi
Pisidium sp.
Erpobdella octoculata
Tanypodinae larvae
Baetis rhodani
B. scambus

Association B.

Tubifex tubifex
Limnodrilus hoffmeisteri
Nais elinguis
Asellus aquaticus
Orthocladiinae larvae

Association C.

Limnodrilus udekemianus
L. profundicola
Monopylephorus irroratus
M. rubroniveus
Enchytraeidae
Chironominae larvae

Table 94.

Mean numbers per square metre of members of the three associations shown collected over the course of the survey at each site.

	----SITE----									
Assoc.	1	2	3	4	5	6	7	8	9	10
A	5	10763	5075	8105	6999	29833	11	6895	244	555
B	106	26131	29696	19883	45858	40388	9005	51390	39513	33580
C	43	1468	228	308	407	9602	3251	13861	36217	13892

Table 95.

Percentage distribution of each association along the length of the river.

	----SITE----									
Assoc.	1	2	3	4	5	6	7	8	9	10
A	0	16	7	12	10	44	0	10	0	1
B	0	9	10	7	16	14	3	17	13	11
C	0	2	0	0	1	14	5	10	51	17

Table 96.

Percentage contribution of each association to the fauna at each site.

	----SITE----									
Assoc.	1	2	3	4	5	6	7	8	9	10
A	3	28	15	29	13	37	0	10	0	1
B	69	68	85	70	86	51	73	71	52	70
C	28	4	1	1	8	12	27	19	48	30

Figure 21

Percentage distribution of each association.

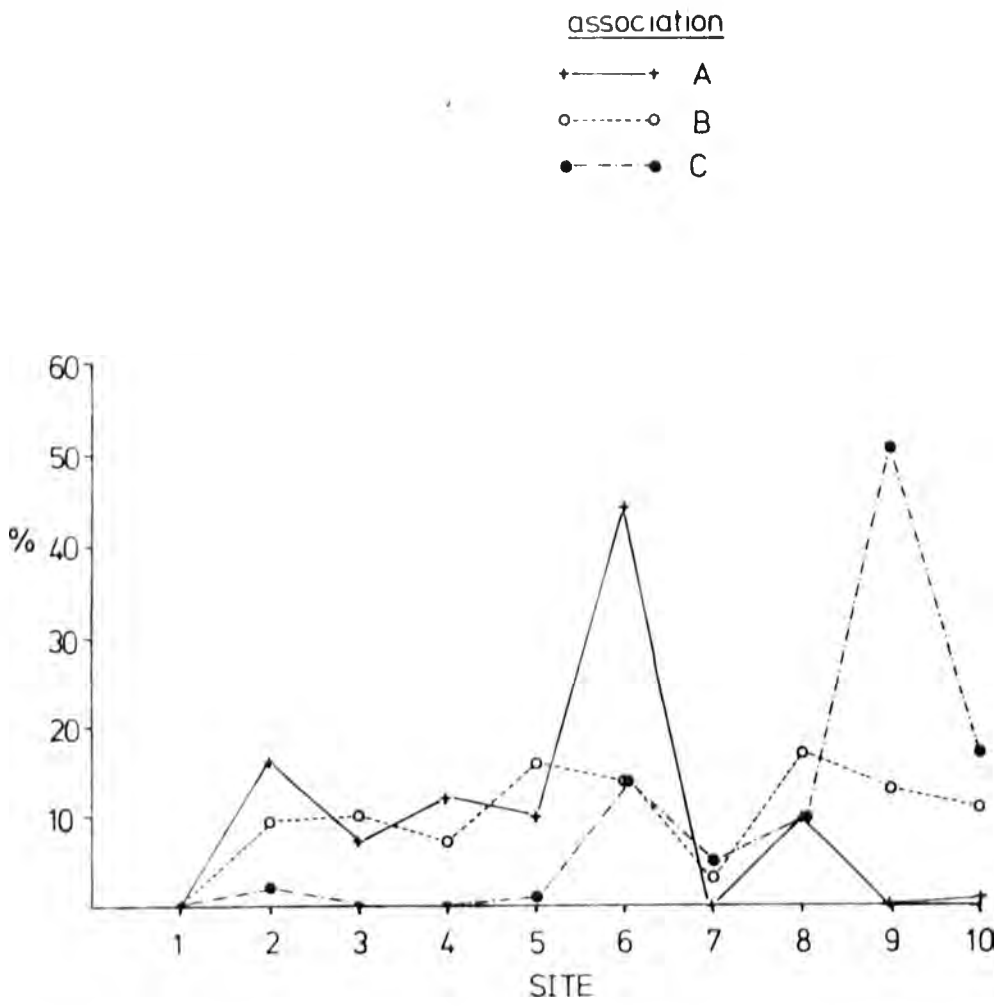
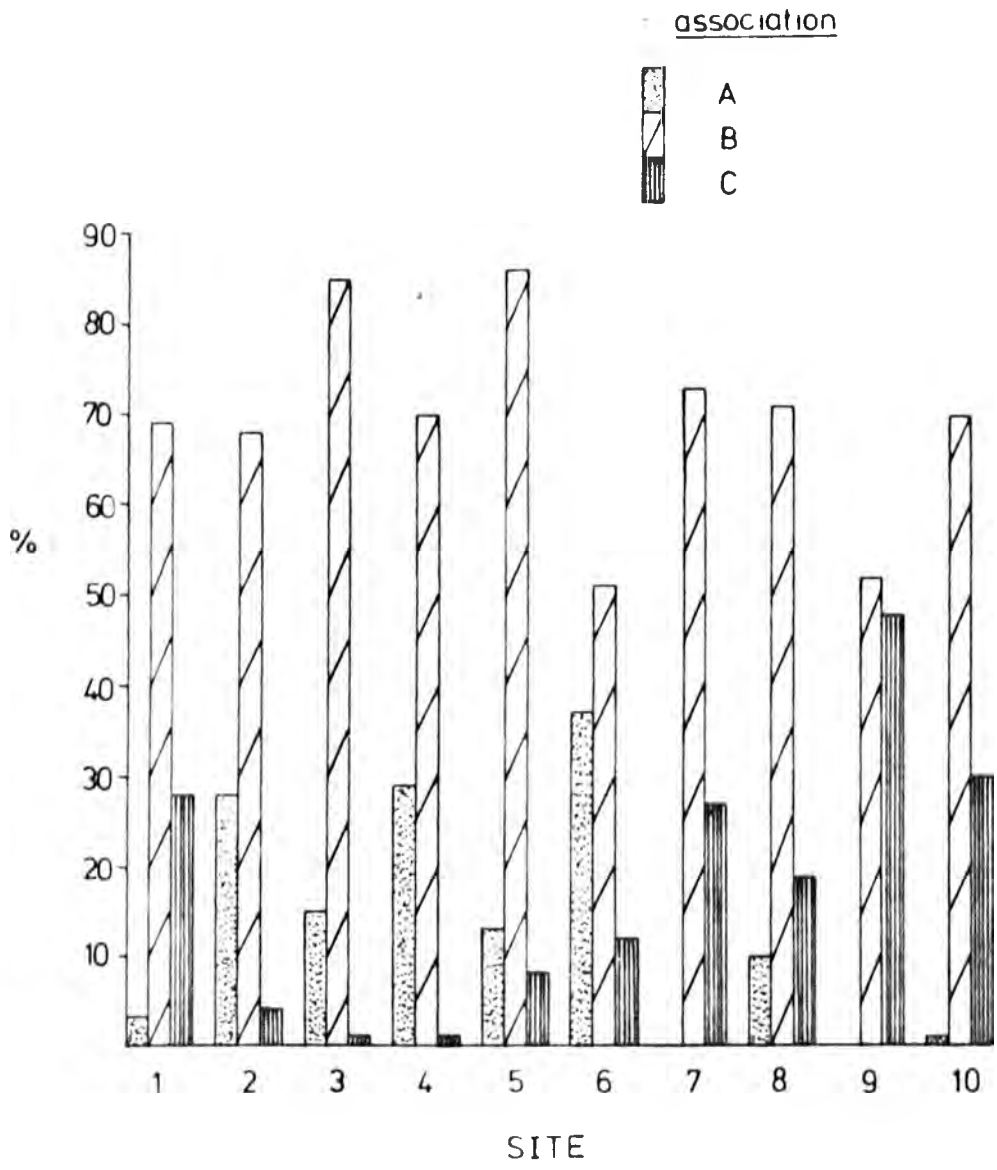


Figure 22

Percentage contributions of associations to the fauna at each site.



of instances where a taxon occurs in an association derived from the pooled data but not in one of the ordinations of monthly data result from the absence of the taxon in that particular month. There are cases, of course, where a species occurs in differing associations in different ordinations; despite this the results of the ordinations are enlightening and are summarized in table 93. This shows the members of associations A, B, and C as derived from the pooled data ordination.

The construction of these associations simplifies the consideration of the factors influencing the distribution of the species present in the Irwell. As has been mentioned, associations can be regarded as groups of organisms with related ecological requirements, and this dispenses with the need to consider each species in turn. Table 94 shows the mean abundance per square metre of each association at each site over the course of the survey (including February 1975). Based on these data, table 95 and figure 21 show the percentage distribution of each association along the length of the river. Table 96 and figure 22 show the percentage contribution of each association to the fauna at each site, the fauna in this context excluding species not on the ordination.

Figure 22 shows the fauna to be dominated, numerically, by association B. At no site does this association comprise less than 50 percent of the fauna (see figure 22). Figure 21 shows that, apart from site 1, association B is fairly evenly distributed along the length of the river. No site shows a particular peak in the abundance of this group of animals and, excluding site 1, only site 7 seems to be unfavourable for colonization by the association although

even here association B is more abundant that either of the other two associations. The ubiquitous distribution of, and domination of the fauna by, association B, is perhaps to be expected, since two of its members, Tubifex tubifex and Limnodrilus hoffmeisteri, are known to thrive in a wide variety of conditions and attain high population densities (Aston, 1973). Nais elinguis is another species well known for tolerating a variety of conditions (Brinkhurst and Jamieson, 1971). Asellus aquaticus has a wide distribution; it is a well documented part of the 'pollution fauna' (Hynes, 1971a), occurring on depositing and eroding substrates in streams, and in canals, lakes, ponds and reservoirs (Holland, 1976), as indeed do the above mentioned tubificids. Although the larvae of the Orthocladiinae occur in association B, less significance can be attached to this than to the occurrence of identified species. Species in this sub-family do not respond to environmental conditions in the same way, as shown by Edwards et al (1973) using similar association techniques. In the absence of specific identification, however, the association of larval Orthocladiinae with Tubifex tubifex, Limnodrilus hoffmeisteri, Nais elinguis and Asellus aquaticus is interesting, since the response of the sub-family to polluted conditions is not well documented.

The abundance of association A is greater at sites with relatively lower degrees of organic pollution where a higher dissolved oxygen concentration is maintained. Figure 21 shows the largest density of the group to occur at site 6, where a constantly high dissolved oxygen concentration is maintained by a large weir. The association is virtually absent from site 1, which is polluted by mine drainage; similarly the very

heavily organically polluted conditions at site 7, in Radcliffe, lead to the elimination of the association. The improvement in water quality brought about by the confluence of the River Croal may be the factor responsible for the colonization of substrates at site 8 by association A animals, but this trend is short lived. At no site does association A make a contribution to the fauna greater than that of association B (see figure 22), but it is second in order of abundance at sites 2, 3, 4, 5, and 6. Figure 6 shows these to be sites with relatively high mean dissolved oxygen concentration and lower degrees of organic pollution than more downstream reaches. It is suggested that, while members of association A can tolerate considerable degrees of organic pollution, they cannot tolerate conditions prevalent at downstream sites where organic, and other, pollution is more severe.

Association C is most abundant at site 9 (figure 21), where the mean B.O.D. over the course of the survey period was over 10 $mg.l^{-1}$ and a substrate bound lead concentration of over 13 $mg.g^{-1}$ (dry weight basis) was recorded. The association never exceeds the ubiquitous group B animals in abundance, but comprises the second most abundant component of the benthos at sites 1, 7, 8, 9 and 10 (figure 22). The fact that these animals show increased abundance at heavily polluted sites may reflect the increased potential productivity of such habitats, but the replacement of association C species by association A species in less polluted conditions suggests that C animals find the type of habitat colonized in the Irwell by A species unsuitable. An examination of figure 4 shows that substrate differences cannot be invoked to explain this observation.

It is pertinent to comment at this stage on the value of association analysis, as has been applied to the present data, in terms of its ability to differentiate between different faunal associations in the benthos. This is best achieved by first pointing to figures 21 and 22 as indicators that the trends indicated by the analysis are real in that these figures show a remarkably clear-cut picture, and secondly by pointing out an apparent weakness in the analysis. Figure 20a shows species 12, Chaetogaster langi, to be spatially very distinct from species 13, C. diaphanus, and yet figure 18 shows the two to have similar percentage mean distribution and percentage mean seasonal abundance. It is clear that some weakness in the association and ordination procedure is causing a far greater distinction to be made between these two Chaetogaster species than is actually the case, but when it is pointed out that the methods applied are among the simpler forms of association analysis, and that when compared with techniques such as principal components analysis the methods are crude, it is apparent that minor inconsistencies are to be expected.

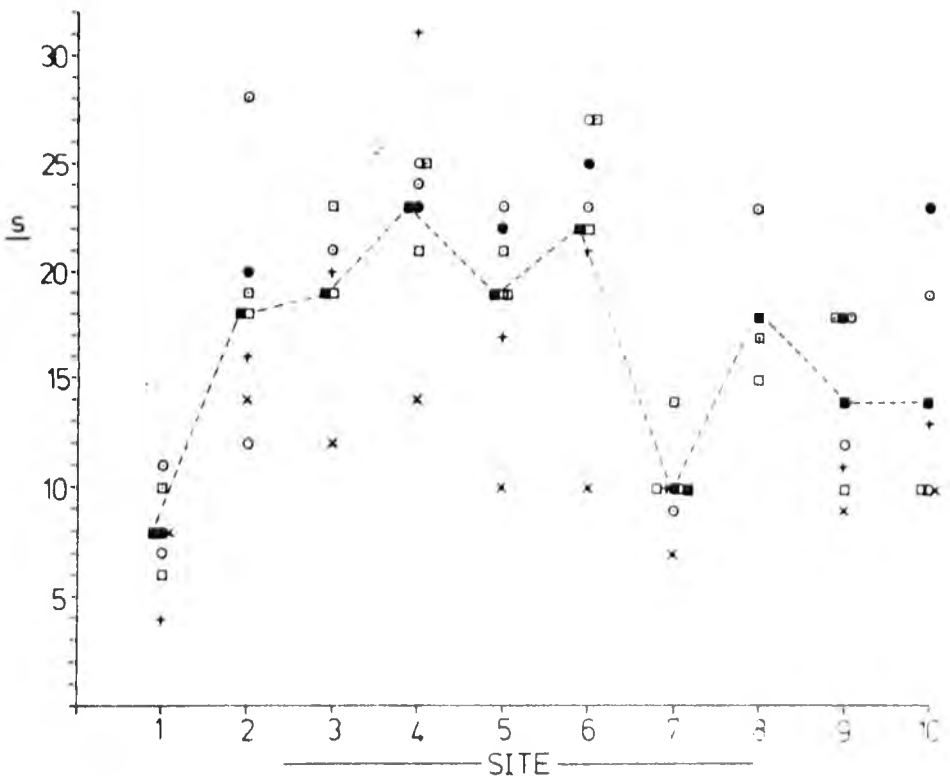
Table 97.

BASIC computer program used for the calculation of biological indices of pollution.

```
100  REM 'DIVERSITY INDICES. BR2101. J.P. EYRES.'
110  LET X=0
120  LET N=0
125  LET S=0
130  READ X
140  REM 'CALCULATE SHANNON'S INDEX'
150  IF X<0 THEN 190
160  LET N=N+X
170  LET S=S+1
180  GOTO 130
190  RESTORE
200  LET D=0
210  FOR I=1 TO S
220  READ X
230  LET D=D+((X/N)*(LOG(X/N)/.6931))
240  NEXT I
250  PRINT 'NUMBER OF SPECIES, S, = ';S
260  PRINT 'TOTAL INDIVIDUALS, N, = ';N
261  PRINT 'LOG10 S = ';LOG(S)*.4343
262  PRINT 'LOG10 N = ';LOG(N)*.4343
263  PRINT
264  PRINT
270  PRINT 'DIVERSITY USING SHANNONS FORMULA = ';-D
280  REM 'CALCULATE REDUNDANCY FOR SHANNON'S FORMULA'
290  LET N1=N
300  LET N2=N/S
310  LET N3=N-(S-1)
320  LET L1=0
330  LET L2=0
340  LET L3=0
350  FOR I=1 TO N1
360  LET L1=L1+LOG(I)
370  NEXT I
380  LET L1=L1/.6931
390  FOR I=1 TO N2
400  LET L2=L2+LOG(I)
410  NEXT I
420  LET L2=L2/.6931
430  FOR I=1 TO N3
440  LET L3=L3+LOG(I)
450  NEXT I
460  LET L3=L3/.6931
470  LET J=(1/N)*(L1-(S*L2))
480  LET K=(1/N)*(L1-L3)
490  LET R=(J-D)/(J-K)
500  PRINT 'THEORETICAL MAXIMUM DIVERSITY = ';J
510  PRINT 'THEORETICAL MINIMUM DIVERSITY = ';K
520  PRINT '                    REDUNDANCY = ';R
530  REM 'CALCULATE SIMPSON'S INDEX'
540  LET D1=0
550  RESTORE
560  FOR I=1 TO S
570  READ X
580  LET D1=D1+(X*(X-1))
590  NEXT I
600  LET D1=D1/(N*(N-1))
610  PRINT
620  PRINT
630  PRINT 'SIMPSONS INDEX = ';D1
640  PRINT '1-SIMPSONS INDEX = ';1-D1
650  REM 'CALCULATE MARGALEF'S 1951 INDEX'
660  PRINT
670  PRINT
680  PRINT 'MARGALEFS 1951 INDEX = ';(S-1)/LOG(N)
690  PRINT
700  PRINT
710  PRINT '      S/N = ';S/N
715  PRINT 'S/SQR(N) = ';S/SQR(N)
720  PRINT 'USING LOG BASE 10,   S/LOG(N) = ';S/(LOG(N)*.4343)
7    PRINT 'LOG(S)/LOG(N) = ';LOG(S)/LOG(N)
750  REM'INDICES FROM MCINTOSH, 1967'
770  LET D3=0
780  RESTORE
790  FOR I=1 TO S
800  READ X
810  LET D3=D3+X^2
820  NEXT I
825  LET D3=SQR(D3)
830  PRINT
840  PRINT
850  PRINT 'INDICES FROM MCINTOSH,1967. SEE LAITEN FOR ORDER'
860  PRINT 'MCINTOSHS INITIAL INDEX = ';D3
890  LET D4=0
900  LET D4=SQR((N-(S-1))^2+(S-1))
910  PRINT 'MAXIMUM INDEX VALUE = ';D4
920  PRINT 'MINIMUM INDEX VALUE = ';(N/S)*SQR(S)
930  PRINT 'INDEX PORTION DUE TO QUANTITATIVE SAMPLING = ';D3-SQR(S)
940  PRINT '1 - INDEX = ';1-D3
950  PRINT 'MCINTOSH DIVERSITY = ';N-D3
960  PRINT 'MAXIMUM DIVERSITY = ';N-(N/SQR(S))
970  PRINT 'ALS.MAX.DIVERSITY = ';N-SQR(N)
980  PRINT 'MIN.DIVERSITY = ';N-D4
990  PRINT 'MCINTOSH 1967 (4) = ';(N-D3)/(N-SQR(N))
1000 PRINT 'MCINTOSH 1967 (5) = ';(N-D3)/(N-N/S)
1010 PRINT 'MCINTOSH 1967 (6) = ';(N-D3)/(N-D4)
1020 PRINT
1030 PRINT
1040 PRINT
1050 PRINT
1060 PRINT
1070 PRINT
2000 DATA 1,2,3,-1
2500 END
>
```

Figure 23

Number of taxa (s) collected at each site



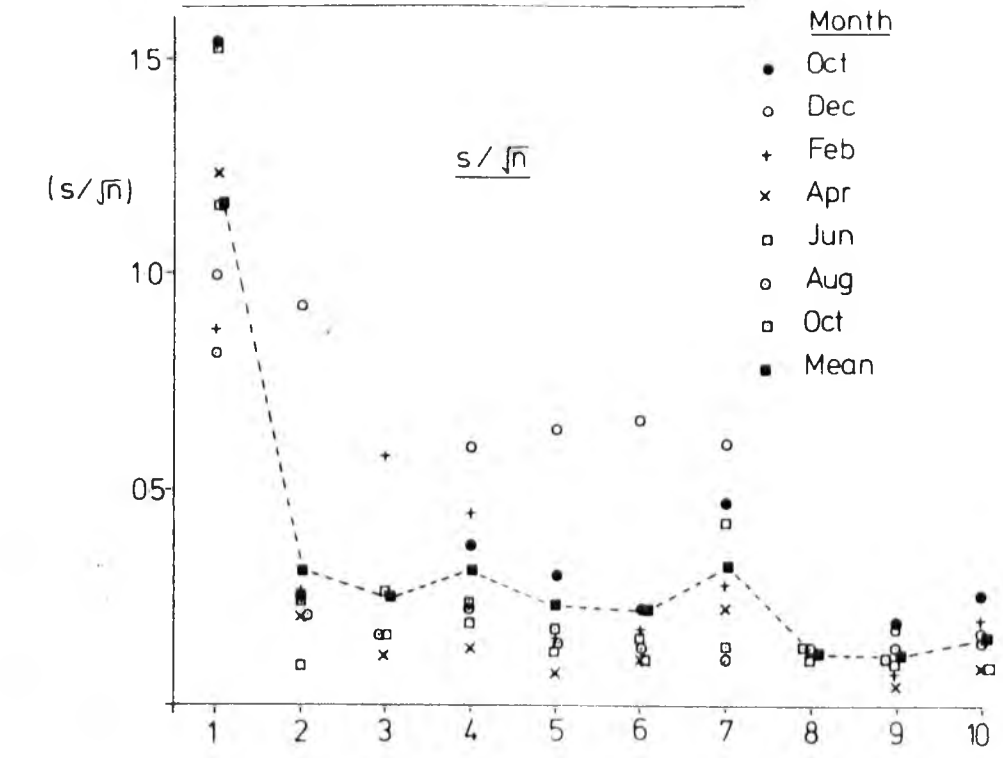
Month

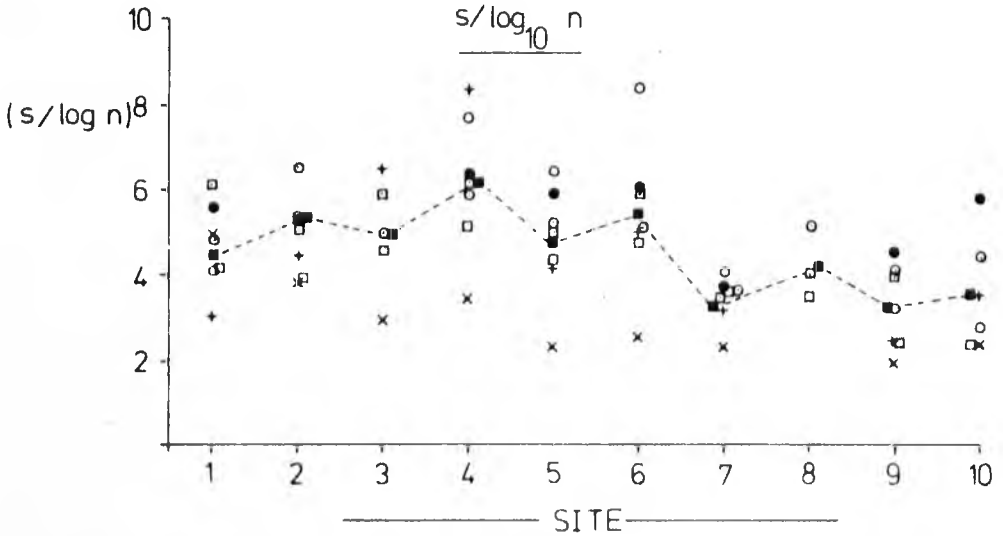
- Oct
- Dec
- Feb
- Apr
- Jun
- Aug
- Oct

- Mean

Figure 24

Relationships between number of taxa (s) and number of individuals(n) for each site





12. Biological assessment of pollution.

Many of the numerical techniques by which biologists have evaluated their data in order to arrive at an indication of the degree of pollution have been discussed in a previous section (literature review). A number of these schemes have been applied to the present data, and the results are displayed in figures 23 to 28. The various indices were calculated using the BASIC computer program shown as table 97.

One of the best documented effects of pollution on stream communities is a reduction in the number of colonizing species (Hynes, 1971a). Figure 23 shows the number of taxa collected each month at each site. The picture is a fairly clear one; the acid mine drainage at site 1 obviously suppresses species abundance. The mean number of taxa at sites 2 to 6 is relatively high. The largest number of taxa in any one collection, 31, was taken from site 4 in February 1973. The grossly polluted conditions at site 7 (Radcliffe) lead to a very clear depression in the number of taxa; the improved water quality at site 8 leads to the site being colonized by rather more species. Figure 6 shows that subsequent to this site, water quality as indicated by mean B.O.D. declines. Substrate lead concentrations rise dramatically (figure 7). These trends are reflected in lower numbers of taxa at sites 9 and 10 as compared with site 8.

Figure 24 shows two relationships between the number of taxa (s) and the sumber of individuals (n), namely $s/\sqrt{n}$ and $s/\log_{10}n$, for each month at each site. Mean values have also been calculated. The latter quantity shows some relationship to the state of the river in terms of pollution, the heavily polluted downstream sites displaying lower mean values; site 7 especially has consistently low values. The quantity $s/\sqrt{n}$

Figure 25

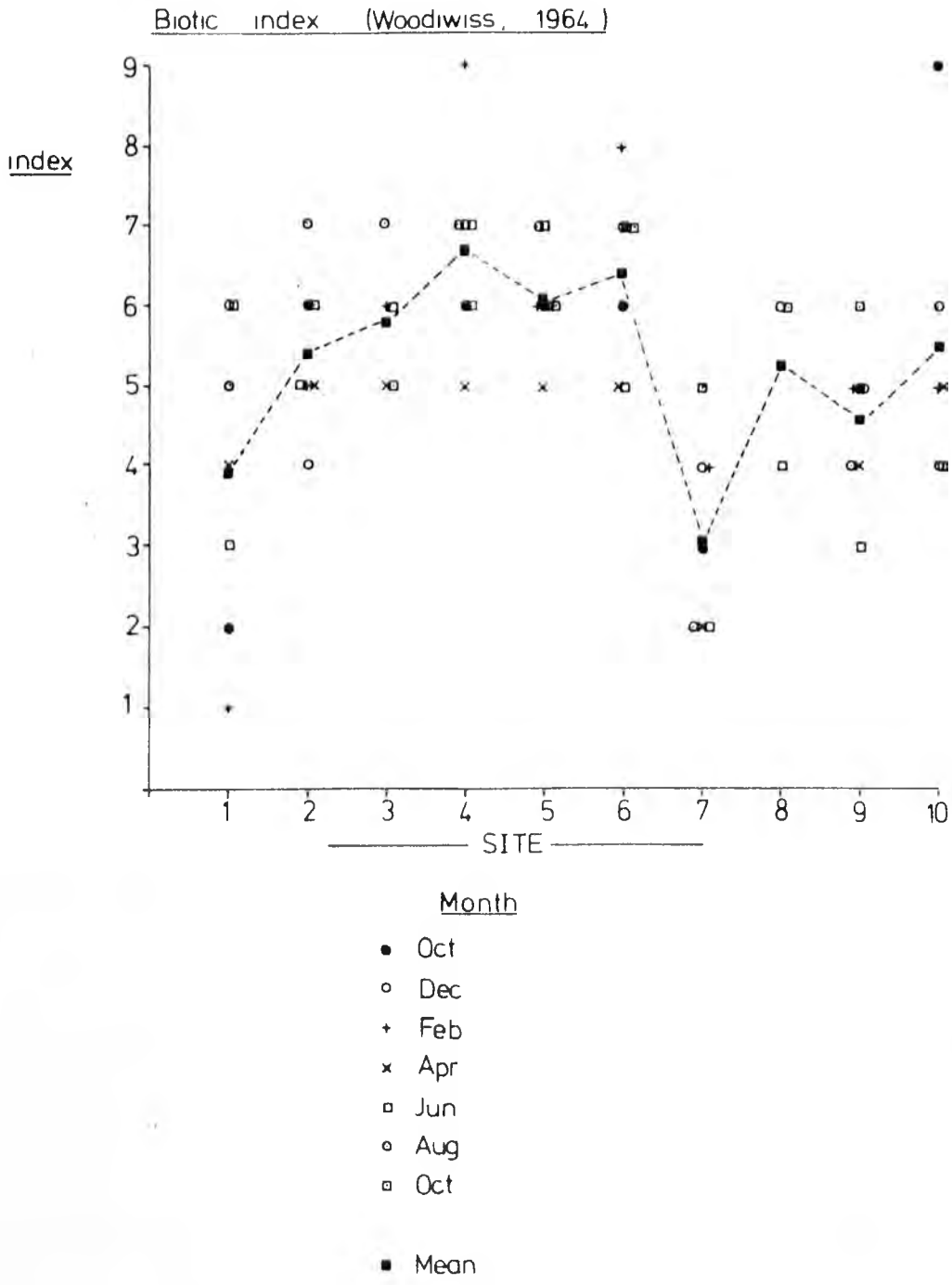
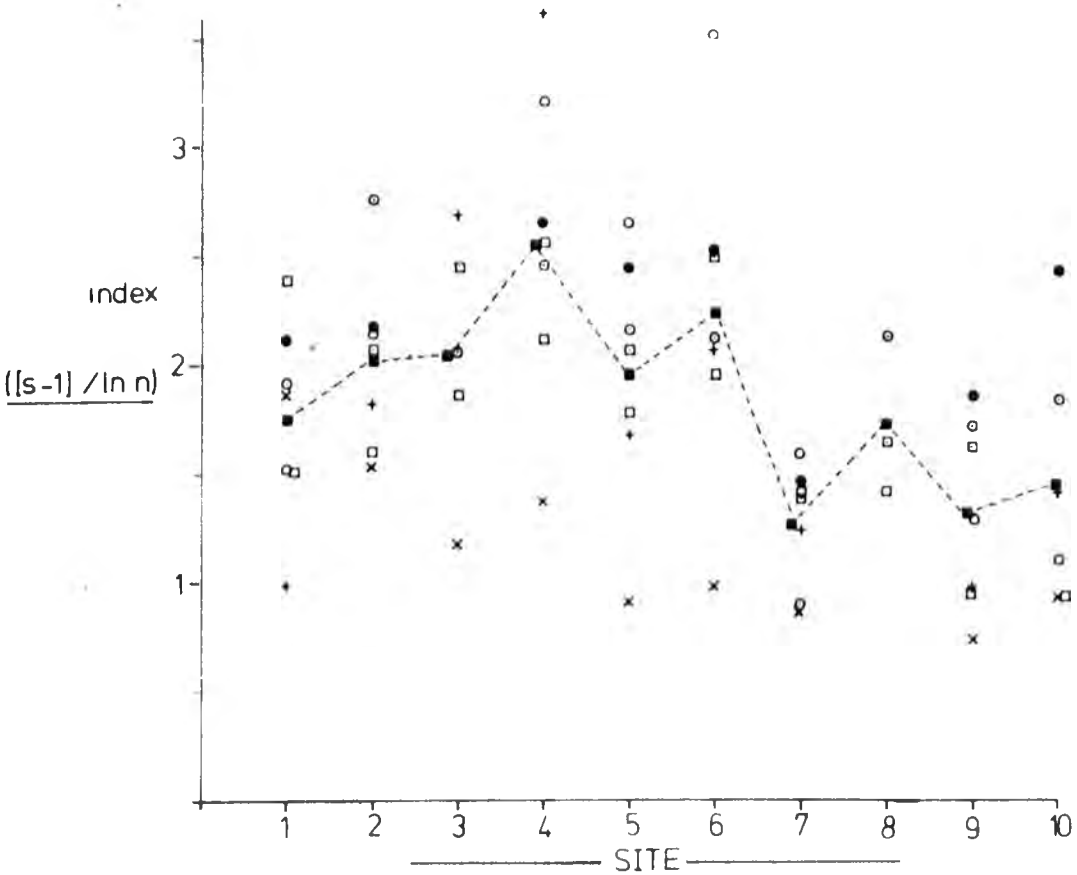

Biotic index (Woodiwiss, 1964)
index
9
8
7
6
5
4
3
2
1
1
2
3
4
5
6
7
8
9
10
SITE
Month
Oct
Dec
Feb
Apr
Jun
Aug
Oct
Mean

Figure 26

Margalef's (1951) index for each site



Month

- Oct
- Dec
- Feb
- Apr
- Jun
- Aug
- Oct

- Mean

Figure 27

Diversity ($\bar{d}$) and redundancy (r) using Shannon's formula

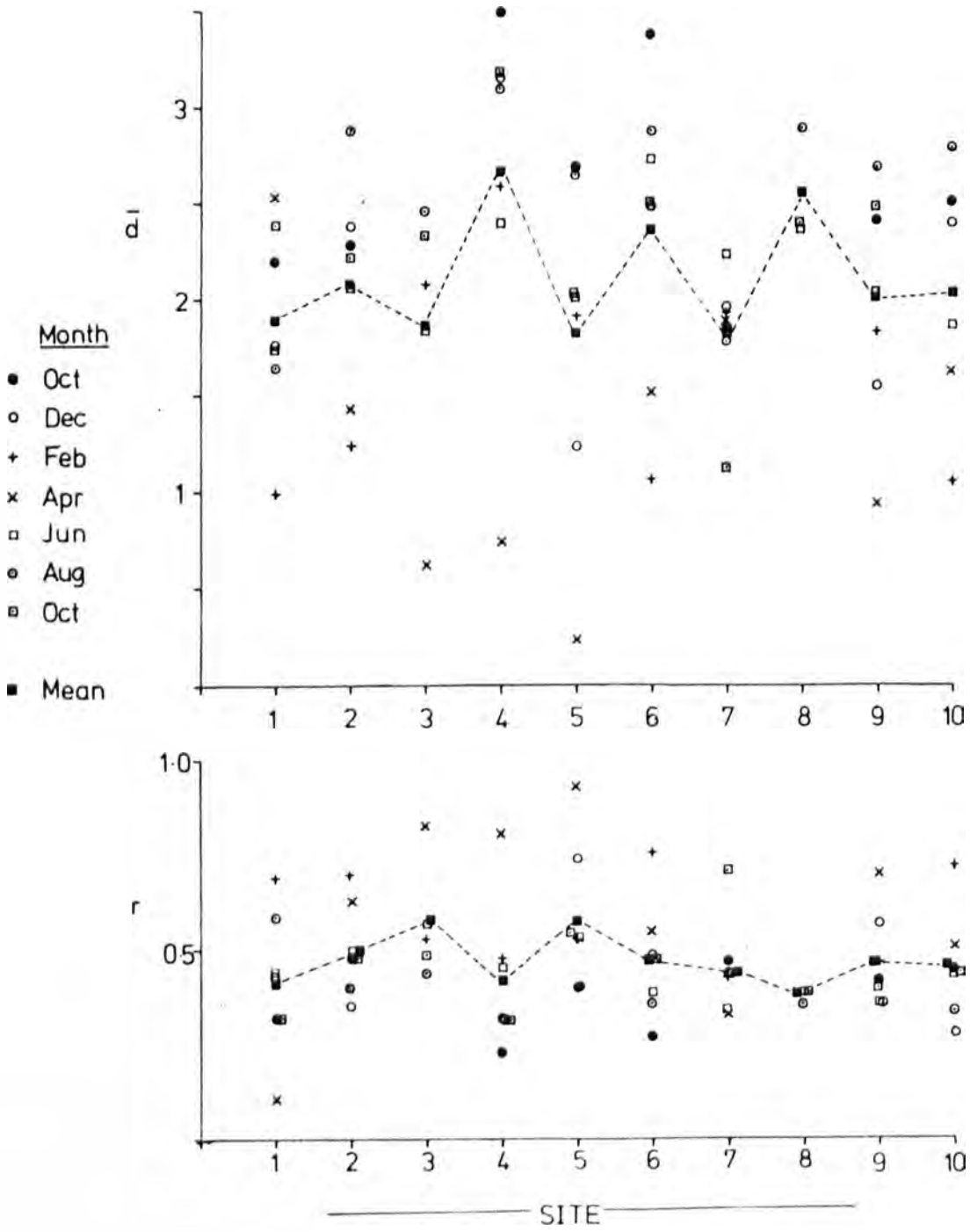
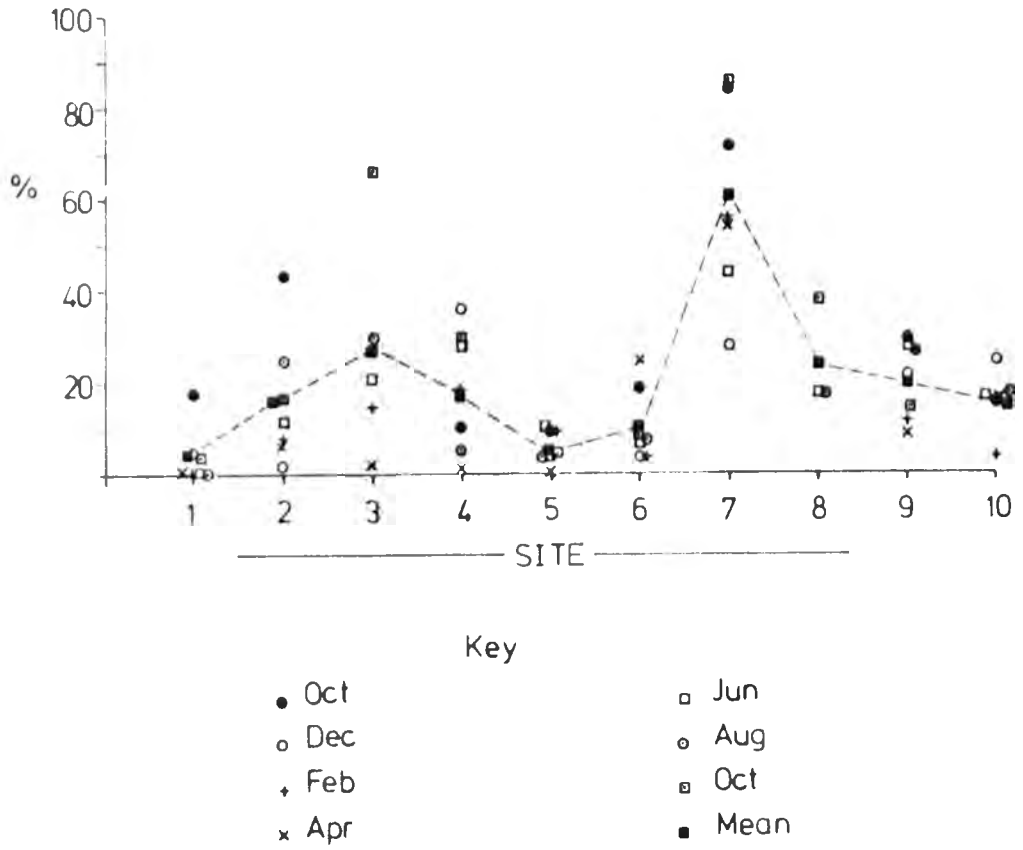


Figure 28

Limnodrilus hoffmeisteri as a percentage of all Oligochaeta



is clearly quite useless as an index of pollution.

The biotic index of Woodiwiss (1964) (figure 25) shows a very similar trend to that of species numbers (figure 23). The large spread of index value for site 1 suggests that this parameter is not a sensitive measure of the type of pollution prevalent at this site. At other sites the trend is one of higher biotic index with lower levels of pollution, as of course might be expected since this index is well tried and proven in practice.

The index of Margalef (1951) (figure 26), namely $(s - 1)/ \ln n$, clearly has higher values at less polluted upstream sites. The graph of mean values of the index follow fairly closely that of mean dissolved oxygen concentration (figure 6). The same cannot be said for either diversity ($\bar{d}$) or redundancy (r) calculated using Shannon's formula (figure 27), which fail to distinguish convincingly between the degrees of pollution encountered in the Irwell.

Brinkhurst (1967) has suggested that the degree of domination of the oligochaete fauna by the ubiquitous Limnodrilus hoffmeisteri is a potentially useful indicator of organic pollution. Figure 28 shows this quantity, numbers of L. hoffmeisteri being expressed as a percentage of all oligochaetes, for each month at each site. Though not a particularly sensitive index, the influence of the grossly contaminated conditions at site 7 is clear.

The above discussion is somewhat subjective, serving to introduce figures 23 to 28. A better indication of the relationships of the various indices to each other and to some generally accepted chemical measure of the degree of organic pollution may be obtained by calculating the degree of statistical correlation between selected parameters. Such a procedure was followed by Wilhm (1967).

Table 98.

The degree of correlation of parameters shown, based on Spearman rank correlation coefficients.

	n	s	Biotic index	Naididae / Tubificidae	L.hoffm. / Oligochaeta	$s/\sqrt{n}$	$s/\log_{10}n$	(s-1)/ln n (Margalef)	r (Shannon)	$\bar{d}$ (Shannon)	D.O.	B.O.D.
B.O.D.	0	0	0	-	++	0	--	--	0	0	0	X
D.O.	0	+	++	0	0	0	++	++	0	0	X	
$\bar{d}$ (Shannon)	0	+++	+++	0	0	0	+++	+++	---	X		
r (Shannon)	0	0	0	0	-	0	-	-	X			
(s-1)/ln n (Margalef, 1951)	0	+++	+++	+++	0	+++	+++	X				
$s/\log_{10}n$	0	+++	+++	+++	0	+++	X					
$s/\sqrt{n}$	---	0	0	0	0	X						
L.hoffmeisteri / Oligochaeta	0	0	0	-	X							
Naididae / Tubificidae	+++	+++	+++	X								
Biotic index (Woodiwiss, 1964)	++	+++	X									
s (no. of spp.)	+++	X										
n (no. of indivs.)	X											

+++	positive correlation	($p < 0.001$)
++	positive correlation	($p < 0.01$)
+	positive correlation	($p < 0.05$)
0	no significant correlation	
-	negative correlation	($p < 0.05$)
--	negative correlation	($p < 0.01$)
---	negative correlation	($p < 0.001$)

Much of the data are such that the calculation of Pearson correlation coefficients is inappropriate, since this procedure can only be employed where values are direct measurements of established units. The present data includes ordinal quantities, that is where cases fall into a number of catagories, for example as with the biotic index of Woodiwiss (1964). In such situations the calculation of a non-parametric correlation coefficient, such as Spearman's rank correlation coefficient, is more appropriate; this was calculated using the computer program NONPAR CORR (Nie et al., 1970).

The relationships between the various calculated indices and other quantities shown in figures 23 to 28, and also the ratio (Naididae numbers/Tubificidae numbers), together with dissolved oxygen concentration and B.O.D., based on Spearman's rank correlation coefficient, are shown in table 98. This table demonstrates the relative value of these indices as indicators of the degree of organic pollution in the Irwell. The following indices are either positively or negatively correlated ($p \leq 0.05$) with both of the above chemical parameters: Margalef's (1951) index ($s-1/\ln n$); $s/\log_{10} n$; the ratio Naididae/Tubificidae. In the light of previous findings (see literature review), it is remarkable that diversity ($\bar{d}$), as calculated using Shannon and Weaver's (1963) formula, is correlated with neither parameter and clearly does not reflect the degree of organic pollution in the river. The biotic index of Woodiwiss (1964) is positively correlated ($p \leq 0.05$) with dissolved oxygen concentration, but is not correlated with B.O.D. It has been shown that the pollution of the Irwell is by no means solely organic in nature; pollution by heavy metals is extensive at certain sites. Thus, the fact that a biotic parameter is not correlated with the

the degree of organic pollution does not mean that the parameter is not an effective indicator of the 'sum-total' of pollution.

A well documented effect of organic pollution is an increase in the density of fauna due to the increased productivity of the habitat favouring the species which can tolerate the conditions. (Hynes , 1971a). The reduction in the number of species present under polluted conditions is also well known. It is therefore most interesting to note that in the Irwell this does not appear to be the case. Table 98 shows a strong positive correlation ($p \ll 0.001$) between number of species and number of individuals. The indices significantly correlated with total invertebrate numbers are $s/\sqrt{n}$ (-ve, $p \ll 0.001$), the ratio (Naididae /Tubificidae) (+ve, $p \ll 0.001$) and the biotic index of Woodiwiss (1964) (+ve, $p \ll 0.01$). Rather more of the indices are significantly correlated with the number of species, namely the biotic index (+ve, $p \ll 0.001$), $s/\log_{10}n$ (+ve, $p \ll 0.001$), $\bar{d}$ (Shannon and Weaver, 1963) (+ve, $p \ll 0.001$), r (Shannon and Weaver, 1963) (-ve, $p \ll 0.05$), and the index of Margalef (1951), $s-1/\ln n$ (+ve, $p \ll 0.001$).

Table 99.

Results of test investigating the toxicity of copper to Erpobdella octoculata.

mg.l^{-1} Cu	pH	number of leeches surviving after time shown (hours)																					
		0.0	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	7.5	9.0	19.5	24.0	30.0	44.5	51.5	68.5	75.5	96.0
10.0	7.2	10	10	10	10	10	6	5	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5.6	7.3	10	10	10	10	10	9	8	7	3	1	1	1	1	1	1	0	0	0	0	0	0	0	0
3.2	7.3	10	10	10	10	10	10	9	6	5	3	2	2	2	1	1	0	0	0	0	0	0	0	0
1.8	7.3	10	10	10	10	10	10	9	7	7	7	7	7	7	4	4	3	3	2	1	1	1	1	1
1.0	7.3	10	10	10	10	10	10	10	10	10	9	8	8	8	8	8	2	2	2	0	0	0	0	0
0.0	7.3	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10

Test commenced 27/5/75.

Ambient temperature 10.5°C.

Table 100.

Results of test investigating the toxicity of lead to Erpobdella octoculata.

$mg.l^{-1}$ Pb.	pH	number of leeches surviving after time shown (hours)																					
		0.0	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	7.5	9.0	19.5	24.0	30.0	44.5	51.5	68.5	75.5	96.0
10.0	7.2	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	4	4	4	4	4	4	4	3
5.6	7.3	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
3.2	7.3																							
1.8	7.3	no further deaths																						
1.0	7.3																							
0.0	7.3																							

Test commenced 27/5/75

Ambient temperature 10.5°C

Table 101.

Results of toxicity tests using Asellus aquaticus commenced 6/8/75.

	number of animals surviving after time shown (hours)							
$mg.l^{-1}$ Zn	0.0	6.0	12.0	24.0	36.0	48.0	72.0	96.0
100	10	10	10	10	10	10	7	1
56	10	10	10	10	10	10	10	10
32	10	10	10	10	10	10	10	9
18	10	10	10	10	10	10	10	10
10	10	10	10	10	10	10	10	10
0	10	10	10	10	10	10	10	10
$mg.l^{-1}$ Pb								
100	10	0	0	0	0	0	0	0
56	10	9	7	6	5	2	2	2
32	10	10	10	10	9	8	7	6
18	10	10	10	10	10	10	9	8
10	10	10	10	10	10	10	10	9
0	10	10	10	10	10	10	10	10
$mg.l^{-1}$ Cu								
10	10	10	10	10	10	10	3	2
5.6	10	10	10	10	10	10	9	9
3.2	10	10	10	10	10	10	9	9
1.8	10	10	10	10	10	10	8	8
1.0	10	10	10	10	10	10	9	9
1.00	10	10	10	10	10	10	10	10
0.56	10	10	10	10	10	10	10	10
0.32	10	10	10	10	10	10	10	10
0.18	10	10	10	10	10	10	10	10
0.10	10	10	10	10	10	10	10	10
0	10	10	10	10	10	10	10	10
0	10	10	10	10	10	10	10	10
$mg.l^{-1}NH_3$								
100	10	10	10	10	9	9	9	9
56	10	10	10	10	10	10	10	10
32	10	10	10	10	10	10	10	10
18	10	10	10	10	10	10	10	10
10	10	10	10	10	10	10	10	10
0	10	10	10	10	10	10	10	10

Ambient temperature 12.5°C - 15.0°C.

Table 102.

Results of toxicity tests using Asellus aquaticus commenced 16/9/75.

		number of animals surviving after time shown (hours)				
$mg.l^{-1}$ Zn	pH	0	24	48	72	96
320	6.5	10	9	6	1	0
180	6.5	10	8	5	4	2
100	----------	no data	----------			
56	----------	no data	----------			
32	6.6	10	9	9	9	8
0	7.7	10	10	10	10	9
$mg.l^{-1}$ Pb	pH					
100	2.5	10	0	0	0	0
100	2.5	10	0	0	0	0
100	2.5	10	0	0	0	0
56	2.9	10	3	3	1	1
56	3.0	10	9	8	7	5
56	2.9	10	8	5	5	5
32	4.1	10	10	10	10	9
32	4.1	10	10	10	9	8
32	4.0	10	7	5	5	3
18	6.6	10	9	8	5	5
18	6.7	10	10	10	9	9
18	6.7	10	10	10	10	10
10	6.9	10	10	10	10	10
10	7.1	10	10	10	10	10
10	7.0	10	10	9	9	9
0	7.8	10	10	10	10	10
0	7.8	10	10	10	10	10
0	7.7	10	10	10	10	10
$mg.g^{-1}$ Cu	pH					
18.0	7.0	10	9	7	3	2
10.0	7.1	10	8	4	3	2
5.6	7.2	10	10	9	9	7
3.2	7.4	10	10	10	10	9
1.8	7.5	10	10	10	10	9
0	7.7	10	10	10	10	10

Ambient temperature 11.5°C

Figure 29.

96 hour survival of Asellus aquaticus in zinc solutions.

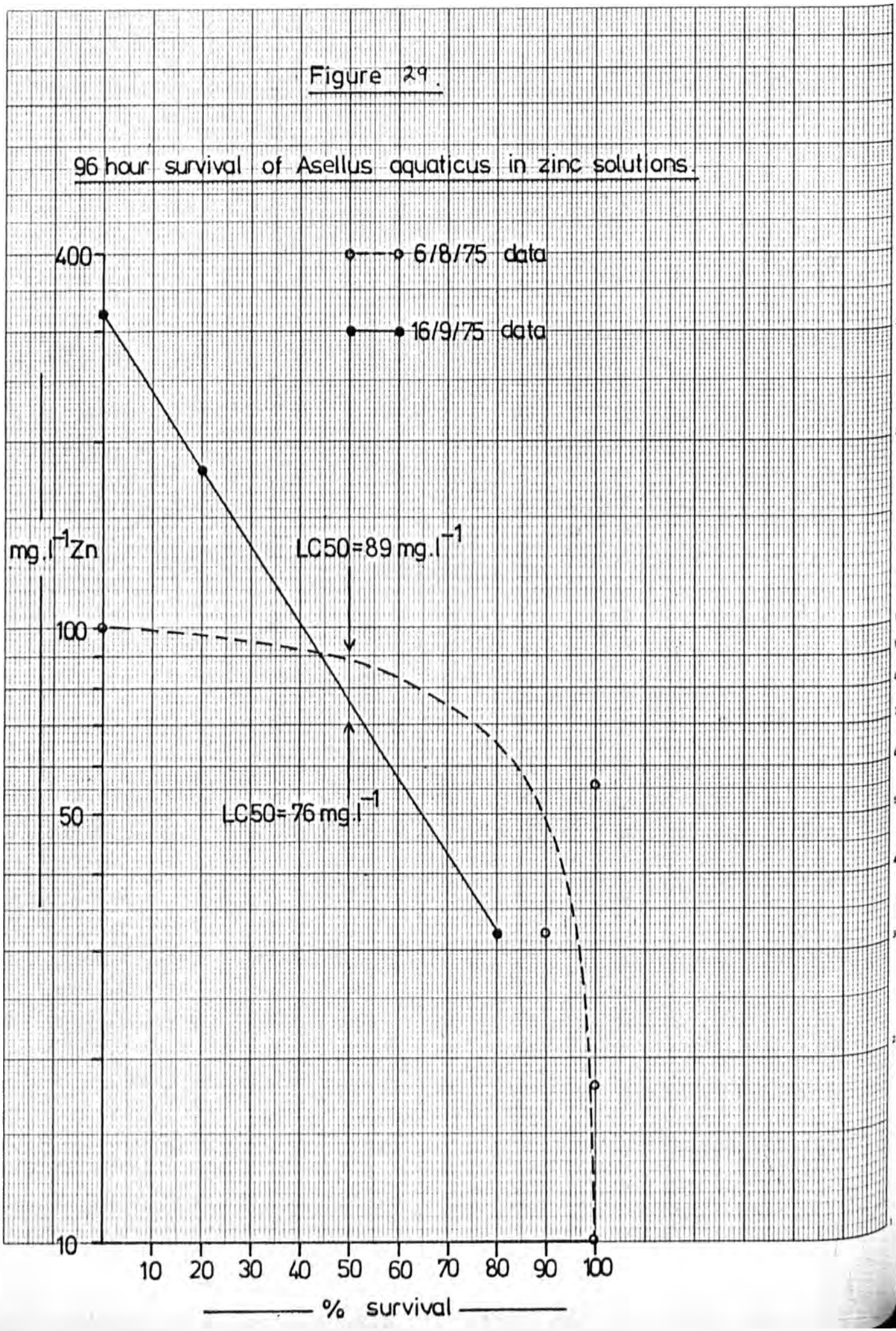


Figure 3o.

96 hour survival of Asellus aquaticus in lead solutions.

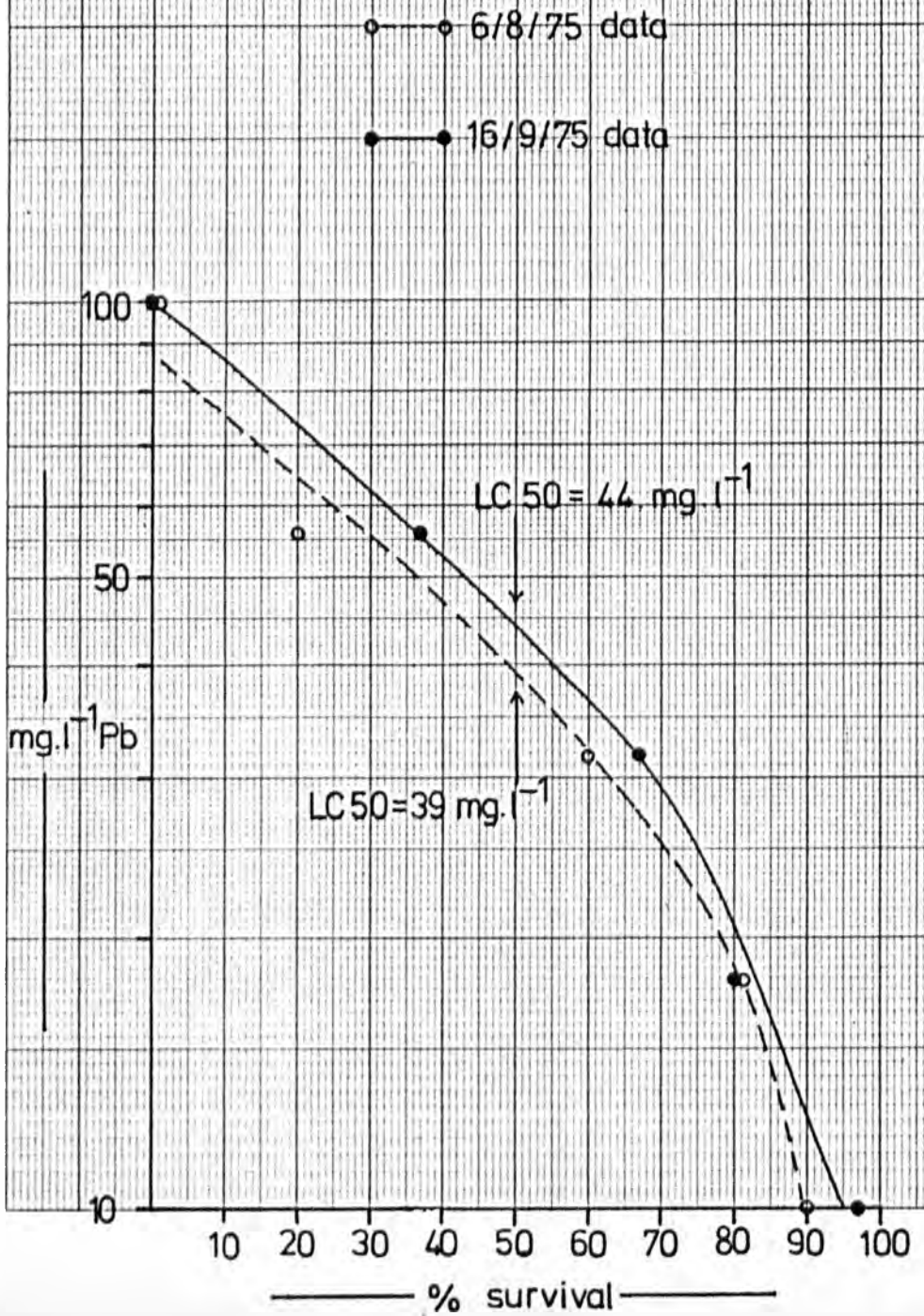
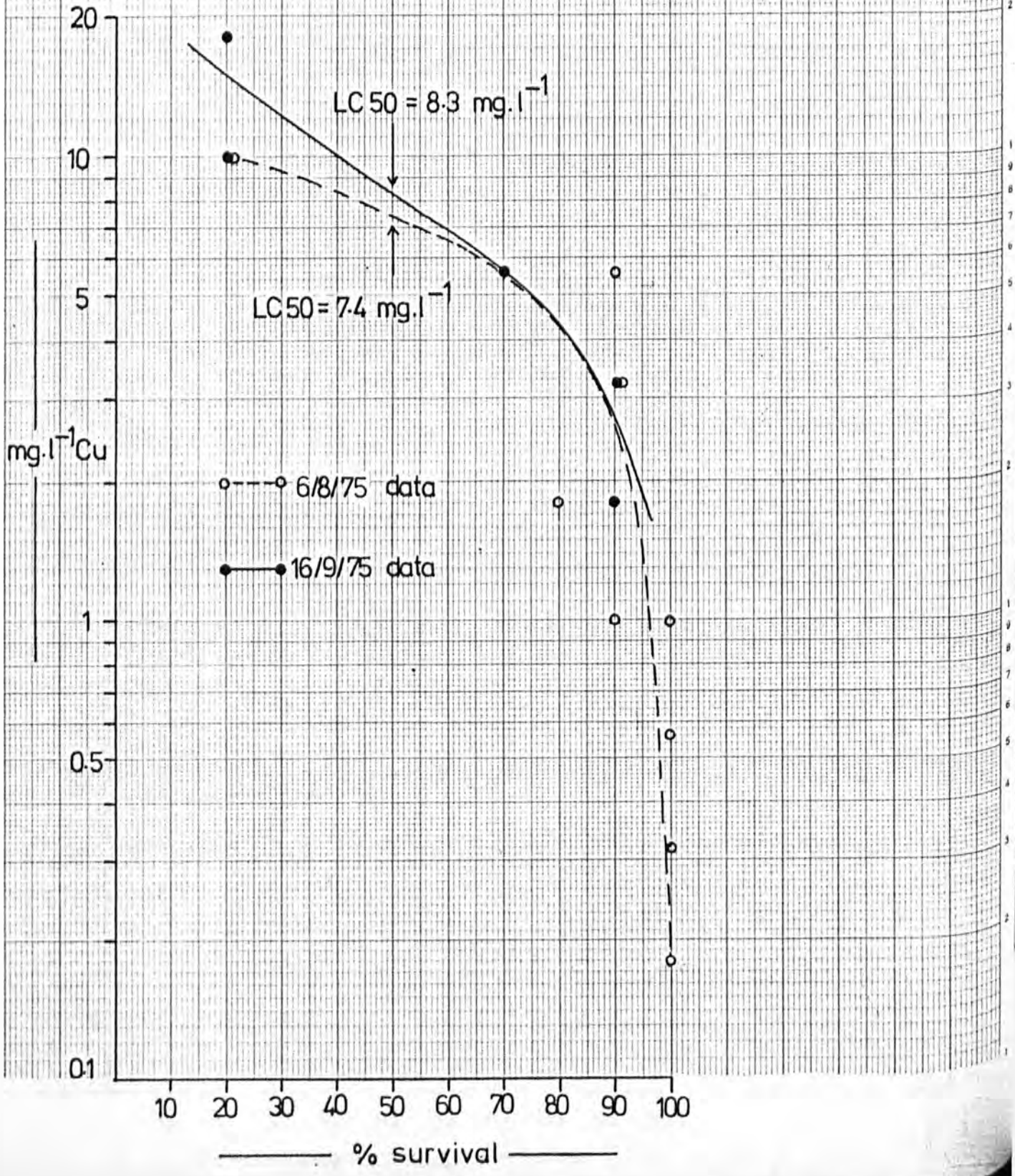


Figure 31.

96 hour survival of Asellus aquaticus in copper solutions.



13. Toxicity tests.

This work must be regarded as being of a preliminary nature. The results for Erpobdella especially are not at all conclusive. One set of bioassays was performed on E. octoculata but sufficient specimens could not be obtained for subsequent tests. Test solutions ranging from 0 to 10 $mg.l^{-1}$ of copper, lead, zinc and ammonia were used; in the solutions of zinc and ammonia no leeches died during the 96 hour test period. The results of tests using copper and lead are given in tables 99 and 100. In neither case do the data allow the estimation of LC_{50}, but it is clear that copper is very much more toxic to Erpobdella than are the other toxins tested. The relative toxicities of the substances may be summarized thus:

$$Cu \gg Pb > (Zn \text{ and } NH_3).$$

Two sets of tests using Asellus aquaticus as test animal were performed, commencing on 6/8/75 and 16/9/75. The results of these tests are given in tables 101 and 102. Figures 29, 30 and 31 show the percentage survival of Asellus after 96 hours at each of the concentrations of zinc, lead and copper tested. The concentration of toxicant is plotted on a logarithmic scale, percentage survival on an arithmetic scale. The curves, which are fitted by eye, are such that LC_{50} can be read off. For copper (figure 31) the mean LC_{50} is 7.85 $mg.l^{-1}$. Although the points from which the curves are plotted are somewhat scattered, especially for the 6/8/75 data, the two LC_{50} values agree closely (see figure 31). For lead, the mean 96 hour LC_{50} is 41.5 $mg.l^{-1}$, and the two curves tally closely (figure 30). Even for zinc, where the data are most erratic, the 96 hour LC_{50} values agree well, with a mean of 82.5 $mg.l^{-1}$ (figure 29). Although there was one mortality at the highest concentration of ammonia (100 $mg.l^{-1}$) used in the test commencing on 6/8/75 (table 101), the data are clearly

not suitable for the estimation of LC_{50}. No second test was run with ammonia as toxicant.

For Asellus aquaticus, the order of toxicity of the pollutants tested is the same as has been given for Erpobdella, thus:

Copper	(96 hour LC_{50} 7.85 $mg.l^{-1}$)
∨	
Lead	(96 hour LC_{50} 41.5 $mg.l^{-1}$)
∨	
Zinc	(96 hour LC_{50} 82.5 $mg.l^{-1}$)
∨	
Ammonia	(96 hour $LC_{50} \gg 100$ $mg.l^{-1}$)

Table 103.

Faunal analysis for basket samplers collected 4/1/75. Sampling at site 4 (Summerseat), using local substrate materials. Baskets 14x14x14 cm.

Taxon	Number of animals per basket.	
	Basket 1.	Basket 2.
Aeolosomatidae	0	100
Tubifex tubifex	0	100
Limnodrilus hoffmeisteri	50	100
Nais elinguis	29600	36500
N. barbata	550	200
N. variabilis	200	0
Chaetogaster langi	7200	13200
C. diaphanus	150	300
Stylaria lacustris	50	0
Enchytraeidae	300	400
Oligochaeta indet.	350	100
Glossiphonia complanata	0	1
Hellobdella stagnalis	1	0
Polycelis nigra	0	1
Nematoda	1	0
Baetis rhodani	10	10
B. scambus	0	1
Asellus aquaticus	875	825
Copepoda	1	0
Orthocladiinae larvae	1225	1250
Chironomidae pupae	1	0
Dicranota sp.	1	0
Tipulinae	0	1
TOTAL	40565	53095

Current speeds ($m.sec^{-1}$) recorded prior to basket removal.

current speed	I 0.59 II 0.71 III 0.65	I 0.49 II 0.58 III 0.42

(Dissolved oxygen on 4/1/75 95 percent of saturation, water temperature 5.5°C.)

Table 104.

Faunal analysis of basket and Surber samples collected from site 2 on 24/3/75.

a. Basket samples.

Taxon	Sample number 1	2	3	4	5
Oligochaeta	4350	8450	7200	7300	4800
Chironomidae (larvae and pupae)	1059	1834	1915	2063	913
Asellus aquaticus	8	10	22	9	15
Baetis rhodani	1	3	2	4	4
Limnaea peregra	1	0	0	0	0
Gammarus pulex	0	3	0	0	0
TOTAL	5419	10300	9139	9376	5732
Flow ($m.sec^{-1}$)	0.25	0.28	0.43	0.54	0.38

b. Surber samples.

Taxon	Sample number 1	2	3	4	5
Oligochaeta	17400	7800	5050	11000	12500
Chironomidae (larvae and pupae)	1864	571	605	708	920
Baetis rhodani	3	11	13	6	6
Asellus aquaticus	7	4	7	3	9
Ancylus fluviatilis	5	0	0	0	0
Pericoma sp. larvae	1	0	0	0	0
Glossiphonia complanata	1	0	0	0	2
Erpobdella octoculata	0	0	0	2	1
Pisidium sp.	0	0	0	0	1
TOTAL	19281	8386	5675	11719	13439
Flow ($m.sec^{-1}$)	0.45	0.37	0.61	0.41	0.37

Table 105.

Faunal analysis of basket and Surber samples collected from site 6 on 24/3/75.

a. Basket samples.

Taxon	Sample number 1	2	3	4	5
Oligochaeta	2750	7301	6850	7450	8201
Chironomidae (larvae and pupae)	90	138	138	163	199
Ceraptopogonidae	1	0	0	1	0
Tipulinae	0	0	0	0	1
Pericoma sp.	0	0	0	0	2
Empididae	0	0	0	0	1
Hydracarina	0	0	0	0	1
Collembola	0	3	0	0	0
Asellus aquaticus	0	1	2	2	3
Ancylus fluviatilis	2	4	1	1	0
Baetis rhodani	4	1	4	6	3
TOTAL	2846	7450	6995	7624	8411
Current speed ($m.sec^{-1}$)	0.23	0.69	0.64	0.65	0.37

b. Surber samples.

Taxon	Sample number 1	2	3	4	5
Oligochaeta	8050	5750	2950	10900	6500
Chironomidae (larvae and pupae)	162	59	16	58	29
Baetis rhodani	2	11	6	2	4
Asellus aquaticus	1	1	0	0	0
Glossiphonia complanata	0	1	0	0	0
Pisidium sp.	0	1	0	0	0
Nematoda	1	2	5	3	5
TOTAL	8216	5825	2977	10963	6538
Current speed ($m.sec^{-1}$)	0.46	0.46	0.45	0.47	0.53

14. The use of artificial substrate samplers.

Table 103 shows the results of the faunal analysis of the 14 x 14 x 14 cm basket samplers collected from site 4 on 4/1/75. The baskets had been filled with local substrate materials. Examination of table 103 shows that the baskets were colonized by vast numbers of animals, especially Nais elinguis, and emphasises the reason for not examining the contents of the larger (20 x 20 x 20 cm) baskets.

Tables 104 and 105 give the results of the analyses of basket and Surber samples collected from sites 2 and 6 on 24/3/75. In this case, the baskets (14 x 14 x 14 cm) were filled with uniformly sized pebbles. For present purposes it was not felt necessary to identify Oligochaeta or Chironomidae further than the family level.

Elliott (1971) discusses methods for deciding upon the number of samples necessary for a given degree of accuracy with respect to the mean of counts. The percentage error can be expressed as the standard error of the mean, which for a given standard deviation or variance (s^2) is a function of the number of sampling units (n). The ratio of the standard error to the mean ($\bar{x}$) is called, by Elliott (1971), an 'index of precision' (D). Elliott (1971) regards an error of 20 percent of the mean as being reasonable for bottom fauna studies. This is equivalent to D = 0.2. The number of sampling units required (N) is given by $N = s^2/0.2^2\bar{x}^2 = 25s^2/\bar{x}^2$ if the sample data are normally distributed. In the case of the present data, the variance of the counts is very much greater than the mean of counts (see table 106) and the negative binomial distribution is clearly a better model for the data. In such cases, D is best given by:

$$D = \sqrt{(1/n\bar{x}) + (1/nk)}^{*} \quad \text{Elliott (1971)}$$

(*n = number of samples taken)

Table 106.

Statistics calculated from data obtained from faunal analysis of basket and Surber samples collected from sites 2 and 6 on 24/3/75.

	Mean of counts.	Variance	Standard deviation	Standard error of mean	Dispersion parameter (k) of the negative binomial *	Index of precision (D) **	Number of samples needed for standard error less than or equal to 20 percent of the mean ***
SITE 2.							
a. Baskets.							
Oligochaeta	6420	3.1×10^5	1762	788	13.31	0.123	1.88
Chironomidae	1557	2.8×10^4	530	237	8.68	0.152	2.90
All fauna	7993	5.1×10^5	2252	1007	12.62	0.126	1.98
b. Surber.							
Oligochaeta	10750	2.2×10^6	4705	2104	5.22	0.196	4.79
Chironomidae	934	2.9×10^4	538	240	3.03	0.258	8.29
All fauna	11700	2.7×10^6	5191	2321	5.08	0.198	4.92
SITE 6.							
a. Baskets.							
Oligochaeta	6510	4.7×10^5	2158	965	9.12	0.148	2.75
Chironomidae	146	1590	39.9	17.8	14.67	0.122	1.88
All fauna	6665	4.8×10^5	2195	982	9.23	0.147	2.71
b. Surber							
Oligochaeta	6830	8.6×10^5	2932	1311	5.43	0.192	4.61
Chironomidae	65	3298	57.4	25.7	1.30	0.396	19.63
Total fauna	6904	8.7×10^5	2955	1321	5.46	0.191	4.58

** Index of precision (D) = $\sqrt{(1/n\bar{x} + 1/nk)}$

* Dispersion parameter of the negative binomial estimated by

$$k = \bar{x}^2 / (s^2 - \bar{x})$$

where k = dispersion parameter
$\bar{x}$ = mean of counts
s^2 = variance
and n = number of samples taken

*** Number of samples needed for a standard error less than 20 percent of the mean given by

$$N = \left(\frac{1}{0.2^2}\right)(1/\bar{x} + 1/k) = 25(1/\bar{x} + 1/k)$$

and N by:

$$N = 25(1/\bar{x} + 1/k) \text{ for 20 percent error.}$$

k is the dispersion parameter of the negative binomial and can be estimated by:

$$k = \bar{x}^2/(s^2 - \bar{x})$$

Table 106 shows, for Oligochaeta, Chironomidae and total invertebrate numbers, the statistics discussed above, based on samples collected on 24/3/75. The object is to compare the basket and Surber samplers in terms of the number of samples necessary to achieve standard error less than or equal to 20 percent of the mean. This is not to say that the calculated value of N is suitable for use in practice for anything other than the quantity for which it was calculated. Many more samples would be necessary if, for example, oligochaetes indentified to species were to be estimated satisfactorily since more samples will be necessary for estimation of the numbers of rarer species. The data are for comparitive puposes. Table 106 makes it clear that fewer samples are necessary for estimating numbers of oligochaetes, chironomids and all invertebrates when using the basket samplers than when using the Surber sampler. With the baskets, three samples would be adequate. Five Surber samples are needed to determine Oligochaeta and total invertebrate numbers. Up to 20 Surber samples would be necessary for the estimation of Chironomidae.

It is likely that the discrepency between the number of samples necessary with basket samplers and the Surber sampler is due to the standardization of substrate obtained with the former device. In practice this advantage is outweighed by the susceptibility of the samplers to vandalism; this problem has been encountered by North West Water Authority biologists as well as by the author. Vandalism would probably be less serious

in rural areas and it is suggested that artificial substrate samplers of the type used in the present work would provide a useful means of sampling stream benthos in such areas. The number of samples needed should be determined by a preliminary survey, with due regard to the aim of the investigation.

The analysis of baskets collected on 1/8/75 from sites 2, 6, 7, and 9, many of which were lost, together with the analysis of the associated Surber samples, are given in tables 107 to 110, in Appendix V.

DISCUSSION.

1. The pattern of pollution.

No part of the River Irwell is free of pollution; the headwaters receive the drainage from disused colliery workings, while a short distance downstream the river becomes organically polluted. The extent of pollution in the upper reaches of the river has been mitigated by the construction of the sewage works at Ewood Bridge, but much effluent still enters the Irwell in this area partly via the River Ogden and Limy Water which are both polluted by wastes from textile bleaching and printing. While at no point from site 2 to site 6 could the river be described as grossly contaminated, figure 6 emphasizes that at all these sites the river is organically polluted; tables 18 to 39, especially table 20 (B.O.D.), make it clear that on occasions the degree of contamination is great. The load of organic pollution carried by the river increases dramatically at site 7, where the confluence of the River Roch and the discharge of waste from paper manufacturing concerns leads to the water here having a mean B.O.D. of 13.8 $mg.l^{-1}$ and a dissolved oxygen concentration as low as 5 percent of saturation on occasions (table 17). Although the relatively cleaner waters of the River Croal have an ameliorating effect on the state of the Irwell, the mean B.O.D. remains above 9 $mg.l^{-1}$ downstream of Radcliffe. The highest biochemical oxygen demand recorded during the survey was 21.6 $mg.l^{-1}$, for site 10 in December 1972.

The pollution of the river other than by materials of a primarily organic nature was not well documented prior to the present work. It is clear that while levels of heavy metals in water are low at all sites, considerable levels can build up in substrate materials as represented by the slime covering stones on the river bed. Sediments at all sites except

site 1 are contaminated with copper (see figure 7), a marked peak in the degree of contamination by the metal occurring at site 7 which is the site most seriously affected by organic pollution. Slightly elevated levels of lead were detected at all sites except site 1; between sites 8 and 9 there is a massive input of lead to the river leading to the very high substrate concentrations of the metal recorded at site 9 (13.9 $mg.g^{-1}$, dry weight basis). It is suggested that while the high zinc levels at site 7 originate from the same source or sources as the copper at this site, much of the zinc at sites 9 and 10 enters the river with the large lead input discussed above. This explains the two peaks in the zinc curve (figure 7), one coinciding with the copper peak and one with the lead peak. In addition to sites with obvious contamination, the river is polluted by zinc at all sites except site 1.

2. The fauna.

The riffle benthos of the Irwell is dominated by oligochaete worms, which make up over 83 percent of the fauna (see table 52). By far the most abundant animal is Limnodrilus hoffmeisteri, comprising 31.72 percent of the fauna. Nais elinguis is also extremely numerous (17.06 percent), as are Tubifex tubifex (9.72 percent) and the Enchytraeidae (12.67 percent), although it is not clear whether this latter family is represented by one or a number of species since specific identifications, requiring the examination of live material, were not made. The other oligochaetes making up 1 percent or more of the fauna are Nais barbata (6.3 percent), Stylaria lacustris (2.23 percent), Limnodrilus udekemianus (1.41 percent), Chaetogaster diaphanus (1.03 percent) and Nais variabilis (1.00 percent). The other

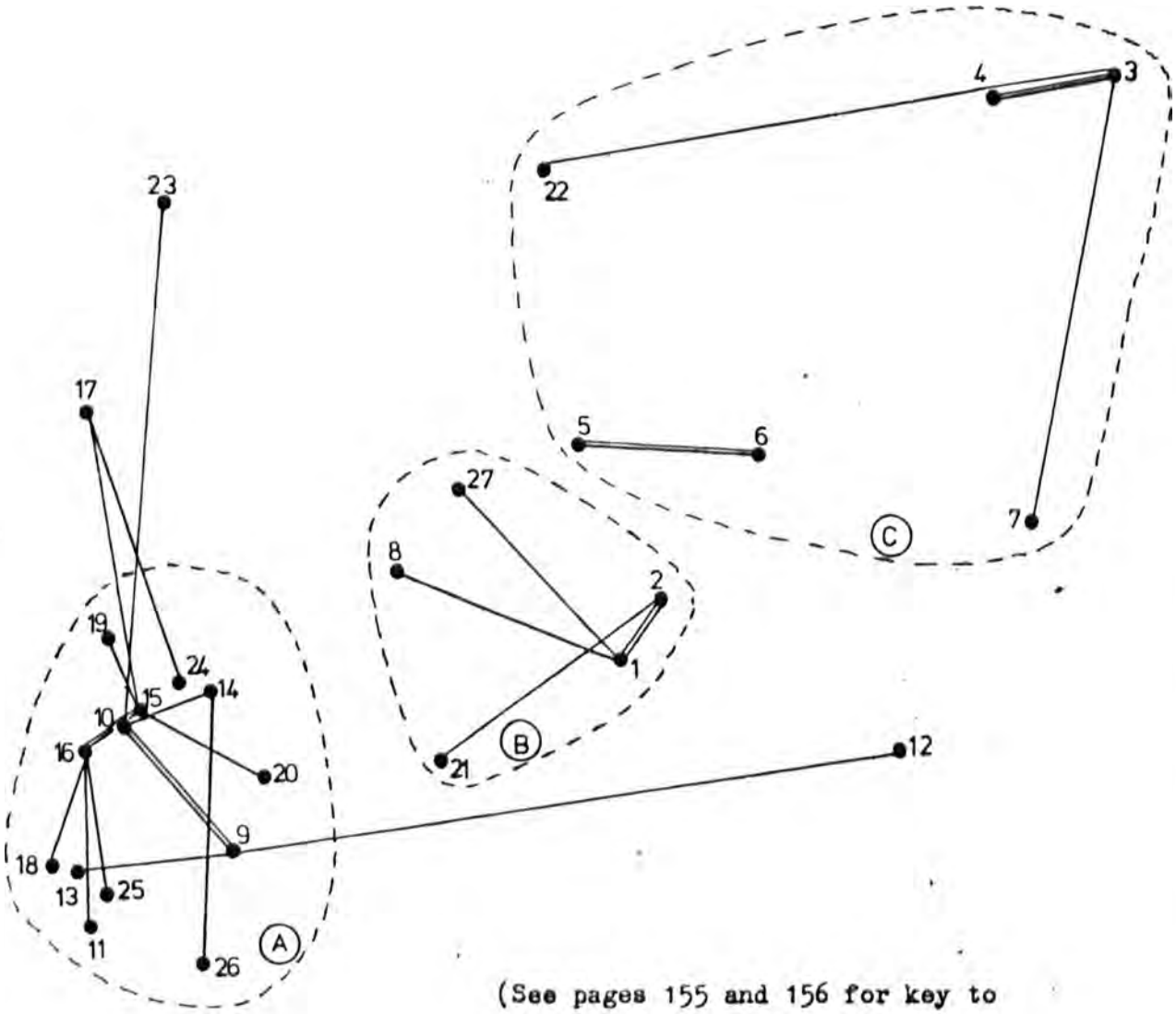
numerically important group of animals in the river is the Chironomidae (12.64 percent of the fauna). Of these, the larvae of the sub-family Orthocladiinae dominate (11.35 percent), although as with the Enchytraeidae it is unclear how many species are involved. Apart from the taxa already mentioned, only Asellus aquaticus, which makes up 2.28 of the fauna of the river, contributes more than 1 percent of the animals collected during the study.

The domination of the fauna by tubificid worms (43.55 percent of all fauna) is worthy of comment, since this family is usually regarded as being associated with depositing substrates in slow flowing or standing waters (Hynes, 1971a). This is probably because such habitats offer the richest potential food supply in terms of organic content which in turn leads to high bacterial productivity. Wachs (1967) has demonstrated a correlation between tubificid abundance and the organic carbon content of the sediment, while it is clear from work by Brinkhurst et al. (1972) and Coler et al.(1967) that the role of bacteria in the diet of tubifids is a vital one. Thus physical sediment characteristics might be expected to be of secondary importance as compared to the potential productivity of the habitat in determining suitability for tubificid colonization. In the Irwell, the very large suspended solid load leads to the interstices between the stones in the riffles becoming clogged with organic material, even in areas with high current speed. Conditions in the river favour the development of sewage fungus, which also serves to modify the substrate. Thus microhabitats of deposited material exist even in swiftly flowing reaches and it is this material that forms the basis of the tubificid food chain. In a study of superficially similar substrates in the unpolluted River Lune where the amount of allochthonous organic material in the river might be expected to be far less, Edwards,L (1975) did not collect

FIGURE 32.

Faunal associations based on **Pearson correlation coefficients**.

Each taxon is linked (——) to that taxon with which its abundance is most highly positively correlated (highest 'r' value).



(See pages 155 and 156 for key to numbers identifying taxa.)

a single tubificid during the course of his entire study period. Edwards et al. (1972) found that the filling of interstices between stones in the Taff system (S. Wales) led to the creation of a niche suitable for colonization by burrowing animals; this is clearly a situation paralleling that in the Irwell.

3. The distribution of taxa.

Association analysis has been applied to the data obtained in the course of the study. The method has the advantage that it allows relationships between sites or taxa to be examined using objective means, although in practice it is necessary to use subjective judgements to a certain extent when one wishes to group taxa into what may be termed 'ecological assemblages'. In spite of this the method has been shown to be a useful one. The macroinvertebrate riffle fauna of the river is divided into three associations on the basis of the degree of statistical correlation between the abundances of 27 taxa. The ordination whence the associations are derived is shown as figure 20a. This ordination is repeated as figure 32; however here each taxon is only shown linked to that taxon with which its abundance is most highly positively correlated on the basis of Pearson correlation coefficients. This presents a somewhat clearer picture than that implied by figure 20a, where all statistically significant positive correlations are shown, and is better suited to the present purpose of discussion. One assemblage, termed association B, is fairly evenly distributed along the length of the river and dominates the fauna at all sites (see figures 21 and 22). The taxa in association B are Tubifex tubifex, Limnodrilus hoffmeisteri, Nais elinguis, Asellus aquaticus, and the larvae of the chironomid sub-family Orthocladiinae. These taxa are clearly well adapted to a range of degrees of pollution, although examination of figure 18 shows that they vary in their ability to tolerate the most grossly contaminated situations. Only L. hoffmeisteri is able to thrive at Radcliffe, for example.

L. hoffmeisteri, T. tubifex, and N. elinguis are cosmopolitan species and have been reported from every continent (Brinkhurst

and Jamieson, 1971). L. hoffmeisteri is the commonest and most widely distributed tubificid , and its domination of the fauna in the present case is not surprising. The ubiquitous distribution of the species appears to be related to its highly adaptable life-cycle (Kennedy, 1966) enabling the populations to recover more rapidly that those of other species after adverse conditions. Kennedy (1966) found the life-cycle of L. hoffmeisteri to be dependent upon local conditions, the most influential factor being the productivity of the habitat. Aston (1973) has shown L. hoffmeisteri to be capable of laying eggs at very low oxygen concentrations, although the effect of such conditions on the development of the eggs was not examined. Kennedy (1965) found it difficult to define factors controlling the distribution of Limnodrilus spp., including L. hoffmeisteri. Finding that distributions could not be related to any of the physical or chemical factors of the environment usually measured in freshwater habitats, he suggests that biotic influences are great. It is possible that the conspicuous success of L. hoffmeisteri in the Irwell is related to a relative lack of success of competitors and predators.

While T. tubifex is grouped into the same 'ecological assemblage' as L. hoffmeisteri, it appears to be rather less able to tolerate conditions at the most heavily organically polluted site, although the mere fact that it is less abundant than the former species need not imply lack of tolerance since L. hoffmeisteri is often the commonest species anywhere (Brinkhurst, 1966). Eyres (1973) found that in depositing substrates in the Irwell T. tubifex was the more abundant species; this implies that its relative failure in the riffles may be related to substrate characteristics rather that to water quality. T. tubifex appears to have an adaptable life-cycle in that it is

similar to that of L. hoffmeisteri (Eyres, 1973). Young (1974), whose data confirm that the two life-cycles are similar, has shown that in addition to the main breeding period, which is common to both species, L. hoffmeisteri continues breeding at a low level throughout most of the year. This ability would be of advantage in enabling the population to recover from setbacks outside the main period of recruitment; lack of such ability may explain why T. tubifex appears not to thrive at site 7. T. tubifex is well able to tolerate low oxygen concentrations (Aston, 1973), although there appears to be no data on the ability of the worm to breed successfully under conditions of severe oxygen depletion. Sediments at site 7 have been shown to be contaminated with the highest concentration of copper recorded for the river, and it is possible that this has a detrimental effect on T. tubifex; however, Whitley (1968) has shown Limnodrilus sp. and Tubifex sp. to have similar tolerances to toxins although his tests did not include copper. Brinkhurst and Kennedy (1965) found no correlation between the distributions of T. tubifex and L. hoffmeisteri in Ditton Brook and postulate that their abundances may be determined by different environmental factors. Brinkhurst and Chua (1969) have shown that although L. hoffmeisteri and T. tubifex ingest all available food material, and while most of the bacteria found in the substrate may also be found in the guts of the worms, a different species of bacterium survives digestion in each worm. The authors infer from this that there are differences in the ability of the two species to utilize the nutritional resources of the mud. It is suggested, in the light of the data from the present study, that the differences in the ability of these two ubiquitous tubificids to thrive at site 7 may be due to the nature of the bacterial flora able to flourish under conditions in the river at that

site; bacteriocidal properties of copper may be involved.

The tolerance of the wide range of conditions in the Irwell by Nais elinguis, and its association with T. tubifex and L. hoffmeisteri, is to be expected since it is well known as a species tolerant of polluted conditions. Brinkhurst (1965) records the association of the species with sewage fungus in organically polluted water. In a stream polluted by refuse tip liquor, N. elinguis dominated the macroinvertebrate fauna (Nuttall, 1973), where the species was found to be associated with the massive growths of sewage fungus which trapped silt and blocked the interstices between stones. Ladle (1971) found N. elinguis making up 3.4 percent of the oligochaete fauna of an organically polluted ditch; the species was absent from similar substrates in an unpolluted stream nearby. Examination of figures 18h and 16 suggests that N. elinguis cannot tolerate extremes of pollution, as represented, for example, by site 7. This reflects the situation encountered by Edwards et al. (1972), who found the species to be abundant in the River Taff except at sites where there were deep deposits of fine material coupled with low oxygen concentrations. Similarly, Eyres (1973) found the animal to be less successful in depositing substates than the present work has shown it to be in riffles. The wide range of habitat type suitable for colonization by N. elinguis is emphasized when it is mentioned that Edwards,L (1975) collected the species in large numbers from the unpolluted River Lune.

The occurrence of Asellus aquaticus in association B is not surprising, since the species is well documented as part of the 'pollution fauna' (Hynes, 1971a). Hynes reports that where naturally eroding substrates are enriched with organic material Asellus may reach enormous numbers, and in Cladophora beds it

may be "astonishingly abundant". The species is not characteristic of the most grossly contaminated conditions, and was extremely rare at site 7. Holland (1976) states that A. aquaticus is normally an inhabitant of muddy substrata where it feeds on decaying organic matter but that it does invade eroding substrata. This presumably occurs only under the conditions described above. Holland (1976) finds that A. aquaticus does not occur in waters where B.O.D. rises above 10.0 to 11.5 $mg.l^{-1}$, corresponding to the figure of 10 $mg.l^{-1}$ given by Woodiwiss (1964). Examination of figure 20 in Appendix II shows that at site 10, where the species thrives, a mean B.O.D. of 12.0 $mg.l^{-1}$ was recorded over the course of the survey. At site 9, where the species is most abundant, a B.O.D. of 19.2 $mg.l^{-1}$ was recorded for February 1975. Values in excess of 12 $mg.l^{-1}$ are certainly not uncommon. Holland (1976), deriving his data from Woodiwiss (1964), finds the mean annual dissolved oxygen concentration at which Asellus thrives to be 5.8 $mg.l^{-1}$ and that the minimum mean level for survival is approximately 2.0 $mg.l^{-1}$. Figure 18 in Appendix II shows mean dissolved oxygen concentrations to be greater than 5.8 $mg.l^{-1}$ at all sites; only at site 7 were monthly figures of less than 2.0 $mg.l^{-1}$ recorded on occasions. It seems that the distribution of Asellus in the Irwell may be restricted by the occurrence of extremes of oxygen depletion, but that where its survival is assured the species develops highest population densities in areas of greatest organic enrichment. This explanation accounts for the absence of the species from site 7, where potential food supply is great and for its relative lack of success in the well oxygenated but less enriched upper reaches. The influence of toxic substances on the distribution of Asellus cannot be discounted, but the animal is known to survive in the field

at ammonia concentrations of up to 14.5 $mg.l^{-1}$ (Holland, 1976) and is clearly very tolerant of lead. It thrives at site 9 in the Irwell despite a substrate lead concentration of 13.9 $mg.g^{-1}$ (dry weight basis). The toxicity of lead to A. aquaticus, expressed in terms of LC_{50}, has been shown to be of the order of 41.5 $mg.l^{-1}$. For copper, the equivalent figure is much lower, at 7.85 $mg.l^{-1}$, and it is quite possible that the metal is involved in preventing the colonization of site 7 by the species.

The final association B taxon that remains to be considered is the Orthocladiinae, larvae of this sub-family of the Chironomidae being very numerous at all sites except sites 1 and 7, and exhibiting an ability to tolerate conditions in a wide spectrum of polluted situations. Bryce and Hobart (1972) report that dense populations of Orthocladiinae may develop on Cladophora in shallow polluted streams. The sub-family is part of the characteristic fauna of stony streams (Hynes, 1970). Some genera are well adapted to such environments, secreting silk to attach themselves to the substrate. Hynes (1971a) finds larval Orthocladiinae to be little affected by intermittent discharges of a small toxic effluent, and also mentions that they can thrive in organically polluted waters as long as the water remains well oxygenated. Larval Orthocladiinae appear to be quite unaffected by levels of copper cyanide which are capable of eliminating completely such organisms as Asellus and Limnaea (Hynes, 1971a). The sediment bound copper at site 7 (figure 7) is thus unlikely to pose a problem to the animals, and it appears that the relative lack of success of the taxon at this site (see figure 18v) is a result of periodic oxygen depletion. Generalizations about the ecological requirements of Orthocladiinae, in the absence of specific identifications, can be misleading since it is clear that there is a wide diversity of habits within the sub-family.

For example, some species are hygropetricous, the larvae living on wet vertical rock faces (Bryce and Hobart, 1972).

While the taxa comprising association B differ in their ability to tolerate the most grossly contaminated conditions, they have in common their ability to exploit a wide variety of habitats with different degrees of pollution.

The assemblage of animals that has been grouped together as association A display marked success in the upper reaches of the river, although the group never approaches the ubiquitous association B in abundance. The members of association A are listed in table 93.

Little is known of the ecological requirements of naidid worms other than Nais elinguis. This is partly because the animals have generally been overlooked in river studies (Edwards et al., 1972), and partly because difficulties with the identification of the worms have quite probably often led to all members of the genus Nais being grouped together as N. elinguis. N. barbata, which at times was very abundant at certain sites (figure 17), was collected in large numbers from polluted sites in the Taff catchment by Edwards et al. (1972) and from similar habitats in the River Kinzig, in Germany, by Besch et al. (1967). Figure 18 (j and k) shows N. communis and N. variabilis to have very similar patterns of percentage mean distribution. Using characteristics given in Sperber (1950), these two species are very difficult to separate since many of the relevant characters show wide variation and some overlap. Brinkhurst and Jamieson (1971) find the distinction between the species one of the most difficult to make when using preserved material. Chen (1940) suggests that the two are in fact a single species. The species certainly merit attention from the taxonomic point of view. Both species were collected from the Taff catchment by Edwards et al.

(1972); N. communis was one of the dominant naidids in the River Kinzig (Besch et al., 1967). Stylaria lacustris is clearly well able to tolerate conditions at site 8 on occasions (figure 181) although the size of the peak in abundance at this site is somewhat biased in that samples were only collected from this site when the animal was at its most abundant in any case. S. lacustris is obviously tolerant of organic pollution; it was extremely abundant at site 8 in August 1973 (table 73), at which time the B.O.D. was measured at 6.8 $mg.l^{-1}$. Its relative lack of success at sites 7, 9, and 10 may be associated with toxic pollution, these sites being those most seriously contaminated by heavy metals (see figure 7). The reason for the low percentage mean abundance of S. lacustris at upstream sites, especially 2 and 3, is unclear. There is little detailed work on the food requirements of the Naididae, but the family is generally regarded as being herbivorous (Edwards et al., 1972). Brinkhurst and Jamieson (1971) feel that the animals may graze 'aufwuchs' that develops on vegetation, and, reporting the work on Yoshizawa (1928), note that S. lacustris has been shown to feed on algae, including diatoms, and plant fragments.

The molluscs make up only 1.07 percent of the fauna of the Irwell; the three most abundant species are Ancylus fluviatilis, Limnaea peregra and Physa fontinalis. Of these, all but the latter are grouped with association A, and examination of the ordination shown as figure 32 makes it clear that Physa fontinalis is quite closely related to the association, being excluded from it on spatial rather than statistical grounds. Edwards et al. (1972) found Limnaea peregra and Ancylus fluviatilis to be widely distributed in the Taff catchment, and Hydrobia jenkinsi (also present in the Irwell) was the only other mollusc. Hynes (1971a) finds that L. peregra and P. fontinalis may occur in

abnormally large numbers in what he terms the "Asellus zone". Examination of figure 18 (p,q and z'') demonstrates this not to be the case in the Irwell, the molluscs being almost completely restricted to the upper reaches of the river. A. fluviatilis is an animal well able to thrive in a wide variety of lotic and lentic environments, being found almost wherever a suitable substrate, in the form of bare rocks and stones, is available (Geldiay, 1956). The latter author suggests that the limpets browse indiscriminately on the algal felt that covers the rocks and stones; Berg (1961) notes that the animals prefer smooth stones covered with a thin layer of diatoms and other algae. The diet of A. fluviatilis has been investigated by Calow (1973), who found the animal to be a microherbivore, ingesting epilithic algae. The limpet seeks its food by random movement and contact chemoreception. There is thus general agreement as to the herbivorous nature of A. fluviatilis. It is generally regarded as an animal requiring well circulated water abounding in oxygen. Thus the availability of suitable food and the degree of aeration of the water will be factors influencing the distribution of the species.

Limnaea peregra is the commonest and most abundant species of British freshwater snail. Calow (1970) has shown the mollusc to be an unspecialized herbivore, but it does appear to prefer epiphytic algae to macrophytic tissue. Green filamentous algae are preferred to diatomaceous tissue, this probably being due to the protective nature of the diatom envelope.

The success of the molluscs at site 6 as compared to the other sites appears to be partly related to the high dissolved oxygen concentration maintained at this site by a weir (mean 96, minimum 82 percent of saturation). This is probably especially influential in the case of Ancylus fluviatilis. Limnaea peregra

and Physa fontinalis, however, are known to be able to thrive in conditions normally associated with huge populations of Asellus aquaticus (Hynes, 1971a), and it is clear that factors other than dissolved oxygen concentration are limiting the distibution of these molluscs in the Irwell. Site 6 has the lowest mean suspended solid load of any site (figure 6), probably because these materials settle out behind the weir. It is possible that high suspended solid loads are deleterious to molluscs in that they block respiratory mechanisms; this would help to explain the success of the animals at site 6. It should be noted, however, that P. fontinalis, L. peregra and A. fluviatilis are able to tolerate high concentrations of fine coal particles (Learner et al., 1971). The peak in mollusc abundance at site 4 (figure 18) may be related to the very extensive nature of the epilithic algal community observed at this site. At sites 7, 9 and 10 all molluscs are scarce or absent (figure 18, o to s). Figure 7 shows these to be sites most heavily polluted by toxic metals. It is suggested that, as with many organisms, the distribution of molluscs in the Irwell is governed by a complex of biotic, physical and chemical factors.

Of the four leech species collected from the Irwell, Erpobdella octoculata is the most numerous, although when compared with many other taxa it is scarce. It is a large animal, however, and its importance is greater than is implied by simple abundance considerations. E. octoculata is carnivorous, swallowing insect larvae, oligochaetes and Cladocera whole (Mann, 1964). The availability of suitable food is clearly not a factor influencing the distribution of the species in the Irwell. It is well able to tolerate mild organic pollution (Mann, 1964), although Hynes (1971a) feels that E. testacea is the more tolerant erpobdellid. E. testacea was not encountered in the present study, but the species

is in any case sparsely distributed in England, whereas E. octoculata occurs in all kinds of habitat, in hard and soft water, in lentic and lotic situations (Mann, 1964). The occurrence of Glossiphonia complanata and Helobdella stagnalis, albeit in small numbers, is not surprising since both are regarded as being tolerant of organic pollution (Hynes, 1971a). The collection of Trocheta bykowskii from the Irwell (site 2, February 1975) is worthy of comment. The species was first recorded in Britain in 1959, and Mann (1964) states that there are eleven records from England, S. Scotland and Ireland. A twelfth is that of Edwards et al. (1972), who collected the animal from the Taff in S. Wales. The species is clearly widespread, but seems to be very rare; it is known to breed in moderately fast to rapid streams but is amphibious in that it leaves the water in search of food although it does not travel more than a few feet from the stream. Its diet consists of earthworms and other small invertebrates.

The Tanypodinae larvae, making up 0.11 percent of the fauna, are grouped with association A on the ordination in figure 20a; examination of figure 18y makes it clear that while the larvae do better at upstream sites, they are able to achieve relative success at sites 8 and 9. These larvae are carnivores, feeding on Tubificidae (Hynes, 1971a).

Baetis rhodani (0.13 percent of the fauna) and B. scambus (less than 0.01 percent of the fauna) are both almost completely restricted to the upper reaches of the river (figure 18, z and z'). While little appears to be known of the diet of B. scambus, B. rhodani is known to be a detritus feeder (Brown,D.S, 1961). Clearly the availability of suitable food is not a factor limiting the distribution of B. rhodani in the Irwell. The animal

is known to be tolerant of organic pollution (Edwards et al., 1972; Woodiwiss, 1964) but far less is known about the response of B. scambus. Edwards,L (1975) found both species in the unpolluted River Lune. Macan (1957) regards B. scambus as being a species of stony rivers whereas B. rhodani is more prevalent in small streams; Edwards et al. (1972) found this situation to be reversed in the Taff catchment. The latter authors find that the two species are equally tolerant of the water quality of the Taff system. It is suggested in the light of the present work, and of that of Edwards et al. (1972), that B. scambus may not be less tolerant of pollution than B. rhodani, merely that it appears to be so due to its restricted distribution in the British Isles, its shorter period of residence in the rivers, and possibly because it is intrinsically rarer. Further work, including laboratory studies, is called for, but it is possible that a modification to the scheme of classification upon which the biotic index of Woodiwiss (1964) is based might be called for.

Of the animals grouped together as association C (table 93), only the Chironominae larvae are not oligochaete taxa. The sub-family is probably represented almost entirely by Chironomus thummi. Bryce and Hobart (1972) report that large numbers of this fly occur in the Irwell at Manchester. As has been mentioned earlier, this sub-family is not normally associated with swift currents and stony substrates, but in rivers such as the Irwell the clogged interstices between stones provide a suitable microhabitat for the animals. The Chironominae show their greatest abundance at site 7, emphasizing their ability to colonize habitats totally unsuitable for the vast majority of organisms.

The Enchytraeidae are well able to tolerate polluted conditions,

forming as they do a major part of the fauna of sewage filter beds. In the present study over 55 percent of all specimens were collected from site 9, where the mean B.O.D. was 10.4 $mg.l^{-1}$ and substrate bound lead concentrations of over 13 $mg.g^{-1}$ (dry weight basis) were recorded.

The remaining members of association C are tubificids. Two of them, Monopylephorus irroratus and M. rubroniveus, are members of a genus normally associated with brackish water and the marine environment (Brinkhurst and Jamieson, 1971). As so little is known of their distribution, however, their occurrence in the Irwell cannot be regarded as anomalous. Limnodrilus udekemianus makes up 1.41 percent of the fauna of the river, and is almost exclusively restricted to the lower reaches downstream of site 5. Greatest abundance of the animal occurs at site 8, but it is well able to survive even the grossly contaminated conditions at site 7. Kennedy (1966) finds that while L. hoffmeisteri thrives in all types of habitat, L. udekemianus is less common and occurs more locally and patchily. Brinkhurst (1965) feels that although L. udekemianus is tolerant of oxygen lack, it does not usually inhabit grossly polluted waters. That this is not the general case is emphasized by the present data, and by those of Ladle (1971) who collected the species from an organically polluted ditch. Brinkhurst and Kennedy (1965) collected L. udekemianus in Ditton Brook, and found that the abundance of the species increased over the course of their study. They also found the worm to be more abundant at downstream sites, and they explain this finding with the suggestion that the species is moving upstream, colonizing the system. This explanation is not felt to be appropriate in the case of the present situation; ecological factors are felt to be limiting the success of association C in the upstream reaches of the river, as will be mentioned

subsequently.

L. profundicola attains maximum abundance in the Irwell at site 7, but even here it is very scarce. The species is not at all widespread in Britain, having only been collected from a small pond in the Wirral, Cheshire, and from Ditton Brook (Brinkhurst, 1971), and from the Leeds and Liverpool Canal (Kennedy, 1965). All these locations are in direct connection with, or very close to, the River Mersey, and Kennedy (1965) feels that the species has been introduced to Britain via the port of Liverpool. It will be noted from figure 1 that the Irwell is also in dirct connection with the Mersey, albeit via the Manchester Ship Canal. This theory is worthy of consideration; however, as no species of Limnodrilus is known to survive in salt water, and only L. hoffmeisteri can tolerate brackish conditions (Kennedy, 1965), it is difficult to see how such colonization could have taken place. The worldwide distribution of the species, as it is at present understood, is odd. It is recorded from Switzerland but not from Austria, Italy or Germany, and from U.S.A. but not from Canada or Mexico (Kennedy, 1965). It is suggested that the species may have been overlooked in many studies, confusion with L. hoffmeisteri being possible if material is not properly cleared, and that it may be widely distributed although possibly rare.

The almost total exclusion of association C animals from the upstream reaches of the Irwell is interesting. It might be expected that if their success were solely related to the degree of organic enrichment of the habitat, their numbers would simply be reduced in proportion to the lowered organic loading in this area. This is not the case. Differences in substrate characteristics cannot be invoked, since particle size analysis

(figure 4) shows no trends that can be related to the distribution of group C animals. It is suggested that the lack of success of association C taxa in the upper reaches of the river is due to competition from group A animals. Were conditions to improve sufficiently to allow association A to become well established in downstream stony areas, association C might be expected to show a consequential demise.

4. Biological assessment of pollution.

If they are to be of value, biological methods of pollution assessment must either provide information as to the state of a river that is not otherwise obtainable, or furnish routine data more quickly or more cheaply than can other means. When considering the effectiveness of the methods that have been applied to the present data, it should be born in mind that the Irwell is polluted along its entire length and that the aim is to assess the effects of different degrees of pollution which is both organic and inorganic in nature and which fluctuates in degree. This is not as simple as detecting pollution of a river on which there are clean sites against which the polluted sites may be compared.

Only two of the indices considered in table 98 are significantly correlated with both biochemical oxygen demand and dissolved oxygen concentration, viz. $s/\log_{10}n$ and $(s-1)/\ln n$, where s = number of taxa and n = number of individuals. These two are obviously mathematically very similar, and as in all respects they behave in the same way (see table 98), comment will be restricted to the latter which will be known as the Margalef (1951) index. One effect of both organic and inorganic (toxic) pollution is a reduction in the number of colonizing species, and it might be expected that indices significantly

correlated with number of taxa (s in table 98) would be useful as indicators of 'community health'. Such indices are $\bar{d}$ (Shannon and Weaver, 1963), the ratio Naididae/Tubificidae, Margalef's (1951) index and the biotic index of Woodiwiss (1964). Of these, only Margalef's (1951) index is significantly correlated with both B.O.D. and D.O. The ratio Naididae/Tubificidae is significantly correlated with B.O.D. but not with D.O., possibly being influenced more by substrate modifications brought about by organic enrichment than by oxygen concentrations, while the biotic index is significantly correlated with D.O. but not with B.O.D. and is thus perhaps better at detecting the effects of organic pollution in terms of oxygen depletion than its degree in terms of B.O.D. Margalef's (1951) index must be recommended on the grounds that it reflects the degree of organic pollution in terms of B.O.D., its effect in terms of reduction of dissolved oxygen concentration, and the influence of the pollution on the fauna reflected in any reduction in the number of taxa. Wilhm (1967) found the index of Margalef (1951) to be the most highly correlated with number of species of all the indices that he examined. He found the quantity $\bar{d}$ to be highly correlated with number of species but poorly correlated with number of individuals; this is also the case with the present data.

None of the expressions devised for quantifying community diversity have been shown to be satisfactory under all conditions; that of Margalef (1951), while useful, is not independent of sample size, and does not make full use of the data available in that the abundances of each species are not involved in its calculation. This objection is overcome in the calculation of Shannon and Weaver's (1963) index of diversity, which is independent of sample size, but even here the actual identity of species is of no consequence and communities at different sites

made up of quite different species can have the same diversity. The identity of species is an integral part of the assignation of a biotic index (Woodiwiss, 1964) to a sample. The index has been shown to be useful in distinguishing between the degrees of pollution occurring in the Irwell. The ratio Naididae/Tubificidae appears to be equally effective.

The Irwell is clearly recognisable as a river polluted by organic material merely by examining the results of the chemical analyses of water samples. The degree of contamination fluctuates but the pollution is always readily detectable by chemical means. It is suggested that the value of biological survey in a river such as the Irwell lies in the elucidation of the complex of factors impinging upon the fauna and limiting the distribution of taxa. The type of detailed survey that has been carried out, and the modes of analysis employed, have achieved more than the mere reiteration of the polluted nature of the river; they have served to pin-point the greatest problems and allow the formulation of priorities for their solution, as will be discussed subsequently.

5. Conclusions and recommendations.

The riffle fauna of the Irwell is dominated by the Oligochaeta, which make up 84 percent of the fauna, and especially by Limnodrilus hoffmeisteri (32 percent). It is probable that this results from the formation in the riffles of microhabitats suitable for oligochaete colonization, due to the clogging of interstices between stones with suspended material and growths of sewage fungus. A lack of tubificid diversity, especially at upstream sites where a relatively rich naidid community develops, is surprising. Only six tubificid species were collected from the river, and four of these were absent or virtually so in the

upper reaches. In his work on the River Derwent in various stages of recovery from organic pollution, Brinkhurst (1965) collected twelve tubificid species; Learner et al. (1971) collected nine tubificids from a polluted station on the River Cynon (S. Wales). It is suggested that toxic substances, such as heavy metals, are preventing the colonization of the upper reaches of the Irwell by Tubificidae that might otherwise be expected to thrive there. Levels of toxic metals at these sites, while lower than those recorded downstream, are still a good deal higher than those prevailing in the unpolluted River Lune. It is to be expected that improvements in this aspect of the water quality of the river would lead to the appearence of tubificid species such as Limnodrilus claparedianus, Psammoryctes barbatus and Potamothrix hammoniensis. Any attempt to reduce the heavy metal burden of the Irwell might usefully be accompanied by routine monitoring of the tubificid fauna, since this would be an economical means of monitoring the abatement programme.

It is suggested that the modes of data analysis, and the approach to the discussion of results, employed in the present work, which aid the recognition of groups of organisms with similar ecological characteristics (so called'ecological assemblages' or associations) are of greater value in elucidating the complex of chemical, physical and biological factors impinging upon the benthos than are simple numerical quantifications of 'community diversity' or 'species richness'. The former methods, in their very application, involve the investigator with the situation as it exists in the field; the identity of organisms is not submerged in a single mathematical expression and yet findings can still be presented in a lucid manner (see, for example, figures 21 and 22). It is an often emphasized truism that river faunas must be treated to a great degree on individual merits. While this is merely, perhaps, an admission that much still

remains to be learned of the factors limiting the distribution of lotic biota, the reduction of the wealth of information gathered in studies of stream biology to too simplistic a level, and the comparison of rivers at this level, can be misleading. Consideration of the biology of individual species forms an invaluable part of the interpretation of biotic data.

The Irwell can be divided into two distinct regions on the basis of faunal characteristics. The upper reaches are characterized by the species which have been grouped together as association A and the lower reaches by association C. The most easily recognized members of association A, such as Baetis spp. and the molluscs would, it is suggested, be valuable 'indicator species' for this particular river. They can be identified in the field and it can be assumed that their continued presence upstream indicates that conditions are at least not deteriorating while their establishment at downstream sites on a permanent basis would suggest that the situation is improving. Data as to relative abundance of chosen species at selected sites would be of greater value than records of presence or absence. Before conclusions were to be drawn from decline in abundance or absence of a taxon, due regard should be taken of the life-cycle of the animal as indicated by reference to the relevant literature.

The site most seriously affected by organic pollution is site 7, in Radcliffe, but the paucity of the fauna here cannot be explained solely in these terms and it is suggested that the effects of copper at this site are at least as serious as those of oxygen lack. Similarly, at sites 9 and 10, where sediments are grossly contaminated by lead, certain species, such as Limnaea peregra and Physa fontinalis, are virtually absent although they can survive at site 8 where contamination

by metals is less severe. There is some indication of lower levels of organic pollution at site 8 as compared to sites 9 and 10 but it is felt that the difference in sediment bound lead concentration is the influential factor. Metals appear to be implicated in the reduction in tubificid diversity of the river as a whole as compared to similar situations elsewhere, and to exert especially damaging influences at sites 7, 9 and 10. At site 7, productivity is depressed and at sites 9 and 10 species are precluded which might otherwise be expected to thrive, or at least to survive.

In any attempt to improve the biological status of the Irwell, a priority must be a reduction of the heavy metal burden of the river. The situations with respect to copper at site 7, in Radcliffe, and lead in the Agecroft area, and to a lesser extent zinc at both these sites, should be ameliorated as a matter of priority. In the light of toxicity tests on Asellus aquaticus and Erpobdella octoculata copper appears to be the most serious of the three pollutants. Were heavy metal pollution of the Irwell to cease, and pollution were to be limited to the discharge of sewage and other organic wastes, then its influence on the benthos would result primarily from substrate modification and the physical effects on organisms of suspended solids, since in a river such as the Irwell turbulence and weirs ensure relatively high dissolved oxygen under all but the most grossly contaminated conditions. Gross organic pollution of the type prevalent at Radcliffe would still have serious consequences, but the success of species able to tolerate oxygen lack, such as Tubifex tubifex, would be greater and overall production might be expected to increase. The effects of organic pollution are, perhaps, undesirable, and would ensure that oligochaetes

still dominated the benthos, but the more serious consequences of pollution such as long term accumulation of toxic metals would be avoided.

SUMMARY.

1. Data obtained from analysis of bi-monthly samples of riffle benthos collected from ten sites on the River Irwell show the fauna to be dominated by Oligochaeta, notably Limnodrilus hoffmeisteri. Despite this, 76 taxa, including 24 Oligochaeta, have been recorded.

2. Except at its source, which is contaminated by mine drainage, the Irwell is organically polluted along its entire length. The degree of contamination increases dramatically in Radcliffe, after the confluence of the River Roch, but the physical nature of the watercourse ensures that except under the most grossly contaminated conditions dissolved oxygen concentrations remain high.

3. Over almost the entire length of the river, substrate materials are contaminated with lead, zinc and copper. The high pH of the water leads to rapid precipitation from solution of the metals and this emphasizes the need to take into account such factors when interpreting data as to dissolved heavy metal concentrations. Site 7 (Radcliffe) is most seriously affected by copper, site 9 (Agecroft) by lead. Zinc concentrations are high at both these sites.

4. Of the three metals studied (copper, lead and zinc), copper is the most toxic and zinc the least toxic to both Erpobdella octoculata and Asellus aquaticus.

5. To simplify the classification of taxa, association analysis has been applied to data and shows the fauna of the Irwell to be divisible into three 'ecological assemblages'. One assemblage,

association B, dominates the fauna at all sites and apart from site 1 (Irwell Springs) is fairly evenly distributed along the length of the river. This association is dominated by Limnodrilus hoffmeisteri and also includes Tubifex tubifex, Nais elinguis, Asellus aquaticus and Orthocladiinae larvae. Association A is restricted to the upper reaches of the river, association C to the downstream sites. The lack of success of association C at upstream sites may be related to the inability of its members to compete with association A animals which in turn cannot tolerate downstream conditions.

6. A major factor determining the nature of the riffle benthos of the Irwell is the modification of the substrate by suspended material and sewage fungus. Heavy metals also exert a deleterious effect, and may be implicated in causing the very impoverished species diversity of the Tubificidae in the river.

7. Samples of substrate material have been analysed by dry sieving. It is felt that substrate differences are not instrumental in causing the observed differences in fauna in different regions of the river.

8. The use of artificial substrate samplers has been evaluated. While results obtained from the use of these devices show less variability that do comparible data from Surber samples, the problem of vandalism in an urban area precludes the recommendation of their use in pollution surveys except in rural situations.

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APPENDIX I.

Analysis of substrate samples.

Tables 4 to 13 show the results of particle size analyses carried out on substrate samples collected in February 1975.

Table 4.

Results of particle size analyses of substrate samples collected in February 1975 from site 1.

Sieve mesh (mm)	Weight of substrate retained (g)				% of total	Cumulative percentage
	Sample 1	Sample 2	Sample 3	Σ		
76.2	991.89	1719.07	2029.57	4740.53	20.92	20.92
63.5	474.97	593.46	597.27	1665.78	7.35	28.27
50.8	845.70	875.07	374.27	2095.04	9.24	37.51
38.1	871.37	392.38	612.85	1876.60	8.28	45.79
25.4	427.56	597.25	714.64	1739.45	7.68	53.47
19.05	302.14	340.87	280.64	923.65	4.08	57.55
12.7	499.64	491.72	355.06	1346.42	5.94	63.49
6.35	954.69	1002.71	689.74	2647.14	11.68	75.17
4.76	337.73	406.69	256.53	1060.95	4.68	79.85
2.0	742.22	971.00	501.60	2214.82	9.77	89.62
1.18	431.97	518.93	214.23	1165.13	5.14	94.76
0.60	313.56	354.25	128.46	796.27	3.51	98.27
0.42	70.11	88.00	32.59	190.70	0.84	99.11
0.30	28.92	40.48	16.03	87.43	0.39	99.50
0.21	12.54	19.26	10.42	42.22	0.19	99.69
0.15	6.41	9.12	5.47	21.00	0.09	99.78
0.075	8.91	11.52	9.12	29.55	0.13	99.91
Pan	6.19	8.13	6.51	20.83	0.09	100.00
Total				22663.71		

Table 5.

Results of particle size analyses of substrate samples collected in February 1975 from site 2.

Sieve mesh (mm)	Weight of substrate retained (g)				% of total	Cumulative percentage
	Sample 1	Sample 2	Sample 3	Σ		
76.2	1074.67	2360.24	1184.84	5520.45	21.48	21.48
63.5	483.45	1098.05	722.97	2284.47	8.89	30.37
50.8	1315.34	315.30	790.01	2350.25	8.91	39.28
38.1	756.49	565.33	1537.00	2858.91	11.12	50.40
25.4	686.01	518.98	1217.76	2422.65	9.42	59.82
19.05	449.69	351.71	364.96	1206.26	4.69	64.51
12.7	653.89	742.55	623.74	2020.18	7.86	72.37
6.35	1035.26	1239.47	784.15	3118.88	12.13	84.50
4.76	245.93	320.80	175.74	742.47	2.89	87.39
2.0	398.29	496.94	305.29	1200.52	4.67	92.06
1.18	209.76	249.31	123.84	582.91	2.27	94.33
0.60	338.38	320.52	115.35	774.25	3.01	97.34
0.42	175.17	126.83	37.93	341.93	1.33	98.67
0.30	100.64	66.36	20.23	187.23	0.73	99.40
0.21	47.36	32.12	9.42	88.92	0.35	99.75
0.15	14.84	11.24	3.30	29.38	0.11	99.86
0.075	10.34	9.73	3.61	23.68	0.09	99.95
Pan	5.34	4.99	2.61	12.94	0.05	100.00
Total				25705.38		

Table 6 .

Results of particle size analyses of substrate samples collected in February 1975 from site 3.

Sieve mesh (mm)	Weight of substrate retained (g)			Σ	% of total	Cumulative percentage
	Sample 1	Sample 2	Sample 3			
76.2	2518.71	2434.17	3183.90	8136.78	31.37	31.37
63.5	781.54	0	1194.16	1975.70	7.62	38.99
50.8	836.26	908.77	101.56	1846.59	7.12	46.11
38.1	293.62	1089.39	814.67	2166.74	8.35	54.46
25.4	1088.26	1055.18	1076.91	3220.35	12.42	66.88
19.05	629.70	491.69	569.86	1691.55	6.52	73.40
12.7	599.07	696.34	419.38	1715.79	6.62	80.02
6.35	665.72	663.15	732.54	2261.41	8.72	88.74
4.76	206.95	258.47	204.87	670.29	2.58	91.32
2.0	430.42	509.89	370.92	1311.23	5.06	96.38
1.18	211.88	242.10	134.25	588.23	2.27	98.65
0.60	102.00	121.73	56.09	279.82	1.08	99.73
0.42	10.27	14.40	5.33	30.00	0.17	99.90
0.30	7.30	7.36	2.43	16.62	0.06	99.96
0.21	2.12	5.28	1.49	8.89	0.03	99.99
0.15	1.21	2.69	0.96	4.86	0.02	100.01
Pan	0.97	1.63	1.03	3.63	0.01	100.04
Total				25934.31		

Table 7 .

Results of particle size analyses of substrate samples collected in February 1975 from site 4.

Sieve mesh (mm)	Weight of substrate retained (g)			Σ	% of total	Cumulative percentage
	Sample 1	Sample 2	Sample 3			
76.2	3547.54	4323.53	2766.5	10637.57	39.91	39.91
63.5	1826.26	484.54	1002.33	3313.13	12.43	52.34
50.8	387.97	745.26	1416.69	2549.92	9.57	61.91
38.1	636.66	499.02	598.80	1734.48	6.51	68.42
25.4	563.27	627.21	890.85	2081.33	7.81	76.23
19.05	327.33	397.33	376.60	1101.26	4.13	80.36
12.7	396.53	450.58	681.52	1528.63	5.74	86.10
6.35	694.57	509.61	828.28	2032.66	7.63	93.73
4.76	151.07	145.17	244.51	540.75	2.03	95.76
2.0	229.01	150.59	362.36	791.93	2.97	98.73
1.18	29.54	44.52	62.58	136.64	0.51	99.24
0.60	5.81	26.43	21.23	53.47	0.20	99.44
0.42	1.50	17.55	10.60	29.65	0.11	99.55
0.30	1.33	24.65	15.05	41.03	0.16	99.71
0.21	0.99	19.68	15.01	35.68	0.13	99.84
0.15	0.60	10.11	8.26	18.97	0.07	99.91
0.075	1.15	8.69	7.78	17.62	0.07	99.98
Pan	1.03	3.00	3.16	7.19	0.03	100.01
Total				26652.74		

Table 8 .

Results of particle size analyses of substrate samples collected in February 1975 from site 5.

Sieve mesh (mm)	Weight of substrate retained (g)				% of total	Cumulative percentage
	Sample 1	Sample 2	Sample 3	Σ		
76.2	2927.22	3065.79	2675.0	8668.62	32.59	32.59
63.5	294.53	470.29	1074.21	1839.03	6.91	39.50
50.8	1044.51	373.91	1444.90	2863.32	10.77	50.27
38.1	561.34	1361.22	1112.31	3034.87	11.41	61.68
25.4	1357.49	849.02	735.64	2942.15	11.06	72.74
19.05	281.38	510.99	328.79	1121.16	4.22	76.96
12.7	519.61	376.85	451.39	1347.85	5.07	82.03
6.35	552.15	423.59	455.26	1431.00	5.38	87.41
4.76	109.21	87.89	107.07	304.17	1.14	88.55
2.0	274.48	181.32	193.12	648.92	2.44	90.99
1.18	322.79	144.89	132.87	600.55	2.26	93.25
0.60	713.52	242.55	214.84	1170.91	4.40	97.65
0.42	234.93	83.17	76.33	394.43	1.48	99.13
0.30	83.88	28.94	29.34	142.16	0.53	99.66
0.21	28.83	9.03	11.11	49.97	0.18	99.84
0.15	9.81	3.02	4.24	17.07	0.06	99.90
0.075	7.36	2.57	3.67	13.60	0.05	99.95
Pan	3.33	1.60	2.06	6.99	0.03	99.98
Total				26595.77		

Table 9 .

Results of particle size analyses of substrate samples collected in February 1975 from site 6.

Sieve mesh (mm)	Weight of substrate retained (g)				% of total	Cumulative percentage
	Sample 1	Sample 2	Sample 3	Σ		
76.2	0	0	460.91	460.91	1.90	1.90
63.5	0	381.59	0	381.59	1.58	3.48
50.8	1525.33	2911.59	1275.35	5712.27	23.60	27.08
38.1	1333.61	552.19	1007.36	2893.16	11.95	39.03
25.4	1583.74	1150.56	1231.41	3965.71	16.38	55.41
19.05	906.90	455.50	961.66	2324.06	9.60	65.01
12.7	693.05	622.94	908.87	2214.86	9.15	74.16
6.35	945.03	691.33	885.71	2522.07	10.42	84.58
4.76	244.62	193.79	225.36	663.76	2.74	87.33
2.0	513.91	319.45	412.69	1246.05	5.15	92.47
1.19	274.61	161.53	218.12	654.26	2.70	95.17
0.60	348.19	205.61	180.11	733.88	3.03	98.20
0.42	103.91	87.55	41.36	252.82	1.04	99.24
0.30	42.99	31.95	18.53	93.47	0.39	99.63
0.21	16.97	11.03	11.97	40.02	0.17	99.80
0.15	8.06	5.23	7.22	20.51	0.08	99.88
0.075	7.19	4.46	6.82	18.47	0.08	99.96
Pan	3.08	1.74	2.28	7.10	0.03	99.99
Total				24204.97		

Table 10.

Results of particle size analyses of substrate samples collected in February 1975 from site 7.

Sieve mesh (mm)	Weight of substrate retained (g)			Σ	% of total	Cumulative percentage
	Sample 1	Sample 2	Sample 3			
76.2	0	334.60	0	334.60	1.25	1.25
63.5	741.74	551.85	621.78	1914.97	7.14	8.39
50.8	505.59	652.32	659.57	1817.47	6.77	15.16
38.1	1290.72	1330.83	1740.36	4421.91	16.49	31.64
25.4	1219.23	1576.79	1507.59	4303.60	16.04	47.68
19.05	604.51	842.96	787.88	2235.35	8.33	56.01
12.7	929.06	777.72	1326.15	3032.93	11.30	67.31
6.35	1207.34	273.05	1100.92	2582.11	9.62	76.93
4.76	323.23	1120.66	246.44	1690.38	6.30	83.23
2.0	589.88	544.03	460.79	1592.70	5.94	89.17
1.18	376.61	382.79	296.63	956.03	3.56	92.73
0.60	516.65	413.94	284.84	1214.53	4.53	97.26
0.42	145.96	166.54	84.45	399.95	1.49	98.75
0.30	63.96	86.55	42.47	192.98	0.72	99.47
0.21	32.34	33.36	18.59	84.29	0.31	99.78
0.15	13.25	11.37	7.13	31.75	0.12	99.90
0.075	9.36	7.36	5.15	22.37	0.08	99.98
Pan	3.33	2.69	2.16	8.38	0.03	100.01
Total				26835.60		

Table 11.

Results of particle size analyses of substrate samples collected in February 1975 from site 8.

Sieve mesh (mm)	Weight of substrate retained (g)			Σ	% of total	Cumulative percentage
	Sample 1	Sample 2	Sample 3			
76.2	320.19	1322.0	2440.23	4082.42	15.84	15.84
63.5	853.65	380.12	329.37	1563.14	6.07	21.91
50.8	543.53	224.75	1114.33	1882.61	7.31	29.22
38.1	837.00	967.32	452.33	2306.65	8.95	38.17
25.4	1405.69	930.62	777.43	3113.74	12.09	50.26
19.05	774.47	823.35	680.73	2278.55	8.84	59.10
12.7	824.25	731.95	626.10	2202.30	8.55	67.65
6.35	921.98	849.52	650.79	2421.66	9.40	77.05
4.76	130.93	204.66	167.18	502.67	1.95	79.00
2.0	343.94	359.39	280.58	983.81	3.82	82.82
1.18	215.05	232.04	232.35	679.44	2.64	85.46
0.60	514.66	532.00	559.60	1606.26	6.23	91.69
0.42	383.95	401.61	403.81	1189.37	4.62	96.31
0.30	284.39	206.13	191.92	679.93	2.64	98.95
0.21	65.89	45.47	47.02	178.37	0.69	99.64
0.15	21.13	11.96	13.84	46.93	0.18	99.82
0.075	12.08	10.47	9.65	32.20	0.13	99.95
Pan	5.13	4.37	3.62	13.12	0.05	100.00
Total				25765.18		

Table 12.

Results of particle size analyses of substrate samples collected in February 1975 from site 9.

Sieve mesh (mm)	Weight of substrate retained (g)			Σ	% of total	Cumulative percentage
	Sample 1	Sample 2	Sample 3			
76.2	1823.0	3944.93	736.49	6404.32	21.99	21.95
63.5	1464.26	1148.81	0	2613.07	8.95	30.90
50.8	912.48	1194.04	1311.40	3317.92	11.37	42.27
38.1	645.94	589.08	1143.26	2378.28	8.15	50.42
25.4	1346.52	836.05	1761.27	3943.84	13.51	63.93
19.05	546.05	409.60	808.92	1764.57	6.05	69.98
12.7	594.42	449.01	1103.31	2136.74	7.32	77.30
6.35	885.47	462.24	1033.95	2381.66	8.16	85.46
4.76	263.53	125.40	275.59	664.52	2.28	87.74
2.0	432.61	171.95	483.78	1088.34	3.73	91.47
1.18	189.74	94.08	329.33	613.15	2.10	93.57
0.60	272.23	100.07	565.84	938.34	3.22	96.79
0.42	135.90	62.77	249.74	449.41	1.54	98.33
0.30	104.33	54.29	101.07	259.69	0.89	99.22
0.21	64.56	33.52	43.91	141.99	0.49	99.71
0.15	24.35	13.97	12.77	51.09	0.18	99.89
0.075	12.00	9.69	6.45	28.14	0.10	99.99
Pan	3.45	2.55	2.46	8.46	0.03	100.02
Total				29183.43		

Table 13.

Results of particle size analyses of substrate samples collected in February 1975 from site 10.

Sieve mesh (mm)	Weight of substrate retained (g)			Σ	% of total	Cumulative percentage
	Sample 1	Sample 2	Sample 3			
76.2	3660.00	2755.37	1909.60	8324.97	39.62	39.62
63.5	0	464.21	894.08	1378.29	6.61	46.23
50.8	333.73	393.85	480.06	1207.64	5.79	52.02
38.1	196.43	231.35	359.26	789.04	3.76	55.80
25.4	432.47	865.33	696.07	1793.86	8.60	64.40
19.05	335.07	356.57	405.76	1097.70	5.26	69.66
12.7	280.00	480.87	343.36	1104.23	5.29	74.95
6.35	495.76	601.99	554.22	1651.97	7.92	82.87
4.76	167.93	203.24	180.29	551.46	2.64	85.51
2.0	358.66	324.48	402.19	1145.33	5.49	91.00
1.18	213.35	230.39	317.11	760.85	3.65	94.65
0.60	218.43	242.99	323.02	784.44	3.76	98.41
0.42	48.65	54.12	59.84	162.61	0.78	99.19
0.30	28.72	26.02	26.12	80.86	0.39	99.58
0.21	19.89	14.41	11.87	46.17	0.22	99.80
0.15	10.31	6.86	5.43	23.10	0.11	99.91
0.075	7.91	4.86	3.13	15.90	0.08	99.99
Pan	2.26	1.58	0.96	4.81	0.02	100.01
Total				20863.23		

APPENDIX II.

Chemical analyses of water samples.

Tables 18 to 39 show the results of chemical analyses carried out on water samples collected monthly from 9 sites.

Table 18.

Dissolved oxygen concentration measured over the course of the survey period and in February 1975. Results as $mg.l^{-1}$.

Site.	1	2	3	4	5	6	7	8	9	10
Month.										
October 72	9.0	8.6	8.0	-	7.9	7.7	0.6	7.4	6.8	6.2
November	12.2	11.4	11.1	-	11.5	11.6	10.4	10.7	10.9	9.8
December	10.1	11.7	12.4	-	10.5	11.5	5.2	9.0	8.5	8.4
January	10.6	11.1	10.1	-	9.8	9.9	10.9	10.9	11.2	11.2
February	10.1	12.5	11.9	-	12.2	11.9	11.0	11.4	10.9	11.1
March	10.6	11.9	12.0	-	12.2	12.1	10.2	11.0	10.5	9.8
April	11.1	12.3	11.5	-	11.5	11.3	8.7	9.8	9.1	8.9
May	9.2	10.3	9.5	-	9.4	9.1	4.0	7.8	6.3	6.9
June	8.0	8.6	8.0	-	6.2	5.4	0.9	5.2	5.7	3.9
July	9.2	10.6	9.5	-	10.2	9.4	7.5	8.8	8.5	8.4
August	9.4	10.2	9.5	-	9.6	9.9	7.9	9.0	8.7	7.8
September	7.0	9.0	8.5	-	8.9	8.9	1.1	6.7	6.9	6.2
October 73	8.7	9.4	7.7	-	8.3	6.6	3.5	6.0	6.9	6.7
MEAN	9.6	10.6	10.0	-	9.9	9.6	6.3	8.7	8.5	8.1
February 75	11.4	12.6	12.0	-	12.0	11.8	10.2	7.4	9.5	9.1

Table 19.

Dissolved oxygen concentration measured over the course of the survey period and in February 1975. Results as percent saturation.

Site.	1	2	3	4	5	6	7	8	9	10
Month.										
October 72	82	82	77	-	77	75	6	73	68	63
November	100	96	92	-	96	97	86	89	95	84
December	85	95	102	-	87	95	44	77	74	73
January	78	92	85	-	82	84	90	90	91	91
February	82	97	96	-	100	99	93	99	94	96
March	86	99	99	-	104	102	87	95	89	83
April	82	96	94	-	92	92	72	85	78	76
May	78	88	82	-	88	85	38	77	64	66
June	75	86	80	-	64	57	10	55	60	42
July	83	98	88	-	96	91	74	87	84	83
August	83	94	88	-	90	92	77	87	86	77
September	62	85	83	-	88	90	12	71	72	64
October 73	79	89	75	-	81	64	35	60	69	67
MEAN	81	92	88	-	88	86	55	80	79	74
February 75	85	96	94	-	94	95	84	60	76	71

Table 20.

Biochemical oxygen demand measured over the course of the survey period and in February 1975. Results as $mg.l^{-1}$.

Site.	1	2	3	4	5	6	7	8	9	10
Month.										
October 72	1.9	5.6	8.6	-	9.7	2.6	20.5	9.7	13.5	19.0
November	1.8	5.9	5.2	-	3.6	3.2	9.6	8.4	8.1	6.6
December	1.9	8.0	8.4	-	12.4	11.0	17.5	18.0	17.1	21.6
January	2.4	3.7	8.7	-	10.7	8.4	12.0	8.0	7.0	13.1
February	3.6	3.2	5.2	-	6.8	5.8	18.8	13.2	15.0	11.3
March	2.7	3.0	3.8	-	5.1	4.2	8.7	9.6	9.5	9.9
April	3.4	2.9	4.9	-	6.6	6.2	17.5	13.5	11.0	11.0
May	1.8	2.8	5.7	-	9.9	5.9	19.0	8.1	8.6	11.5
June	1.8	2.6	3.4	-	5.3	5.0	10.5	5.8	7.5	17.0
July	2.7	2.0	3.7	-	4.2	3.6	11.7	9.0	7.5	7.8
August	2.9	2.1	2.7	-	5.6	3.6	9.0	6.8	6.6	8.3
September	1.7	5.4	3.2	-	5.1	5.3	11.0	7.7	14.4	11.0
October 73	1.4	4.2	4.1	-	12.0	7.5	13.2	10.8	9.0	8.4
MEAN	2.3	4.0	5.2	-	7.5	5.6	13.8	9.9	10.4	12.0
February 75	2.0	2.7	3.9	-	7.2	8.6	19.0	18.8	19.2	17.7

Table 21.

Total hardness measured over the course of the survey period and in February 1975. Results as $mg.l^{-1}$.

Site.	1	2	3	4	5	6	7	8	9	10
Month.										
October 72	-	-	162	-	-	158	-	168	-	186
November	-	-	92	-	-	90	-	110	-	121
December	-	-	70	-	-	86	-	98	-	119
January	-	-	166	-	-	151	-	177	-	179
February	-	-	130	-	-	120	-	136	-	152
March	-	-	112	-	-	112	-	141	-	154
April	-	-	124	-	-	121	-	152	-	160
May	-	-	153	-	-	154	-	188	-	200
June	-	-	168	-	-	160	-	175	-	186
July	-	-	116	-	-	108	-	130	-	140
August	-	-	88	-	-	90	-	118	-	132
September	-	-	152	-	-	146	-	168	-	204
October 73	-	-	132	-	-	160	-	152	-	168
MEAN	-	-	128	-	-	127	-	147	-	162
February 75	-	-	155	-	-	139	-	159	-	167

Table 22 .

Permanganate value (3 minute) at 27°C measured over the course of the survey period and in February 1975. Results as $mg.l^{-1}$.

Site.	1	2	3	4	5	6	7	8	9	10
Month.										
October 72	0.8	1.0	2.6	-	3.0	2.6	4.8	3.6	3.4	4.4
November	2.6	0.8	0.6	-	1.2	0.4	1.8	1.8	1.6	2.6
December	3.0	3.2	3.4	-	3.0	2.0	4.2	3.8	3.4	3.4
January	2.6	0.4	2.0	-	3.2	3.0	4.2	3.0	3.6	3.0
February	2.0	0.8	1.0	-	1.4	1.2	3.0	2.2	2.8	2.4
March	1.4	0.4	0.8	-	1.4	1.4	1.8	2.4	2.2	2.0
April	2.4	1.0	1.4	-	2.4	2.0	3.6	2.6	2.6	2.8
May	1.4	0.8	2.2	-	2.6	2.2	4.4	3.0	2.6	3.4
June	0.6	1.0	2.0	-	3.8	3.2	4.4	4.0	4.8	4.6
July	1.4	0.8	0.8	-	1.0	1.2	2.0	2.0	2.2	2.2
August	2.6	1.6	1.6	-	2.2	1.6	2.8	2.2	2.6	2.6
September	0.4	1.6	2.8	-	3.0	2.6	3.2	2.4	3.4	3.2
October 73	0.6	0.6	1.0	-	3.4	3.2	3.8	3.0	3.0	3.2
MEAN	1.7	1.1	1.7	-	2.4	2.0	3.4	2.8	2.9	3.1
February 75	2.0	0.6	0.8	-	1.4	1.2	2.6	2.4	2.6	2.6

Table 23.

Permanganate value (4 hour) at 27°C measured over the course of the survey period and in February 1975. Results as $mg.l^{-1}$.

Site.	1	2	3	4	5	6	7	8	9	10
Month.										
October 72	2.8	4.6	9.8	-	11.0	9.0	15.6	11.8	11.6	15.4
November	4.6	3.8	3.8	-	4.2	4.0	7.4	7.4	7.2	7.6
December	4.6	15.4	15.0	-	13.8	13.4	17.2	15.0	15.6	14.0
January	2.6	2.6	7.8	-	11.0	8.2	12.8	11.0	12.2	11.6
February	3.6	3.0	3.8	-	4.8	5.8	10.6	8.6	10.4	9.8
March	3.2	2.4	3.2	-	4.8	4.8	6.6	8.0	8.2	7.6
April	4.0	2.8	5.8	-	8.0	6.4	11.6	8.6	9.0	9.0
May	3.0	3.4	7.6	-	10.2	7.4	15.2	11.0	11.8	10.2
June	0.6	2.2	5.4	-	10.2	8.2	11.8	10.6	13.4	13.2
July	3.6	3.8	4.6	-	5.4	4.6	9.6	7.8	7.4	8.4
August	6.8	5.4	6.8	-	8.0	5.8	9.2	7.6	8.4	9.2
September	1.0	6.0	7.4	-	8.6	8.6	12.6	9.6	10.6	10.0
October 73	2.4	3.6	5.6	-	10.4	9.2	13.0	11.6	11.4	9.0
MEAN	3.3	4.5	6.7	-	8.5	7.3	11.8	9.9	10.6	10.4
February 75	3.0	2.4	4.0	-	6.2	5.8	10.0	9.6	10.8	10.4

Table 24.

Nitrogen as N (nitrate) measured over the course of the survey period and in February 1975. Results as $mg.l^{-1}$.

Site.	1	2	3	4	5	6	7	8	9	10
Month.										
October 72	1.0	1.8	9.0	-	5.4	4.4	0.3	1.0	1.4	3.2
November	1.0	1.6	2.4	-	2.1	1.6	2.5	2.6	2.3	2.2
December	0.4	1.0	1.2	-	1.3	1.7	1.5	1.7	1.8	1.8
January	0.7	1.0	7.0	-	4.0	3.9	2.4	2.1	0.8	2.2
February	0.9	1.4	2.4	-	2.3	2.2	1.7	1.7	1.6	1.7
March	1.0	1.2	1.7	-	2.3	2.0	2.1	2.1	1.9	2.1
April	0.9	1.3	3.3	-	2.9	3.2	2.6	2.2	2.3	2.6
May	0.7	1.4	5.5	-	4.1	3.7	0.8	2.2	2.1	2.9
June	0.7	1.2	7.5	-	4.7	4.8	<0.1	0.8	0.8	3.1
July	0.8	1.2	2.6	-	3.0	2.6	2.0	2.1	2.0	2.1
August	0.6	1.0	1.2	-	1.3	1.5	1.7	1.6	1.9	2.0
September	<0.1	1.8	6.6	-	5.0	3.8	0.1	1.2	1.9	2.6
October 73	1.2	1.8	3.6	-	2.9	2.6	1.8	1.7	2.0	2.7
MEAN	0.8	1.4	4.2	-	3.2	2.9	1.5	1.8	1.8	2.4
February 75	0.9	1.2	2.7	-	2.2	2.2	1.7	1.9	1.6	1.9

Table 25.

Phosphate measured over the course of the survey period and in February 1975. Results as $mg.l^{-1}$.

Site.	1	2	3	4	5	6	7	8	9	10
Month.										
October 72	<0.1	<0.1	6.4	-	3.8	2.0	3.4	2.3	4.0	6.6
November	<0.1	0.3	0.4	-	0.3	0.4	0.6	0.5	0.4	0.4
December	<0.1	<0.1	0.1	-	<0.1	0.1	<0.1	<0.1	<0.1	<0.1
January	<0.1	<0.1	3.3	-	2.0	1.6	1.6	1.6	1.3	2.4
February	0.6	<0.1	0.4	-	0.5	0.4	0.3	0.3	0.7	0.9
March	0.5	<0.1	0.7	-	0.8	0.5	0.4	<0.1	0.4	0.5
April	<0.1	<0.1	0.9	-	0.7	0.7	0.6	0.7	0.9	1.3
May	<0.1	<0.1	3.1	-	2.3	1.8	1.0	1.5	1.9	2.1
June	<0.1	<0.1	4.7	-	3.1	2.6	4.0	3.5	5.8	3.8
July	<0.1	<0.1	0.6	-	0.8	0.5	<0.1	<0.1	<0.1	0.9
August	0.5	0.2	0.3	-	0.4	0.3	0.3	0.3	1.1	0.6
September	<0.1	<0.1	4.4	-	2.8	1.5	2.6	2.1	3.1	3.0
October 73	<0.1	<0.1	1.3	-	1.3	0.9	1.0	1.0	0.7	0.9
MEAN	0.2	0.1	2.0	-	1.5	1.0	1.2	1.1	1.6	1.8
February 75	<0.1	<0.1	1.1	-	0.8	0.7	0.5	0.4	0.6	0.7

Table 26.

Nitrogen as N (NH_3) measured Over the course of the survey period and in February 1975. Results as $mg.l^{-1}$.

Site.	1	2	3	4	5	6	7	8	9	10
Month.										
October 72	1.2	1.2	1.2	-	0.7	1.3	9.1	7.9	8.8	10.0
November	0.8	0.4	0.3	-	0.3	0.1	0.8	0.7	0.8	0.7
December	1.0	0.5	0.6	-	0.5	0.5	0.5	0.8	0.8	1.2
January	1.0	2.1	2.3	-	2.8	1.3	7.2	6.5	8.5	8.3
February	0.9	1.1	1.1	-	0.8	0.8	1.6	1.4	3.1	3.1
March	0.7	0.7	0.7	-	0.4	0.3	1.2	1.1	1.7	2.2
April	1.2	1.1	1.1	-	0.6	0.6	3.3	3.3	5.0	5.1
May	0.5	1.5	1.1	-	1.5	0.3	3.9	3.9	6.3	6.7
June	0.5	<0.1	<0.1	-	0.3	0.3	9.9	8.3	10.4	10.2
July	0.4	0.6	0.5	-	0.3	0.2	1.9	1.5	1.7	2.0
August	0.3	0.2	0.2	-	0.2	0.2	0.4	0.6	0.9	1.1
September	0.2	2.3	1.8	-	0.5	0.2	6.4	5.0	5.6	5.9
October 73	0.7	1.5	1.5	-	0.9	0.8	3.8	3.5	5.0	3.8
MEAN	0.7	1.0	1.0	-	0.8	0.5	3.8	3.4	4.5	4.6
February 75	0.5	0.5	0.5	-	0.6	0.7	2.9	3.7	4.5	5.1

Table 27.

Nitrogen as N (nitrite) measured over the course of the survey period and in February 1975. Results as $mg.l^{-1}$.

Site.	1	2	3	4	5	6	7	8	9	10
Month.										
October 72	0	0.1	<0.1	-	0.2	0.2	0	0.1	0.2	0.3
November	0	<0.1	<0.1	-	<0.1	<0.1	0.1	0.1	0.1	0.1
December	0	0	0	-	0	<0.1	<0.1	<0.1	0.2	0.2
January	0	0.1	<0.1	-	0.1	0.1	0.2	0.2	0.2	0.2
February	0	0	0	-	0	0	0.1	0.1	0.1	0.1
March	0	<0.1	<0.1	-	<0.1	<0.1	<0.1	<0.1	0.1	0.1
April	<0.1	<0.1	<0.1	-	<0.1	<0.1	0.2	0.2	0.2	0.1
May	<0.1	<0.1	0.1	-	0.2	0.1	0.4	0.2	0.2	0.3
June	<0.1	<0.1	<0.1	-	0.3	0.3	<0.1	0.4	0.4	0.5
July	0	<0.1	0.1	-	0.1	0.1	0.2	0.2	0.3	0.3
August	0	0	<0.1	-	<0.1	<0.1	0.1	0.1	0.3	0.3
September	<0.1	0.2	0.1	-	0.4	0.1	<0.1	0.2	0.4	0.6
October 73	<0.1	0.1	0.15	-	0.3	0.2	0.2	0.3	0.3	0.3
MEAN	<0.1	<0.1	<0.1	-	0.15	0.1	0.1	0.2	0.2	0.3
February 75	<0.1	<0.1	<0.1	-	0.1	0.1	0.1	0.1	0.1	0.1

Table 28.

pH values recorded over the course of the survey period and in February 1975.

Site.	1	2	3	4	5	6	7	8	9	10
Month.										
October 72	3.3	7.1	6.9	-	7.1	7.2	7.0	7.2	7.2	7.1
November	3,2	7.1	8.9	-	7.2	7.1	7.3	7.4	7.2	7.2
December	3.5	7.0	7.1	-	7.1	7.1	7.1	7.4	7.2	7.2
January	4.7	7.5	7.1	-	7.3	7.2	7.1	7.4	7.4	7.3
February	3.2	7.2	7.2	-	7.1	7.3	7.0	7.1	7.2	7.1
March	3.4	7.4	7.3	-	7.2	7.3	7.1	7.1	7.2	7.2
April	4.4	7.2	7.0	-	7.2	7.2	7.0	7.1	7.2	7.5
May	4.4	7.5	7.2	-	7.3	7.2	6.8	7.2	7.2	7.2
June	4.7	7.2	7.1	-	6.9	7.1	7.1	7.1	7.2	7.9
July	3.6	7.3	7.0	-	7.0	7.2	7.0	7.2	7.2	7.7
August	3.5	7.3	7.3	-	7.1	7.3	6.9	7.1	7.15	7.05
September	7.1	7.3	7.0	-	7.4	8.1	6.9	7.1	7.2	7.1
October 73	4.0	6.7	6.7	-	7.2	9.2	7.0	6.9	7.0	7.0
MEAN	4.1	7.2	7.2	-	7.2	7.4	7.0	7.2	7.2	7.3
February 75	4.1	7.4	7.1	-	7.2	7.3	7.1	7.2	7.0	6.9

Table 29.

Chloride (Cl^-) concentrations measured over the course of the survey period and in February 1975. Results as $mg.l^{-1}$.

Site.	1	2	3	4	5	6	7	8	9	10
Month.										
October 72	32	24	44	-	52	64	78	74	84	132
November	18	24	26	-	28	28	38	34	40	38
December	12	20	24	-	22	28	24	30	34	40
January	18	24	44	-	46	60	86	80	88	92
February	20	208	272	-	180	156	216	236	244	184
March	26	28	34	-	40	36	52	52	58	72
April	26	32	44	-	46	64	80	72	72	100
May	28	32	54	-	60	76	100	90	86	130
June	22	28	44	-	58	52	104	84	88	132
July	22	22	24	-	28	28	48	50	48	66
August	16	16	18	-	24	24	34	36	38	42
September	16	26	44	-	54	68	100	80	88	154
October 73	26	26	34	-	36	38	72	68	70	96
MEAN	22	39	54	-	51	56	79	76	80	98
February 75	16	28	40	-	46	58	74	68	80	112

Table 30.

Alkalinity as $CaCO_3$ (methyl orange) measured over the course of the survey period and in February 1975. Results as $mg.l^{-1}$.

Site.	1	2	3	4	5	6	7	8	9	10
Month.										
October 72	10	90	65	-	95	115	155	155	150	135
November	20	60	65	-	55	55	75	75	70	70
December	40	60	55	-	55	55	65	80	70	85
January	45	110	100	-	105	100	145	145	155	155
February	40	55	65	-	60	60	75	85	90	90
March	neut-ral	60	65	-	60	70	90	85	100	100
April	30	70	70	-	70	65	95	95	115	115
May	40	90	85	-	95	85	130	115	130	130
June	20	90	80	-	115	105	190	165	180	185
July	40	70	70	-	65	70	100	100	95	105
August	10	55	60	-	60	65	90	85	85	85
September	230	95	90	-	95	110	135	125	140	135
October 73	30	75	80	-	140	165	135	130	125	120
MEAN	46	75	73	-	82	86	114	112	116	116
February 75	10	65	70	-	65	75	105	100	110	100

Table 31.

Chemical Oxygen Demand (C.O.D.) measured over the course of the survey period and in February 1975. Results as $mg.l^{-1}$.

Site.	1	2	3	4	5	6	7	8	9	10
Month.										
October 72	15	24	51	-	53	46	84	71	66	76
November	20	22	24	-	21	26	40	41	39	36
December	62	65	78	-	68	59	70	38	48	60
January	<4	10	32	-	47	30	64	35	34	35
February	10	15	21	-	32	22	55	44	26	37
March	16	5	12	-	11	13	34	44	40	52
April	18	15	30	-	37	37	58	46	41	38
May	7	21	38	-	54	40	79	46	50	48
June	8	13	26	-	39	34	61	42	69	68
July	12	12	16	-	17	16	44	38	34	32
August	35	17	21	-	29	24	42	27	22	42
September	7	21	30	-	39	35	64	52	52	44
October	5	16	35	-	43	41	55	48	44	41
MEAN	17	20	32	-	38	33	58	44	43	47
February 75	14	21	25	-	31	33	54	58	62	55

Table 32.

Conductivity, measured over the course of the survey period and in February 1975. Results as μmho.

Site.	1	2	3	4	5	6	7	8	9	10
Month.										
October 72	-	-	600	-	-	710	-	950	-	1200
November	-	-	325	-	-	300	-	385	-	420
December	-	-	245	-	-	285	-	320	-	430
January	-	-	620	-	-	630	-	879	-	910
February	-	-	-	-	-	760	-	1060	-	950
March	-	-	379	-	-	360	-	528	-	630
April	-	-	425	-	-	490	-	690	-	820
May	-	-	625	-	-	640	-	845	-	1020
June	-	-	570	-	-	600	-	1040	-	1040
July	-	-	378	-	-	378	-	508	-	590
August	-	-	281	-	-	290	-	912	-	484
September	-	-	685	-	-	670	-	940	-	1200
October 73	-	-	515	-	-	610	-	804	-	900
MEAN	-	-	434	-	-	517	-	759	-	815
February 75	-	-	460	-	-	480	-	650	-	830

Table 33.

Anionic synthetic detergents, measured over the course of the survey period and in February 1975. Results as $mg.l^{-1}$.

Site.	1	2	3	4	5	6	7	8	9	10
Month.										
October 72	-	-	-	-	-	-	-	-	-	0.3
November	-	-	-	-	-	-	-	-	-	0.1
December	-	-	-	-	-	-	-	-	-	0.1
January	-	0.1	0.3	-	0.3	0.24	0.5	0.34	0.33	0.4
February	-	-	-	-	-	-	-	-	-	0.15
March	-	-	-	-	-	-	-	-	-	0.28
April	-	-	-	-	-	-	-	-	-	0.54
May	-	-	-	-	-	-	-	-	-	0.36
June	-	-	-	-	-	-	-	-	-	0.55
July	-	-	-	-	-	-	-	-	-	0.23
August	-	-	-	-	-	-	-	-	-	0.17
September	-	-	-	-	-	-	-	-	-	0.33
October	-	-	-	-	-	-	-	-	-	0.3
MEAN	-	-	-	-	-	-	-	-	-	0.29
February 75	-	-	-	-	-	-	-	-	-	0.40

Table 34.

Suspended solids (total), measured over the course of the survey period and in February 1975. Results as $mg.l^{-1}$.

Site.	1	2	3	4	5	6	7	8	9	10
Month.										
October 72	14	26	25	-	38	9	32	28	27	48
November	28	14	12	-	13	14	28	35	32	37
December	131	314	356	-	250	215	332	272	237	158
January	45	8	33	-	13	9	22	14	15	24
February	38	24	22	-	23	20	34	49	61	52
March	33	17	13	-	13	12	21	22	39	32
April	30	9	12	-	19	12	38	24	29	22
May	37	7	13	-	13	11	25	13	14	14
June	61	6	13	-	16	15	14	10	35	51
July	26	12	12	-	10	9	32	35	20	26
August	26	20	55	-	45	15	40	29	31	45
September	7	12	10	-	9	10	24	15	14	22
October 73	18	28	21	-	18	14	27	29	23	29
MEAN	38	38	46	-	37	28	51	44	44	42
February 75	19	12	12	-	15	17	32	32	27	31

Table 35.

Suspended solids (minimum), measured over the course of the survey period and in February 1975. Results as $mg.l^{-1}$.

Site.	1	2	3	4	5	6	7	8	9	10
Month.										
October 72	9	14	13	-	24	6	15	17	14	29
November	20	9	7	-	8	11	17	22	19	23
December	94	256	294	-	201	177	269	221	188	107
January	34	4	15	-	4	2	8	6	7	15
February	28	16	14	-	13	13	15	27	38	32
March	27	13	6	-	9	5	8	8	18	17
April	24	7	8	-	10	6	13	11	16	13
May	27	3	6	-	5	6	6	6	7	7
June	43	4	6	-	6	8	4	5	19	30
July	17	7	7	-	7	6	12	19	10	14
August	14	14	42	-	31	9	22	16	19	30
September	5	6	5	-	4	5	10	6	6	13
October 73	12	20	15	-	12	7	12	15	13	11
MEAN	27	29	34	-	27	20	32	29	29	26
February 75	12	6	6	-	7	9	12	10	12	15

Table 36 .

Total solids (total), measured over the course of the survey period and in February 1975. Results as mg.l^{-1}.

Site.	1	2	3	4	5	6	7	8	9	10
Month.										
October 72	-	-	440	-	-	480	-	662	-	738
November	-	-	162	-	-	190	-	250	-	300
December	-	-	482	-	-	372	-	500	-	428
January	-	-	392	-	-	408	-	578	-	580
February	-	-	684	-	-	462	-	686	-	608
March	-	-	270	-	-	242	-	354	-	392
April	-	-	262	-	-	292	-	450	-	500
May	-	-	400	-	-	410	-	514	-	644
June	-	-	342	-	-	368	-	656	-	726
July	-	-	242	-	-	256	-	396	-	378
August	-	-	234	-	-	230	-	310	-	354
September	-	-	402	-	-	422	-	534	-	718
October 73	-	-	336	-	-	408	-	526	-	552
MEAN	-	-	358	-	-	349	-	494	-	532
February 75	-	-	290	-	-	302	-	416	-	528

Table 37.

Total solids (minimum), measured over the course of the survey period and in February 1975. Results as mg.l^{-1}.

Site.	1	2	3	4	5	6	7	8	9	10
Month.										
October 72	-	-	280	-	-	334	-	492	-	572
November	-	-	78	-	-	48	-	106	-	164
December	-	-	348	-	-	248	-	352	-	282
January	-	-	268	-	-	274	-	452	-	440
February	-	-	562	-	-	346	-	536	-	472
March	-	-	140	-	-	116	-	210	-	268
April	-	-	122	-	-	120	-	310	-	300
May	-	-	316	-	-	270	-	368	-	480
June	-	-	248	-	-	258	-	496	-	538
July	-	-	146	-	-	166	-	222	-	254
August	-	-	138	-	-	136	-	186	-	216
September	-	-	296	-	-	324	-	398	-	608
October 73	-	-	242	-	-	324	-	400	-	396
MEAN	-	-	245	-	-	228	-	350	-	383
February 75	-	-	240	-	-	248	-	354	-	466

Table 38.

Transparency (shaken) measured over the course of the survey period and in February 1975. Results as mm seen through.

Site.	1	2	3	4	5	6	7	8	9	10
Month.										
October 72	210	395	295	-	295	290	160	275	260	195
November	170	350	375	-	435	315	225	165	160	210
December	75	55	45	-	75	155	50	60	70	70
January	120	>600	230	-	350	>600	310	350	390	230
February	70	280	240	-	240	255	230	210	180	220
March	110	285	450	-	380	400	250	220	220	150
April	280	450	400	-	335	400	190	270	280	235
May	250	>600	350	-	315	465	190	350	350	395
June	170	>600	600	-	300	420	315	405	240	185
July	180	545	>600	-	>600	>600	205	270	305	290
August	175	330	220	-	250	350	250	260	240	205
September	>600	360	540	-	440	520	220	280	290	305
October 73	235	270	250	-	255	>600	185	135	205	280
MEAN	203	394	353	-	325	413	214	250	245	228
February 75	180	370	480	-	310	260	200	220	230	215

Table 39.

Transparency (settled) measured over the course of the survey period and in February 1975. Results as mm seen through.

Site.	1	2	3	4	5	6	7	8	9	10
Month.										
October 72	255	580	400	-	320	335	190	320	305	290
November	390	>600	>600	-	>600	420	330	235	215	305
December	275	110	100	-	115	180	125	140	145	170
January	370	>600	430	-	395	>600	400	390	430	380
February	170	320	335	-	290	290	270	250	200	250
March	180	450	550	-	450	450	300	260	245	220
April	560	>600	490	-	470	430	240	295	320	275
May	>600	>600	430	-	375	510	250	400	400	450
June	450	>600	>600	-	330	480	425	510	270	270
July	400	>600	>600	-	>600	>600	300	400	420	395
August	380	950	450	-	360	410	365	365	360	295
September	>600	505	580	-	510	550	230	340	350	350
October 73	460	350	375	-	>600	>600	250	265	245	305
MEAN.	392	528	449	-	417	450	283	321	300	304
February 75	295	580	>600	-	340	320	330	300	270	280

APPENDIX III.

Basic faunal analysis.

Tables 53 to 60 show the numbers of each taxon collected from each site, each month. Results are expressed as mean numbers per square metre.

Table 53

NUMBERS OF ANIMALS PER SQUARE METRE COLLECTED AT EACH SITE IN OCTOBER 1972.

(MEANS OF NUMBERS FROM 3 SAMPLES.)

TAXA.	SITE 1.	SITE 2.	SITE 3.	SITE 4.	SITE 5.	SITE 6.	SITE 7.	SITE 8.	SITE 9.	SITE 10.	MEAN.
NEMATODA.	-	-	no data	-	-	-	-	no data	7	4	1
OLIGOCHAETA.											
Naididae.											
Chaetogaster langi.	-	359		179	-	-	-		-	-	67
C. limnaei.	-	718		1543	1005	269	-		-	-	442
Nais alpinula.	-	144		2727	8791	2260	-		359	359	1830
N. variabilis.	-	179		1543	718	2099	-		179	-	590
N. alpina.	-	-		-	-	54	-		-	-	7
N. barbata.	-	1902		1543	646	5795	-		-	-	1236
N. communis.	-	-		72	144	54	-		-	-	34
N. pretneri.	-	-		-	-	-	-		-	-	-
N. simplex.	-	-		-	-	-	-		-	-	-
Stylaria lacustris.	-	144		897	610	5131	43		-	-	853
Tubifex tubifex.	-	-		-	-	-	-		-	-	-
T. ashmani.	-	-		-	-	-	-		-	-	-
T. ferox.	-	-		-	-	-	-		-	-	-
Tubificidae.											
Tubifex tubifex.	18	7894		431	2763	3373	7		3229	6701	3302
Limnodrilus claparedianus.	-	-		-	-	-	136		538	1345	252
Limnodrilus hoffmeisteri.	4	8503		700	789	4772	919		7176	8252	3889
L. profundicola.	-	-		-	-	-	4		179	-	23
Monopylephorus rubroniveus.	-	-		-	-	-	-		-	-	-
Monospilus limosus.	-	-		-	-	-	-		-	-	-
Aeolosomatidae.											
Aeolosoma hadlarti(?).	-	-		-	-	-	-		-	-	-
Lumbriculidae.				72							9
Lumbriculus variegatus.	-	-		-	-	-	-		-	-	-
Stylodrilus heringianus.	-	-		-	-	-	-		-	-	-
Enchytraeidae.	-	-		502	36	1274	50		12558	5113	2442
Unidentified Oligochaeta.	-	144		664	897	71	118		-	448	293
HIRUDINEA.											
Erpobdella octoculata.	-	4		29	4	4	-		-	4	6
Glossiphonia complanata.	-	-		-	-	-	-		-	-	-
Helobdella stagnalis.	-	-		-	-	7	-		-	4	1
Trocheta bykowski.	-	-		-	-	-	-		-	-	-
COLLEMBOLA.	4	4		7	11	4	-		4	-	4
CRUSTACEA.											
Cladocera.	-	-		-	-	-	-		4	72	10
Copepoda.	-	-		-	-	-	-		-	11	1
Asellus aquaticus.	-	176		344	276	9096	11		6267	4994	2630
Gammarus pulex.	-	-		-	-	-	-		-	-	-
EPHEMEROPTERA.											
Baetis rhodani.	-	14		213	93	4	-		4	7	43
B. scambus.	-	-		-	-	-	-		-	-	-
Rhithrogena semicolorata.	-	-		-	-	-	-		-	4	1
Ephemerella ignita.	-	-		-	-	-	-		-	11	1
Heptagenia dispar.	-	-		-	-	-	-		-	-	-
Ecdyonurus sp.	-	-		-	-	-	-		-	14	2
PLECOPTERA.											
Amphinemura nubecollis.	-	-		-	-	-	-		-	4	1
Amphinemura sp.	-	-		-	-	-	-		-	-	-
Leuctra sp.	-	-		-	-	-	-		-	-	-
TRICHOPTERA.											
Rhyacophila dorsalis.	-	-		-	-	-	-		-	4	1
Polycentropus sp.	-	-		-	-	-	-		-	-	-
Plectrocnemia conspersa.	-	-		-	-	-	-		-	-	-
Hydropsyche sp.	-	-		-	-	-	-		-	-	-
Hydroptila sp.	-	-		-	-	-	-		-	-	-
Limnephilus sp.	-	-		-	-	-	-		-	-	-
COLEOPTERA.											
Dytiscinae.	-	-		-	-	-	-		-	-	-
Haliplidae.	-	-		-	-	-	-		-	-	-
Noterinae.	-	-		-	-	-	-		-	-	-
NEUROPTERA.											
Sialis sordi.	-	-		-	-	-	-		-	-	-
MOLLUSCA.											
Ancylus fluviatilis.	-	14		262	83	5434	-		4	204	792
Bithynia tentacula.	-	130		30	57	165	-		7	4	53
Lymnaea peregra.	-	-		312	427	5310	-		32	57	767
Physa fontinalis.	-	-		-	-	7	-		-	-	1
Pisidium sp.	-	4		11	7	29	-		-	-	6
Sphaerium sp.	-	-		-	-	-	-		-	-	-
DIPTERA.											
Tipulinae larvae.	4	-		-	-	-	-		-	-	1
Psychodidae larvae.	7	-		4	4	-	-		-	-	2
Dolichopodinae larvae.	-	-		-	-	-	-		-	-	-
Stratiomyinae larvae.	-	-		-	-	-	-		-	-	-
Simulium sp. larvae.	-	-		-	-	4	-		-	-	1
Tabanus sp. larvae.	-	-		-	-	-	-		-	4	1
Haematopota sp. larvae.	-	-		-	-	-	-		-	-	-
Atherix ibis sp. larvae.	-	-		-	-	-	-		-	-	-
Ephydridae sp. larvae.	-	-		-	-	-	-		-	-	-
Dixa sp. larvae.	-	-		-	-	-	-		-	-	-
Unidentified Diptera larvae.	7	-		-	-	-	-		-	-	1
Tipulinae pupae.	-	4		-	-	-	-		-	-	1
Chironomidae.											
Orthocladiinae larvae.	50	1715		2470	1196	1003	65		2870	1213	1363
Chironominae larvae.	-	11		30	25	72	300		287	251	111
Tanypodinae larvae.	-	83		181	134	215	4		-	-	77
Diamesinae larvae.	-	215		-	-	36	-		36	-	36
Corynoneurinae larvae.	-	-		-	36	-	-		-	-	5
Unidentified Chironominae larvae.	4	76		197	115	72	-		72	-	54
Chironomidae pupae.	-	215		685	359	215	4		573	161	283
HYDRACARINA.	-	-		-	-	-	-		-	-	-
TOTAL.	102	22636		15412	20214	47547	1727		34025	30794	21557

NUMBERS OF ANIMALS PER SQUARE METRE COLLECTED AT EACH SITE IN DECEMBER 1972. Table 54

(MEANS OF NUMBERS FROM 3 SAMPLES.)

TAXON.	SITE 1.	SITE 2.	SITE 3.	SITE 4.	SITE 5.	SITE 6.	SITE 7.	SITE 8.	SITE 9.	SITE 10.	Mean.
NEMATODA.	-	-	no data	-	-	-	-	no data	-	-	-
OLIGOCHAETA.											
Aeolosomatidae.											
Aeolosoma hedlardi(?).	-	-		-	-	-	-		-	-	-
Naididae.											
Chaetogaster langi.	-	4		4	-	-	-		-	-	1
C. diaphanus.	-	4		-	-	-	-		-	-	1
Nais elinguis.	-	165		222	108	2088	-		-	72	332
N. variabilis.	-	-		122	25	260	-		-	-	53
N. alpina.	-	-		-	-	39	-		-	-	5
N. barbata.	-	-		-	-	18	-		-	-	2
N. communis.	-	-		47	4	7	-		-	-	7
N. bretscheri.	-	-		-	-	-	-		-	-	-
N. pseudobtusa.	-	-		-	-	-	-		-	-	-
Stylaria lacustris.	-	-		-	-	4	-		-	-	1
Pristina menoni.	-	-		-	-	-	-		-	-	-
P. aequiseta.	-	-		-	-	-	-		-	-	-
P. foreli.	-	-		-	-	-	-		-	-	-
Tubificidae.											
Tubifex tubifex.	14	240		664	2619	2232	466		3319	4306	1733
Limnodrilus hoffmeisteri.	7	11		732	122	208	266		3857	2655	982
L. claparedianus.	-	-		-	-	36	72		50	359	70
Peloscolex velutinus.	-	-		-	-	-	-		-	-	-
Potamothrix moldaviensis.	-	-		-	-	-	-		-	-	-
Lumbriculidae.											
Lumbriculus variegatus.	-	7		-	-	-	-		-	-	1
Stylodrilus heringianus.	-	-		-	-	-	-		-	-	-
Enchytraeidae.	115	90		219	154	108	154		10495	2949	1786
Unidentified Oligochaeta.	-	4		11	-	237	7		161	72	62
HIRUDINEA.						4					1
Erpobdella octoculata.	-	-		18	7	4	-		4	-	4
Glossiphonia complanata.	-	-		-	-	-	-		-	-	-
Helobdella stagnalis.	-	-		-	-	-	-		-	-	-
Trocheta bykowskii.	-	-		-	-	-	-		-	-	-
COLLEMBOLA.	11	-		7	7	4	4		-	-	4
CRUSTACEA.											
Cladocera.	-	-		83	14	36	4		7	-	18
Copepoda.	-	22		18	4	-	-		4	-	6
Asellus aquaticus.	4	-		1439	22	459	11		205	1166	501
Gammarus pulex.	-	-		-	-	-	-		-	-	-
EPHEMEROPTERA.											
Baetis rhodani.	-	18		136	7	22	-		11	-	24
B. scambus.	-	-		-	-	-	-		-	-	-
Arthroplea bicolorata.	-	-		-	-	-	-		-	-	-
Ephemerella ignita.	-	-		-	-	-	-		-	-	-
Ecdyonurus dispar.	-	-		-	-	4	-		-	-	1
Ecdyonurus sp.	-	-		-	-	-	-		-	-	-
PLECOPTERA.	4										1
Amphinemura sulcicollis.	-	-		-	-	-	-		-	-	-
Amphinemura sp.	-	-		-	-	-	-		-	-	-
Leuctra sp.	-	-		-	-	-	-		-	-	-
TRICHOPTERA.											
Rhyacophila dorsalis.	-	-		-	-	-	-		-	-	-
Polycentropus kingi.	-	-		-	-	-	-		-	-	-
Plectrocnemia conspersa.	-	-		-	-	-	-		-	-	-
Hydropsyche sp.	-	-		-	-	-	-		-	-	-
Rhyacophila sp.	-	-		-	-	4	-		-	-	1
Limnephilus sp.	-	-		-	-	-	-		-	-	-
COLEOPTERA.											
Dytiscinae.	-	-		-	-	-	-		-	-	-
Haliplidae.	-	-		-	-	-	-		-	-	-
Noterinae.	-	-		-	-	-	-		-	-	-
HYDRACARINA.	-	-		4	-	-	-		-	-	1
HEMIPTERA.											
Velia caprai.	-	-		-	-	-	-		-	-	-
MOLLUSCA.											
Ancylus fluviatilis.	-	-		540	11	129	-		4	-	136
Bithynia tentaculata.	-	-		47	18	14	-		-	-	10
Lymnaea truncatula.	-	-		100	7	11	-		-	7	18
Lymnaea peregra.	-	-		-	-	-	-		-	-	-
Pisidium sp.	-	-		14	-	4	-		-	-	2
Sphaerium sp.	-	-		-	-	-	-		-	-	-
DIPTERA.											
Tipulinae larvae.	-	-		7	-	-	-		-	-	1
Limoniidae larvae.	-	-		4	-	-	-		-	-	1
Dolichopodidae larvae.	-	-		-	-	-	-		-	-	-
Stratiomyidae larvae.	-	-		-	-	-	-		-	-	-
Simulium sp. larvae.	-	-		-	-	-	-		-	-	-
Tabanus sp. larvae.	-	-		-	-	4	4		-	-	1
Ptychoptera sp. larvae.	-	-		-	4	-	-		-	-	1
Atherix ibis sp. larvae.	-	-		-	-	-	-		-	-	-
Brillia sp. larvae.	-	-		-	-	-	-		-	-	-
Diamesinae sp. larvae.	-	-		-	4	-	-		-	-	1
Unidentified Diptera larvae.	-	4		7	-	-	-		-	-	1
Tipulidae pupae.	-	-		-	-	-	-		-	-	-
Chironomidae.											
Orthocladiinae larvae.	25	39		1254	57	104	11		100	594	327
Chironominae larvae.	-	-		18	-	22	4		4	72	15
Tanypodinae larvae.	-	-		39	-	69	-		-	36	13
Diamesinae larvae.	-	4		22	4	72	-		-	-	13
Corynoneurinae larvae.	-	-		-	-	-	-		-	-	-
Unidentified Chironomidae larvae.	-	-		14	4	14	-		11	4	6
Chironomidae pupae.	-	-		14	-	4	-		11	-	4
TOTAL.	180	612		6256	3302	6201	1003		18283	13192	6146

Table 55.

NUMBERS OF ANIMALS PER 1/20th METRE COLLECTED AT EACH SITE IN FEBRUARY 1973.

(RESULTS OF NUMBERS FROM THREE SAMPLES.)

TAXON.	SITE 1.	SITE 2.	SITE 3.	SITE 4.	SITE 5.	SITE 6.	SITE 7.	SITE 8.	SITE 9.	SITE 10.	MEAN.
NEMATODA.	-	-	-	-	-	-	-	no data	-	-	-
OLIGOCHAETA.											
Ascolosomatidae.											
Ascolosoma bellardi (?).	-	-	-	-	-	-	-		-	-	-
Naididae.											
Chaetogaster langi.	-	-	-	72	-	179	-		-	-	28
C. diaphanus.	-	-	-	72	-	-	-		-	-	8
Nais elinguis.	-	1005	2594	5454	20344	44464	4		-	359	9516
N. variabilis.	-	-	-	-	-	-	-		-	-	-
N. spp.	-	-	-	-	-	-	-		-	-	-
P. serrata.	-	-	-	-	-	538	-		-	-	60
P. variata.	-	-	-	-	-	-	-		-	-	16
P. communis.	-	-	72	72	-	-	-		-	-	-
P. breviseta.	-	-	-	-	-	-	-		-	-	-
P. pectinata.	-	-	-	-	-	-	-		-	-	-
Stylaria lacustris.	-	-	-	-	-	-	-		-	-	-
Tubifex tubifex.	-	-	-	-	-	-	-		-	-	-
T. spp.	-	-	-	-	-	-	-		-	-	-
Tubificidae.											
Tubifex tubifex.	7	1005	190	718	7319	3229	710		12020	1166	2030
Limnodrilus hoffmeisteri.	-	1005	563	1650	3588	2332	2669		10220	592	2514
L. claparedianus.	-	-	25	-	-	-	256		718	-	111
L. udekemianus.	-	-	-	-	-	-	111		-	-	12
L. spp.	-	-	-	-	-	-	-		-	-	-
Monopylephorus rubroniveus.	-	-	-	-	-	-	-		-	-	-
Monopylephorus irroratus.	-	-	-	-	-	-	-		-	-	-
Lumbriculidae.											
Lumbriculus variegatus.	4	-	-	-	-	-	-		-	-	1
Stylodrilus heringianus.	-	-	-	72	-	179	-		-	-	28
Enchytraeidae.	61	215	262	502	789	179	1041		59740	14350	4575
Unidentified Oligochaeta.	-	72	-	287	4449	359	7		-	233	601
HIRUDINEA.											
Erpobdella octoculata.	-	-	7	11	-	7	-		-	-	3
Glossiphonia complanata.	-	-	-	-	-	-	-		-	-	-
Helobdella stagnalis.	-	-	-	-	-	-	-		-	-	-
Piscicola geometra.	-	-	-	-	-	-	-		-	-	-
COLLEMBOLA.	4	11	183	208	29	50	-		11	11	56
CRUSTACEA.											
Cladocera.	-	4	18	4	4	11	-		-	4	5
Copepoda.	-	11	7	14	11	39	-		-	14	11
Asellus aquaticus.	-	11	14	1084	79	254	-		15017	351	1650
Gammarus pulex.	-	-	-	4	-	-	-		-	-	1
EPHEMEROPTERA.											
Baetis rhodani.	-	75	7	215	97	25	4		79	4	56
B. scambus.	-	-	-	-	-	-	-		-	-	-
Caenis horaria.	-	-	-	-	-	-	-		-	-	-
Ecdyonurus dispar.	-	-	-	-	-	-	-		-	-	-
Ecdyonurus spp.	-	-	-	-	-	-	-		-	-	-
PLECOPTERA.											
Amphinemura sulcicollis.	-	-	-	-	-	-	-		-	-	-
Amphinemura sp.	-	-	-	-	-	-	-		-	-	-
Leuctra sp.	-	-	-	4	-	4	-		-	-	1
TRICHOPTERA.											
Rhyacophila dorsalis.	-	-	-	-	-	-	-		-	-	-
Polycentropus kingi.	-	-	-	-	-	4	-		-	-	1
Plectrocnemia geniculata.	-	-	-	-	-	-	-		-	-	-
Hydroptila sp.	-	-	-	-	-	-	-		-	-	-
Rhyacophila sp.	-	-	-	4	-	-	-		-	-	1
Limnephilus sp.	-	-	-	-	-	-	-		-	-	-
COLEOPTERA.											
Dytiscinae.	-	-	-	4	-	-	-			-	1
Haliplidae.	-	-	-	-	-	-	-			-	-
Noterinae.	-	-	-	-	-	-	-		-	-	-
TRICLADIDA.	-	-	4	-	-	-	-			-	1
DIPTERA.											
Tipula carnea.	-	-	-	4	-	-	-			-	1
PISCIDIA.											
Anodus fluviatilis.	-	-	4	1145	15	97	-			-	140
Pisidium tenuis.	-	7	11	54	43	14	-			-	14
Pisidium spp.	-	-	-	22	11	-	-			-	3
Sphaerium corneum.	-	4	-	7	7	7	-			-	3
Sphaerium sp.	-	-	-	14	4	-	-		-	-	3
Sphaerium sp.	-	-	-	-	-	-	-		-	-	-
DIPTERA.											
Tipulinae larvae.	-	-	-	-	-	-	-		-	-	-
Dixa nubilipennis larvae.	-	-	-	-	-	-	-		-	-	-
Dolichopodidae larvae.	-	-	-	-	-	-	-		-	-	-
Stratiomyidae larvae.	-	-	-	-	-	-	-		-	-	-
Simulium sp. larvae.	-	-	-	-	-	-	-		4	-	1
Tanytarsus sp. larvae.	-	-	29	11	4	-	-		4	7	6
Cricotopus sp. larvae.	-	-	-	-	-	-	-		-	-	1
Orthocladius sp. larvae.	-	-	-	4	-	-	-		-	-	1
Metriocnemus sp. larvae.	-	-	-	-	-	-	-		-	-	-
Diamesa sp. larvae.	-	-	-	-	-	-	-		-	-	-
Unidentified Diptera larvae.	-	-	-	4	-	-	-			-	1
Tipulidae pupae.	-	-	-	-	-	-	-			-	-
Chironomidae.											
Orthocladiinae.	-	470	183	8602	13570	2228	222		5813	470	2098
Chironominae.	-	-	-	36	-	-	-		-	4	4
Tanypodinae.	-	7	-	36	7	-	7		-	4	7
Diamesinae.	-	7	11	-	-	29	4		-	-	6
Corynoneurinae.	-	-	7	4	-	-	-		-	-	1
Unidentified Chironominae larvae.	-	-	-	-	-	-	-		-	4	1
Chironomidae pupae.	-	7	36	237	57	39	-		147	18	60
Total.	76	13310	4231	13631	50430	56217	5098		101703	17669	29723

NUMBERS OF ANIMALS PER SQUARE METRE COLLECTED AT EACH SITE IN APRIL 1973.

(MEANS OF HOLDERS FROM 3 SAMPLES.)

Table 56

TAXA.	SITE 1.	SITE 2.	SITE 3.	SITE 4.	SITE 5.	SITE 6.	SITE 7.	SITE 8.	SITE 9.	SITE 10.	MEAN.
NEMATODA.	-	72	-	4	-	-	-	no data	-	-	8
OLIGOCHAETA.											
Aeolosomatidae.											
Aeolosoma hemprichi(?).	-	-	-	-	-	-	-		-	-	-
Naididae.											
Chaetogaster langi.	-	-	-	-	-	-	-		-	-	-
C. limnaei.	-	-	-	-	-	-	-		-	-	-
Nais elinguis.	-	12450	37584	38757	68351	538	25		-	287	17555
N. variabilis.	-	179	-	-	-	-	-		-	-	20
N. alpina.	-	-	-	-	-	-	-		-	-	-
N. barbata.	-	-	-	-	-	-	-		-	-	-
N. communis.	-	-	179	-	-	-	-		-	-	20
N. pseudobtusa.	-	-	-	-	-	-	-		-	-	-
N. simplex.	-	-	-	-	-	-	-		-	-	-
Stylaria lacustris.	-	-	-	-	-	-	-		-	-	-
Pristina menoni.	-	-	-	-	-	-	-		-	-	-
P. aequiseta.	-	-	-	-	-	-	-		-	-	-
P. foreli.	-	-	-	-	-	-	-		-	-	-
Tubificidae.											
Tubifex tubifex.	22	1938	1076	560	538	1256	240		10405	16575	3623
Limnodrilus hoffmeisteri.	-	1005	879	359	179	7714	1808		16623	9042	4179
L. udekemianus.	-	-	-	-	-	-	133		179	173	55
L. profundicola.	-	-	-	-	-	-	-		179	-	20
Monopylephorus rubroniveus.	-	-	-	-	-	-	-		-	-	-
Potamothrix moldaviensis.	-	-	-	-	-	-	-		-	-	-
Lumbriculidae.											
Lumbriculus variegatus.	-	72	-	-	-	-	-		-	-	9
Stylodrilus heringianus.	-	-	-	-	-	-	-		-	-	-
Enchytraeidae.	-	1005	179	266	359	20990	1091		148962	27699	22283
Unidentified Oligochaeta.	-	-	269	194	359	-	47		3348	431	516
HIRUDINEA.											
Erpobdella octoculata.	-	-	11	-	-	4	-		-	-	2
Glossiphonia complanata.	-	-	-	4	-	-	-		-	-	1
Helobdella stagnalis.	-	-	-	-	-	-	-		-	-	-
Trocheta bykowski.	-	-	-	-	-	-	-		-	-	-
COLLEMBOLA.	61	-	57	7	39	4	4		-	-	19
CRUSTACEA.											
Cladocera.	-	-	-	-	-	7	-		-	-	1
Copepoda.	-	-	-	-	-	-	-		-	-	-
Asellus aquaticus.	-	4	4	-	-	-	-		617	97	80
Gammarus pulex.	-	-	-	-	7	-	-		-	-	1
EPHEMEROPTERA.											
Baetis rhodani.	14	7	18	7	36	11	-		22	4	13
B. scambus.	-	-	-	-	-	-	-		-	-	-
Rhithrogena semicolorata.	-	-	-	-	-	-	-		-	-	-
Ephemerella ignita.	-	-	-	-	-	-	-		-	-	-
Ecdyonurus dispar.	-	-	-	-	-	-	-		-	-	-
Ecdyonurus sp.	-	-	-	-	-	-	-		-	-	-
PLECOPTERA.											
Amphinemura sulcicollis.	-	-	-	-	-	-	-		-	-	-
Amphinemura sp.	-	-	-	-	-	-	-		-	-	-
Leuctra sp.	-	-	-	-	-	-	-		-	-	-
TRICHOPTERA.											
Rhyacophila dorsalis.	-	-	-	-	-	-	-		-	-	-
Polycentropus kingi.	-	-	-	-	-	-	-		-	-	-
Plectrocnemia reticulata.	-	-	-	-	-	-	-		-	-	-
Hydropsyche sp.	-	-	-	-	-	-	-		-	-	-
Rhyacophila sp.	-	-	-	-	-	-	-		-	-	-
Limnephilus sp.	-	-	-	-	-	-	-		-	-	-
COLEOPTERA.											
Dytiscinae.	-	-	-	-	-	-	-		-	-	-
Haliplidae.	-	-	-	4	-	-	-		-	-	1
Noterinae.	-	-	-	-	-	-	-		-	-	-
HYDRACARINA.	-	-	-	-	-	-	-		-	-	-
HEMIPTERA.											
Velia caprai.	-	-	-	-	-	-	-		-	-	-
MOLLUSCA.											
Ancylus fluviatilis.	-	-	-	144	-	25	-		-	-	19
Limnaea peregra.	-	4	4	4	-	-	-		-	-	1
Physa fontinalis.	-	-	-	-	-	-	-		-	-	-
Sphaerium lacustre.	-	-	-	-	25	-	-		-	-	3
Pisidium sp.	-	-	4	4	-	-	-		-	-	1
Sphaerium sp.	-	-	-	-	-	-	-		-	-	-
DIPTERA.											
Tipulinae larvae.	-	-	-	-	-	-	-		-	-	-
Psychodidae larvae.	-	-	-	-	-	-	-		-	-	-
Dolichopodidae larvae.	11	-	-	-	-	-	-		-	-	1
Stratiomyidae larvae.	-	-	-	-	-	-	-		-	-	-
Simulium sp. larvae.	11	4	-	-	-	-	-		-	-	2
Pericoma sp. larvae.	-	-	-	-	4	-	-		-	-	1
Ceratopogon sp. larvae.	-	-	-	-	-	-	-		-	-	-
Atrichopogon sp. larvae.	-	-	-	-	-	-	-		-	-	-
Eristalis sp. larvae.	-	-	-	-	-	-	-		-	-	-
Dicranota sp. larvae.	-	-	-	-	-	-	-		-	-	-
Unidentified Diptera larvae.	-	-	-	-	-	-	-		-	-	-
Tipulinae pupae.	-	-	-	-	-	-	-		-	-	-
Chironomidae.											
Orthocladiinae.	22	319	1237	4474	764	2913	470		3168	721	1564
Chironominae.	-	-	-	-	-	-	-		-	4	1
Tanypodinae.	4	7	-	97	-	-	-		65	11	20
Diamesinae.	-	4	-	-	-	-	-		-	-	1
Coryneurinae.	7	-	-	-	-	-	-		-	-	1
Unidentified Chironomidae larvae.	-	-	-	-	-	25	-		61	7	10
Chironomidae pupae.	-	13	29	222	126	72	22		459	104	117
TOTAL.	152	17058	41420	45107	70787	33559	3840		184088	55162	50148

Table 57

NUMBERS OF ANIMALS PER SQUARE METER COLLECTED AT EACH SITE IN JUNE 1973.

(MEANS OF NUMBERS FROM 3 SAMPLES.)

TAXON.	SITE 1.	SITE 2.	SITE 3.	SITE 4.	SITE 5.	SITE 6.	SITE 7.	SITE 8.	SITE 9.	SITE 10.	MEAN.
NEMATODA.	-	667	25	4	-	-	-	-	-	-	70
OLIGOCHAETA.											
Aeolosomatidae.											
Aeolosoma hedleyi(?)	-	-	-	-	-	-	-	-	-	-	-
Naididae.											
Chaetogaster langi.	-	179	-	-	-	179	-	-	-	-	36
C. diaphanus.	-	15249	1525	538	-	-	-	-	-	-	1731
Nais elinguis.	-	173	628	718	1844	1435	-	-	-	179	798
N. variabilis.	-	-	179	2691	718	1794	-	-	-	-	538
N. alpina.	-	-	-	-	-	-	-	-	-	-	-
N. barbata.	-	54896	13634	6458	5203	33727	-	-	-	-	11352
N. communis.	-	-	179	1256	2870	8073	-	179	-	-	1256
N. bretscheri.	-	-	-	-	-	-	-	-	-	-	-
N. pseudobtusa.	-	-	-	-	-	-	-	-	-	-	-
Stylaria lacustris.	-	-	-	-	179	14890	-	179	-	-	1525
Pristina [illegible].	-	-	-	-	-	359	-	-	-	-	36
P. aequiseta.	-	-	-	-	-	-	-	-	-	-	-
P. foreli.	-	-	-	-	-	-	-	-	-	-	-
Tubificidae.											
Tubifex tubifex.	39	2691	1973	3947	24578	10405	187	25833	6100	21169	9692
Limnodrilus hoffmeisteri.	-	10764	4933	6279	5023	9329	865	8970	6997	5382	5944
L. udekemianus.	-	-	-	-	-	-	520	2332	359	-	321
L. profundicola.	-	-	-	-	-	-	36	-	-	-	4
Monopylephorus rubroniveus.	-	-	-	-	-	359	36	897	718	897	291
Monopylephorus irroratus.	-	-	-	-	-	-	-	538	179	-	72
Lumbriculidae.											
Lumbriculus variegatus.	-	-	-	-	-	-	-	-	-	-	-
Stylodrilus heringianus.	-	-	-	-	-	-	-	-	-	-	-
Enchytraeidae.	57	5023	538	179	-	43414	258	9867	10764	3409	7351
Unidentified Oligochaeta.	-	1256	90	718	2870	2691	57	1256	-	359	930
HIRUDINEA.											
Erpobdella octoculata.	-	7	14	7	7	4	-	-	-	-	4
Glossiphonia complanata.	-	-	-	-	-	-	-	-	-	-	-
Helobdella stagnalis.	-	-	-	-	-	-	-	-	-	-	-
Trocheta bykowskii.	-	-	-	-	-	-	-	-	-	-	-
COLLEMBOLA.	7	4	36	32	7	-	11	-	-	-	10
CRUSTACEA.											
Cladocera.	4	-	-	-	-	4	-	377	65	108	56
Copepoda.	-	11	4	7	18	18	-	1374	14	14	146
Asellus aquaticus.	-	57	29	4	4	32	-	273	1238	797	243
Gammarus pulex.	-	-	-	-	-	-	-	-	-	-	-
EPHEMEROPTERA.											
Baetis rhodani.	-	11	4	68	61	-	-	-	-	-	14
B. scambus.	-	-	-	11	7	-	-	-	-	-	2
Rhithrogena semicolorata.	-	-	-	-	-	-	-	-	-	-	-
Ephemerella ignita.	-	-	-	-	-	-	-	-	-	-	-
Ecdyonurus dispar.	-	-	-	-	-	-	-	-	-	-	-
Ecdyonurus sp.	-	-	-	-	-	-	-	-	-	-	-
PLECOPTERA.											
Amphinemura sulcicollis.	-	-	-	-	-	-	-	-	-	-	-
Amphinemura sp.	4	-	-	-	-	-	-	-	-	-	1
Leuctra sp.	-	-	-	-	-	-	-	-	-	-	-
COLEOPTERA.											
Dytiscinae.	-	-	-	-	-	-	-	-	-	-	-
Haliplidae.	-	-	-	-	-	-	-	-	-	-	-
Noterinae.	-	-	-	-	-	-	-	-	-	-	-
HYDRACARINA.	-	-	-	-	-	-	-	-	-	-	-
HEMIPTERA.											
Velia caprai.	-	-	-	-	-	-	-	-	-	-	-
MOLLUSCA.											
Ancylus fluviatilis.	-	12	18	671	11	1195	-	4	-	-	191
Limnaea peregra.	-	11	22	111	7	47	-	50	-	-	25
Physa fontinalis.	-	-	-	-	-	29	-	-	-	-	3
Hydrobia jenkinsi.	-	4	-	4	4	-	-	-	-	-	1
Pisidium sp.	-	-	11	14	4	25	-	-	-	-	5
Sphaerium sp.	-	-	-	-	-	4	-	-	-		1
DIPTERA.											
Tipulinae larvae.	4	-	-	-	-	-	-	-	-	-	1
Psychodidae larvae.	-	-	-	-	-	-	-	-	-	-	-
Dolichopodidae larvae.	-	-	-	-	-	-	-	-	-	-	-
Stratiomyidae larvae.	-	-	-	-	-	-	-	-	-	-	-
Simulium sp. larvae.	-	-	-	-	4	4	-	-	-	-	1
Pericoma sp. larvae.	-	4	-	-	-	-	-	-	-	-	1
Hemerodromia sp. larvae.	-	-	-	-	-	-	-	-	-	-	-
Atrichopogon sp. larvae.	-	-	-	-	-	-	-	-	-	-	-
Eristalis sp. larvae.	-	-	-	-	-	-	-	-	-	4	1
Dicranota sp. larvae.	-	-	-	-	-	-	-	-	-	-	-
Unidentified Diptera larvae.	-	-	-	-	-	-	7	-	-	-	1
Tipulidae pupae.	-	-	-	-	-	-	-	-	-	-	-
Chironomidae.											
Orthocladiinae.	22	45029	29960	21169	40165	36956	100	19806	21368	23681	23826
Chironominae.	-	-	-	-	-	-	-	251	-	179	43
Tanypodinae.	-	-	-	-	-	-	7	-	-	-	1
Diamesinae.	-	-	-	179	-	-	-	-	-	-	18
Corynoneurinae.	-	-	-	-	-	-	-	-	-	-	-
Unidentified Chironomidae larvae.	-	-	-	179	718	359	4	179	538	897	287
Chironomidae pupae.	-	3749	3459	1507	2171	2603	4	570	599	391	1506
TRICHOPTERA.											
Rhyacophila dorsalis.	-	-	-	-	-	-	-	-	-	-	-
[illegible]	-	-	-	-	-	-	-	-	-	-	-
[illegible] reticulata.	-	-	-	-	-	-	-	-	-	-	-
[illegible] sp.	-	-	4	-	-	-	-	-	-	-	1
[illegible] sp.	-	-	-	-	-	-	-	-	-	-	-
Limnephilus sp.	-	-	-	-	-	-	-	-	-	-	-
TOTAL.	137	139333	57265	45751	89495	167940	2092	72935	48919	37466	68376

Table 58.

NUMBERS OF ANIMALS PER SQUARE METRE COLLECTED AT EACH SITE IN AUGUST 1973.
(MEANS OF NUMBERS FROM 3 SAMPLES.)

TAXON.	SITE 1.	SITE 2.	SITE 3.	SITE 4.	SITE 5.	SITE 6.	SITE 7.	SITE 8.	SITE 9.	SITE 10.	MEAN.
NEMATODA.	-	57	-	-	-	-	-	-	-	-	6
OLIGOCHAETA.											
Aeolosomatidae											
Aeolosoma hedjardi(?).	-	-	-	-	179	-	-	-	-	-	18
Naididae.											
Chaetogaster langi.	-	718	359	-	179	-	-	179	-	-	144
C. diastrophus.	-	359	-	6279	8791	6997	-	-	-	-	2243
Nais elinguis.	-	11840	6100	1256	10943	8073	-	17043	7894	15600	7846
N. variabilis.	-	1794	4664	4126	2512	3229	-	1256	179	359	1812
N. simplex.	-	-	-	-	-	-	-	-	-	-	-
N. barbata.	-	4306	3050	2691	1256	43056	-	1435	179	1973	5795
N. communis.	-	2691	1615	-	179	179	-	-	-	-	466
N. bretscheri.	-	179	-	-	-	-	-	-	-	-	18
N. pseudobtusa.	-	-	-	-	-	-	-	-	-	-	-
Stylaria lacustris.	-	1794	538	4664	24757	14531	-	24039	359	179	7036
Pristina rosea.	-	-	-	4	-	718	-	-	-	-	72
P. aequiseta.	-	-	359	-	-	-	-	-	-	-	36
P. foreli.	-	179	-	-	-	-	-	-	-	-	18
Tubificidae.											
Tubifex tubifex.	452	7355	3588	6100	24219	1973	269	20093	5741	8611	7840
Limnodrilus hoffmeisteri.	-	11123	9329	1794	2870	7355	12020	15249	12917	7355	8001
L. claparedianus.	-	-	-	-	-	-	628	1973	538	179	332
L. profundicola.	-	-	-	-	-	-	359	179	179	-	72
Monopylephorus rubroniveus.	-	-	-	-	-	-	-	179	1794	897	287
Monopylephorus irroratus.	-	-	-	-	-	-	-	-	-	-	-
Lumbriculidae.											
Lumbriculus variegatus.	-	-	-	-	-	-	-	-	-	-	-
Stylodrilus heringianus.	-	-	-	-	-	-	-	-	-	-	-
Enchytraeidae.	72	1794	-	179	-	3767	179	8970	16146	4664	3577
Unidentified Oligochaeta.	-	538	1615	538	1794	718	807	897	1794	538	924
HIRUDINEA.											
Erpobdella octoculata.	-	22	54	11	-	11	-	22	7	4	13
Glossiphonia complanata.	-	-	-	4	-	-	-	-	-	-	1
Helobdella stagnalis.	-	-	-	-	-	29	-	-	-	-	3
Trocheta bykowski.	-	-	-	-	-	-	-	-	-	-	-
COLLEMBOLA.	4	4	169	4	-	-	-	-	-	-	18
CRUSTACEA.											
Cladocera.	-	-	-	-	4	7	11	7	11	4	4
Copepoda.	-	22	11	4	-	-	4	-	4	7	5
Asellus aquaticus.	4	115	246	83	36	240	-	474	2404	6458	1006
Gammarus pulex.	-	-	-	7	-	-	-	-	-	-	1
EPHEMEROPTERA.											
Baetis rhodani.	-	169	268	610	316	219	-	4	-	4	159
B. scambus.	-	4	7	151	126	61	-	-	-	-	35
Ecdyonurus semicolorata.	-	-	-	-	-	-	-	-	-	-	-
Ephemerella ignita.	-	36	-	-	-	-	-	-	-	-	4
Rhyacophila dorsalis.	-	-	-	-	-	-	-	-	-	-	-
Polycentropus sp.	-	-	-	-	-	-	-	-	-	-	-
PLECOPTERA.											
Amphinemura sulcicollis.	-	-	-	-	-	-	-	-	-	-	-
Amphinemura sp.	-	-	-	-	-	-	-	-	-	-	-
Leuctra sp.	-	-	-	-	-	-	-	-	-	-	-
TRICHOPTERA.											
Rhyacophila dorsalis.	-	-	-	-	-	-	-	-	-	-	-
Polycentropus kingi.	-	-	-	-	-	-	-	-	-	-	-
Plectrocnemia conticulata.	4	-	-	-	-	-	-	-	-	-	1
Hydropsyche sp.	-	-	-	-	-	-	-	-	-	-	-
Rhyacophila sp.	-	-	-	-	-	-	-	-	-	-	-
Limnephilus sp.	-	-	-	-	-	-	-	-	-	-	-
COLEOPTERA.											
Dytiscinae.	4	-	-	-	-	-	-	-	-	-	1
Haliplidae.	-	-	-	-	-	-	-	-	-	-	-
Noterinae.	-	-	-	-	-	-	-	-	-	-	-
HYDRACARINA.	11	-	-	-	-	-	-	-	-	-	1
HEMIPTERA.			4								1
Velia caprai.	-	-	-	-	-	-	-	-	-	-	-
MOLLUSCA.											
Ancylus fluviatilis.	-	22	75	2558	25	5716	-	14	4	4	642
Limnaea peregra.	-	57	50	66	4	144	-	11	-	-	33
Physa fontinalis.	-	-	-	140	108	402	-	79	-	7	74
Bithynia tentaculata.	-	7	7	7	7	18	-	-	-	-	5
Pisidium sp.	-	4	-	-	7	7	-	-	-	-	2
Sphaerium sp.	-	-	-	-	-	-	-	-	-	-	-
DIPTERA.											
Tipulinae larvae.	-	-	-	-	-	-	-	-	-	-	-
Psycholidae larvae.	-	-	-	-	-	-	-	-	-	-	-
Dolichopodidae larvae.	-	-	-	-	-	-	-	-	-	-	-
Stratiomyidae larvae.	-	-	-	-	-	-	-	-	-	-	-
Simulium sp. larvae.	-	-	-	-	-	-	-	-	-	-	-
Tabanus sp. larvae.	-	-	-	-	-	-	-	-	-	-	-
Ceratopogon sp. larvae.	-	-	-	-	-	-	-	-	-	-	-
Dicranota sp. larvae.	-	4	-	-	-	-	-	-	-	-	1
Antocha sp. larvae.	-	-	-	-	-	-	-	-	-	-	-
Pilaria sp. larvae.	-	-	-	-	-	-	-	-	-	-	-
Unidentified Diptera larvae.	72	4	-	-	-	-	-	7	-	-	8
Tipulidae pupae.	4	-	-	-	-	-	-	-	-	-	1
Chironomidae.											
Orthocladiinae larvae.	22	2548	2870	11212	16971	11840	5767	16415	20631	16664	14759
Chironominae larvae.	-	-	-	-	72	-	2416	1256	1076	718	1254
Tanypodinae larvae.	14	179	179	179	144	179	-	90	179	-	114
Diamesinae larvae.	-	-	-	-	72	-	-	-	-	179	25
Corynoneurinae larvae.	-	-	-	-	-	-	-	-	-	-	-
Unidentified Chironomidae larvae.	-	-	173	-	-	-	-	-	-	-	18
Chironomidae pupae.	11	1795	2181	710	1597	599	133	380	563	369	825
TOTAL.	674	68499	63353	43379	97168	110068	27555	113851	72599	64761	65807

Table 59

NUMBERS OF ANIMALS PER SQUARE METRE COLLECTED AT EACH SITE IN OCTOBER 1973.
(MEANS OF NUMBERS FROM 3 SAMPLES.)

TAXON.	SITE 1.	SITE 2.	SITE 3.	SITE 4.	SITE 5.	SITE 6.	SITE 7.	SITE 8.	SITE 9.	SITE 10.	MEAN.
NEMATODA.	-	22	36	-	36	7	-	7	25	no data	15
OLIGOCHAETA.											
Aeolosomatidae.											
Aeolosoma hellardi.(?)	-	-	-	-	-	-	-	-	-		-
Naididae.											
Nais elinguis.	-	6458	1148	718	20072	6817	-	5203	48796		9935
N. variabilis.	4	179	1399	2153	359	7535	-	-	-		1292
N. alpina.	-	-	-	-	-	-	-	-	-		-
N. barbata.	-	179	1866	10405	2332	65122	-	-	179		8898
N. communis.	-	-	72	718	359	179	-	-	-		148
N. bretscheri.	-	-	-	-	-	-	-	-	-		-
N. pseudobtusa.	-	-	-	179	-	-	-	-	-		20
Craestonaster langi.	-	-	359	-	-	-	-	179	-		60
C. diaphanus.	-	-	-	179	-	179	-	-	-		40
Stylaria lacustris.	-	-	72	538	-	1973	-	-	-		287
Pristina menoni.	-	-	-	-	-	-	-	-	-		-
P. aequiseta.	-	-	-	-	-	-	-	-	-		-
P. foreli.	-	-	-	-	-	-	-	-	-		-
Tubificidae.											
Tubifex tubifex.	75	7535	1579	3588	26372	4664	718	18837	8432		7978
Limnodrilus hoffmeisteri.	4	3588	15536	8432	2870	8791	33368	20093	13634		106316
L. claparedianus.	-	-	-	-	-	179	1794	1076	1435		448
L. profundicola.	-	-	-	-	-	-	1794	-	179		1973
Monopylephorus rubroviveus.	-	-	-	-	-	-	179	-	-		20
Monopylephorus irroratus.	-	-	-	-	-	-	179	-	-		20
Lumbriculidae.											
Lumbriculus variegatus.	-	-	179	-	-	-	-	-	-		20
Stylodrilus heringianus.	-	-	-	-	-	-	-	-	-		-
Enchytraeidae.	14	3229	287	-	179	1615	718	6279	17402		3303
Unidentified Oligochaeta.	-	179	1148	1435	-	1435	-	718	179		566
HIRUDINEA.											
Erpobdella octoculata.	-	4	39	14	14	4	-	-	7		9
Glossiphonia octoculata.	-	-	-	4	4	-	-	4	11		3
Helobdella stagnalis.	-	-	-	-	-	11	-	-	-		1
Trocheta bykowski.	-	-	-	-	-	-	-	-	-		-
COLLEMBOLA.	4	4	205	18	18	-	-	-	-		28
CRUSTACEA.											
Cladocera.	-	-	-	-	-	4	-	11	-		2
Copepoda.	4	-	-	-	7	4	-	-	-		2
Asellus aquaticus.	11	36	222	1550	79	5368	-	492	23996		3528
Gammarus pulex.	-	-	-	-	-	-	-	-	-		-
EPHEMEROPTERA.											
Baetis rhodani.	-	118	283	402	653	75	4	4	11		172
B. scambus.	-	-	-	-	-	-	-	-	-		-
Rhithrogena semicolorata.	-	-	-	-	-	-	-	-	-		-
Ephemerella ignita.	-	-	-	-	-	-	-	-	-		-
Ecdyonurus dispar.	-	-	-	-	-	-	-	-	-		-
Ecdyonurus sp.	-	-	-	-	-	-	-	-	-		-
PLECOPTERA.											
Amphinemura sulcicollis.	-	-	-	-	-	-	-	-	-		-
Amphinemura sp.	-	-	-	-	-	-	-	-	-		-
Isoptera sp.	-	-	-	-	-	-	-	-	-		-
TRICHOPTERA.											
Rhyacophila dorsalis.	-	-	-	-	-	-	-	-	-		-
Polycentropus kingi.	-	-	-	-	-	-	-	-	-		-
Plectrocnemia conspersa.	-	-	-	-	-	-	-	-	-		-
Hydropsyche sp.	-	-	-	-	-	-	-	-	-		-
Rhyacophila sp.	-	-	-	-	-	-	-	-	-		-
Limnephilus sp.	-	-	-	-	-	-	-	-	-		-
COLEOPTERA.											
Dytiscinae.	-	-	-	-	-	-	-	-	-		-
Haliplidae.	-	-	-	-	-	-	-	-	-		-
Noterinae.	4	-	-	-	-	-	-	-	-		1
HYDRACARINA.	-	-	7	-	-	-	-	-	-		1
HEMIPTERA.						4					1
Velia caprai.	-	-	-	-	-	-	-	-	-		-
MOLLUSCA.											
Ancylus fluviatilis.	-	7	233	3230	341	7341	4	11	22		1250
Limnea peregra.	-	18	18	154	25	405	4	32	4		73
Physa fontinalis.	-	-	4	642	240	743	-	154	-		198
Bithynia tentaculata.	-	4	-	57	-	172	-	-	-		26
Pisidium sp.	-	4	-	39	11	39	-	-	47		16
Sphaerium sp.	-	-	-	-	-	-	-	-	-		-
DIPTERA.											
Tipulinae larvae.	-	-	-	-	-	-	-	-	-		-
Psychodidae larvae.	-	-	-	-	-	-	-	-	-		-
Dolichopodidae larvae.	-	-	-	-	-	-	-	-	-		-
Stratiomyidae larvae.	-	-	-	-	-	-	-	-	-		-
Simulium sp. larvae.	-	-	-	-	-	-	-	-	-		-
Perlodes sp. larvae.	-	-	-	-	-	-	-	-	-		-
Eukiefferiella sp. larvae.	-	-	-	-	-	-	-	-	-		-
Tanytarsus sp. larvae.	-	-	-	4	-	4	-	-	-		1
Orthocladius sp. larvae.	-	-	-	-	-	-	-	-	-		-
Orthocladius sp. larvae.	-	-	-	-	-	-	-	-	-		-
Diamesa sp. larvae.	-	-	-	-	-	-	-	-	-		-
Unidentified Diptera larvae.	-	-	-	-	-	-	-	-	-		-
Tipulidae pupae.	-	-	-	-	-	-	-	-	-		-
Chironomidae.	29	501	4801	6577	2034	7445	358	3368	10764		3966
Orthocladiinae larvae.	-	14	4	330	205	136	1223	2630	1435		644
Chironominae larvae.	-	22	11	779	502	585	7	240	226		264
Tanypodinae larvae.	7	72	100	90	-	-	4	-	-		30
Diamesinae larvae.	-	-	-	-	-	-	-	-	-		-
Corynoneurinae larvae.	-	-	-	-	-	-	-	-	-		-
Unidentified Chironomidae larvae.	-	22	176	639	147	248	32	79	273		179
Chironomidae pupae.											

Table 60.

NUMBERS OF ANIMALS PER SQUARE METRE COLLECTED AT EACH SITE IN FEBRUARY 1975.

(MEANS OF NUMBERS FROM 3 SAMPLES.)

TAXON.	SITE 1.	SITE 2.	SITE 3.	SITE 4.	SITE 5.	SITE 6.	SITE 7.	SITE 8.	SITE 9.	SITE 10.	MEAN.
NEMATODA.	-	14	-	11	14	4	-	-	-	14	6
OLIGOCHAETA.											
Aeolosomatidae.											
Aeolosoma leidigi(?).	-	-	-	-	-	-	-	-	-	-	-
Naididae.											
Chaetogaster langi.	-	179	179	-	-	179	-	-	-	359	90
C. diaphanus.	-	-	-	-	179	-	-	-	-	-	18
Nais elinguis.	-	15249	24757	12199	48796	90237	1015	1435	6997	33189	23397
N. variabilis.	-	-	-	-	-	-	-	-	-	179	18
N. alpina.	-	-	-	-	-	-	-	-	-	-	-
N. barbata.	-	-	-	-	179	359	-	-	-	718	126
N. communis.	-	-	-	-	-	-	-	-	-	179	18
N. bretscheri.	-	-	-	-	-	-	-	-	-	-	-
N. pseudobtusa.	-	-	-	-	-	-	-	-	-	-	-
Stylaria lacustris.	-	-	-	-	-	-	-	-	-	-	-
Vejdovskyella comata.	-	-	-	-	-	-	-	-	-	-	-
P. neglecta.	-	-	-	-	-	-	-	-	-	-	-
P. foreli.	-	-	-	-	-	-	-	-	-	-	-
Tubificidae.											
Tubifex tubifex.	7	3409	287	2332	2870	11123	657	15069	3050	14890	5369
Limnodrilus hoffmeisteri.	-	1435	-	718	1076	6997	10585	16684	13634	15966	6710
L. udekemianus.	-	-	-	-	-	359	1733	1973	359	897	532
L. profundicola.	-	-	-	-	-	-	1195	-	538	897	263
Peregrinephorus rubromaculatus.	-	-	-	-	-	-	-	359	-	-	36
Peloscolex irroratus.	-	-	-	-	-	-	-	179	-	-	18
Lumbriidae.								7			1
Lumbriculidae.						718				1615	233
Lumbriculus variegatus.	-	-	-	-	-	-	-	-	-	-	-
Stylodrilus heringianus.	-	-	-	-	-	-	-	-	-	-	-
Enchytraeidae.	25	359	72	179	1435	4306	2332	16505	2691	32112	6002
Unidentified Oligochaeta.	-	-	-	-	-	538	420	3229	718	1435	634
HIRUDINEA											
Erpobdella octoculata.	-	-	-	7	-	4	-	-	151	4	17
Glossiphonia complanata.	-	4	-	4	-	4	-	-	-	-	1
Helobdella stagnalis.	-	-	-	-	-	7	-	-	4	-	1
Trocheta bykowski.	-	4	-	-	-	-	-	-	-	-	-
COLLEMBOLA.	-	7	11	-	-	4	4	11	4	-	4
CRUSTACEA.											
Cladocera.	-	-	4	-	-	4	-	-	-	-	1
Copepoda.	-	-	25	29	7	4	-	-	-	-	7
Asellus aquaticus.	-	-	-	83	36	183	4	11	1747	1179	324
Gammarus pulex.	-	-	-	-	-	4	-	-	-	-	1
EPHEMEROPTERA.											
Baetis rhodani.	-	466	50	118	43	75	-	-	-	-	75
B. scambus.	-	-	-	-	-	-	-	-	-	-	-
Rhithrogena semicolorata.	-	-	-	-	-	4	-	-	-	-	1
Ephemerella ignita.	-	-	-	-	-	-	-	-	-	-	-
Ecdyonurus dispar.	-	-	-	-	-	-	-	-	-	-	-
Ecdyonurus sp.	-	-	-	-	-	-	-	-	-	-	-
PLECOPTERA.											
Amphinemura sulcicollis.	-	4	-	-	-	-	-	-	-	-	1
Amphinemura sp.	-	-	-	-	-	-	-	-	-	-	-
Leuctra sp.	-	-	-	-	-	-	-	-	-	-	-
TRICHOPTERA.											
Rhyacophila dorsalis.	-	-	-	-	-	-	-	-	-	-	-
Polycentropus kingi.	-	-	-	-	-	-	-	-	-	-	-
Plectrocnemia conspersa.	-	-	-	-	-	-	-	-	-	-	-
Hydropsyche sp.	-	-	-	-	-	-	-	-	-	-	-
Rhyacophila sp.	-	-	-	-	-	-	-	-	-	-	-
Limnephilus sp.	-	4	-	-	-	-	-	-	-	-	1
COLEOPTERA.											
Dytiscinae.	-	-	-	-	-	-	-	-	-	-	-
Haliplidae.	-	-	-	-	-	-	-	-	-	-	-
Noterinae.	-	-	-	-	-	-	-	-	-	-	-
HYDRACARINA.	-	7	-	-	-	-	-	-	-	-	1
HEMIPTERA.											
Velia caprai.	-	-	-	-	-	-	-	-	-	-	-
MOLLUSCA.											
Ancylus fluviatilis.	-	-	-	-	-	7	-	-	18	-	3
Limnaea peregra.	-	-	-	-	-	-	-	-	-	-	-
Pisa fontinalis.	-	-	-	-	-	-	-	-	-	-	-
Sphaerium corneum.	-	-	-	-	-	11	-	-	-	-	1
Pisidium sp.	-	-	-	-	-	4	-	-	-	-	1
Sphaerium sp.	-	-	-	-	-	-	-	-	-	-	-
DIPTERA.											
Tipulinae larvae.	-	-	-	4	-	-	-	-	-	-	1
Psychodidae larvae.	-	-	-	-	-	-	-	-	-	-	-
Dolichopodidae larvae.	-	4	-	-	-	-	-	-	-	-	1
Stratiomyidae larvae.	-	-	-	4	-	-	-	-	-	-	1
Simulium sp. larvae.	-	-	-	-	-	-	-	-	-	-	-
Tipula sp. larvae.	-	7	-	-	-	-	-	4	4	4	2
Heleodromia sp. larvae.	-	-	-	-	-	-	-	-	-	-	-
Atherix ibis sp. larvae.	-	-	-	-	-	-	-	-	-	-	-
Brillia sp. larvae.	-	-	-	-	-	-	-	-	-	-	-
Eukiefferia sp. larvae.	-	-	-	-	-	-	-	-	-	-	-
Unidentified Diptera larvae.	-	-	-	-	-	-	-	-	-	-	-
Tipulinae pupae.	-	-	-	-	-	-	-	-	-	-	-
Chironomidae.											
Orthocladiinae larvae.	7	118	39	330	309	642	172	230	574	797	322
Chironominae larvae.	-	-	-	-	-	-	4	-	11	29	4
Tanypodinae larvae.	-	-	-	14	-	7	-	11	4	4	4
Diamesinae larvae.	-	-	-	-	4	4	-	-	-	7	2
Corynoneurinae larvae.	-	-	-	-	-	-	-	-	-	-	-
Unidentified Chironomidae larvae.	-	-	-	-	-	-	-	-	-	-	-
Chironomidae pupae.	-	11	-	18	7	18	7	4	25	4	9
TOTAL.	39	21281	25424	16050	54355	115806	18128	55711	30529	104478	44247

APPENDIX IV.

Tables 61 to 90 show the abundance of selected taxa each month at each site.

Table 61.

Numbers of invertebrates per square metre collected at each site during the survey period and in February 1974.

Site. Month	1	2	3	4	5	6	7	8	9	10	Mean
October 1972	302	20630	-	15612	20214	47547	1727	-	34025	30754	41557
December 1972	160	612	-	6235	3702	6201	1603	-	10283	13376	6143
February 1973	76	13120	4231	10031	50435	56217	5035	-	101783	17661	20723
April 1973	152	17656	11920	45107	70707	35553	3240	-	104830	55162	50434
June 1973	137	139033	57265	40751	69473	107546	2092	72033	43617	57466	60376
August 1973	674	68405	63353	43779	57168	114068	27005	116251	72599	64741	65807
October 1973	156	21095	29784	42931	57650	121084	40420	59373	127057	-	55544
MEAN	211	40507	35031	31208	55479	77517	11674	82703	83820	39831	
February 1974	39	21281	25424	14050	24755	115806	10128	55711	30529	104478	44247

Table 62.

Numbers of *Tubifex tubifex* per square metre collected at each site during the survey period and in February 1975.

Site. / Month.	1	2	3	4	5	6	7	8	9	10	MEAN
October '72	18	7894	-	431	2763	3373	7	-	3229	8701	3302
December	14	240	-	664	2619	2232	466	-	3319	4366	1733
February '73	7	1005	190	718	7319	3223	718	-	12026	1166	2936
April	22	1933	1076	560	538	1256	240	-	10405	16076	3623
June	39	2691	1973	3047	24578	10405	167	25603	610	21169	9143
August	452	7355	3506	6100	24219	1973	263	20093	5741	5011	7846
October	75	7535	1579	3568	26374	4664	718	13337	5432	-	7972
MEAN	90	4094	1681	2227	12636	3876	372	21503	6251	10088	
February '75	7	3409	207	2332	2570	11123	657	15003	3056	14090	5569

Table 63.

Numbers of *Limnodrilus hoffmeisteri* per square metre collected at each site during the survey period and in February 1975.

Site. / Month.	1	2	3	4	5	6	7	8	9	10	MEAN
October '72	4	2103	-	700	769	4772	319	-	7176	3292	3169
December	7	11	-	730	122	238	266	-	3257	2655	962
February '73	0	1095	563	1650	3583	2332	[illegible]	-	10230	592	2314
April	0	1005	597	359	179	7714	1300	-	15623	3042	4131
June	0	10764	4233	2275	5023	5549	875	2970	6997	5352	5584
August	0	11103	2329	1794	2570	7255	12044	15040	12517	7352	[illegible]
October	4	3563	15536	4432	2670	3751	33503	44003	13032	-	11313
MEAN	2	5143	2202	2210	2200	5720	7413	14771	10224	5500	
February '75	0	1435	-	713	1076	6097	10505	10024	13024	15566	6710

Table 64.

Numbers of *Limnodrilus udekemianus* per square metre collected at each site during the survey period and in February 1975.

Site.	1	2	3	4	5	6	7	8	9	10	Mean
Month.											
October '72	0	0	-	0	0	0	136	-	538	1345	256
December	0	0	-	0	0	36	72	-	50	359	74
February '73	0	0	20	0	0	0	250	-	718	0	141
April	0	0	0	0	0	0	133	-	179	179	58
June	0	0	0	0	0	0	540	2332	359	-	541
August	0	0	0	0	0	0	527	1973	538	179	351
October	0	0	0	0	0	179	1794	1076	1435	-	418
Mean	0	0	5	0	0	31	506	1794	551	344	
February '75	0	0	0	0	0	359	1793	1973	359	897	532

Table 65.

Numbers of *Limnodrilus profundicola* per square metre collected at each site during the survey period and in February 1975.

Site.	1	2	3	4	5	6	7	8	9	10	Mean
Month.											
October '72	0	0	-	0	0	0	4	-	179	0	23
December	0	0	-	0	0	0	0	-	0	0	0
February '73	0	0	0	0	0	0	111	-	0	0	14
April	0	0	0	0	0	0	0	-	179	0	20
June	0	0	0	0	0	0	36	0	0	0	4
August	0	0	0	0	0	0	359	179	179	0	72
October	0	0	0	0	0	0	1794	0	179	-	249
Mean	0	0	0	0	0	0	329	60	102	0	
February '75	0	0	0	0	0	0	1435	0	538	897	249

Table 66.

Numbers of Monopylephorus irroratus per square metre collected at each site during the survey period and in February 1975.

Site.	1	2	3	4	5	6	7	8	9	10	MEAN
Month.											
October '72	0	0	-	0	0	0	0	-	0	0	0
December	0	0	-	0	0	0	0	-	0	0	0
February '73	0	0	0	0	0	0	0	-	0	0	0
April	0	0	0	0	0	0	0	-	0	0	0
June	0	0	0	0	0	0	0	897	179	0	108
August	0	0	0	0	0	0	0	0	0	0	0
October	0	0	0	0	0	0	179	0	0	-	20
MEAN	0	0	0	0	0	0	26	299	26	0	
February '75	0	0	0	0	0	0	0	179	0	0	18

Table 67.

Numbers of Monopylephorus rubroniveus per square metre collected at each site during the survey period and in February 1975.

Site.	1	2	3	4	5	6	7	8	9	10	MEAN
Month.											
October '72	0	0	-	0	0	0	0	-	0	0	0
December	0	0	-	0	0	0	0	-	0	0	0
February '73	0	0	0	0	0	0	0	-	0	0	0
April	0	0	0	0	0	0	0	-	0	0	0
June	0	0	0	0	0	358	36	897	718	897	291
August	0	0	0	0	0	0	0	179	1794	897	287
October	0	0	0	0	0	0	179	0	0	-	20
MEAN	0	0	0	0	0	51	31	359	359	299	
February '75	0	0	0	0	0	0	0	359	0	0	36

Table 68.

Numbers of Enchytraeidae per square metre collected at each site during the survey period and in February 1975.

Site.	1	2	3	4	5	6	7	8	9	10	MEAN
Month.											
October '72	0	0	-	502	36	1274	50	-	12558	5113	2442
December	115	90	-	219	154	108	154	-	10495	2949	1786
February '73	61	215	262	502	789	179	1041	-	59740	14388	8575
April	0	1005	179	266	359	20990	1091	-	148962	27699	22283
June	57	5023	538	179	0	4344	258	9867	10764	3409	7351
August	72	1794	0	179	0	3767	179	8970	16146	4664	3577
October	14	3229	287	0	179	1615	718	6279	17402	-	3303
MEAN	46	1622	253	264	217	10192	499	8372	39438	9704	
February '75	25	359	72	179	1435	4306	2332	16505	2691	32112	6002

Table 69.

Numbers of Nais elinguis per square metre collected at each site during the survey period and in February 1975.

Site.	1	2	3	4	5	6	7	8	9	10	MEAN
Month.											
October '72	0	144	-	2727	8721	2260	0	-	359	359	1830
December	0	165	-	232	108	2088	0	-	0	72	33[illegible]
February '73	0	10405	2594	5434	20304	46454	4	-	0	359	9514
April	0	12450	37584	38757	60351	538	25	-	0	287	17555
June	0	179	628	718	4[illegible]	1435	0	0	0	179	73[illegible]
August	0	11840	6100	1256	10043	8073	0	17043	7894	15608	7870
October	0	6456	1148	718	20272	6817	0	5203	43796	-	9935
MEAN	0	5949	9611	7122	19693	[illegible]66	4	7415	8150	2011	
February '75	0	15243	24757	12[illegible]	48736	96237	1015	1435	6[illegible]7	33189	23387

Table 70.

Numbers of Nais barbata per square metre collected at each site during the survey period and in February 1[illegible].

Site.	1	2	3	4	5	6	7	8	9	10	MEAN
Month.											
October '72	0	1902	-	1543	646	5799	0	-	0	0	123[illegible]
December	0	0	-	0	0	18	0	-	0	0	2
February '73	0	0	0	0	0	538	0	-	0	0	70
April	0	0	0	0	0	0	0	-	0	0	0
June	0	54896	13634	4458	5203	33727	0	0	0	0	11392
August	0	4306	3050	2691	1256	43[illegible]0	0	1435	1[illegible]0	1073	7[illegible]5
October	0	1[illegible]9	1906	12435	2332	65122	0	0	179	-	80[illegible]
MEAN	0	9755	3710	3014	1345	21175	0	478	51	[illegible]28	
February '75	0	0	0	0	179	359	0	0	0	718	126

Table 71.

Numbers of Nais variabilis per square metre collected at each site during the survey period and in February 1975.

Site.	1	2	3	4	5	6	7	8	9	10	MEAN
Month.											
October '72	0	179	-	1543	718	2099	0	-	179	0	590
December	0	0	-	122	25	290	0	-	0	0	53
February '73	0	0	0	0	0	0	0	-	0	0	0
April	0	179	0	0	0	0	0	-	0	0	20
June	0	0	179	2691	718	1794	0	0	0	0	538
August	0	1794	4664	4126	2512	3229	0	1256	179	359	1812
October	4	179	1339	2153	359	7535	0	0	0	-	1292
MEAN	1	307	1248	1519	619	2134	0	419	51	60	
February '75	0	0	0	0	0	0	0	0	0	179	18

Table 72.

Numbers of Nais communis per square metre collected at each site during the survey period and in February 1975.

Site.	1	2	3	4	5	6	7	8	9	10	MEAN
Month.											
October '72	0	0	-	72	144	54	0	-	0	0	34
December	0	0	-	47	4	7	0	-	0	0	7
February '73	0	0	72	72	0	0	0	-	0	0	16
April	0	0	179	0	0	0	0	-	0	0	20
June	0	0	179	1256	2870	8073	0	179	0	0	1256
August	0	2691	1615	0	179	179	0	0	0	0	466
October	0	0	72	718	359	179	0	0	0	-	148
MEAN	0	334	423	309	508	1213	0	60	0	0	
February '75	0	0	0	0	0	0	0	0	0	179	18

Table 73.

Numbers of Stylaria lacustris per square metre collected at each site during the survey period and in February 1975.

Site.	1	2	3	4	5	6	7	8	9	10	Mean
Month.											
October '72	0	144	-	897	610	5131	43	-	0	0	853
December	0	0	-	0	0	4	0	-	0	0	1
February '73	0	0	0	0	0	0	0	-	0	0	0
April	0	0	0	0	0	0	0	-	0	0	0
June	0	0	0	0	179	14890	0	179	0	0	1525
August	0	1794	538	4664	24757	14531	0	24039	359	179	7086
October	0	0	72	0	0	1973	0	0	0	-	227
MEAN	0	277	122	794	3649	5219	6	9073	51	30	
February '75	0	0	0	0	0	0	0	0	0	0	0

Table 74.

Numbers of Chaetogaster largi per square metre collected at each site during the survey period and in February 1975.

Site.	1	2	3	4	5	6	7	8	9	10	MEAN
Month.											
October '72	0	359	-	179	0	0	0	-	0	0	67
December	0	4	-	4	0	0	0	-	0	0	1
February '73	0	0	0	72	0	179	0	-	0	0	28
April	0	0	0	0	0	0	0	-	0	0	0
June	0	179	0	0	0	179	0	0	0	0	36
August	0	718	359	0	179	0	0	179	0	0	144
October	0	0	359	0	0	0	0	179	0	-	60
MEAN	0	180	144	36	26	51	0	119	0	0	
February '75	0	179	179	0	179	179	0	0	0	359	

Table 75.

Numbers of Chaetogaster diaphanus per square metre collected at each site during the survey period and in February 1975.

SITE.	1	2	3	4	5	6	7	8	9	10	MEAN
Month.											
October '72	0	718	-	1543	1005	269	0	-	0	0	442
December	0	4	-	0	0	0	0	-	0	0	1
February '73	0	0	0	72	0	0	0	-	0	0	8
April	0	0	0	0	0	0	0	-	0	0	0
June	0	15249	1525	538	0	0	0	0	0	0	1731
August	0	359	0	6279	8791	6997	0	0	0	0	2243
October	0	0	0	179	0	179	0	0	0	-	40
Mean	0	2333	305	1230	1399	1064	0	0	0	0	
February '75	0	0	0	0	0	0	0	0	0	0	0

Table 76.

Numbers of Ancylus fluviatilis per square metre collected at each site during the survey period and in February 1975.

Site.	1	2	3	4	5	6	7	8	9	10	MEAN
Month.											
October '72	0	14	-	262	33	5454	0	-	4	201	752
December	0	0	-	940	11	129	0	-	4	0	136
February '73	0	0	4	1145	18	97	0	-	0	0	140
April	0	0	0	144	0	25	0	-	0	0	19
June	0	12	18	671	11	1195	0	4	0	0	191
August	0	22	75	2659	35	5716	0	14	4	4	842
October	0	7	235	3290	341	7341	4	11	22	-	1250
MEAN	0	8	66	1287	70	2951	1	10	5	34	
February '75	0	0	0	0	0	7	0	0	18	0	3

Table 77.

Numbers of Physa persons per square metre collected at each site during the survey period and in February 1975.

Site.	1	2	3	4	5	6	7	8	9	10	MEAN
Month.											
October '72	0	136	-	36	57	183	0	-	7	4	53
December	0	0	-	47	17	14	0	-	0	0	10
February '73	0	7	11	52	43	14	0	-	0	0	14
April	0	4	4	4	0	0	0	-	0	0	1
June	0	11	22	111	7	47	0	50	0	0	25
August	0	57	50	68	4	144	0	11	0	0	33
October	0	18	18	154	25	405	4	32	4	-	73
MEAN	0	33	21	68	22	115	1	31	2	1	
February '75	0	0	0	0	0	0	0	0	0	0	0

Table 78.

Numbers of Physa fontinalis per square metre collected at each site during the survey period and in February 1975.

Site.	1	2	3	4	5	6	7	8	9	10	
Month.											
October '72	0	0	-	312	427	5310	0	-	32	57	767
December	0	0	-	100	7	11	0	-	0	7	16
February '73	0	0	0	22	11	0	0	-	0	0	4
April	0	0	0	0	0	0	0	-	0	0	0
June	0	0	0	0	0	29	0	0	0	0	3
August	0	0	0	140	105	402	0	79	0	7	74
October	0	0	4	422	240	743	0	154	0	-	198
MEAN	0	0	1	174	113	928	0	78	5	12	
February '75	0	0	0	0	0	11	0	0	0	0	1

Table 79.

Numbers of Hydrobia jenkinsi per square metre collected at each site during the survey period and in February 1975.

Site.	1	2	3	4	5	6	7	8	9	10	MEAN
Month.											
October '72	0	0	-	0	0	7	0	-	0	0	1
December	0	0	-	0	0	0	0	-	0	0	0
February '73	0	4	0	7	7	7	0	-	0	0	3
April	0	0	0	0	25	0	0	-	0	0	3
June	0	4	0	4	4	0	0	0	0	0	1
August	0	7	7	7	7	18	0	0	0	0	5
October	0	4	0	57	0	172	0	0	0	-	26
MEAN	0	3	5	11	6	29	0	0	0	0	
February '75	0	0	0	0	0	0	0	0	0	0	0

Table 80.

Numbers of Pisidium sp. per square metre collected at each site during the survey period and in February 1975.

Site.	1	2	3	4	5	6	7	8	9	10	MEAN
Month.											
October '72	0	4	-	11	7	29	0	-	0	0	6
December	0	0	-	14	0	4	0	-	0	0	2
February '73	0	4	0	14	4	7	0	-	0	0	3
April	0	0	4	4	0	0	0	-	0	0	1
June	0	0	11	14	4	0	0	0	0	0	3
August	0	4	0	0	7	7	0	0	0	0	3
October	0	4	0	39	11	39	0	0	47	-	16
MEAN	0	2	3	14	5	12	0	0	7	0	
February '75	0	0	0	0	0	4	0	0	0	0	1

Table 81.

Numbers of Erpobdella octoculata per square metre collected at each site during the survey period and in February 1975.

Site.	1	2	3	4	5	6	7	8	9	10	MEAN
Month.											
October '72	0	4	-	29	4	4	0	-	0	4	6
December	0	0	-	18	7	4	0	-	4	0	4
February '73	0	0	7	11	0	7	0	-	0	0	3
April	0	0	11	0	0	4	0	-	0	0	2
June	0	7	14	7	7	4	0	0	0	0	4
August	0	22	54	11	0	11	0	22	7	4	13
October	0	4	39	14	14	4	0	0	7	-	9
MEAN	0	5	25	13	5	5	0	7	3	1	
February '75	0	0	0	7	0	4	0	0	151	4	17

Table 82.

Numbers of Glossiphonia complanata per square metre collected at each site during the survey period and in February 1975.

Site.	1	2	3	4	5	6	7	8	9	10	MEAN
Month.											
October '72	0	0	-	0	0	0	0	-	0	0	0
December	0	0	-	0	0	0	0	-	0	0	0
February '73	0	0	0	0	0	0	0	-	0	0	0
April	0	0	0	4	0	0	0	-	0	0	1
June	0	0	0	0	0	0	0	0	0	0	0
August	0	0	0	4	0	0	0	0	0	0	1
October	0	0	0	4	4	0	0	4	11	-	3
MEAN	0	0	0	2	1	0	0	1	2	0	
February '75	0	4	0	4	0	4	0	0	0	0	1

Table 83.

Numbers of Chironomidae pupae per square metre collected at each site during the survey period and in February 1975.

Site.	1	2	3	4	5	6	7	8	9	10	MEAN
Month.											
October '72	4	215	-	445	309	215	4	-	273	161	203
December	0	0	-	14	0	4	0	-	11	0	4
February '73	0	7	36	237	57	30	0	-	147	18	69
April	0	18	29	222	126	72	22	-	459	104	117
June	0	3749	3459	1507	2171	2608	4	570	599	331	1506
August	11	1765	2191	710	1597	599	133	380	503	309	825
October	0	22	176	639	147	248	32	75	273	-	179
MEAN	2	825	1176	539	630	541	28	342	332	164	
February '75	0	11	0	18	7	19	7	4	25	4	9

Table 84.

Numbers of Orthocladiinae larvae per square metre collected at each site during the survey period and in February 1975.

Site.	1	2	3	4	5	6	7	8	9	10	MEAN
Month.											
October '7?	60	1733	-	2476	2196	1683	65	-	2870	1213	1536
December	25	39	-	1254	57	104	11	-	100	994	327
February '73	0	470	183	6602	13570	2228	222	-	5813	470	3289
April	22	319	1227	4474	764	2913	470	-	3168	721	1564
June	22	45029	29960	21169	40185	36956	100	19506	21548	23681	23826
August	22	21348	28704	11212	16471	11820	3767	10415	20631	16694	14759
October	29	301	4801	6577	2034	7445	398	3348	10764	-	3966
MEAN:	24	9801	12975	7695	10925	9024	719	13190	9242	7284	
February '75	7	118	39	330	309	642	172	230	574	797	322

Table 85.

Numbers of Chironominae larvae per square metre collected at each site during the survey period and in February 1975.

Site.	1	2	3	4	5	6	7	8	9	10	MEAN
Month.											
October '72	0	11	-	35	25	72	366	-	287	251	121
December	0	0	-	18	0	22	4	-	4	72	15
February '73	0	0	0	36	0	0	0	-	0	4	4
April	0	0	0	0	0	0	0	-	0	4	1
June	0	0	0	0	0	0	0	251	0	179	43
August	0	0	0	0	72	0	9418	1256	1076	718	1254
October	0	14	4	330	205	136	1223	2630	1435	-	664
MEAN:	0	4	1	60	43	33	1573	1379	400	205	
February '75	0	0	0	0	0	0	4	0	11	29	4

Table 86.

Numbers of Dixeinae larvae per square metre collected at each site during the survey period and in February 1975.

Site.	1	2	3	4	5	6	7	8	9	10	MEAN
Month.											
October '72	0	215	-	0	0	36	0	-	36	0	36
December	0	4	-	22	4	72	0	-	0	0	13
February '73	0	7	11	0	0	29	4	-	0	0	6
April	0	4	0	0	0	0	0	-	0	0	1
June	0	0	0	179	0	0	0	0	0	0	18
August	0	0	0	0	72	0	0	0	0	179	25
October	7	72	100	90	0	0	4	0	0	-	30
MEAN	1	43	22	42	11	20	1	0	5	30	
February '75	0	0	0	0	4	4	0	0	0	7	2

Table 87.

Numbers of Tanypodinae larvae per square metre collected at each site during the survey period and in February 1975.

Site.	1	2	3	4	5	6	7	8	9	10	MEAN
Month.											
October '72	0	83	-	161	154	215	4	-	0	0	77
December	0	0	-	39	0	29	0	-	0	36	13
February '73	0	7	0	36	7	0	7	-	0	4	7
April	4	7	0	97	0	0	0	-	65	11	20
June	0	0	0	0	0	0	7	0	0	0	1
August	14	179	179	179	144	179	0	90	179	0	114
October	0	22	11	779	502	585	7	240	226	-	264
MEAN	3	43	38	184	115	144	4	110	67	9	
February '75	0	0	0	14	0	7	0	11	4	4	4

Table 88.

Numbers of Beetle rhobant per square metre collected at each site during the survey period and in February 1975.

Site.	1	2	3	4	5	6	7	8	9	10	MEAN
Month.											
October '72	0	14	-	219	93	4	0	-	4	7	43
December	0	18	-	136	7	22	0	-	11	0	24
February '73	0	75	7	215	97	25	4	-	72	4	56
April	11	7	18	7	36	11	0	-	22	4	13
June	0	11	4	68	61	0	0	0	0	0	14
August	0	169	261	610	319	219	0	4	0	4	159
October	0	119	203	402	653	75	4	4	11	-	172
MEAN	2	59	115	237	180	51	1	3	16	3	
February '75	0	466	0	0	0	75	0	0	0	0	54

Table 89.

Numbers of Beetle rhobant per square metre collected at each site during the survey period and in Febr.ary 1975.

Site.	1	2	3	4	5	6	7	8	9	10	MEAN
Month.											
October '72	0	0	-	0	0	0	0	-	0	0	0
December	0	0	-	0	0	0	0	-	0	0	0
February '73	0	0	0	0	0	0	0	-	0	0	0
April	0	0	0	0	0	0	0	-	0	0	0
June	0	0	0	11	7	0	0	0	0	0	2
August	0	4	7	151	126	61	0	0	0	0	35
October	0	0	0	0	0	0	0	0	0	-	0
MEAN	0	1	1	23	19	9	0	0	0	0	
February '75	0	0	0	0	0	0	0	0	0	0	0

Table 90.

Numbers of Asellus aquaticus per square metre collected at each site during the survey period and in February 1975.

Site.	1	2	3	4	5	6	7	8	9	10	MEAN
Month.											
October '72	0	176	-	344	276	9096	11	-	6207	4994	2638
December	4	9	-	1439	22	459	11	-	205	1866	501
February '73	0	11	14	1094	79	251	0	-	13017	391	1650
April	0	4	4	0	0	0	0	-	617	97	80
June	0	57	29	4	4	32	0	273	1238	797	243
August	4	115	248	83	36	240	0	474	2404	6458	1006
October	11	36	222	1550	79	5368	0	492	23996	-	3528
MEAN	3	57	103	643	71	2207	3	413	6812	2434	
February '75	0	0	0	83	36	183	4	11	1747	1179	324

APPENDIX V.

Faunal analysis of basket and Surber samples collected on 1/8/75.

Table 107.

Faunal analysis of basket and Surber samples collected on 1/8/75 from site 2 (Townsend Fold)

a. Basket samples

Taxon	Sample number 1	2	3	4	5
Oligochaeta	1775	-	-	-	900
Chironomidae larvae and pupae	1700	-	-	-	401
Pisidium sp.	1	-	-	-	1
Nematoda	3	-	-	-	3
Erpobdella octoculata	3	-	-	-	0
Pericoma sp.	1	-	-	-	1
Polycentropidae	1	-	-	-	0
Baetis rhodani	17	-	-	-	1
Asellus aquaticus	3	-	-	-	1
Diptera larvae	0	-	-	-	1
TOTAL	3504	-	-	-	1309

Current speed 0.27 $m.sec^{-1}$

b. Surber samples.

Taxon	Sample number 1	2	3	4	5
Oligochaeta	975	800	760	230	170
Chironomidae larvae and pupae	309	428	257	377	883
Baetis rhodani	1	11	13	23	25
Asellus aquaticus	2	3	1	2	1
Nematoda	16	20	2	4	8
Collembola	1	0	0	0	0
Pisidium sp.	1	0	0	0	0
Diptera indet. larva	1	0	0	0	0
Ancylus fluviatilis	0	1	0	0	1
Limnaea peregra	0	0	3	0	1
Gammarus pulex	0	0	0	0	1
TOTAL	1306	1263	1036	636	1090

Current speed 0.36 $m.sec^{-1}$

Table 108.

Faunal analysis of basket and Surber samples collected on 1/8/75 from site 6 (Warth Bridge).

a. Basket samples.

Taxon	Sample number 1	2	3	4	5
Oligochaeta	101	-	-	-	-
Chironomidae (larvae and pupae)	138	-	-	-	-
Asellus aquaticus	36	-	-	-	-
Ancylus fluviatilis	2	-	-	-	-
Limnaea peregra	1	-	-	-	-
Pericoma sp.	1	-	-	-	-
Glossiphonia complanata	1	-	-	-	-
Polycelis sp.	2	-	-	-	-
TOTAL	282	-	-	-	-

*n.b. Basket displaced from original position.

b. Surber samples.

Taxon	Sample number 1	2	3	4	5
Oligochaeta	2450	3350	3350	1175	3200
Chironomidae (larvae and pupae)	1565	1433	1876	1478	1562
Asellus aquaticus	975	2050	275	150	1625
Erpobdella octoculata	4	0	1	0	0
Dendrocoelum lacteum	1	0	0	0	0
Baetis scambus	1	0	0	0	0
Helibdella stagnalis	2	4	1	0	4
Hydrobia jenkinsi	1	2	0	1	1
Ancylus fluviatilis	143	82	18	14	63

continued/

/continued

Limnaea peregra	7	1	1	0	5
Baetis rhodani	12	20	8	1	6
Nematoda	0	1	1	2	0
Sphaerium sp.	0	1	0	0	0
Pisidium sp.	0	0	0	1	2
Polycelis sp.	0	0	0	0	1
TOTAL	5161	6944	5531	2822	6469

Current speed 0.29 $m.sec^{-1}$

Table 109.

Faunal analysis of basket and Surber samples collected on 1/8/75 from site 7 (Radcliffe).

a. Basket samples.

Taxon	Sample number 1	2	3	4	5
Oligochaeta	1750	750	2050	875	825
Chironomidae (larvae and pupae)	2655	2234	4305	2792	3297
Asellus aquaticus	63	3	30	16	8
Copepoda	1	0	0	0	0
Nematoda	0	0	0	1	0
Total	4469	2987	6385	3684	4130

Current speed 0.59 $m.sec^{-1}$

b. Surber samples.

Taxon	Sample number 1	2	3	4	5
Oligochaeta	207	52	35	640	640
Chironomidae (larvae and pupae)	1230	1060	678	923	1048
Asellus aquaticus	8	4	1	1	2
Collembola	0	0	0	1	1
TOTAL	1445	1116	714	1565	1691

Table 110

Faunal analysis of basket and Surber samples collected on 1/8/75 from site 9 (Agecroft).

a. Basket samples.

Taxon.	Sample number 1	2	3	4	5
Oligochaeta	5650	-	-	-	-
Chironomidae (larvae and pupae)	923	-	-	-	-
Asellus aquaticus	1100	-	-	-	-
Nematoda	1	-	-	-	-
Helobdella stagnalis	1	-	-	-	-
Erpobdella octoculata	4	-	-	-	-
TOTAL	7679	-	-	-	-

b. Surber samples.

Taxon	Sample number 1	2	3	4	5
Oligochaeta	3350	8200	12000	7600	4950
Chironomidae (larvae and pupae)	2535	1844	3419	2370	1587
Asellus aquaticus	1450	3550	1700	138	650
Erpobdella octoculata	2	25	10	7	16
Physa fontinalis	1	0	0	0	0
Helobdella stagnalis	0	2	0	0	0
Cladocera	0	2	0	0	0
Nematoda	0	1	0	0	0
Ancylus fluviatilis	0	0	1	1	0
Baetis rhodani	0	0	1	0	1
Simulium sp.	0	0	1	0	0
TOTAL	7338	13624	17132	10116	7204