"The Effects of a Paper Mill discharge on the Benthic Macro-Invertebrates of the River Llynfi."

by

Neil Grabham

MPhil Thesis submitted as partial fulfilment of the requirements of the CNAA

at

The Polytechnic of Wales and UWIST

January 1989

Author: Neil Grabham.

Title: "The Effects of a Paper Mill Discharge on the Benthic Macro-invertebrates of the River Llynfi."

The effects of a kraft paper mill effluent discharge on the benthic invertebrates in the Rivers Llynfi and Ogmore were determined by regular collection of biological samples from six sites. One site was upstream of the effluent discharge, two downstream on the Llynfi, one on the Ogmore before the confluence with the Llynfi and two furher sites downstream of the confluence. The effluent tended to reduce the dissolved oxygen concentration and BOD_5 concentrations in the water immediately below the discharge and this adversely affected the benthic invertebrate community at these sites.

The Chironomidae and more particularly the Oligochaeta were very important constituents of the benthic macro-invertebrate community at the sites immediately downstream of the effluent. The most common oligochaetes were the Enchytraeidae, Tubifex tubifex and Nais elinguis. The most common species of Chironomidae recorded during the survey were Brillia longifurca, Tvetania calvescens, Orthocladius(O) rubicundus, and Eukiefferiella clarripennis. Cricotopus bicinctus was very numerous in the summer collections.

With improving water quality downstream of the discharge species belonging to the Plecoptera, Ephemeroptera and Trichoptera tended to become more important members of the benthic community.

The biological results were analysed with standard statistical tests, various biotic indices and computer programs.The results of the survey undertaken indicated that the river was polluted immediately below the effluent outfall but to a lesser extent than was expected. However, a typical pollution fauna was found to be associated with Sites 2 and 3 and as such this is attributable to the organic effluent discharge from the paper mill at Llangynwydd.

Contents.

1. Introduction.

Generally in Britain water is not in short supply, but comprehensive management is necessary if an adequate supply is to be maintained. The quality of water flowing past a given point in a river reflects the conditions prevailing in the catchment above that point. Wisdom(1956) has defined river pollution as 'the addition of something to water which changes its natural qualities so that the riparian owner does not get the natural water of the system transmitted to him.' It is implied in Wisdom's definition that pollution is not simply the presence in the environment of an alien substance or unnatural disturbance; there must be an unwanted effect. The National Research Council report of 1978 indicates that substances introduced into the environment become pollutants only when 'their distribution, concentration or physical behaviour are such as to have undesirable consequences.'

The problem of waste disposal has been with mankind since time immemorial. Ancient civilisations in Assyria and Babylonia possessed sophisticated sanitary systems. Both the Indus(2550 BC) and the Aegean(3000 - 1000 BC) civilisations had elaborate drainage systems costructed of brick or stone.

During the middle ages when habits of cleanliness were at a low ebb, the streets in the cities of Europe were foul, and this was mainly responsible for the frequent occurrence of plagues and epidemics in these times.

The coming of the industrial revolution in the early nineteenth century heralded an acute form of river pollution which to a certain extent exists today. During this period there was a marked increase in the size of the population, and this together with the advent of the modern water-carriage system of sewage disposal in the thriving towns and cities of Britain, resulted in the filth being transferred from the streets into the rivers.

It was not until 1865 that the government attempted to do something about this problem as cotton mills, tanneries, paper mills, gas works and chemical works were all freely discharging into the nearest stream. Two Royal Commissions were appointed at this time and their recommendations resulted in the passing of the Public Health Act in 1875. This act recognised for the first time that care of public health was a national responsibility and a system of local health administrations were set up.

The act of 1875 was superceded by a more comprehensive document in the following year. This Rivers Pollution Prevention Act led to the formation of river authorities in the more highly industrialised areas. This 1876 act stayed in force until 1951 when a new awareness of the problems of river pollution emerged. This was further revised with the 1973 and 1974 acts which set up the ten regional water authorities now in existence and swept away much of the secrecy surrounding requirements of effluent discharges into rivers.

Biological studies of river pollution have been in use for most of this century in Britain, with the work of Jones (1949) on Cardiganshire streams being one of the earliest. The pollution in this investigation was derived from zinc mining dumps. Zinc mining in this area ceased to operate in 1918, but these dumps provided a long term pollution problem as heavy metals were leached from these sites. Only 14 invertebrate species were recorded from the river prior to 1922. The number of species improved with time such that investigations in 1932 showed that 103 species were now present.

Another extensive survey carried out on the effect of heavy metals on a stream community was that of Pentelow and Butcher(1938) who investigated copper pollution on the River Churnet. Above the copper works the fauna was abundant, but below, no fauna was present and even stream algae were limited. It took 11 miles for the previous upstream fauna of leeches, Asellus, tubificids and chironomids to become re-established.

Butcher (1955) was one of the first British workers to study the effects of an organic effluent on a river system. He worked on the Trent and showed that the recovery of the river took 35 miles below the effluent outfall.

Butcher's and later workers eg. Hawkes(1962) revealed that the main effects of organic pollution on stream communities is to alter both the species composition and the total number of individuals. There are often a number of distinct communities present related to the level of pollution. If pollution is severe enough the clean water fauna may be replaced by a tubificid community, as one proceeds downstream new communities appear, dominated in turn by, Chironomus riparius, Asellus and leeches, Baetis rhodani and Hydropsyche, and then finally the clean water community. In case of toxic pollution, although some species of organisms are characteristically more tolerant of generally toxic conditions than other species there are cases of species showing a marked specificity to a particular poison. The reduction in interspecific competition resulting from the selective elimination of the less tolerant species may in some cases permit the population of tolerant species to increase. The toxic effects of most poisons is affected by the environment eg. temperature, oxygen concentration, pH and dissolved salts.

However, even though pollution studies on stream communities have documented the deleterious effects that some discharges have, it has not until recently been widely accepted that the biological monitoring can become an integral part in the assessment of pollution on a river.

Traditionally, chemical analysis has been used for assessing pollutional levels.

Prior to 1950 only limited work had been carried out by water undertakers who sampled discharges from the sewage treatment works. This work was followed by systematic monitoring of individual catchments and then, with the commencement of pollution control by river boards in the early 1960's the results from the previous surveys became integrated and as a consequence inter-laboratory comparability testing and quality control was introduced.

A tiered approach is that most commonly used in chemical analysis of rivers, consisting of simple, cheap tests performed routinely, followed by increasingly complicated and expensive tests performed less often. In the former category are such determinands as pH, dissolved oxygen, temperature etc. while increasing sophistication of equipment can test for BOD_5 and total organic nitrogen to liquid chromatography and mass spectrometry.

However, in a truely comprehensive investigation biological considerations are needed in addition to chemical monitoring. Biological methods have, unlike chemical methods, been developed independently by numerous workers such that until recently there has not been a concerted attempt to standardise systems. The earliest such system in Europe was the 'Saprobien system' developed by Kolkowitz and Marsson(1909). This system is based upon the classification of lists of organisms into different 'saprobia.' These are groups of organisms associated with different stages of organically enriched waters. Four zones were distinguished by these two workers, Polysaprobic, Alpha-Mesosaprobic, Beta-Mesosaprobic and Oligosaprobic on the basis of decreasing organic enrichment. This system and the subsequent indices of pollution are for the most part based on the fact certain species become less abundant and eventually disappear as organic pollution increases, whereas other species become more abundant. In most cases sensitive species are rated highly and tolerant species rated with a low value. Indices that are commonly used in this country are those proposed by Woodiwiss(1964) and Chandler(1970).

The assessment of water quality using biological methods can prove invaluable, and in some cases essential. To determine to what extent a specific discharge is affecting a river, a biological survey of upstream and downstream fauna will often provide direct evidence of any affects.

Initially, pollution studies concentrated on the whole community aspect, but there has also been detailed work carried out on the two most typical polluted water fauna taxa, the Oligochaeta and Chironomidae. It has been recognised that these two groups are generally associated with the most polluted stretches of rivers, although both Hynes(1960) and Hawkes(1962) have commented that heavy pollution affects whole taxonomic groups of macro-invertebrates rather than individual species.

In heavily polluted waters the Oligochaeta and particularly the Tubificidae may be present in large numbers with densities of $1x10^6/m^2$ being recorded by Brinkhurst (1962). With increasing pollution, successive species of tubificids are eliminated with only Limnodrilus hoffmeisteri and/orTubifex tubifex being typically present in very severe conditions. Their success in these regions is related to the fact that the haemoglobin in their blood exhibits a negative Bohr effect and that glycogen is able to be metabolised anaerobically.

Hynes(1960) has noted that the Chironomidae generally cannot withstand oxygen levels as low as the tubificids, but similarly, in red forms the haemoglobin present is able to act as a carrier when oxygen tensions are low.

The aim of the investigation undertaken was to ascertain the effect of a paper mill discharge on the stream benthic invertebrate community present in the Rivers Llynfi and Ogmore. This paper mill, sited downstream of Maesteg(fig 2), opened in 1950 and as such is a relative newcomer in terms of the industrial development of the Llynfi valley.

The valley to the North of Bridgend was, until the early nineteenth century, composed of a few scattered houses on the valley sides. However, with the advent of the industrial revolution, development accelerated such that by 1826 the town of Maesteg was first formed. Shortly after, in 1828, a tramroad was opened to carry material from the ironworks which was then under construction. This development went on through the 1830's with the abundant coal deposits being exploited by local industrialists.

By 1873 the Iron Era was coming to a close, but by this time the coal trade came into it's own and flourished through the latter part of the nineteenth century and the early part of the twentieth century. By the 1940's, coal was also in decline. However, a combination of government policy, abundant supplies of soft water and good communications persuaded British Tissues Ltd to open a paper mill at Llangynwydd, 1.5Km from Maesteg in 1950.

The main products produced at the mill include soft and hard toilet rolls, hand towels and wipes, including the brand names Dixcel and Cresco, have enabled British Tissues by 1984 to have a 23% share of the British market for such items. Paper is also supplied to other manufacturers for conversion to other products. Annual turnover by 1985 was around £100 million.

The paper making process used by British Tissues is broadly similar to that used by other manufacturers and mainly utilises the kraft pulping process. In this process the so-called 'cooking chemicals' consist of a solution of sodium sulphite in caustic soda. Following digestion of the lignin present in wood fibres the cooking chemicals are washed out of the pulp. Several such processes are used to minimise the carry-over chemicals to the bleaching plant. The residual chemicals from this pulping process are black and contain caustic soda and sulphide plus dissolved lignins.

At this stage wet strength resins are added for certain grades of towelling. Following bleaching of this so-called 'stock', the diluted solution is pumped onto a wire section where the tissue is formed. The paper making machines used attain speeds of around 950m/minute such that the very watery stock entering the machine has a vacuum applied in order that 80% of the water contained may be lost and recycled. The newly formed sheets are then passed onto a felt section and further water is removed. From this stage the sheet is pressed onto a drying cylinder which is steam heated to around 350°C which ensures rapid drying. The final sheets are then creeped in order to give texture.

Around four million gallons of water per day are used at the Llangynwydd plant which is cleaned before being returned to the river. However, it is inevitable that some pollutants will find their way into the receiving waters. The pollution stems from two directions;suspended solids and organic chemicals. The former has a blanketing effect such that elimination of some species will be expected below the point of discharge. Gaufin(1958) has illustrated the effect that suspended solids have on a river system, and Kringstaad and Lindstrom(1984) have isolated chemicals from spent liquors from pulp bleaching. Juul and Shireman(1978) have studied the effects that a kraft pulp bleaching plant has on benthic populations in a channel adjoining a paper mill and have shown that the fauna is adversely affected.

In order to assess the impact that the paper mill had on the stream benthic invertebrates, it was necessary to work out a sampling programme. Six sites were chosen for investigation, one upstream of the paper mill discharge and five downstream of the discharge.It was therefore hoped to show that with progressive improvements in water quality downstream there would be parallel changes in the benthic community. The river was sampled on six occasions over thirteen months so that the influence of seasons could also be investigated. The six sites were chosen for accessibility and closeness to points where the Welsh Water Authority scientists made routine sample visits. In order to obtain sufficient quantitative and qualitative information about the stream fauna it was decided to take ten samples per site per visit using a saw cylinder sampler which enclosed an area of $0.05m^2$. The samples were preserved on site and identified at a later date.

In order to assess the impact of the paper mill on the stream community, it was necessary to use simple statistical tests and biotic indices. For a more comprehensive guide to the impact of the mill, computer packages were used to analyse the data. Two were selected, ARTHUR 81 and SPSS-X which are pattern recognition and clustering programs.

All routine chemical data was obtained from the Welsh Water Authority's South-Western laboratories. To supplement this a 24 hour survey was carried out on July 21-22 1986 so enabling the diurnal pattern of dissolved oxygen at each site to be ascertained.

2. Review of literature.

2.1 Freshwater ecology.

Although freshwater organisms have attracted the attention of biologists for many years, it is only in the last seventy years or so with the development of identification keys for most of the common groups, that really detailed scientific studies have been made possible.

Some of this earliest work examined the longitudinal distribution of benthic organisms in rivers, while later work focused on factors which influences the distribution of organisms.

2.1.1 Longitudinal distribution of benthic organisms.

Numerous studies have been carried out on the longitudinal distribution of different benthic organisms in rivers. One of the earliest was the classical study by Thienemann (1912) who found that in upland streams of the Sauerland in West Germany there was a succession of species of Planaria, with Crenobia alpina occupying the uppermost zone. This was followed by Polycelis felina and Dugesia gonocephala. Further studies, eg. Beauchamp and Ullyot(1932) have confirmed a succession of planarians, but which involved different species.

Towards the end of the last century German fishery biologists developed a system of classifying river zones on the basis of the dominant fish species present by which they named the zone eg. Trout zone, Grayling zone, Barbel zone and Bream zone. Similar methods were developed in other parts of the continent.

Carpenter(1928) was probably the first British worker to attempt a similar classification. She worked on Cardiganshire streams and described a typical river as arising by several sources on high ground to give rise to the upper reaches characterised by their swift current, steep gradient and pronounced erosion. The fauna in these regions tends to be rather sparse and dominated by microphages. Downstream, with a lessening of gradient the current becomes less rapid and the stream deepens and widens. With the progressive reduction in current, stones, gravel and sand are successively deposited on the stream bed. Still further downstream on the plain where the current may be appreciably reduced, the river widens and meanders with the bed usually covered with deposited silt.

Associated with these different conditions, different communities become established. Initially Carpenter classified river zones into Highland brooks and Lower courses. Then, the Highland brooks were further divided into Head streams, Trout becks and Minnow reaches, while Upper and Lower reaches made up the Lower courses.

From the relatively sparse fauna of the Head streams, the Trout beck region tends to be quite well populated with the organisms present showing various adaptations to life in rapidly flowing stretches of water eg. dorso-ventral flattening shown by some mayflies, and net-spinning by certain caddis such as Hydropsyche and Philopotamus.

As deposition occurs in the Minnow reaches and into the Lowland courses, so the fauna changes such that burrowing types become quite common, including worms belonging to the families Tubificidae and Naididae, mayflies such as Ephemera and various chronomid species.

Thus, by examining the causes of longitudinal distribution, some light may be shed on the ecological identity of the river. Factors of ecological significance which exhibit a progessive change along the length of rivers include chemo-physical factors such as substratum, current velocity, temperature, dissolved oxygen, dissolved nutrients, hardness and biotic factors such as predator/prey relationships and competition. These factors can also produce marked seasonal changes in the abundance of certain species. Therefore, in any biological survey of a polluted stream it is necessary to be aware of these factors when assessing the effect the pollutant exerts on the river system.

The effect of these factors on freshwater organisms will now be considered in more detail.

2.1.2 Substratum.

This is the place where most benthic invertebrates find food, it can also provide protection and shelter. There are a wide range of types of substratum which are strongly influenced by current speed. No sedimentation occcurs in strongly flowing stretches and as such the substratum will tend to be solid rock and large clean stones, while in slower flowing regions there may be a build up of sediments.

Thus, as the type of substratum varies, then we would expect to find different benthic communities inhabiting these regions. Percival and Whitehead(1929) made one of the first detailed studies. They identified seven main types of stony habitat and showed that the distribution of these organisms was strongly influenced by the substrate. For example, they found that Rhithrogena semicolorata was most abundant in stones with Potomageton(11,000/dm^2). Ephemerella ignita was most numerous in loose moss and Cladophora(19800/dm^2 and 3900/dm^2 respectively). Gammarus pulex preferred loose moss and thick moss(2800/dm^2 and 800/dm^2). Conversely, Ancylus fluviatilis was found in the greatest numbers on stones covered by Potomageton(300/dm^2).

In their study of the Black river, Missouri, O'Connell and Campbell(1953) found that the average numbers of animals in riffles was 1003, and 650 in pools. However, there were also marked differences in the distributions of certain groups.

Egglishaw(1964) demonstrated that other factors may alter the detailed distribution pattern of invertebrates. He also sampled a single riffle and measured the volume of vegetation caught, and clearly showed that numbers of many species increased with increasing detritus. This was particularly true for detritivores such as Leuctra, Rhithrogena, Baetis and Chironomidae, but did not hold for carnivores such as Chloroperla.

The presence of vegetation on the substratum was shown by Percival and Whitehead(1929) to greatly affect the fauna as they found greater numbers in moss, algae etc. Other workers such as Greze(1954) and Harrod(1964) have shown that not only does the presence (or absence) of vegetation influence the benthic community, but also the type of vegetation can cause variations. Greze found that even similar species of plants eg. three different species of Potomageton had quite different invertebrate communities. Harrod also noticed differences in the invertebrates present on different species of aquatic macrophytes and suggested it was caused by differing amounts of shelter provided by the plants.

It is therefore clear that the substratum does have a marked effect on the numbers and composition of organisms in the benthic community.

2.1.3 Current speed.

Water movement is one of the main factors determining the composition of the biocoenoses. Current probably exerts its most important effect on the benthic community indirectly through its effect on the nature of the substratum. It nevertheless has a direct effect in its own right such that it is difficult to consider substratum and current separately. Ambuhl(1959) noted that many of the invertebrates of the rapidly flowing upland streams with stony beds live amongst the stones out of the main current, with those which venture onto the surface of the stones still not being subjected to the full current of the stream due to the so-called boundary layer present(This is a layer 2-3mm thick where the current is effectively zero).

There are a number of field and experimental observations that indicate that current by itself can in some cases influence the distribution of certain species.

Many invertebrates have a need for current either for respiratory purposes or else they rely on it for feeding purposes eg. Simulium and net-spinning caddis. Scott(1958) made a study of caddis fly larvae. He found that there was a certain current speed at which they were most abundant and that they became less numerous with increasing distance from a mode. For Rhyacophila dorsali the optimum speed was 80-90cm/s, while for Hydropsyche fulvipes and Stenophylax sp it was 40-50cm/s and 0-10cm/s respectively. Similarly Edington(1965) showed that different species of net-spinning caddis are found in fast flowing and slow flowing areas.

Dorier and Vaillant(1954) and also Dittmar(1955) have carried out laboratory work experiments which show that certain species have abilities to withstand currents at different velocities. Dittmar found that Simulium was very resistant and could withstand a current of over 240cm/s, other species investigated however, were progressively less tolerant eg. Ecdyonurus at 48 - 77cm/s.

Maitland(1966) has suggested that current may also exert a direct effect when in spates, the stones in the river bed are moved causing the organisms on and between them to be washed away. Although in stretches of rapid flow there are sheltered places, microhabitats of almost lentic water, there are on the other hand no rapid microhabitats in the slower flowing areas.

Generally, it may be concluded that current velocity acting both directly and indirectly in determining the nature of the substratum is a major factor affecting the composition of benthic communities. Since there is a change in current velocity as we progress down the length of a river, then this factor is probably a major one influencing the longitudinal distribution of some organisms.

2.1.4 Temperature.

This is an important ecological factor, although the manner in which it exerts its effects are somewhat complex. Every species has an optimum temperature but this is not always easy to define eg. Kinne(1953) showed that the quickest growth in Gammarus duebeni takes place at a temperature which is unfavourable for reproduction. Unfavourable low temperatures act by depressing activity such as movement or reproduction. This is avoided in many species by having a geographical range, and according to Macan (1962), species will be prevented from colonising colder water because;

a) The temperature is lethally low at some time during the year.

b) The threshold for development or activity is not exceeded.

c) Many species do not occupy the whole range which their temperture tolerances would permit as they encounter species towards their limits which are better adapted to that particular temperature.

Conversely, animals are prevented from colonising warm water because;

1) It is lethal.
2) Competition as for cold water.
3) The temperature is never low enough to stimulate reproduction.

In the case of insects that have different temperature tolerances, Edington(1966) has considered that the pattern of temperature fluctuations as measured by the rate at which bodies warm up is probably as important as actual temperatures. Dodds and Hisaw(1925) concluded that temperature was the main climatic cause for the altitudinal zonation of insects in the lakes and rivers of the Colorado Rockies.

Thus, it can be concluded that although temperature is an important factor determining distributions of insects along a river, it is more important in some cases than others and the manner in which it operates differs from taxa to taxa.

There is considerable variation in the chemical composition of natural waters and it is possible to recognise soft and hard waters, acid and alkaline waters etc. These differences in chemical composition are known to influence the distribution of animals and plants in freshwaters and many investigations have been carried out to study the influence of water hardness.

2.1.5 Dissolved oxygen.

Because different organisms have different oxygen requirements, the dissolved oxygen content is obviously an important factor in determining their distribution. In fast flowing stretches, the oxygen concentration will usuall be close to saturation. In slow flowing rivers, it may be found that photosynthesis will produce supersaturation by day, while respiration will produce a concentration well below saturation at night.

An experiment by Ambuhl(1959) on mayflies showed that variations in current speed can influence the lethal oxygen concentration. The concentration lethal to Rhithrogena dropped from nearly 6ppm at a current speed of 0.3cm/s to 3ppm at 6cm/s. However, Ecdyonurus was little affected by changes in current speed over the range used. This difference was caused by the fact that although quite similar structurally, the gills in Rhithrogena are adapted to serve as a sucker and thus cannot be used to waft a current of water over the body.

Hubault(1927) studied the invertebrate fauna of Eastern France and found that organisms had a greater respiratory rate than corresponding organisms of lowland rivers. He concluded by saying that dissolved oxygen concentration was the most important factor in the distribution of many freshwater animals, current playing a secondary role.

This work can be contrasted with that of Grenier(1949) on Simulidae. He found that this group was confined to well aerated waters even though experimentally they were found to survive in low dissolved oxygen conditions.

Temperature has a considerable influence on the dissolved oxygen content of freshwaters and also appreciably affects the oxygen levels that different organisms can withstand. Furthermore, low oxygen tolerance is affected by current velocity with many organisms, especially those not having mechanisms for creating their own respiratory currents, being able to tolerate lower oxygen concentrations at higher current velocities.

2.1.6 Dissolved nutrients and hardness.

Increasing nutrient concentrations along the length of a river and the resultant increase in productivity have a direct effect on benthic invertebrate communities. Water hardness is due to the presence in a river of dissolved salts, particularly, calcium and magnesium. Boycott(1936) stated that an increase in water hardness encourages Crustacea and Mollusca.

The distribution of many groups of freshwater organisms has been investigated in relation to water hardness. Mann(1955) collected leeches in fifty-eight bodies of water and found that Hemiclepsis marginata was not recorded in waters if the calcium concentration was less than 7ppm. In regions where the calcium concentration was between 7 - 24ppm, he found that Helobdella stagnalis was the most abundant leech. Erpobdella octoculata was the only species found in waters with less than 7ppm calcium. It appeared that generally leeches prefer hard waters, but the size of the water body was also important.

It appears that Gammarus pulex abounds in many Lake District streams but does not occur in others. Its distribution has been related to the calcium content, but there is no conclusive evidence that shows its distribution is affected by water hardness.

Reynoldson(1961) investigated the distribution of Asellus and found it generally occurs in most places where there is more than 12.5ppm calcium, but only in a few places where there is less than 5ppm calcium. In places with intermediate concentration it may or may not occur.

Macan(1963) concluded that in some animal groups calcium appears to favour all the species and the number drops as calcium concentration decreases. In other groups there are species typical of soft waters and these often have close relatives typical of hard water.

2.1.7 Acidity.

Acid waters are almost by definition poor in calcium, and it is difficult from field studies to distinguish the effects of high concentrations of hydrogen ions from softer water conditions. Acid waters have been shown to be poor in species which are known to occur elsewhere in soft but neutral waters. Thus pH does appear to exert an influence.

Gammarus was found to be absent in the spring regions of a small Flemish stream although it was abundant downstream. This variation was attributed by Albrecht(1953) to low pH.

Moon(1939) compared the streams of the New Forest with those of the Hampshire Avon, and showed how chemical factors such as pH and hardness control the distribution of fauna over large areas. New Forest streams were generally acid(pH 6-6.5) while the Avon tributaries were more alkaline(pH 7.5-8). In the former case the average number of animals per square foot was 68 with 10 different species, while in the latter it was 380 animals/ft^2 with 15 different species.

2.1.8 Biotic factors.

These factors can operate through such aspects as food requirements, competition, predation etc. Most stream organisms are not very specialised in their diets, but some species such as Eucricotopus brevipalpis only feeds on Potomageton natans.

Macan(1965) has observed the effect of predation in a small stream in the Lake District. This stream became enriched with small amounts of sewage which resulted in large increases in the population of the flatworm Polycelis felina together with many species of insects. However, the numbers of Polycelis continued to rise, but several species of mayfly were adversely affected. This was particularly true of Ecdyonurus torrentis which disappeared altogether, while the numbers of Rhithrogena semicolorata and Baetis rhodani declined. Polycelis is a carnivore and traps prey with mucus strings laid down on the tops of stones, thus the decline in numbers of mayflies could be attributed to predation.

2.1.9 Seasonal cycles.

In aquatic habitats in temperate regions, there are definite annual sequences in the invertebrate benthos. Many species appear and disappear from collections made at intervals throughout the year.

Hynes(1970) states that many species have one generation per year and tend to be found in the water at certain limited periods. These so-called univoltine animals include Ephemerella sp, Baetis sp, Rhithrogena sp and also many plecopterans.

Animals with more than one generation per year tend to be more common in still waters, but there are a number of examples found in lotic habitats. These include chironomids such as Eukieferriella clarripennis which has three generations per year, Chironomus riparius which has five, and various species belonging to the Simulidae such as Simulium ornatum and Simulium vittatum which have three and four generations per year respectively.

Conversely, it appears that no plecopterans or trichopterans have more than one generation per year. There are however, many species belonging to a variety of taxa that have life cycles exceeding one year. These include certain leeches eg Erpobdella octoculata and Glossiphonia complanata.

Hynes(1970) states that the autumn tends to be a period of hatching of eggs of species which will grow during the winter, and also a period of growth of permanent species eg. Gammarus. In winter the growth of many species slows down and also recruitment from eggs slows down. While early spring tends to be a period of loss of biomass as early flying species emerge. This drop in biomass is accelerated as spring progresses. At the end of spring the biomass starts to decrease as summer species emerge. Throughout the summer the biomass increases. If insects dominate the fauna, then the late summer is a period of low biomass. However, numbers may be quite high if there is recruitment from over-wintering species.

2.2 River pollution.

It is convenient to classify the various types of pollutants into a number of categories, but it must be realised that these divisions are arbitrary and that many effluents transgress these boundaries. The main categories are as follows;

1) Organic.
2) Toxic.
3) Suspended matter.
4) Heat.

Organic pollution.

There have been many biological studies of rivers polluted by a wide variety of organic effluents. Hynes(1960) states that heavy organic pollution affects whole taxonomic groups of macro-invertebrates rather than individual species. Specific differences only become important in cases of mild pollution.

There are a number of effects that organic pollution has on water quality, Hawkes (1962) suggested that the main changes and effects are as follows;

a) Great increases in nutrients in the form of organic material.

b) The increase in nutrients stimulates a subsequent rise in saprobic micro-organisms such as bacteria and fungi.

c) The rise in micro-organisms results in an increased oxygen demand. This is particularly pronounced in summer.

d) Decomposition of organic material yields ammonia, phosphates etc. which may prove toxic.

e) Slime growth increases as a result of the presence of organic material.

f) The nature of the substratum may change as slime fungi collect silt, thus allowing burrowing animals to colonise the area.

The chemical and physical changes can affect the fauna in the following ways;

1) The numbers of clean water species are reduced with less tolerant species being eliminated eg Gammarus, Ecdyonurus and Perla.

2) In the less severe cases of pollution moderately tolerant species may increase in numbers eg Baetis rhodani, Hydropsyche and Erpobdella. If the degree of pollution increases these species are then reduced.

3) An invasion of the riffle habitats by non-riffle species eg. Chironomus riparius and Tubifex tubifex. Their absence normally may be due to the fact that the environment was not previously suitable. These organisms tend to be members of silted communities in primarily lentic or slower flowing regions. However, as pollution becomes more severe these are also successively eliminated.

Hynes(1960) outlines the effects on the benthic invertebrates as, if the river is badly polluted the clean water fauna are replaced by a very abundant pollution fauna consisting largely of Tubifex tubifex, Chironomus riparius and Asellus aquaticus. These three types of animals succeed one another in importance proceeding downstream from an effluent outfall. Also present in the Asellus zone are leeches eg. Erpobdella testacea and Helobdella stagnalis, molluscs eg. Limnaea pereger and Sphaerium corneum may be present.

Toxic pollution.

Poisons in solution occur in waste waters from many industries. Some substances such as copper and lead tend to be rapidly precipitated in hard water, while other pollutants such as ammonia are destroyed fairly rapidly by oxidation.

Poisons tend to decrease in concentration quite rapidly downstream from an effluent outfall. Hynes(1970) suggests that the main biological effects of poisons occur because;

1) They are toxic to some organisms.

2) They may be accumulated in small doses and ultimately through a build up in the tissues they prove fatal.

Poisons tend to affect both the numbers of species, and the total numbers of individuals. Toxic discharges tend to affect benthic populations differentially and as the toxin becomes diluted downstream a successive reappearance of more tolerant organisms occurs. The toxic effect of most poisons tends to be affected by temperature, dissolved oxygen, pH and dissolved salts.

Suspended solids.

The effects of suspended solids according to Hynes(1960) are two-fold;

a) If the particulates are light or very finely divided then they may not settle readily and so cause a river to become opaque to light. This in turn makes plant growth impossible. However, there is no direct evidence of deleterious effects of suspended matter on animals except fish, but of course food chains will be destroyed if plant life is absent, and animal populations will be affected in the this way.

b) Inert solids settle out on the river bed if they are large and heavy or the current is slack. These deposits will then smother algal growth and will destroy plants and mosses, and as a result, will alter the nature of the substrate.

Thermal pollution.

Biological effects from a discharge of a clean but hot effluent will depend on how much this effluent raises the ambient temperature. A small increase will result in a general speeding up of biological processes. A steep rise of 10°C or more will result in marked biological consequences. A temperature of around 40°C would result in the elimination of all organisms, but these would be expected to reappear downstream as the temperature drops.

A further result of thermal pollution occurs because the solution of gases in water is influenced by temperature, warm water holds considerably less oxygen than cold water.

Studies on the affects of organic pollution in Britain really began with the work of Butcher et al.(1955), who showed the disastrous results of organic pollution in streams.

The Trent in 1937 was organically polluted at Stoke. The biology of the river was studied for a length of 35 miles. The oxygen content above Stoke was 107%, but this dropped to zero below Stoke. A figure of 77% saturation was achieved after 35 miles. Ammoniacal nitrogen showed a very different pattern being 0.2 ppm above Stoke, 14 ppm below and 1 ppm after 35 miles.

The fauna above Stoke consisted of Gammarus, molluscs, caddis, mayflies and leeches. However, two miles below the effluent outfall the only animals encountered were tubificid worms. An improvement was seen after eight miles with Chironomus accompanying the tubificid fauna. Asellus appeared after 13 miles and increased in abundance to reach a peak at about 24 miles.Leeches appeared after 17 miles and Gammarus and caddis appeared at 22 miles and 28 miles respectively below the outfall.

The work of Butcher was confirmed by the study of Hawkes(1956) performed on Langley Brook. At 100m below the outfall he observed a tubificid and Chironomus riparius community. At 500m, Asellus and leeches became dominant. Hydropsyche became abundant at 1500m, and Gammarus was most abundant at 2000m.

The distances over which these invertebrate zones extend obviously varies greatly. According to Hynes(1970) if the initial load of polluting matter is small or it has been well mineralised, the upper part of the succession may be absent. Butcher et al.(1937) found that in the River Tees all the zones were present and the normal invertebrate community returned after 600 yards.

Work by Hawkes and Davies(1971) also showed the quantitative effects of organic enrichment on the stream community. In their study of the River Cole they found that the distributions of different chironomids could be linked to the level of pollution. The abundance pattern of leeches and crustaceans were also found to show similar patterns. Six stations were sampled, one above the sewage outfall and five below over a period of one year. The most abundant organisms at Station 1 were Gammarus, Baetis and Hydropsyche. However, at Station 2, Chironomus riparius became abundant. This species also dominated at Station 3, but here it was joined by other red chironomids. By Station 4 Chironomus riparius had usually declined in numbers, with non-red chironomids such as Brillia longifurca, Prodiamesa olivacea and Eukiefferiella clarripennis becoming the dominant species. By Station 5, C.riparius had disappeared with P.olivacea reaching its maximum density. Severe oxygen depletion occured in the summer months such that the polluted zone extended downstream as far as Station 4. This was reflected by changes in the chironomid community such that C.riparius became particularly numerous here during the summer.

Learner et al.(1971) investigated the River Cynon. This river suffers severe pollution stemming from a number of discharges entering the river, including coal washery effluents, sewage discharges, cyanide, phenol and ammonia. Twenty-two stations on the river were sampled, thirteen for fish and invertebrates and nine for fish only. The number of species below an organic effluent outfall at Station 5 were severely affected. There was a further decline in number of invertebrate families downstream of this discharge, but the species composition of the community remained stable downstream to the River Taff.

The principle effects of organic enrichment in the middle and lower Cynon seem to be the increased proportion of Limnodrilus hoffmeisteri to other oligochaetes, the increased representation of tubificids, and a decline in the numbers and diversity of chironomids. It appeared that although cyanides and phenols entered the river between stations 9 - 11, they did not affect the macro-invertebrate community, although toxic discharges rather than organic pollution were largely responsible for the distribution of fish.

Nuttall and Purves(1974) studied the distribution of 82 macro-invertebrate taxa from the River Tamar. This river system is in the South-West of England and has a catchment of 923Km^2 and a mean summer flow of 11.84m^3/s. Organic effluents polluting the river come from a number of small sewage works, farms and milk product wastes.

Ninety-eight samples were taken from fifty-one sampling stations. Pollution in the catchement was mild in 1973 and this accounted for the widespread distribution of Gammarus pulex. Asellus was only found at Stations 5, 8 and 10 immediately downstream of an organic waste discharge. Stoneflies were eliminated from Stations 3, 8, 9 and 27 mainly due to sewage effluent and farm wastes enriching the stream at these points. Mayfly species were widespread and abundant. Rhithrogena and Ephemerella ignita were present at forty stations. C.riparius became the most prolific species when associated with sewage fungus at Station 43 which received an organic effluent from a dairy.

Thus, the benthic community in the Tamar responded to the mild pollutional conditions in the river such that stoneflies and mayflies, although not completely eliminated, made up a smaller proportion of the community in the areas where organic enrichment occurred. These stations favoured chironomids and snails.

A general feature of pollution is the variation in species diversity such that, in non-polluted regions, the number of species is large. Surber(1937) in his study of the Kalamazoo River found twenty-two species at a density of 729/yd^2 above an effluent and three species at 8000/yd^2 below an outfall. Pentelow et al.(1938) found similar results in the River Avon with 1336 animals/yd^2 above and 5778/yd^2 below an outfall

2.3 Pollution by paper mill wastes.

The impact of pulp and paper discharges on receiving waters results from the integrated action of oxygen demand, suspended solids, pH, colour and toxicity. Production of tissues results in a complex mixture of organic compounds. Considerable quantities of chlorine are used in the pulping process such that large amounts of chlorinated organic matter will be discharged. A knowledge of the identities and quantities of organic compounds in wastewaters is a valuable basis for pollution treatment and control.

2.3.1 Composition of wood pulp.

According to Sjostrom(1981), wood is by far the most important material for the production of chemical pulp. Its main component groups are cellulose, hemicelluloses, lignin and extactives.

1) Cellulose is a linear polysaccharide, the molecules of which are bundled together to form microfibrils. These in turn build fibrils and, finally, cellulose fibres. About 40% of most wood is cellulose.

2) Wood hemicelluloses are composed of different carbohydrate units which are branched to varying extents. The content and types of hemicelluloses in softwoods differ considerably from those in hardwoods.

3) Lignin is an aromatic polymer whose relative molecular mass is considered infinite. In wood, lignin is probably chemically linked to hemicelluloses.

4) The term extractives is normally used for those components of wood that can be extracted by organic solvents. The total content of extactives in wood varies between about 1.5-5%.

2.3.2 Principles of pulping.

Rydholm(1965) states that most chemical pulping is carried out according to the kraft(sulphate) process or the sulphite process. In the production of tissues both processes are used, with the kraft process being the dominant type. The purpose of pulping is to remove lignin in order to facilitate fibre seperation and to improve the paper making properties of the fibres.

The kraft process entails treating wood chips at 160-180^{o}C with a sodium hydroxide/sodium sulphate liquor to promote cleavage of the fibres. 90-95% of the lignin present may be removed by being dissolved into this alkaline pulping liquor.

Hemicelluloses and extractives are dissolved during pulping such that 55% of the total weight of wood is dissolved in the pulping liquor. The spent liquor is seperated from the pulp, evaporated and then burned in order to recover energy and inorganic chemicals.

The sulphite process results in the sulphonation of lignin at high temperatures. The subsequent pulping liquor contains sulphur dioxide and an alkaline oxide.

Neither the kraft or the sulphite process removes all lignin, about 5-10% of the original lignin remains in the pulp. Removal of this lignin is achieved by multistage bleaching. This bleaching is normally achieved by successive treatments with chlorine, alkali, chlorine dioxide, alkali and chlorine dioxide. Hypochlorite may be inserted between the first alkali/chlorine stage.

During conventional bleaching of a softwood kraft pulp, 70Kg of material for each tonne of pulp will dissolve from the pulp into the bleaching liquors:50Kg of which originates from the residual lignin, 19Kg from the cellulose fraction and 1Kg from extractives.

2.3.3 Spent liquor composition.

This is an extreme mix of organic chemicals from spent chlorination and alkali extraction liquors. In the bleaching of a softwood kraft pulp, the amount of organically bound chlorine is about 4Kg/tonne for the two liquors. Since the total world production of bleached chemical pulp is in the order of 50 million tonnes/year, then 4Kg/tonne corresponds to a figure of 250000 tonnes/year.

Organically bound chlorine is present in a wide range of organic material in spent liquors. According to Hardell(1977) this can be seen by dividing the organic material into fractions of different relative molecular mass and then determining the organically bound chlorine in each of these fractions.

Lindstrom(1981) has stated that in spent chlorination liquors it appears that about 40% of the organically bound chlorine is present as high-relative-molecular-mass material(M_r>1000). Conversely, 95% has an M_r>1000 in spent alkali liquors. Low-relative-molecular-mass organically bound chlorine has figures of 39% in chlorination liquors and 5% in alkali extraction liquors, where M_r<1000.

High-relative-molecular-mass material.

These are biologically inactive because they cannot pass through cell membranes. However, these materials are still of environmental importance since they have chromophoric properties that cause bleaching effluents to absorb light in receiving waters. Further, the biological effects of degradation products are known, and these may have a detrimental ecological effects in the environment.

Low-relative-molecular-mass material.

Materials in this group are of three types, acidic, phenolic and neutral compounds.

(i) **Acidic compounds.**

This has five sub-divisions, fatty, hydroxy, dibasic, aromatic and resin acids. The higher fatty acids and resin acids originate from extractives. Formic and acetic acids are the most important fatty acids, while glyceric acid is the most important hydroxy acid. Dibasic acids are present in considerable quantities in spent liquors and include malonic, malic, oxalic and succinic acids. The aromatic content tends to be quite low, while resin acids only tend to be found in caustic extraction liquor.

Lindstrom(1985) has found that the numbers of chlorinated acids are very low. This is rather surprising as the M_r<1000 acid fraction, organically bound chlorine, constitutes 70%.

(ii) **Phenolic compounds.**

Voss(1981) suggests that the amount of phenolic compounds in spent liquors depends greatly on the charge of chlorine and the end-pH used in the chlorination stage.

(iii) **Neutral compounds.**

Methanol and some hemicelluloses tend to dominate here. In general, the neutral compounds consist of a wide variety of chemicals including, aldehydes, ketones and esters.

2.3.4 Pollution studies.

The acute toxicity of kraft mill wastes to aquatic invertebrates was first observed by Van Horn(1947). Examinations were made on the toxicity of components of kraft mill wastes to various aquatic species including Daphnia and insect larvae. The results obtained seem to indicate that the invertebrate fauna are more resistant to pulping wastes than fish, and certain species such as Chironomus were substantially more resistant. The higher tolerance levels of invertebrates was further demonstrated by Dimick and Haydu(1952) who found that mayfly and stonefly nymphs had greater resistances to kraft effluents than fish.

Juul and Shireman(1978) investigated populations of both fish and benthic macro-invertebrates inhabiting a kraft mill effluent channel at the Hudson Pulp and Paper Corporation, Florida. The waste water treatment facility investigated discharged water from its oxidation pond through a cement riffleway into an earthen channel. With the exception of the mouth of the riffleway, the channel has a uniform depth ranging from 0.5 - 0.7m. Water flow characteristics cause substantial eddies in either of the deep pools. Channel width ranged from 10 - 11m.

Monthly benthos samples were collected between November 1974 - September 1975. Chironomid larvae were the most abundant organisms. The average numbers for the mid-channel were $519.8/m^2$, while $11628/m^2$ was the mean value from the sloped shoreline. These numbers are generally greater than those reported from river studies.

Oligochaetes were only present in low numbers, but increased during the study period. The presence of Ephemeroptera, Trichoptera, Gastropoda, Ampihopda and Collembola was also recorded.

Thus, it appeared that the water quality within the effluent channel remained favourable for macro-invertebrate growth and survival. The Chironomidae in general tended to inhabit the bottom slopes of the channel, with other aquatic macro-invertebrates being more associated with the vegetation that was present in the eddy areas.

According to Walden(1977), in general it seems that spent chlorination and alkali extraction liquors from softwood pulp are only mildly toxic to fish and to other aquatic organisms, with the spent liquor having less of an effect than the extraction liquor.

Voss et al.(1980)stated that since much larger volumes of spent chlorination liquors are produced, the total toxicity is considerably larger. Voss further states that it also appears that the toxicity of these liquors is enhanced with increasing number of chlorine substitutions.

Ander (1979) found that spent chlorination liquors are also mutagenic and carcinogenic. Among the carcinogens are chloroform and carbon tetrachloride. Further, benzenes and phenols in effluents are suspected of being carcinogens. Unfortunately, at present the fate of these genetically active compounds is not known.

Voss et al.(1984) made a study of the neutral organic compounds found in biologically treated bleached kraft mill effluents. It was found that about forty such compounds from nine bleached pulp mill sites over a six year period. The mean concentration for these compounds was found to be 30mg/l, ranging from 4-200mg/l. Upon discharge, and with the resulting dliution factor(typically 1:100 and greater), the concentrations of these neutral organic compounds was found to be at the sub-microgram/litre level. However Voss et al were unable to say at what levels these compounds would have a deleterious effect on the environment.

Sewage fungus can be a serious problem in rivers receiving organic effluents. When environmental conditions are suitable, it can form a massive slimy growth which rapidly colonises all submerged surfaces. Roberts(1977) made a study of sewage fungus in the receiving waters of a paper mill. It was found that dissolved carbohydrate in the form of polysaccharides with a molecular weight in the range of 2000 to greater than 10000 formed a high percentage of the total soluble organic content of the effluent. These effluent polysaccharides could be utilised by the dominant bacteria in sewage fungus, Sphaerotilus natans. However, the polysaccharides found to be most useful to S.natans were found to be derived mainly from waste paper and not wood pulp. Curtis(1969) discovered that S.natans was capable of growth on a variety of sugars, but not on cellulose, such that it could be expected that the amount of sewage fungus is not only a function of the sugar content of an effluent, but also the nutrient supply and flow rate of the river. Cormack and Amsberg(1969) reported that sewage fungus occurred in the lower Columbia River, where the average BOD_5 increase was only 0.4 ppm and rarely exceeding 1 ppm. This confirmed Cawley's(1959) work on the Atahama River where he showed that heavy sewage fungus growths occurred at locations receiving very low BOD_5 additions.

The final problem associated with paper mill wastes is that of the presence of suspended matter flushed into the receiving waters. Walden(1976) states that suspended matter is detrimental to the benthic community as wood fibres after settling cause anaerobic conditions in the bottom sediments. The effect is due to the depletion of oxygen, and to the toxic action of generated hydrogen sulphide.

Gaufin(1958) studied the Mad River in Ohio which receives a discharge from a paper mill. It was found that oxygen depletion and that settlement of finely divided particles were important in determining the composition of the benthic community. A distance of 15-20 miles below the mill was affected, with the discharge turning the the water a milky white. On settling, it formed a blanket over the stream bed in which few organisms could exist. Over the three year period of study, the substrate became more densely covered. Three miles below the outfall, the numbers of snails, leeches and worms increased, with the population of mayflies and gill breathing organisms declining. The fauna was similar at 5 miles below the outfall with only eleven species being present. The number of species had increased to fifteen at 14 miles below the discharge with flatworms dominating in the shallow regions.

Dines and Wharfe(1985) studied the effect of a paper mill on the Swale, a tidal channel on the South-East coast of England. They found that disposal of paper mill wastes over many years has changed this former wildlife refuge to such an extent that abatement measures were needed.

A survey of the soft sediment fauna found that the most severe effects were in a small creek which joined the Swale close to the major waste discharge. In the main channel, blanketing effects of the high suspended solid load was considered to be mainly responsible for the detrimental effect on wildlife. Further, it was seen that the toxic effects of the semi-chemical liquor component of the discharge directly restricted the settlement and growth of juvenile bivalves.

The benthic fauna of the Swale was restricted to a few tolerant species which were mainly deposit feeders, and some opportunists. Oligochaeta and Polychaeta being dominant here.

Oligochaetes were also found to prosper in a study of the Upper Medway estuary in Kent. Dines and Wharfe(1986) recorded numbers in the estuary of $1x10^6/m^2$. A particular feature of the paper mill effluent investigated was its high particulate content. Suspended solid concentrations in water samples taken from the vicinity of the paper mill ranged from 25 - 190mg/l. The sediments in much of the Medway estuary were quite unstable with up to 8cm being removed or deposited in a month. As a consequence, organic waste discharges were less severe than those recorded by Dines and Wharfe(1985) in Milton Creek and as such the effect of cellulose fibres settling out was also reduced.

2.4 The distribution and ecology of the Oligochaeta and Chironomidae.

Many investigations have revealed that the presence of oligochaetes and chironomids in large quantities in a stream are strong indicators that an organic pollutant is present. Brinkhurst(1970) has shown that in heavily polluted waters the family Tubificidae are frquently very abundant, often forming monocultures with densities over $10^6/m^2$. With increasing pollution, successive species of tubificids tend to be eliminated with only Tubifex tubifex and /or Limnodrilus hoffmeisteri remaining. In general, tubificids, most lumbriculid worms and naidid worms are adapted to burrowing in soft sediments and they are consequently able to survive considerable oxygen depletion in the environment. Brinkhurst(1972) has suggested that competition is avoided by selective digestion of the bacteria in a sediment.

Learner(1978) has observed that naidid worms also respond to organic pollution with a large increase in numbers, especially in areas of stony substratum. Eyres et al.(1978) demonstrated that Nais elinguis is particularly tolerant of pollution.

Brinkhurst and Kennedy(1965) showed that as the water below an organic discharge becomes more oxygenated tubificids tend to decrease in abundance and are replaced by the Chironomidae. In their investigation in Ditton Brook and its tributary they observed the co-existence of Oligochate species. The most abundant oligochaetes were Tubifex tubifex and Limnodrilus hoffmeisteri, although during the period of study Limnodrilus udekemianus also became well established. They also found that chironomid larvae adversely affected the worm population. This was mainly due to the activities of Chironomus larvae in the surface layers of mud.

Over the four stations investigated by Brinkhurst and Kennedy it was seen that the horizontal distribution of species varied consistently. There was no overall correlation however, between the observed differences in distribution of T.tubifex and L.hoffmeisteri which led to the conclusion that other environmental factors affected their abundance.

Eyres et al.(1978) found that oligochaete worms dominated the benthic fauna of the River Irwell in North-West England. This river was polluted by domestic and industrial wastes. The Tubificidae were seen to account for almost 87% of the worm fauna, with T.tubifex, L.hoffmeisteri and L.udekemianus the dominant species. The Naidae were the next most abundant group, with N.elinguis being particularly important in this group.

Eyres observed that T.tubifex and L.hoffmeisteri were abundant along most of the 63Km of the river. However, greatest numbers of these species were observed in the organically polluted stretches of the lower reaches of the river. The main population recruitment for each of the species mentioned occured from April to September for T.tubifex, May to November for L.hoffmeisteri, June to October for L.udekemianus and around April for N.elinguis.

Lazim and Learner(1986) examined both T.tubifex and L.hoffmeisteri in a moat feeder stream in Cardiff. The moat feeder stream is an organically enriched environment. It was found that the T.tubifex population had an annual life-cycle with a prolonged period of reproductive activity throughout the winter and spring. Cocoons were produced mainly during late winter and early spring, but none were found during August and September when there were few mature worms.

Conversely, even though it was considered that L.hoffmeisteri had a single generation/year life-cycle, it appeared that this organism has quite a long period of reproductivity in this habitat thus leading to an overlap of generations. Lazim and Learner interpreted this as L.hoffmeisteri over-winters, with the major recruitment taking place in May - September.

Population densities of T.tubifex ranged from between $5420/m^2$ in mid-September to $61300/m^2$ in mid-May. The average population for L.hoffmeisteri was estimated to be $3x10^5/m^2$ over the period of study. These figures are similar to those quoted by Eyres(1978) of $2.8x10^5/m^2$. Palmer(1968) has also recorded very large populations($2.8x10^6/m^2$) of T.tubifex in an organically polluted site on the River Thames.

Kennedy(1966) has suggested that low temperatures will cause cessation of breeding activities in L.hoffmeisteri. He investigated this tubificid in the Shropshire Union Canal in Cheshire. Into this canal drains water from rich arable land and the substratum consists of a rich organic mud. Samples were taken at intervals of three weeks for twelve months, and at monthly intervals from November 1961 to April 1963. It was found that worms bred in this habitat throughout the year which could be attributed to the productivity of the habitat. However, the greatest number of breeding specimens were found in the winter months. It seems this phenomena is related to temperature and this was demonstrated for L.hoffmeisteri by Proddubnaya(1959). It appears that in unproductive areas, very low temperatures will cause a cessation of breeding activity, while in productive areas breeding will only take place in low temperatures.

Aston(1973) made a study of tubificids and water quality and found that if there were conditions of low dissolved oxygen concentrations as when water bodies were heavily polluted by sewage then, L.hoffmeisteri and T.tubifex became the dominant organisms. The respiratory physiology of these species are adapted to operate at very low oxygen concentrations and thus they are able to survive for long periods in anaerobic conditions. Dausend(1931) noticed that tubificids could survive for up to four weeks in anaerobic conditions in which time they could metabolize glycogen anaerobically.

Palmer and Chapman(1970) suggest that the ability of T.tubifex and L.hoffmeisteri to survive at low oxygen concentrations is due to the fact that they contain the pigment haemoglobin in their blood, which in T.tubifex, exhibits a negative Bohr effect thus enabling oxygen to be taken up at low pH. This is a common occurrence in organically polluted waters when the carbon dioxide content of the water is high. However, even though this pigment functions in the transport of oxygen, it does not appear to store oxygen during long periods of anoxia.

Chapman (1982) studied the effects of species interactions on the survival and respiration of L.hoffmeisteri and T.tubifex exposed to various pollutant and environmental factors. This work indicated that these two species were most tolerant of toxicants such as cadmium, mercury and pentachlorophenol in mixed than pure culture. This suggested that mixed species interactions enhanced survival under stress. However, mixed species were far less tolerant of anoxia than individual species. This result although unexpected may explain why monocultures predominate under totally anoxic conditions. Chapman also found that mixed species did not regulate respiration. Despite this lack of regulation, the respiratory rate of mixed species was generally below that for individual species. This work was consistent with the study made by Chua and Brinkhurst(1973) which indicated that lower respiration rates can be found in mixed as opposed to pure cultures.

It seems that the main source of food for burrowing worms consists of micro-organisms which are extracted from the large volume of sediment that is continually ingested by these organisms. However an investigation of Nais elinguis by Bowker(1985) found that this species selects algae as its main food. This organism is particularly abundant in mats of filamentous algae and according to Learner(1978), tends to be quite tolerant of organic pollution. Bowker et al.(1983) also demonstrated that the seasonal maximum population density of N.elinguis in the River Ely occured in spring. This coincided with an increase of benthic diatoms and filamentous algae in the environment.

Bowker(1985) found that in the field and in controlled experiments, N.elinguis congregated on mats of filamentous algae. This was considered to be of an ecological advantage for N.elinguis since filaments provide a structural micro-habitat which is protected from excessive water currents, light intensities and predators and which promotes accumulation of food particles such as diatoms. Bowker found evidence that N.elinguis is able to actively search out and congregate in a suitable habitat.

Numerically the Chironomidae are probably the other most important taxon in organically polluted rivers. Several studies have shown that the abundance of chironomid larvae is closely correlated with detritus and the organic content of sedoments(Learner et al, 1978; Egglishaw, 1964; Fahy, 1975), but not with current and stone size(Barber and Kevern, 1973; Shelly, 1979).

The effects of an organic effluent on the distribution and seasonal incidence of Chironomidae has been described in detail by Davies and Hawkes(1981). The survey was carried out on the River Cole, a tributary of the River Blythe, South-West of Birmingham. This stream flows northwards through some highly industrialized areas. The upper reaches of the river studied received organic pollution from an overloaded sewage works. Six stations were used, one above and five below the discharge. Samples were taken monthly from December 1966 to December 1967.

Water samples were also taken for chemical analysis.

The six stations investigated were all riffles, dissolved oxygen below the outfall was considerably reduced and ammonia, nitrates, carbon dioxide and orthophosphates had high levels. Water quality was further seen to deteriorate during the summer months.

The distribution of chironomid species was clearly seen to be affected by water quality. C.riparius was seen to be the most pollution tolerant species and was found to be practically restricted to the most polluted areas. Its presence here was probably associated with a rich food supply and by the fact that C.riparius is very tolerant of low oxygen tensions and high concentrations of ammonia(Davies, 1971).

With increasing water quality other species became more abundant. Brillia modesta was the only species that became most abundant at Station 4, 50% of all individuals collected from this site were of that species.

Station 5 appeared to exhibit the most favourable conditions for seven species, including Cricotopus sylvestris, Cricotopus bicinctus, Eukiefleriella clarripennis and Paratrichocladius rufiventris. The two Cricotopus species were particularly numerous during the summer months.

Another species, Prodiamesa olivacea was most numerous at Station 6, although it was scarce at Station 5. The unsuitability of the substratum was indicated as having been responsible. Roback(1957) has also demonstrated that this species prefers a soft substratum. Thus, Station 6 appeared to be more muddy than Station 5.

A seasonal variation in numbers was also observed and the seasonal patterns varied between species. For example, C.riparius had two peaks in larval numbers, in February and October. No larval stages were recorded in May. Gower and Buckland (1978) revealed a similar pattern from their study of Moat Brook, where larval density was greatest in October, but was least in May.

P.olivacea and E.clarripennis showed similar seasonal patterns with three similar peaks in numbers being recorded during the year. This pattern was analagous to that found in three other streams by Davies(1971) where quite large numbers were found in July to September.

The two Cricotopus species found, C.bicinctus and C.sylvestris exhibited distinctive peaks during the summer months and only small populations were present during the winter. This was very different to that recorded for B.longifurca and P.rufiventris whose numbers achieved peak populations in the winter-spring period.

Conchapelopia melanops appeared to be bivoltine, having population peaks in spring and summer at four stations. However, at Station 5 there appeared to be a summer generation, such that larvae were present in the River Cole throughout the year.

In summer it was seen that the severely polluted zone extended downstream such that Station 4 also became severely polluted. This is similar to the results obtained by Gaufin and Tarzwell(1955) in their work on the Lyttle Creek, Ohio. This increase in the polluted zone however, favoured C.riparius which thus became abundant at Site 4 during the summer. The populations of B.longifurca, E.clarripennis and P.rufiventris became suppressed during the summer at Stations 2 and 3 but not at Stations 4 - 6. These species were often found to be present at other times of the year such that their distributions were linked to the seasonal changes of pollution in the river.

Lindegaard-Peterson(1972) conducted an extensive survey into the relationship between chironomid distribution and substrate in a lowland Danish stream, Linding A. Samples from nine stations of the stream were collected monthly from January 1964 to May 1965 with 67 species of Chironomidae being found.

Common species(i.e more than 50 individuals) occurred at nearly all the stations, although not in the same numbers. Numbers increased downstream from Station 1 to Station 9 with only Station 1 showing significant differences from the other stations. It was found at Station 1 that ochre was precipitated, thus species such as Conchapelopia melanops, Heterotrisocladius marcidus, Microfendipes sp, Paratendipes sp and Polypedilum convictum were absent. These species however, only became numerous at Stations 7 - 9.

These differences between Station 1 and the other stations can also be seen from the fact that at least twice as many species were found at Station 5 and Station 7 as at Station 1(21 species at Station 1, 42 at Station 5 and 51 at Station 7).

In the Linding A in slower flowing regions where the bottom of the stream was covered with mud, Chironomus species became numerous. In a weak current regime with a sediment consisting of both mud and sand with abundant detritus, species such as P.olivacea, Macropelopia nebulosa, Procladius sp and Polypedilum laetum became numerous. With increasing current and a stony bottom, Orthocladius(E)rivolorum, Rheotanytarsus photophilis and Diamesa insignipes were present in large numbers.

Many species were found on vegetation and include C.melanops, B.modesta, B.longifurca, C.bicinctus, Rheocricotopus fuscipes and Rheocricotopus effusus. The dominant vegetation being Helodea and Sparganium.

A characteristic of the Linding A, except of the upper reaches, is that there is a strong sand movement. The substrate on single localities often becomes covered with sand. Further, the development of the vegetation changes from year to year and it is cut-off in the autumn months.

McClachan et al.(1978) and Mackey(1979) showed that many Orthocladinae were relatively unselective in their use of detritus. This behaviour explained the similarity of the density profiles of six common Orthocladinae, C.bicinctus, C.fuscus, C.sylvestris Orthocladius species A, O(E)thienemanni and Synorthocladius semivirens.The differences in the mean density of the detritus along the leaves was probably caused by seston being deposited at rates that varied with the inclination of the leaves to the current. Also as leaves grew from their bases, epiphytic algae and other micro-organisms were established longer on more distal sections of leaf. The results are similar to those recorded by Entz(1947), Opalinski(1971) and Smock and Stoneburner (1980).

Laboratory experiments performed by Drake showed that chironomid larvae behaved much like marine invertebrates by drifting and settling randomly because they swim non-directionally. The density profiles of larvae on leaves with abundant detritus suggested that larvae move basally before making tubes, whereas they move distally on leaves with little detritus.

Drake suggests that five factors affect spatial distributions; natality, mortality, immigration, emmigration and re-positioning within a habitat. In streams, drift tends to be a major method of dispersion for all stages of larvae. The availability of detritus largely determined mean densities such that larvae actively determined their own spatial distribution. This conclusion concurs with the work of Taylor and Taylor(1977) who also found that distributive behaviour produces spatial patterns.

Tokeshi(1986) investigated the population dynamics and species richness of an epiphytic chironomid community on the Spiked Water-Milfoil(Myriophyllum spicatum). The Water-Milfoil is the dominant aquatic macrophyte in the River Tud in the South of England. Sampling was carried out at various intervals between April 1983 and June 1984. A total of nineteen chironomid species were recorded with eight species occuring commonly. The range of life histories observed was one to five generations/year. However, the total number of species was small when compared with Drake's(1982) survey where forty-one species were found. This fact is largely attributable to differences in stream width, with the former being 2 - 2.5m wide and the latter 15 - 20m wide.

There appears to be conflicting information on the importance of plant architecture in influencing species diversity. Two investigations, Lawton and Price(1979) and Strong and Levin(1979) suggested that it is important. However, Tokeshi and Pinder(1985) found no appreciable difference in species richness between epiphytic fauna on two co-existing but architecturally distinct aquatic macrophytes of the genus Potomageton.

Tokeshi observed that a significantly larger number of species occurred as larvae in spring. This he suggested was a consequence of selection adjusting the life-cycles of species thus leading to an exploitation of abundant food resources during the season. This is similar to that seen by Shapiro(1975) in his work on lepidopterans in which the highest species richness corresponded to the maximum vegetation growth.

2.5 Methods of assessment of river pollution.

Changes in water quality will be expected to result in changes in the biocoenose. Many workers have attempted to utilize these changes in various ways into schemes that can be used as tools for the assessment of pollution. However, because natural criteria such as substratum and current velocity will also influence the benthic community, variations in these factors should also be taken into account when assessing the effect of a pollutant on a river.

The first attempt at assessing the quality of water using a biological approach was that made by Kolkowitz and Marsson(1909). This so-called 'Saprobien System' has been modified since but basically it deals with lists of organisms classified into saprobia. These are groups of organisms associated with different stages of oxidation in organically enriched waters in order to express their dependence on decomposing organic nutrients. Kolkowitz and Marsson distinguished four major zones; Polysaprobic, Alpha-Mesosaprobic, Beta-Mesosaprobic and Oligosaprobic on the basis of increasing degrees of mineralization of the organic matter. Pantle and Buck(1955) attempted to take into account the relative abundance of organisms in this system rather than their mere presence or absence. By contrast, Butcher(1946) favoured the use of algae as an indicator but it appears that most workers prefer the benthic invertebrates as indicators.

Biologists have found it difficult in presenting results in an understandable form to the layman. Because of this, it was felt necessary to convert results into a numerical value or Biotic Index. Beck(1955) produced the first index, this was based on the principle that macro-invertebrates may be classified into two groups according to their tolerance of organic pollution. This system was later refined by Woodiwiss(1964) into the Trent biotic index. Originally values of 0 - 10 were determined on the numbers of different defined groups of invertebrates present weighted in their sensitivity to pollution. This range was further extended to 0 - 15. This is a practical system and it is easy to use even by inexperienced individuals as only qualitative sampling of benthic invertebrates is required. Also taxonomy is not demanding. This system has been adapted for use in the Lothian area of Scotland by Graham(1965) who introduced six categories.

Chandler(1970) adapted the Trent biotic index in much the same way as Pantle and Buck adapted the Saprobien system in order that abundances could be accounted for. Scores between 0 - 100 are allocated for each species in a sample such that the resulting total may then be considered as an index of pollution in itself or may alternatively be divided by the number of species present giving an average Chandler score. This system has been further refined by Bryce et al.(1978), although it is still less straightforward than the Trent biotic index as a measure of abundance is required.

A national strategy for the biological assessment of river pollution was reported by the Department of the Environment in 1970. This was an attempt to supplement the established chemical classifications. The system was a simple one having four classes, A - D, with each being characterized by groups of animals indicative of different water qualities such that Class A had a widely diverse fauna with Class D having a macroscopic fauna of only those organisms that could tolerate pollution. This system was however, reported to have drawbacks and the disappointing results following the 1970 survey prompted the Department of the Environment to set up the BMWP(Biological Monitoring Working Party) in order to recommend a biological classification of river water quality for use in national pollution surveys. They failed to recommend a biological classification of the 'biological condition of rivers.' This system was intended as a surveillance tool to monitor changes at defined points on the river over a period of time and was not intended to be used comparatively. The system is a simple non-exacting one for broad classification and is based on a score derived from points attributed to different invertebrate families according to their degree of tolerance to organic pollution. The scores range from 1 - 10.

Diversity indices are also commonly used by biologists, they, unlike biotic indices are quantitative values derived mathematically from quantitative data. No use is made of autecological information regarding the response of individual species. Diversity indices are probably best applied to toxicity and physical pollution. The Shannon index is one of the most commonly used. This takes into account the proportional composition of the community, the more uniform the distribution between component species, the higher the index value. A further simple quantitative co-efficient is that developed by Czekanowski(1913) and is used as a comparative measure between two communities.

Qualitative indices have also been developed and they compare joint species presences or absences between two samples or communities. Field(1969) has suggested that such co-efficients may arrive at an index of affinity which could give misleading results in extensive surveys. Kothe's species deficit(Kothe, 1962) is one such qualitative index and was derived from the general observation that pollution often causes a reduction in the number of species in a community and is useful for measuring the difference in the number of species between communities above and below an effluent outfall. An index of 100% would mean complete suppression of the fauna but only if the disappearing species were not replaced by others. In cases of mild organic enrichment, the number of species below an outfall may increase, in such cases it would be appropriate to measure the suppresion of the upstream fauna. In conjunction with this index, a co-efficient of similarity such as Jacard's co-efficient is appropriate.

Multivariate techniques are fairly common tools for the biologist in handling data. Two of the more frequently used are clustering and Principal Component Analysis. Principal Component Analysis(PCA) is a mathematical treatment which allows communities to be organized on a graph so that those most similar in both species composition and relative abundance will appear closest together, while those most dissimilar will appear furthest apart.

The results obtained from thirty-four locations in streams in Southern England (Townsend, 1983) were subjected to PCA. Clear relationships were revealed between pH and position of communities along the x-axis generated, and between average water temperature and position along the y-axis. Thus communities with predictable compositions occurred under specific sets of environmental conditions. Further, if pH is known in a new stream in the area it is possible to use the ordination data to predict the invertebrate fauna and, if only the fauna is known so pH could be predicted.

Clustering as opposed to PCA begins with the assumption that communities consist of relatively discrete entities. It produces groups of related communities by a process similar to taxonomic classification. In taxonomy individuals are grouped together in species, similar species, in genera etc. In clustering, communities with similar species compositions are grouped together in subsets, similar subsets etc (Gauch, 1982).

With the thirty-four Southern English streams subjected to PCA, five distinct classes were found. At each class level a significant difference in environmental conditions existed. A relationship between PCA and clustering indicates pH was a critical environmental factor.

A detailed Cluster Analysis was used on the benthic communities of Oslofjord in Scandanavia(Gray, 1981). Seven reasonably distinct classes of communities were derived, with community structure varying according to position in relation to the City of Oslo and its output of pollutants. Class A was totally dominated by organisms which could tolerate organically enriched sediments. This approach to community analysis shows its role adapted in ecology by revealing the extent of pollution. Further analysis could indicate if anti-pollution measures were having an effect or whether typical polluted water organisms were becoming common.

Cairns and Kaesler(1969) have studied the occurrence and distribution of insect species in a portion of the Potomac River. Jaccard co-efficients were used for Cluster Analysis which refer to the presence or absence of species rather than absolute numbers. The survey was carried out between 1956-1965 and 370 insect species in fifty aggregations were analyzed to determine the effects of operation of the PEPCO Dickerson power station on the aquatic biota. Samples were collected at three stations on each of four high-water and six low-water surveys.

Similarities of aggregations of species within a survey were in all cases greater than similarities among aggregations from different surveys. This indicated that there were relatively strong within-year and along-stream influences. Clusters from middle-year data showed greater similarities than for earlier or later results. This was taken to indicate environmental change at all stations. Increased urbanization was thought to affect the last survey carried out(1965) as this would cause environmental change.

Thus, the use of complex data analysis techniques can therefore be used to reduce large quantities of survey data to easily understood patterns. They do not produce indices of water quality,but allow subjective assessments to be made, particularly of sampling points containing fauna representative of a clean stream and a polluted stream of similar type to the others under investigation.

3. Field work and methods.

3.1 Sampling methods and materials.

The quantitative samples of the stream benthos were taken using a Saw Cylinder Sampler(Fig 1) and based on that developed by Neill and described by Macan(1958).

The sampler consists of a metal cylinder which encloses an area of $0.05m^2$.The lower edge was serrated to facilitate it being pushed into the stream bed. Water flowed into the cylinder through a perforated plate facing upstream and then passed out through a detachable net made of nylon attached to a tube on the downstream portion of the cylinder. Attached to the net was a one-litre collecting jar. The mesh count of this net was 24x24/cm which, according to Maitland(1969), should prevent all but the very smallest individuals passing through.

Prior to the sampling programme a field trial was performed using the sampler to determine the most suitable length of sampling time. It was intended to use a sampling time that would enable at least 90% of the benthos to be collected. This was carried out in the following way:-

Sampling of benthic invertebrates must be carried out so as to be representative of the whole population, therefore sampling must be without bias. True random selection is generally difficult to achieve, many workers using random number tables in order to reduce this bias(eg Fisher and Yates, 1963). However this method is often laborious and it tends to be much easier to use a large two-dimensional grid with each square equal to the area of a sampling unit. The squares on two adjacent sides of the grid are numbered, and each sampling unit is thus located by a pair of co-ordinates.

Stratification may also be used to optimise the accuracy of population estimates and also ensures that sub-divisions of the population are adequately represented. However, stratified sampling is of greatest value when the sampling area contains a variety of biotopes. This was not found to be the case in the Llynfi however, where the substrate was predominantly stony. Thus the random sampling routine at each site in the survey carried out relied on the two-dimensional grid method. Results for the initial sampling programme can be seen in Table 62, Appendix 3.

In the laboratory the animal material was first separated from any sediment present and placed in a sample tube appropriately labelled which also contained formalin. All organisms were counted at this stage. The oligochaetes and chironomids were identified at a later time while the identification of the Ephemeroptera, Plecoptera etc was carried out using keys produced by the Freshwater Biological Association and other relevant keys.

The Oligochaeta were identified by placing them on a tray and, in the cases where large numbers were present, at least fifty animals were selected and mounted on a slide using lactophenol. If the numbers were small all specimens were identified. Brinkhurst(1971) was used to identify the Oligochaeta.

In almost all cases, all the Chironomidae were identified in a particular sample. In cases of uncertainty, head and whole body mounts were made using lactophenol. Orthocladinae were identified using the key by P.S Cranston(1982) while other Chironominae present were identified using Bryce's(1960) key. Where large numbers were found fifty animals were selected to be identified.

Chemical analysis.

Because of the large number of biological samples that were taken, it was decided that it would be difficult to also carry out detailed chemical analysis of the river. Thus approaches were made to the Welsh Water Authority(South-Western division) at Swansea who kindly provided their routine analysis.

It was also decided that a 24-hour survey during the summer would provide useful information on the diurnal fluctuations of dissolved oxygen along the length of the river. Sampling was carried out by collecting water in a 250ml stoppered jar at each site at four-hourly intervals. The water in the jars were subjected to the azide-alkali method of determining dissolved oxygen. The oxygen was fixed on site. For method see Appendix 9.

3.2 Site description.

The River Ogmore rises some 500m above sea-level and flows in a general North-South direction for approximatley 40Km to enter the sea at Merthyr Mawr. Of the four main tributaries, the Llynfi, Garw, Ogwr Fach and Ogwr Fawr, it is only the Llynfi that needs to be considered. This tributary(Fig 3) arises in the hills above the town of Maesteg and flows for a distance of 8Km before converging with the Ogmore at Aberkenfig.

Six sites were sampled on this river system, one upstream of the paper making plant and two downstream on the River Llynfi, one on the River Ogmore before the confluence with the Llynfi, and two further sites downstream of the confluence. Fig 4 gives the relative positions of these sites on this river system. All the sites were in riffle zones. Biological sampling took place on six occasions between October 1985 to November 1986.

<u>Site 1</u> Grid Reference: SS 873 891

This site was located above the paper mill to show the possible impact of the mill discharge on the benthic community. A sampling point above Maesteg was not acceptable due to the chanelling of the stream, thus making an artificial environment. The site chosen was unfortunately affected by urbanization and in no way be described as an ideal clean water stream although the main characteristics of upland oligotrophic streams were present.

At this point the river is approximately 5m wide with areas of riffle and also some stretches of deeper water. Immediately upstream of the sample site a small tributary joins the Llynfi, thus cleaner water is introduced to the system. The stream here is lined with trees and flows through mainly agricultural land.

Site 2 Grid Reference: SS 889 865

This site is approximately 500m below the outfall of the paper mill. The river has widened at this point to around 8m but is similar in physical characteristics to the previous site. During the summer the stream depth was about 15cm in the riffle regions.

Site 3 **Grid Reference:896 848**

This site is some 5Km below the effluent outfall, but receives a discharge from a sewage treatment works 3Km above the site. The river is about 7 - 8m wide at this point and is mainly composed of riffle regions with some deeper areas. The depth of the stream during the summer was similar to that at Site 2. The bank vegetation had changed from trees to mainly shrubs and bushes.

Site 4 **Grid Reference: SS 897 837**

This site is on the Ogmore immediately upstream of the confluence of the Llynfi and Ogmore. The Ogmore at this point is fast flowing with riffle regions, but tends to be deeper than that of the Llynfi. The river is about 25m wide at this point and has flowed through agricultural land and scattered areas of urbanization.

Site 5 Grid Reference: SS 896 831

It was intended that this site should show the effect that the relatively clean Ogmore had upon the more polluted Llynfi. A degree of chanelling had occurred here due to the construction of a flyover for the M4 Motorway. The dimensions of the river were similar to that of Site 4, although it was noticeable that the river was becoming deeper, there were still however, many easily accessible shallower riffle regions.

<u>Site 6</u> Grid Reference: SS 891 784

The river had widened still further by this point to approximately 30m. This site is down river of Bridgend, thus pollution from the town may be expected to have become well dispersed. During the course of the survey, work was carried out at the sampling point to modify the structure of the bank. This in no way affected the accessibility of the site, but it did introduce some suspended matter to the river.

4. Data and Data Analysis.

4.1 Chemical data.

These are summarised in Appendix 2(Tables 1 - 24). Using this data graphs have been drawn to show parameter concentration against time for the sampling period(Figs 5 - 10). Also, results for the 24 hour survey can be seen in Table 25 and Fig 11.

4.2 Biological data.

These are summarised in Tables 26 - 61 in Appendix 3. Graphs have also been drawn to show both species abundance and seasonal variation using 95% Confidence Limits (Figs 12 - 33). Figs 27 - 32 show comparisons of the benthic community at each sampling occasion. Initial survey data can be found in Table 62

4.3 Data analysis.

The biological results were subjected to a number of different tests. These can be grouped accordingly:

1) Qualitative comparisons.
2) Quantitative comparisons.
3) Biotic indices.
4) Statistics.
5) Multivariate analysis.

1) Qualitative comparisons.

Kothe's species deficit.

This is given by:

$$D_m = \frac{A-M \times 100}{A}$$

A = number of species above outfall.

M = number of species above outfall which are missing from the downstream species list.

Thus comparisons between sites can be given. A full table of comparisons is given in Table 63 in Appendix 6.

2) Quantitative comparisons.

a) Block histograms.

The data has been processed in order that block histograms can be constructed to show a comparison of the faunal composition at each sampling occasion(Figs 27-33).

b) Shannons diversity index.

This is given by:

$$H = -\sum pi \log pi$$

H = Shannon index.
pi = probability function.

With this index, the higher the value obtained, the greater the diversity such that the cleaner water fauna is characterised by large numbers of different species and polluted water fauna tends to consist of few species. The data obtained is given in Table 64 in Appendix 6.

c) Czekanowski's co-efficient.

This is given as:

$$C_z = \frac{2W}{A+B}$$

W = sum of the lesser measures of abundance. of each species common to both communities.
A = sum of measures of abundance in community A.
B= sum of measures of abundance in community B.

It is similar in effect to Shannon in that similarity between communities is tested for. The data obtained is listed in Tables 65, Appendix 6.

3) Biotic indices.

a) Trent biotic index.

The extended Trent biotic index is used here. The revision of the earlier index extends the upper limit to 15, and is based on the species groups present. The results of the extended index performed are shown in Table 66 and Figs 33 - 38. The scoring system used in this index is given in Table 70

b) Chandler score.

The results for the Chandler score revised by Bryce et al(1978) are given in Table 67 and Figs 33 - 38. In this classification, scores of 0 - 100 are assigned to each species present. The scoring system used is given in table 71.

c) BMWP score.

The scoring system used is given in Table 72. Values between 0 - 10 are ascribed to scoring taxa, and the data obtained can be seen in Table 68 and Figs 33 - 38.

d) Welsh Water Authority score.

This system was derived by the Welsh Water Authority biologists and was intended for application in Welsh rivers. The scoring system is given in Table 73, and data obtained from this system is given in Table 69 and Figs 33 - 38.

4 Statistics.

Use is made here of the logarithmic transformation described by Elliot(1977). This transformation enables confidence limits to be expressed in terms of a derived mean divided by a common factor and, as such, is easy to use. Stabilisation using the transformation enables confidence limits to be expressed in terms of a derived mean divided and multiplied by a common factor. A straight logarithmic transformation is used for most small samples, but log(x+1) is used when zero counts are present in the sample. The mean of the transformed counts is given by:

$$y = \frac{\log x}{n}$$

n = number of samples.

The 95% confidence limits for y are:

$$y + t\sqrt{\frac{\text{variance of transformed counts}}{n}}$$

Values of 't' are found in 'Student's t-distribution'(Pearson and Hartley, 1966). However, due to the fact that 10 samples were collected from each site at every sampling occasion, for 9 degrees of freedom(ie n-1) the value of 't' was always 2.262. A sample calculation is given in Fig 39.

The selection of species for confidence limits was dependent on the most populous species at each sampling occasion. 95% confidence limits can be seen for both species abundance and seasonal variation in Figs 13-26.

5) **Multivariate analysis.**

a) **SPSS-X.**

This is a comprehensive and 'user friendly' statistical and cluster analysis package. Use of the CLUSTER command enables clustering to be carried out using the variables specified in input. The clustering methods used are generally based on the following procedures:

1) The smallest element in a distance matrix(calculated either by using CITY BLOCK method or Squared Euclidean method).
2) These two objects are clustered.
3) If there is more than one such pair, all these pairs are formed simultaneously.
4) A new distance matrix is calculated taking into account distances of objects and old clusters from the newly formed cluster.It is at this stage that different clustering methods can be applied.

1) SINGLE.

This is the smallest possible distance between an object and the objects in a cluster or between the objects of one cluster and another cluster. This routine is referred to as the 'nearest neighbours' method.

2) COMPLETE.

This is known as the 'furthest neighbour' method and is based on complete linkage between points in a cluster.

3) BAVERAGE.

This is based on average linkage between groups.

4) WAVERAGE.

This is also based on average linkage between groups.

5) CENTROID.

Here the centroid of a cluster is found and linked to the centroid of an adjoining cluster.

6) MEDIAN.

When two objects are merged they are then represented by the co-ordinates of their centroid. If two clusters are merged they are represented by their centroid which is calculated by averaging the co-ordinates of the centroids of the two clusters.

7) WARD.

Ward's method is used here.

In order to see the output of these routines they are plotted as dendograms which are scaled by joining the distances of the clusters. The data into SPSS-X is autoscaled.

b) ARTHUR 81.

This is a more dedicated pattern recognition package than SPSS-X and offers a wide range of multivariate methods. Primary concern is given to the classification of samples with respect to the elements that they comprise, indicating similarities and differences. A description of the sub-routines used is given:

1) UTILIT.

Provides line listings.

2) CORREL.

This routine calculates co-variance and correlation matrices.

3) SCALE.

This method of scaling features in the data which have been derived from data vectors. This routine is applied to all the data.

4) KAPRIN and KATRAN.

These two features are known as the Karhunen-Loeve transform. This consists of extraction of the largest values and their corresponding vectors from the co-variance matrix. The vectors are placed in order from the highest to the lowest value. KAPRIN performs the principal component extraction indicating which elements have the largest spread. KATRAN changes co-ordinates creating a new data matrix of he data extracted by KAPRIN.

5) VARVAR.

This routine plos components in two ways;firstly plots of two features against each other as x and y axes, and secondly the data property may be plotted against one feature(x-axis). Thus the two plots are the data vectors with respect to the two axes under consideration.

6) SELECT.

This is a feature selection technique with respect to their importance to classification. This is achieved by generating orthogonal features. It can be seen that the highest weighted feature is selected first with the remaining being de-correlated from the chosen feature. These features are then re-weighted such that the feature whose new weight is highest becomes the second selected feature etc. This process continues until either a specified number of features is chosen or a given minimum weight attained. The three previous sub-routines are then performed which produce PRIPLO plots.

7) DIST.

This calculates a matrix of the distance between all pairs of data points.

8) KNN.

This is the single linkage clustering method with 10 'nearest neighbours' to a particular data point being produced.

9) HIER.

A distance matrix is produced here which plots a dendogram indicating which two points are nearest.

From the raw biological data in Tables 26 - 61 it is apparent that there are many species which only occurred irregularly. It was decided that in order to make the data matrices manageable it was necessary to amalgamate the species belonging to certain taxonomic groups so as to make a single entry eg in many cases R.semicolorata and Ecdyonurus sp were combined. Also, if only isolated recordings of a species were present then that species may be ignored as having very little impact on the clustering routines. It is obvious from this that some data will be lost, but it was felt that in order to maximise ease of interpretation of results then it was a necessary step.

Line listings from SPSS-X and ARTHUR are given in Figs 46 - 87, Appendix 7.

5. Results.

5.1 Chemical results.

The River Llynfi was routinely sampled by the Water Authority over the thirteen months of the study.

The chemical results for the sampling stations are given in Tables 1 - 24 in Appendix 2. The results clearly show the effect of an organic effluent on the river system. Site 1 on the Llynfi was generally in quite good condition and the main source of pollution here was undoubtedly from the town of Maesteg about 1.5Km above. Site 2 immediately below the effluent outfall generally showed the poorest conditions along the length of the river sampled. However, Site 3 only tended to be marginally improved. Site 4 which had no specific pollutants discharged immediately upstream of the sampling point was of good quality. Sites 5 and 6 showed improved quality from site 3.

Dissolved oxygen.

The dissolved oxygen(Fig 6) figures for the period of study show the effect that the paper mill discharge had upon the river, although it can be seen that generally the dissolved oxygen content to be quite high even at the more polluted sites. At site 1 the % saturation of oxygen on occasions exceeded 100%. Downstream of the paper mill discharge at Sites 2 and 3, the oxygen content of the water was always lower than at Site 1 with the lowest figure usually being recorded at Site 2. The river showed improved quality by Sites 5 and 6 where levels in excess of 100% saturation were sometimes recorded. At Site 4 high levels for dissolved oxygen were usually recorded.

At Site 1 the lowest figures were recorded in December 1985 and October 1986, these were 82.6% and 82.2% saturation(8.9 and 9.5 ppm). However, these results were out of character with the rest of the results, as the average value obtained at this site for the sampling period was 96% saturation(11.1 ppm).

At Site 2 oxygen levels showed large fluctuations,the concentration was generally quite high from October 1985 to February 1986, but after this the oxygen concentration became gradually less, with the lowest values being recorded in October. The results for Site 3 did not follow such a pattern, the oxygen concentration did not vary much from October 1985 to July 1986, after which there was a decrease in oxygen concentration. The lowest values for these two sites were 17.2%(1.7 ppm) and 56.4% saturation(5.8 ppm) respectively.

Site 4 only experienced small fluctuations in dissolved oxygen content. The maximum value recorded was 107%(11.6 ppm) and the minimum 86.6% saturation (5.8 ppm).

Sites 5 and 6 showed similar patterns with the water usually being well oxygenated. The highest concentrations were recorded in October 1985 and June 1986 for Site 5 and October 1985 and July 1986 for Site 6. Lowest values at these two sites were recorded in December 1985 for Site 5 and September 1986 for Site 6, these being 89.3%(9.3 ppm) and 82.6% saturation(8.5 ppm) respectively.

Diurnal fluctuations.

Samples were taken over a period of 24 hours at 4 hourly intervals for all six stations. The results are given in Table 25 and Fig 11. At all sites except Site 2 there were distinct diurnal fluctuations. At sites 1, 4, 5 and 6 there were marked diel fluctuations in oxygen concentration due to the photosynthetic activity of autotrophic plants. However at Sites 2 and 3 there was little variation in oxygen concentration during the sampling period because of the absence of green plants.

Site 1 showed quite a marked diel fluctuation ranging from 2.9 ppm to 10.1 ppm. The initial value was 7.3 ppm at 7 a.m. The oxygen content then rose to its highest point at 3 p.m. After this the oxygen concentration then steadily fell to its lowest value at 3 a.m. A small increase at 7 a.m was then observed.

Conversely, Site 2 showed very little fluctuation in O_2 concentration. The lowest value obtained was 2 ppm at 3 a.m, while the highest was 2.9 ppm at 3 p.m. Similarly, Site 3 did not show wide fluctuations in O_2 concentration but all value recorded were greater than at the previous site. The maximum and minimum values being, 6.4 ppm and 2.4 ppm respectively. As at Site 2 a drop in concentration at 3 a.m with a recovery occurring after this point.

Sites 4, 5 and 6 showed marked fluctuations during the course of the 24 hours. Lowest values for these three sites occured at 3 a.m with values of 2.6, 2.3 and 2.1 ppm respectively being recorded. All 3 sites showed their greatest oxygen concentrations at 7 p.m.

Temperature.

The temperatures recorded were broadly similar for all sites showing the expected trends of being at their lowest during winter and highest during summer(Fig 6). The discharge into the river did not appear to be particularly warm as the temperatures at Site 2 were generally similar to those recorded at Site 1. Generally as one proceeded downstream the river became warmer. However, the highest value during the routine sampling period was at Site 2(18°C). Lowest temperatures for all sites were recorded in February and March, when 2°C was recorded at Site 2 and this was the lowest recorded during the sampling period.

The 24 hour survey was undertaken during a warm dry period and as such high ambient water temperatures were recorded(Table 25 and Fig 11). The highest figure recorded was 20.5°C at Site 6 at 11 a.m and 20°C at 3 p.m at Sites 2 and 6. Generally, the highest temperatures were recorded at 3 p.m. The lowest values were obtained at the first 7 a.m sampling period. Overall, the trend was increasing temperature during the day until 3 p.m followed by a gradual decrease in temperature. Site 1showed only a 3°C variation throughout the day, Sites 2 and 3 had a 3.5°C variation, Site 4 had a 4.5°C variation, Site 5, 5.5°C and Site 6, 5°C.

Hardness.

The water of the Rivers Llynfi and Ogmore could be described as generally soft. Site 1 showed very little variation in hardness. Site 2 was generally quite soft, had a value of 742 ppm in February 1986. This value is quite significantly higher than any value recorded elsewhere in the river. Sites 3 - 6 generally followed the trend set by Site 1. Site 4 had the lowest overall values. A total hardness of only 4.3 ppm being recorded in December 1985.

Ammoniacal nitrogen.

Only small concentrations of ammoniacal nitrogen were recorded at each site over the sampling period(Fig 7). The first three sites showed the highest values and widest fluctuations but even so the highest value recorded was only 1.2 ppm at Site 2. In general the concentration of ammoniacal nitrogen present throughout the system was extremely low. Site 4 had the lowest overall levels and the maximum value recorded at this site was only 0.23 ppm. Sites 5 and 6 had similar patterns of ammoniacal nitrogen concentrations but at these sites concentrations were generally very low.

Total oxidised nitrogen and nitrite.

The values recorded were similar to that of ammoniacal nitrogen with only very low concentrations being recorded along the course of the river.

Orthophosphates.

The concentrations were almost always lower than 1 ppm. The maximum value for the sampling period was recorded at Site 2, but this was only 2.1 ppm.

pH.

Generally this river system tended to have alkaline waters with values of less than 7 being recorded only frequently(Fig 5). Site 1 was particularly alkaline when compared with the rest of the river with an average pH of 7.7.Sites 2 and 3 were usually less alkaline than Site 1. The minimum values recorded at these sites was 7 as compared to 7.2 for Site 1. The lowest value recorded was pH 6.8 at Site 4. Sites 5 and 6 had fairly similar values the lowest values for thse sites were 7.2 and 7.3 respectively, while the maximum values were 7.7 and 7.9 respectively.

Biochemical Oxygen Demand(BOD_5).

Site 1 showed considerable variation of this parameter (Fig 9). The lowest value recorded was 0.4 ppm, but in January 1986 a high value of 12.4 ppm was recorded. Site 2 however, experienced the highest concentration on the river. The highest value recorded at this site was 18.2 ppm and the lowest 2.5 ppm. Sites 3-6 all had low levels for BOD_5, with Site 4 having particularly lower levels which never exceeded 2.2 ppm.

Particulate solids.

Although the recorded values at the six sites were generally quite low, on certain occasions Site 2 had very high recorded concentrations eg. November 1985 the recorded concentration was 498 ppm(Fig 8). This could be considered to be deleterious to life. Following this high input, the rest of the sites, with the exception of Site 4, showed an increased concentration of particulate solids. For the remainder of the sampling period the levels of particulate solids were quite low.

Heavy metals.

The recorded levels of heavy metals for all the sites were extremely low and as such are unlikely to affect stream life.

5.2 Biological results.

The results from the biological sampling programme(Tables 26 - 61, Appendix 3) show that in the river system studied a wide variety of species were recorded. However, the fauna particularly at Sites 2 and 3 could be considered to be a polluted water type, while at the other sites,particularly Site 4, a typical clean water fauna existed.

Site 1.

The fauna at this site tended to be quite diverse with no one species being really dominant. Even though the Plecoptera were present they were not recorded in great numbers. The species recorded were Leuctra moselyi, Isoperla grammatica, Perlodes microcephala and Nemoura avicularis. Leuctra was the most common species. There was little seasonal variation in numbers, however, no plecopterans were recorded in November 1986.

The Ephemeropterans were quite abundant in the samples at certain times during the year. This group tended to be dominated by Baetis rhodani(Fig 18), although Ecdyonurus dispar, Rhithrogena semicolorata and Ephemerella ignita were also present in quite large numbers. The last of these species was particularly numerous during the summer months(Fig 15).

The Trichopterans were represented at this site by the larvae of seven species. Rhyacophila dorsalis was the most common species encountered and was present in five of the six sampling occasions. The hydropsychid species, H.instabilis and H.siltalai were the other species usually present.

The larvae of species belonging to the Coleroptera and Diptera were also present here but never in large numbers. The mollusca were also present at this site but, with the exception of Hydrobia jenkinsi in the October 1985 sample, this group tended to be scarce.

Malacostracan Crustaceans were represented by Gammarus pulex and Asellus aquaticus,however, these were never found in great numbers and they appeared only rarely in collections.

The Oligochaeta were represented at this site by species belonging to the Naididae, Tubificidae, Enchytraeidae and Lumbriculidae. With the exception of the October 1985 and April 1986 collections(Figs 12 and 14) however, they were never present in large numbers. Six species of Naididae were present with Nais elinguis(Fig 25) being the most common. The other members of this group were only present in small numbers.

Ophinodais serpentia and Nais variablis were only collected infrequently.

The most important tubificid numerically was Tubifex tubifex, although Limnodrilus hoffmeisteri and Rhyacodrilus coccineus were also present. The Enchytraeidae were an important group at this site with large numbers of individuals often present(Fig 26). This was particularly so in the October, April and June collections(Figs 12, 14 and 15). The Lumbriculidae were represented by three species although no one species from this group was ever abundant.

The Chironomidae were also well represented, a wide variety of species being recorded. Tvetania calvescens was the most frequently found species in the winter months(Fig 12), while Cricotopus bicinctus had a peak population in the summer(June) sample(Fig 15). Both Brillia longifurca and Brillia modesta were quite frequently found, as was Rheocricotopus fuscipes(Figs 12 - 17). Generally it appeared that conditions at this site were not favourable for the Chironomidae.

Site 2.

Compared to Site 1 there appeared to be a marked change in the benthic community. The Oligochaeta and Chironomidae were the dominant taxa, with very large populations being recorded. However, at most sampling occasions,other taxa were present including Plecoptera, Ephemeroptera, Trichoptera, Coleoptera, Crustacea and Diptera.

The only plecopteran recorded was Leuctra moselyi. This was collected on two occasions, in April and September, and as such the prevailing conditions did not seem favourable for this group.

The Ephemeroptera were present in greater numbers and variety than the Plecoptera. Baetis rhodani was the most common species and was present in quite large numbers on several occasions, particularly during the summer/autumn period(Fig 18). Greatest numbers were collected in the September sample(Fig16). Rhithrogena semicolorata and Ecdyonurus dispar were often present in the samples but not in great numbers. During the summer, in addition to B.rhodani, the nymphs of two other species namely, Baetis scambus and Ephemerella ignita(Fig 15) were quite numerous at this site. However, the numbers of E.ignita markedly decreased after June(Fig 19), while B.scambus was not recorded in the next collection (September). During the winter months B.rhodani was the only mayfly present at this site(Fig 18).

Although five different species of trichopteran larvae were caught during the course of the sampling programme, no species was collected in large numbers.

However, it was only in the October sample that no trichopterans were collected.

Both Gammarus pulex and Asellus aquaticus were recorded for this site but conditions did not appear to suit them as they were never present in large numbers. This was also true for the Coleoptera.

By contrast the Oligochaeta were present in very large numbers. The species present were similar to those found at Site 1. As at this previous site the dominant groups were Naidae, Tubificidae and Enchytraeidae. Nais elinguis was the dominant Naidid, and this species was most abundant in April(Fig 14) where it was the most abundant organism at this site. On other sampling occasions the populations of this species were much smaller(Fig 25), and in fact, this organism was completely absent from the January sample. The other Naidae present at this site were Stylaria lacustris, Nais variablis and Nais alpina. These species were mainly recorded in the summer/autumn period and even then not in large numbers. Throughout most of the year it was species belonging to the Tubificidae and Enchytraeidae that were the dominant organisms at this site(Figs 24 and 26). In the October samples Tubifex tubifex, Limnodrilus hoffmeisteri and species belonging to the Enchytaeidae were present in large numbers(Fig 12). The peak population of L.hoffmeisteri was found at this time. By January the numbers of T.tubifex had markedly reduced(Fig 24). However, increased numbers of this species were then recorded for the rest of the sampling programme with a peak in population density recorded in the September sample(Fig 16). The numbers of the Enchytraeidae remained high throughout the sampling programme(Fig 26). The Lumbriculidae were also present in quite large numbers at this site but were never as abundant as species belonging to the other three groups previously mentioned. Stylodrilus herringianus was particularly numerous in the October sample(Fig 12).

The numbers of the Chironomidae showed considerable variation throughout the year. Species present tended to be similar to those found at Site 1. Peak abundances for many species occurred in the October sample(Fig 12). At this time Eukiefferiella clarripennis was numerically the dominant chironomid present. However the numbers of this organism declined in later samples. Although it was not present in large numbers in the October sample the seasonal abundance of Tvetania calvescens followed a similar pattern to E.clarripennis. Two of the most ubiquitous chironomids found were Brillia longifurca and Rheocricotopus fuscipes. The numbers of both species initially declined after the October collection, but then increased after January(Figs 21 and 23). Of the other species present at this site, Cricotopus bicinctus was only present in the summer(Fig 20), while Orthocladius(O)rubicundus was present in quite large numbers in October(Fig 12), but there was then a marked reduction in numbers. After January however, its numbers began to increase gradually such that its peak abundance was attained in September(Figs 16 and 22). At this time it was in fact the most numerous chironomid present. Brillia modesta, Prodiamesa olivacea and Conchapelopia sp were also recorded but were never present in large numbers.

Site 3.

The fauna at this site was broadly similar to that found at Site 2 with the Chironomidae and Oligochaeta still the dominant groups. However, species belonging to the Plecoptera, Ephemeroptera, Trichoptera, Crustacea, Coleoptera and Diptera were collected from this site.

Only two species of Plecoptera were found namely, Nemoura avicularis and Leuctra moselyi. L.moselyi was found infrequently at this site while the former species was only recorded on one occasion.

The most abundant Ephemeropteran was B.rhodani although the nymphs of this species were virtually absent from the October collection and totally absent from the January samples. Peak numbers for this species were reached in the September collection(Fig 16) following marked increases in numbers in the April and June samples(Figs 14, 15 and 18). Three other Ephemeropterans were also present in the June samples namely, E.ignita(Fig 15), B.scambus and E.dispar. However, they never matched the population density of B.rhodani.

The Trichopterans, Crustaceans and Diptera were only found in small numbers at this site.

As at Site 2 the dominant Oligochaetes were Nais elinguis, Tubifex tubifex and Enchytraeid sp. Large numbers of Nais elinguis were present in the October sample (Fig 12) but maximum abundance of this species occurred in April(Fig 14). After this time the numbers of this species decreased(Fig 25). The numbers of T.tubifex were often smaller than at Site 2, but as at this previous site a peak in population size occurred in the September samples(Fig 24). With the exception of the October samples(Fig 12) another tubificid, Limnodrilus hoffmeisteri was usually present in the samples but in small numbers. By contrast the Enchytraeidae were abundant throughout much of the year(Fig 26). The dominance of this group can be seen in the fact that it was the only oligochaete group present in the January samples(Fig 13). The numbers of this group tended to be quite high at all sampling occasions but a definite peak was observed in October(Fig 12).

The chironomid species present were similar to those found at Site 2, although the number present were usually smaller than at Site 2. Brillia longifurca, O(O)rubicundus and Rheocricotopus fuscipes were usually present at this site throughout the year,but all three reached peaks in larval numbers in October(Fig 12). However, it was Tvetania calvescens that was the most abundant Chironomid of the October samples(Fig 12). Following the peak in larval numbers of E.clarripennis in October, there was a marked reduction in population size such that this species was not present after January. As at Site 2 C.bicinctus was most abundant in the summer collection(Fig 15) although the numbers of this species showed a reduction to those encountered at Site 2(Fig 20). Brillia modesta and Conchapelopia melanops also tended to be found in samples throughout the year but not in large numbers.

Site 4.

Of the six sites studied this site had species more typical of clean water conditions. Plecoptera, Ephemeroptera, Trichoptera, Diptera, Coleoptera, Mollusca, Hirudinea, Chironomidae and Oligochaeta were well represented.

Four species of Plecoptera were recorded from this site, these were, Isoperla grammatica, Perlodes microcephala, Leuctra moselyi and Nemoura avicularis. P.microcephala was present on four sampling occasions and was most abundant in June. L.moselyi was also quite common and this species became abundant in September. The other two species mentioned were only rarely found and then in small numbers.

The Ephemeroptera were present in far greater numbers than the Plecoptera. As at other sites B.rhodani was the most numerous species. It was present in large numbers in all samples but with a definite peak in numbers occurring in June(Fig 15). From this peak the numbers recorded declined such that the smallest population of this species was recorded in November(Figs 17 and 18). R.semicolorata and E.dispar were also recorded at all sampling occasions. However, the numbers present in the samples were always less than those of B.rhodani. E.ignita(Figs 15 and 19) and B.scambus(Fig 15) were generally confined to the samples taken during the Summer months. Caenis moesta was also present during the sampling period but was not abundant at any time.

The Trichoptera were represented by larvae belonging to six species, but none of these species appeared to be abundant at this site. Glossosoma conformis, R.dorsalis, H.siltalai and H.instabilis were the most numerous species in the samples,being present at most sampling occasions. Philapotomus montanus and Polycentropus flavomaculatus were only present infrequently and then in very small numbers.

Species belonging to the Diptera, Coleoptera, Mollusca and Hirudinea were present in the samples throughout the year but were not present in great numbers.

Although species belonging to the Oligochaeta and Chironomidae were present in the samples from this site they showed a marked reduction in numbers when compared to those from Sites 2 and 3. Quite a wide variety of both oligochaetes and chironomids were recorded. Once again N.elinguis and Enchytraeid sp seemed to be the most common oligochaetes(Figs 25 and 26). T.tubifex(Fig 24) was only present in very small numbers at this site and did not approach the populations recorded at Sites 2 and 3. The Chironomidae, although represented by nine species were not populous T.calvescens was the most abundant species in the October and January samples (Figs 12 and 13) while in April it was O(O)rubicundus(Fig 14). Species such as B.longifurca(Fig 21), B.modesta and Conchapelopia melanops were also usually present in the samples. As at other sites C.bicinctus was present in greatest numbers in the June collection(Fig 15 and 20).

Site 5.

Throughout the period of the survey, Site 5 also exhibited quite a diverse fauna. However, the Oligochaeta and Chironomidae were numerically more important here than at the previous site but only on certain occasions did they reach levels seen at Sites 2 and 3.

The Plecoptera were generally well represented at this site, and with the exception of the October samples, representatives of this group were present in all collections. L.moselyi was particularly numerous in the September sample. Other Plecopterans present throughout the year were P.microcephala, I.grammatica and N.avicularis.

The dominant Ephemeropteran was again B.rhodani, although quite large nymphal populations of this species were present throughout the year(Fig 18), peak numbers were found in the summer/autumn samples(Figs 15 and 16). E.ignita was present in greatest numbers during the June collection(Fig 15), but as at other sites numbers dropped markedly by the next collection(Fig 19). E.dispar and R.semicolorata were also quite common at this site and both species were recorded on five sampling occasions. E.dispar appeared to reach a peak in numbers in January, by contrast, R.semicolorata did not show any noticeable peaks in larval numbers during the year. Two other species were only recorded on only one sampling occasion, these were B.scambus in the June samples, and E.danica from the April samples.

Six species of Trichopterans were recorded with R.dorsalis, H.silitalai and H.instabilis being the most common.Plectrocnemia geniculata was found in the April collection but was absent from all others.

Quite large numbers of Coleopterans and Dipterans were recorded at certain times of the year. Limnius volkmari and Dicranota sp were particularly numerous in the January samples.

Asellus aquaticus and Gammarus pulex were never abundant at this site, although they were present throughout the year. Molluscs such as Hydrobia jenkinsi and Ancylus fluviatile were also found in most samples but never in great numbers. The Hirudinea were represented by two species, namely, Glossiphonia complanata and Erpobdella octoculata.

The Oligochaete community was dominated by N.elinguis and the Enchytraeidae. However, it was only in the October samples(Fig 12) that large numbers were recorded. Two species of Lumbriculid, namely, Stylodrilus herringianus(Fig 12) and Stylaria lacustris were also present in large numbers in the October samples. T.tubifex was also recorded and reached a peak in numbers during April(Fig 14). The numbers of oligochaetes was then low throughout the rest of the year with the numbers present in the November samples being very much smaller than those of the October samples.

The seasonal abundance of the Chironomidae followed a broadly similar pattern to that of the Oligochaeta, with large populations present in the October to April period followed by a noticeable reduction in numbers after this point. T.calvescens and R.fuscipes were the most numerous species in October(Fig 12). The former species was also the most abundant species in January(Fig 13). After this time it disappeared from the samples and only reappeared in September when its numbers were quite small. Two other species, B.longifurca(Fig 21) and O(O)rubicundus(Fig 22) were present in samples throughout the year but were never abundant. C.bicinctus was recorded from this site, and as at other sites it was only found in the June samples (Fig 15) when it was the most abundant species.

Site 6.

This site was broadly similar to site 5 possessing a diverse fauna. This included Plecopterans such as I.grammatica and P.microcephala. However, these were never present in large numbers.

As at other sites, B.rhodani was the dominant ephemeropteran. Large populations of this species seemed to be present throughout the year(Fig 18) but particularly in the October and September(Figs 12 and 16). E.dispar was also recorded at this site and was numerous in the June collection. Two other species, E.ignita(Figs 15 and 19) and B.scambus showed their typical seasonal pattern of abundance and were only recorded from the June samples.

The Trichopterans were never present in large numbers at this site. This was also the case for species belonging to the Diptera, Mollusca, Hirudinea and Crustacea. Although G.pulex and A.aquaticus were never abundant, they were recorded in greater numbers than at any other site.

The Oligochaeta wer quite numerous at this site with N.elinguis(Fig 25) and Enchytraeidae being numerically the most important species. This was particularly so in the June samples(Fig 15). T.tubifex(Fig 24) and L.hoffmeisteri were never abundant as at other sites but were usually present in the samples.

The Chironomidae also showed a general decrease in numbers at this site. However, there was quite a diverse Chironomid fauna including C(C)bicinctus which was particularly numerous during the summer(Fig 15). Two other species, R.fuscipes (Fig 23) and O(O)rubicundus(Fig 22) seemed to have large populations at this site for most of the year. The latter species was particularly abundant during April (Fig 14). O(E)thienemanni was another species which increased markedly in numbers in the April(Fig 14) collection. Other species such as Conchapelopia melanops, B.longifurca(Fig 21) and B.modesta were present in many samples but were never abundant.

5.3 Computer analysis of the biological results.

The results were analysed using both ARTHUR 81 and SPSS-X. The species lists used for these programs are listed in Figs 40-45. Hard copies of printouts can be found in Appendix 7.

October 1985.

Both SPSS-X and ARTHUR showed that Site 2 was very distinct from the other sites. Site 3 was almost always the 'nearest neighbour' to Site 2. The dendograms (Figs 46 - 48) plotted by SPSS-X indicate that Sites 5 and 6 were closely related, and both of these were the next 'nearest neighbour' to Sites 2 and 3. Sites 1 and 4 were quite closely linked although points from both Sites 5 and 6 became closely associated. The WARD method of clustering(Fig 46) gives the best separation and further emphasises the isolation of Sites 2 and 3 as does the SELECT routine used in ARTHUR(Fig 49) which clearly separates Site 2 from the others. Site 3 is also very distinct with close clustering occurring between Sites 1, 5 and 6. Correlation and probability values for ARTHUR (Fig 50) show that in a number of cases there are high probabilities with high correlation values indicating that there was an association in the numbers of certain species eg. T.tubifexand L.hoffmeisteri. ARTHUR(Fig 51) also showed that 94.2% of the data could be assigned to the first principal component ie most of the data is aligned orthogonally in one direction and can be seen in the first princial component plot(Fig 52). This indicates that each site tends to be separate in composition from the others. If most of the data does not lie in the first principal component then it can be said to be less well defined and as such each site will tend not to have a typical faunal composition and poor clustering will result. Thus, the principal component plots will show mixed data points.

January 1986.

The picture is not so clear in January with the sites being much more difficult to separate as only 63.9% of the data is found in the first principal component(Fig 53). This fact is reflected in the first principal component plot(Fig 54) which shows indefinite separation of sites. Use of the SELECT routine does aid separation(Fig 55), this shows Sites 5 and 6 being clustered together but he rest being less distinct.

SPSS-X confirms this feature and shows poor separation in the dendograms(Figs 56 -59). This tends to suggest that very few data points were typical for their sites.

April 1986.

The principal component analysis for this sampling occasion produced a much better clustering of the data than for January with 91.5% of the data being represented in the first principal component(Fig 60). Good correlations were found for R.fuscipes with B.longifurca, O(E)thienemanni and O(O)rubicundus(Fig 61). Separation of clusters was not as good as could be hoped for in the first principal component plot(Fig 62), but separation of sites to a small extent was seen. After using the SELECT routine (Fig 63), the sites became very well separated with little mixing of data point occurring. The other data points were not so well clustered. One point from Site 6 appeared to be totally distinct with the others from that site and was probably due to the large population of N.elinguis found at this site in one sample.

This lack of definition was also found with the CENTROID and MEDIAN methods of clustering(Figs 64 and 65). WARD's method(Fig 66) tended to group the points from Site 6 rather well. These were further clustered with points from Site 5. Site 3 appeared to be quite well clustered, although various other points interfered here. The AVERAGE LINKAGE(within groups)method(Fig 67) and COMPLETE LINKAGE method(Fig 68) did not produce definite patterns, but the between groups method(Fig 69) and SINGLE LINKAGE method(Fig 70) both showed that Site 6 was generally quite distinct with seven points being closely clustered.

June 1986.

Five principal components were needed here for 98.1% of the data to be accounted for(Fig 71), and this serves to illustrate the wide spread in the raw data. Fig 72 shows a good correlation was seen between N.elinguis and T.tubifex and between baetid mayflies and flattened mayflies. The plot produced after using SELECT(Fig 73) indicated that while Sites 1 and 4 were rather mixed, the other sites had good separation.

The routines used in SPSS-X gave rather clustering than in ARTHUR. The CENTROID method(Fig 74) clearly separated Site 4 from the other sites. Site 3 was also well clustered. However, two distinct groups were seen with this method, those involving Sites 4, 5 and 6, and those including Sites 1, 2 and 3. This trend was confirmed bythe MEDIAN method(Fig 75). AVERAGE LINKAGE(between groups) (Fig 77) and WARD's method(Fig 78) were not so useful in this respect.

September 1986.

The Eigenvectors extracted from ARTHUR(Fig 79) suggested that the data was quite well grouped in the first orthogonal as the first vector had 82.1% of the data. However, the principal component plot(Fig 80) give as good separation as was expected. Good separation was seen after the selection of best features(Fig 81).

Clustering routines with SPSS-X tended to group Sites 2 and 3 quite closely but not any of the other sites. WARD's method(Fig 82) was particularly good at showing this feature with distinct clusters of these two sites being seen. The SINGLE LINKAGE method(Fig 83) also indicated that Sites 2 and 3 were dissimilar to the other sites.

November 1986.

November data also indicated Sites 2 and 3 were rather alike, and that, Site 6 also appeared rather distinct. 88.4% of the data could be seen in the first orthogonal(Fig 84). This gave the first principal component a rather confused picture(Fig 85). More information could be derived after selection(Fig 86) where the plot shows that Site 6 was clearly distinct from the other sites. Sites 2 and 3 were closely clustered and Sites 1, 4 and 5 tended to be grouped also. This picture was largely confirmed by SPSS-X. The dendogram derived from WARD's method(Fig 87) clearly showing the patterns observed in ARTHUR.

6. Discussion.

6.1 Chemical results.

Keith(1976) has obseved that biological treatment reduces the total organic content of bleached kraft mill effluents, however, despite these processes it is impossible to totally eliminate all pollutants from an effluent. This almost certainly applies to the paper mill at Llangynwydd. The two main problems associated with paper mill wastes are those of reduced dissolved oxygen concentration and increases in suspended solids. It was observed that the general water quality was certainly inferior immediately below the paper mill when compared with the situation upstream. The situation at Site 3 was possibly accentuated by the discharge from a sewage treatment works above the sampling point.

Dissolved oxygen.(Fig 6)

The dissolved oxygen concentration at Site 1 was generally quite good throughout the survey and was frequently above 100% saturation. This is somewhat surprising when considering the fact that the site is only 1.5Km downstream of the town of Maesteg and as such would be subjected to any discharge from the industry of that town. The average concentration for this site was 96% saturation and did not appear to show any marked reduction during the summer months. This fact was highlighted by 112%(11.5 ppm) saturation recorded during July when the ambient water temperature was 14^{o}C.

At Site 2 however, which was downstream of the paper mill, a different pattern of dissolved oxygen was observed. Even so, in the initial part of the investigation the oxygen concentration was surprisingly good, with a dissolved oxygen level of 90.3% (9.4 ppm) saturation being recorded in December. After March the dissolved oxygen concentration dropped quite steadily throughout the summer as the temperature increased which is very much as could be expected. During the 24 hour survey(Fig 11) a level of only 2.9 ppm was recorded at 3 pm for this site.

The dissolved oxygen concentration at Site 3 was generally greater than at the previous site and although there was a drop during the summer/autumn period, severe oxygen depletion did not appear to be a problem. This was also true for the other three sites with only Site 6 showing any pronounced drop in dissolved oxygen concentration during the summer.

BOD$_5$.(Fig 9)

This parameter only appeared to be a significant factor at the first three sites. Site 2 had quite high values especially when dissolved oxygen concentrations were low in the autumn. In general Site 2 showed the highest levels for the river. Site 1 also had high levels during the winter/spring period and this may be interpreted as resulting from discharges above the site in the Maesteg area.

Site 4 had the lowest BOD$_5$ levels and as such may be considered the least polluted site. Sites 5 and 6 had quite high levels but these are unlikely to be deleterious to the environment at these sites.

Particulates.(Fig 8)

Particulates only appeared to be a problem on one occasion during the survey, that is in the December to February period when large amounts of particulates were discharged into the stream from the paper mill and this could have a significant effect on the benthic community. The concentration of particulates reached a level of 498 ppm at Site 2 in December. The concentration of particulates then decreased downstream from Site 2 such that a level of only 203 ppm was recorded at Site 6.

Oxidised and Ammoniacal nitrogen.(Figs 7 and 10)

The concentrations of these two parameters at all six sites were always quite low. These low levels indicate that the effluent was very low in nitrogen and this would be expected as pulping processes tend to use sulphite rather than nitrite, although some nitrogen could be expected to be present.

Other parameters.

The levels of heavy metals and orthophosphates were always low and this may be expected as they are not needed for pulping or bleaching. However chloride levels were much higher than either nitrite or nitrogen levels and this is understandable when it is considered that chlorine is used in bleaching and as such would be expected to be found in an effluent. However, most chlorine in bleaching and pulping tends to be bound organically and more detailed chemical analysis would be required to ascertain the amount that is present in the receiving waters.

The hardness of the water used by the paper mill is quite soft as soft water is required by the paper industry for pulping. The pH(Fig 5) of the stream shows it to be quite alkaline and did not vary much throughout the study and as such it can be said that the effluent produced by the mill was quite neutral.

As stated, the two main problems associated with paper mills are those of oxygen depletion and suspended solids. The effects of these two factors has been extensively documented. Gaufin(1958) found that suspended solids in particular were detrimental to life by blanketing the river for many miles below an outfall on the Mad River. The Mad River seems a particularly severe case and although blanketing of the Llynfi was apparent on the first sampling occasion in this investigation, it was not a problem afterwards. The high discharge of particulates during December would have been expected to be detrimental to any clean water fauna present. However, during the study period this was the only recorded discharge of significant proportions. Dines and Wharfe(1985) certainly found that a high particulate load in the Swale estuary was detrimental to life. Similarly the same workers found this to be the case in the Medway estuary(Dines and Wharfe, 1986). In both cases the paper mills under investigation were discharging continually throughout the year.

Since the particulates discharged by a paper mill are largely organic material, this would be expected to exert an effect on BOD_5 and consequently the amount of dissolved oxygen present. Further, deoxygenation of receiving waters will result from the organic chemicals used in pulping and bleaching. However, Keith(1976) has pointed out the total organic load in kraft mill effluents will be reduced with biological treatment, but, nevertheless the presence of chlorinated organic compounds is of concern. Biological treatment can also significantly reduce the amount of organically bound chlorine. Other deoxygenating agents present in such effluents undoubtedly influence BOD_5. However, the Welsh Water Authority do not routinely test for these products and as a consequence their influence on the oxygenated state of the river is difficult to quantify. Certainly the dissolved oxygen concentration was lower and the BOD_5 levels higher in the Llynfi immediately below the paper mill than elsewhere in the system. Thus it is likely that the effluent entering the receiving water is probably responsible for this deterioration of water quality.

In addition to the toxic compounds already mentioned, neutral organics provide a considerable contribution to the effluent from a kraft mill. Voss(1984) has suggested that typical levels for about forty compounds found in mill effluents was about 3 ppm and ranging from about 0.4-20 ppm. He suggests that dilutions of 1:100 would be expected after entering the receiving waters. However, due to this dilution factor it would be difficult to specify whether such levels would be deleterious to the environment. Indeed, dilution is a major factor reducing toxicity as is pH.

Ladd(1969) has shown that the toxicity to fish is reduced when effluents are in the pH range 8.5-9.5. Similarly, Leach and Thakore(1974) found that the toxicity of resin acids,which are a major component of kraft mill wastes, were substantially greater at pH 6.4 than at pH 7. The pH range found at Site 2 below the effluent outfall was consistently above 7,averaging 7.3, and as such would have a neutralising effect on the effluent. This effect can be explained by the pH-partition theory proposed by Jollow and Brodie(1972) who suggested that a weak acid ionises in alkaline solution with the ionised form not expected to pass through cell membranes as readily as the more lipid soluble unionised form that exists in acid media. Thus, if the effluent is alkaline, toxicity consequently will be reduced. Indeed, pulp mills actively select a pH in this range for the effluent as the acid pH's tend to damage treatment facilities. Further, British Tissues Ltd selected the site of the plant due to the softness of the water present and this was indicated in the levels of total hardness recorded.

In conclusion it can be stated that chemical parameters recorded showed quite a large variation over the sites studied. Site 4 almost invariably had the highest levels of dissolved oxygen and the lowest levels of both particulates and BOD_5. Conversely, the poorest conditions were found principally at Site 2 and to a lesser degree at Site 3. Thus it can be said that any detrimental effect on the river below the paper mill may have been due to the discharges from this facility.

6.2 Biological results.

The chemical results indicated that the paper mill at Llangynwydd affected the water quality of the river. These changes in water quality appeared to produce changes in the benthic community. It was found that certain taxa seemed to be adversely affected while others were favoured by organic enrichment.

Groups that appeared to be adversely affected were the Plecoptera, Ephemeroptera and Trichoptera. The Plecoptera were never abundant at any site during the course of survey even at Site 4. They were, however, usually absent at Sites 2 and 3. Leuctra moselyi was usually the most abundant species encountered but other species such as Nemoura avicularis, Perlodes microcephala and Isoperla grammatica were also recorded. Stoneflies are said to be typically intolerant of organic enrichment (Hynes, 1960) and as such their absence would be expected in a polluted river system. The largest populations were always found at Site 4 and in June stoneflies were relatively numerous(74/m^2). Thus in general, Sites 4, 5 and 6 had the largest populations although stoneflies were recorded at Site 1.

The ephemeropterans were always much more numerous than the plecopterans. Baetis rhodani was very numerous on certain occasions at all sites(Fig 18). Indeed, the large poulations of this species observed at Sites 2 and 3 may have partly resulted from reduced competition with more sensitive species such as Ecdyonurus dispar and Rhithrogena semicolorata for these two species were never abundant at Sites 2 and 3. This was clearly seen in the September sample when 2754/m^2 B.rhodani were recorded at Site 2. Another species, Ephemerella ignita was only numerous during the summer(Fig 19). Similarly, Baetis scambus was only present during the summer although it was not recorded at Site 1. Other Ephemeropterans recorded in the survey included Caenis moesta and Ephemera danica but these were only rarely recorded.

Most Trichopterans have a life-cycle lasting a year and as such may be present in streams at all times. With the exception of Sites 2 and 3 this was the case. Seven species of caddis were recorded from the river with Rhyacophila dorsalis, Hydropsyche instabilis and Hydropsyche siltalai usually being the most abundant species. However, no species was ever present in large numbers at any site. Both caddis and mayflies are tolerant of slight pollution but will disappear if pollution becomes more severe.

Dipterans and Coleopterans were always present and at certain sites a good species diversity was found. Dicranota sp and Limnius volkmari were usually the most ubiquitous, although Hemerodroma sp and Tabanus sp were frequently recorded. The Chironomidae will be considered seperately from the other Dipterans.

The river generally seemed to be unfavourable for malocostracan crustaceans for although Asellus aquaticus and Gammarus pulex were recorded they were usually present in small numbers.

Both the Hirudinea and Mollusca were usually present in small populations. Two species of leech were recorded from the river, Glossiphonia complanata and Erpobdella octoculata. A number of species of molluscs were recorded with Hydrobia jenkinsi being present on one occasion(October) in large numbers at Site 1(320/m^2). Other molluscs recorded included Ancylus fluviatilis and Limnaea pereger.

The distribution of the Chironomidae and Oligochaeta differed to the other groups for these were the dominant organisms at the more polluted sites, and, on occasions were abundant at other sites. It can therefore be suggested that these two taxa are favoured by organic enrichment. The most abundant species of Chironomidae were Brillia longifurca, Tvetania calvescens, Eukieferriella clarripennis, Orthocladius(O) rubicundus, Rheocricotopus fuscipes and Cricotopus bicinctus. C.bicinctus was most abundant in the summer months(Fig 20) and was not found at other times. Sites 2 and 3 usually had large chironomid populations but chironomids were also present at all the other sites and were abundant at certain times. The October samples contained the greatest number of chironomids, but after this time the numbers fell. B.longifurca and E.clarripennis(Fig 12) reached peak abundances at this time. All species tended to have a wide distribution and did not appear to be confined to organically enriched regions. However, at Site 4 only small populations were recorded with the Ephemeroptera tending to dominate. B.longifurca was usually the most numerous species in the more polluted sites and large populations were recorded in the June samples(Figs 15 and 21). Brillia modesta was never particularly numerous at any site.

The oligochaetes were also widely distributed but as expected tended to be the most abundant in those areas receiving organic enrichment ie Sites 2 and 3. At these sites Nais elinguis, Enchytraeidae and to a lesser extent Tubifex tubifex were the dominant forms. These species were also found at the other sites. Generally the oligochaete populations were at their greatest in October . The numbers of worms then fell during the spring/summer period when the Chironomidae and Ephemeroptera became more abundant.

The general effects of the effluent on the benthic community can be seen in Figs 27-32. From Fig 27 we can see that at Sites 2 and 3 the Oligochaeta and to a lesser extent the Chironomidae dominated the benthic community in October. At Site 2 oligochaetes comprised 75% of the community while at Site 3 the proportion had risen to 84.6%. At the other sites, with the exception of Site 5, the oligochaetes and chironomids were considerably less important. At Site 5 however, an oligochaete density of 4932 worms/m^2 was recorded.

In the January samples, the oligochaetes were less important at Site 2, but there was again a large population at Site 3. The Ephemeroptera(Fig 28) were an important group at Sites 4, 5 and 6 however, the Ephemeroptera were almost entirely composed of B.rhodani. For example, at Site 4, 93% of the Ephemeropterans were B.rhodani. At Site 2 however, other species were more important but the benthic community was sparse at this time.

In April(Fig 29) it can be seen that the oligochaetes dominated the benthic community at all sites even at Site 4 where 87% of the animals recorded were oloigochaetes. Site 6 had the largest populations of benthic invertebrates at this time with 9514 animals/m^2 being recorded. The oligochaete N.elinguis comprised 24% of the benthic community.

In the June samples the Ephemeroptera became particularly important at Sites 3-6 and especially at Site 4(Fig 30) where B.rhodani and E.ignita comprised 54% and 30% respectively of the total benthic community. The largest oligochaete population was found at Site 2 with 1602 worms/m^2 being recorded. However, the Chironomidae were the most numerous taxon at this site with a total of 1768/m^2 being recorded. Site 1 also had large chironomid populations with C.bicinctus comprising 38.7% of the total invertebrates recorded.

By September(Fig 31) the general community structure in the river had changed. Site 2 had very large worm populations. However, with the exception of Site 3 the oligochaetes were not a dominant group. T.tubifex comprised 81.2% of the total worms present at Site 2. The large numbers of T.tubifex at this site were matched by B.rhodani which achieved a density of $3754/m^2$. A total invertebrate density of $12954/m^2$ was ecorded at Site 2 and this was much larger than at any other site being twice as dense as Site 3, the next densest, which had $5966/m^2$.

The histograms for November(Fig 32) indicate that Site 6 had by far the largest numbers of benthic invertebrates at this time with $2202/m^2$ being recorded. Another important feature was the marked reduction in numbers at Site 2 where only $826/m^2$ were recorded. The Oligochaeta were again dominant particularly at Site 6 and to a lesser extent at Site 2 where they contributed 83% and 65% respectively to the benthic community.

If each site is considered in detail it will be seen that not only does the benthic community differ at the six sites but there are considerable variations in the benthic communities at a site during the course of the study. These latter variations are mainly due to the natural seasonal influences on the life-cycles of the benthic invertebrates and in some cases to variations in the effect of the effluent on the benthic community which is also related to seasons.

The species composition at Site 1 changed considerably during the period of the survey. The Chironomidae and Oligochaeta were the dominant taxa in October with 352 chironomids/m^2 and 1172 oligochaetes/m^2 being recorded, nevertheless, the general community was quite diverse during October. By January there was a marked reduction in the numbers of the Chironomidae and Oligochaeta with only $54/m^2$ and $132/m^2$ respectively being recorded. However B.rhodani became quite numerous at this time with $578/m^2$ being recorded. This was a significant increase from the numbers found in October(Fig 18) when only $74/m^2$ were recorded. Two species of Plecoptera were also recorded at this time in the form of P.microcephala and N.avicularis. Not only was there a reduction in the total numbers of chironomids present, but also in the number of species which dropped from eight to five. The oligochaetes showed a similar pattern with species numbers dropping from ten to four.

In April there was an increase in the numbers of species at this site with twenty-eight being recorded. There was also a change in the species composition with the proportion of Chironomidae and Oligochaeta increasing with a corresponding decrease in the numbers of B.rhodani. The most important chironomids at this time were

O(O)rubicundus, O(E)thienemanni, R.fuscipes and the most important oligochaetes were N.elinguis.T.tubifex, L.hoffmeisteri and the Enchytraeidae. Figs 25 and 26 indicate that N.elinguis and the Enchytraeidae had a considerable rise in numbers from the previous sampling occasion.

There was generally a continuation of this overall pattern in June. At this time large numbers of C.bicinctus were recorded(Fig 15). The increase in numbers of this species can be further illustrated when considering the fact that only 8/m^2 were recorded in April and 1028/m^2 were recorded in the June samples. The Enchytraeidae were at this time the dominant oligochaetes although Fig 26 shows that there was no significant change in numbers from the previous sampling occasion.

The mayfly E.ignita became quite common at this time with numbers of 42/m^2 being recorded. This species had previously been absent from the collections at this site.

In September it can be seen that there was another increase in the numbers of B.rhodani. This increase can be seen in Fig 18. At this time the Chironomidae were only represented by B.longifurca and R.fuscipes, however Figs 21 and 23 indicate that there was no significant difference in their numbers from the previous sampling occasion. Nine species of oligochaete were recorded but they were only present in small numbers. The numbers of E.ignita decreased significantly from those recorded in June with only 24/m^2 being recorded at this time.

Quite a diverse community was present at Site 1 in November with B.rhodani continuing to be the most abundant organism. However, from Fig 18 we can see that there was a significant decrease in numbers from the previous sampling occasion. Both the Chironomidae and Oligochaeta were only present in small numbers at this time.

At Site 2 the conditions seemed to be suitable for the development of large populations of worms although the conditions were not severe enough to totally eliminate all other species. It was in the first sampling occasion(October) that the Chironomidae and Oligochaeta were at their greatest abundance. T.tubifex and Enchytraeidae were the dominant worms and E.clarripennis the most common chironomid. The numbers recorded were 3608/m^2, 7116/m^2 and 2492/m^2 respectively. At this time in addition to the oligochaetes already mentioned, L.hoffmeisteri, Stylodrilus herringianus and Eclipdrilus lacustris were also abundant. While the chironomids B.longifurca, Tvetanià calvescens, R.fuscipes and O(O)rubicundus were also present in significant numbers.

The proportion of species changed quite drammatically by January. At this time the only oligochaetes present wereT.tubifex and the Enchytraeidae. Figs 24 and 26 show that there was a considerable drop in the numbers of these two species in the January sample when compared to the October sample. The numbers of chironomids also showed a marked reduction in numbers. For example the numbers of E.clarripennis dropped from 2492/m^2 in October to 82/m^2 in January. Increased numbers of cleaner water fauna were also present at this time with B.rhodani being the most numerous of these organisms with 152/m^2 being recorded. Other species present were E.dispar and R.semicolorata.

By April the numbers of certain oligochaete species showed significant increases in numbers. Figs 24-26 show that T.tubifex, N.elinguis and Enchytraeidae showed such increases in numbers. However, E.dispar, R.semicolorata and particularly B.rhodani were still present. O(O)rubicundus was the most numerous chironomid present. However Fig 22 shows that there was a significant decrease in numbers from the previous sampling occasion. Generally the chironomids were poorly represented in the April samples.

However, in June, a different picture was seen. The chironomids had increased in number. From Figs 21-23 we can see that there were significant increases in the numbers of B.longifurca, O(O)rubicundus and R.fuscipes. The overall numbers of oligochaetes dropped from those recorded in April when a density of 6276/m^2 was recorded, compared to only 1602/m^2 in June. B.rhodani, B.scambus and E.ignita were also quite numerous in June showing an increase in numbers compared to the previous sampling occasion.

By September there was another significant increase in the worm population, but a decrease in the numbers of chironomids, 9146 worms/m^2 and 990 chironomids/m^2 were recorded at this time. There was a significant increase in the numbers of T.tubifex(Fig 24). Fig 18 shows that there was a significant increase in the numbers of B.rhodani from the previous sampling occasion.

The fauna during November was generally sparse, B.rhodani, T.tubifex, Enchytraeidae were the most abundant forms but their numbers had markedly reduced from September. The decrease in numbers of these species can be seen in Figs 18, 24 and 26 respectively.

Site 3 had a similar benthic community to Site 2 in that it was generally dominated by the Chironomidae and Oligochaeta. In October other species such as L.moselyi, B.rhodani, Tabanus sp and Asellus aquaticus were also present. The most important chironomids at this site were B.longifurca, T.calvescens, E.clarripennis and R.fuscipes. Eight oligochaete species were present with N.elinguis, T.tubifex, Enchytraeidae and E.lacustris being the most numerous at this time.

In January the oligochaetes were severely reduced in numbers. The 95% confidence limits(Fig 26) show that the numbers of Enchytraeidae were significantly reduced from the previous sampling occasion. Indeed, the Enchytraeidae were the only oligochaetes present at this time. The Chironomidae were also reduced in numbers from October, but there were still eight species present in January. The 95% confidence limits(Figs 21 - 23) show significant drops in the numbers for B.longifurca, O(O)rubicundus and R.fuscipes.

Although the Enchytraeidae and N.elinguis showed a marked increase in numbers and were abundant in the April samples, there were only small populations of Chironomidae and other taxa present. A total worm population of 5178/m^2 was recorded at this time compared to 2508/m^2 in January.

In June the oligochaete Stylaria lacustris became quite numerous together with B.rhodani. Figs(20 and 21) show that there was a significant increase in the populations of the two chironomids, C.bicinctus and B.longifurca.

In September however, there was a significant reduction in the numbers of these two chironomids(Figs 20 and 21), while there was an increase in numbers of B.rhodani, T.tubifex, N.elinguis and Enchytraeidae(Figs 18 and 24 - 26). Other species recorded at Site 3 in September included the more typical clean water forms L.moselyi and E.dispar.

Although there was a general reduction in the numbers of individuals caught in November, the community was quite diverse with six species of chironomid and eight species of oligochaete being recorded. The most abundant species were R.fuscipes, N.elinguis, Enchytraeidae and B.rhodani(Fig 17). Two notable species present were N.avicularis and E.dispar.

At Site 4 the fauna reflected the much better water quality present at this site. It was particularly noticeable that the species composition was very different to that at Site 3. The Plecoptera and Ephemeroptera were far more important members of the benthic community. The Trichoptera were also present in greater numbers than in sites 1 and 2. By contrast the Oligochaeta and Chironomidae were never abundant at this site. The smaller numbers of these two groups could be clearly seen in the October results where only small populations were present. In Figs 21 - 26 the significant drop in numbers from Site 3 of the species B.longifurca, O(O)rubicundus, R.fuscipes, T.tubifex and Enchytraeidae can be seen. The reduced amount of suspended solids in the river at this site and the subsequent changes in the substrate encouraged lithophilic species to become established and, in the case of, B.rhodani to become very abundant (Fig 18). Net-spinning caddis eg. the hydropsychids, H.siltalai and H.instabilis were also quite numerous especially in January with populations of 28/m^2 and 24/m^2 respectively being recorded. Tabanus sp, Clinocera sp, Dicranota sp, Hemerodroma sp and Limnius volkmari were all frequently recorded during the survey.

Sites 5 and 6 had similar benthic communities and tended to have a diverse fauna including Plecoptera, Ephemeroptera, Trichoptera etc. However, the Chironomidae and Oligochaeta were more numerous than at Site 4. The October samples in particular had large numbers of these groups, however the populations seemed to be smaller than at Sites 2 and 3. The improved conditions at these two sites resulted from the confluence of the Llynfi with the Ogmore. There were some areas of deposition however, hence the greater proportion of burrowing forms. Stoneflies were quite numerous at these sites as were the flattened mayflies, E.dispar and R.semicolorata. However, B.rhodani(Fig 18) was again the dominant mayfly, but as at other sites E.ignita(Fig 19) was particularly numerous in June and was only present in small numbers at other times. Two species of Trichoptera were quite numerous at these sites, but even so were less numerous than at Site 4. The crustaceans G.pulex and A.aquaticus and the leeches E.octoculata and G.complanata were more abundant at these sites than elsewhere.

In the Llynfi the effluent discharged into the river will contain the chemical components of bleached kraft mill effluent such that the receiving waters will contain, according to Voss(1984) a mixture of resin acids, terpenes, halogenated acids etc. Voss has suggested that most of these chemicals tend to be inert, however, some such as those containing chlorine may be toxic, although Kringsatad and Lindstrom (1984) have suggested that they are biodegradable. Due to the non-routine sampling programme ofthe Welsh Water Authority for these types of chemicals, their influence is difficult to quantify. However, even though most of these chemicals may be non-toxic to life directly they will exert an effect on the dissolved oxygen present as they degrade. Oxygen depletion is a problem experienced in many cases following a discharge of an organic effluent(Hawkes and Davies, 1971). It was noticeable in this investigation that oxygen levels were often reduced at Sites 2 and 3.

Many workers have studied the effect of organic effluents and oxygen depletion on stream communities. Both Hynes(1960) and Hawkes(1962) have commented that heavy pollution affects whole taxonomic groups rather than individual species. Hawkes has also suggested three main trends in the benthic invertebrate community that will occur with varying degrees of pollution.

1) Progressive reduction and the eventual elimination of the less tolerant species in a succession according to their degrees of tolerance:

eg. Rhithrogena ------ Ephemerella ------ Gammarus

2) Providing pollution is not too severe there may be an initial increase in the numbers

of moderately tolerant species. If the degree of pollution is increased the species are then reduced in numbers in the following sequence:

eg. Baetis rhodani ------ Simulium ornatum ------ Hydropsyche ------ Helobdella stagnalis ------ Erpobdella testacea ------ Limnaea pereger

3) In cases of severe pollution there may be an invasion of the stream bed community by species which under natural conditions are not members of the riffle community. Their absence under normal conditions may be due to the fact that the environment is not suitable or because they are not able to compete successfully with members of the normal community. These organisms are normally members of silted communities in sluggish stretches in rivers or ponds. As the degree of pollution increases these are successively eliminated:

eg. Asellus ------ Sialis ------ Chironomus riparius ------ Tubificidae

Numerically the most important taxa in the Llynfi and Ogmore were the Ephemeroptera, Chironomidae and Oligochaeta. However, because the Plecoptera are very sensitive to organic pollution their presence or absence is often a good indicator of water quality. Indeed according to Hynes(1970) the Plecoptera and Ephemeroptera are eliminated in cases of organic pollution because they have high metabolic rates and therefore are more sensitive to a decrease in oxygen concentration than the slower metabolisers such as chironomids.

The Plecopterans in the Llynfi were never abundant but were recorded at all sites. P.microcephala and L.moselyi were the most abundant species. As one might expect with the reduced oxygen concentration at Sites 2 and 3, stoneflies were not recorded for most of the survey at these sites. With the exception of November, stoneflies were always present at Site 1. This sampling site had an average 96% saturation over the duration of the survey. Four species were recorded at this site, namely, N.avicularis, L.moselyi, P.microcephala and I.grammatica all of which according to Hynes(1960) are intolerant of organic pollution. These four species were recorded at a number of other sites and their numbers tended to increase as one moved downstream from Site 3. At Sites 4, 5 and 6 sizeable populations of stoneflies were recorded at certain times.

On certain occasions the Ephemeroptera were the dominant organisms in the Llynfi and Ogmore. Eight species were recorded during the survey period. The most numerous species was B.rhodani, although at certain times R.semicolorata, E.dispar, and E.ignita were present in large numbers. B.rhodani (Fig 18) was recorded from all sites and was nearly always present at each site throughout the year. Particularly large populations were found at the lower sites. Hynes(1960) suggested that B.rhodani is a mildly tolerant organism and therefore the sizeable populations recorded at Sites 2 and 3 may not only be attributable to tolerance but also possibly to a lack of competition. Indeed, very large populations of $2754/m^2$ and $1310/m^2$ respectively were recorded in September at Sites 2 and 3. At this time only a few other species other than chironomids or oligochaetes were present. The populations of B.rhodani at Sites 2 and 3 in September were much larger than at Sites 4, 5 and 6. The 95% confidence limits (Fig 16) show that there were significantly larger populations at Sites 2 and 3 than at any other site during September. Additionally, the dissolved oxygen concentration at Site 2 and 3 was in September much lower than at Sites 4, 5 and 6, being less than 60% saturation at the upper sites and greater than 90% saturation at Sites 4, 5 and 6. This factor would obviously favour the cleaner water fauna such as the Plecoptera which were present in relatively large numbers at this time and as such may have increased competition. Another feature concerning the seasonal incidence of B.rhodani is that peaks in population density were reached particularly in the autumn. Macan(1957) has indicated that although eggs of B.rhodani hatch throughout the winter, the rate is higher in the autumn and again at the beginning of the year. Indeed populations were quite large in January, but not as great as in the autumn.

The flattened mayflies, R.semicolorata and E.dispar were frequently recorded at all six sites. The former species tends to be more sensitive to pollution than E.dispar, and this may be explained by the fact that E.dispar according to Ambuhl(1959), is able to move its gills to create a current and thus maintain a respiratory flow. Ambuhl noted that this phenomenon, lacking in R.semicolorata, enabled Ecdyonurus to survive at lower oxygen concentrations. However, neither of these two species were ever abundant at Sites 2 and 3, but quite large populations of E.dispar were present at the other sites eg. Site 5 in January when $184/m^2$ were recorded.

Both E.ignita and B.scambus were only present in large numbers during the summer. Indeed very large populations of E.ignita were recorded at all sites, particularly Sites 4, 5 and 6 in June. Fig 15 shows that the populations at these sites were significantly greater than at the upstream sites in June. Fig 19 also shows the scarcity of this species at other sampling occasions. This peak in abundance in June could be expected as many workers including Pleskot(1958), Maitland(1965) and Elliot(1967) have recorded the emergence of E.ignita from June to August, although both Fahy(1973) and Bass(1976) have found nymphs at all times of the year. Even though E.ignita tended to be associated with the cleaner sites, Nuttall and Purves(1974) have recorded this species in mildly polluted areas in the River Tamar. The only time

E.ignita was present in significant numbers at Sites 2 and 3 was in June(Fig 19), but even then, the numbers were significantly very much less than those found at other sites.

B.scambus was also only recorded in relatively large numbers in the June sample. Thibault(1917) and Elliot(1967) have postulated that there are more than one generation/year, but this was not found to be the case on the Llynfi and Ogmore as B.scambus was virtually absent from any collections apart from June.

The other Ephemeropterans recorded, Caenis moesta, Ephemera danica and Heptagenia lateralis were only very rarely encountered.

The dominant groups numerically in the survey were the Chironomidae and Oligochaeta, with the latter group usually being the most numerous at all sites. Although the faunal composition varied considerably during the year in both taxa, the numbers recorded at Sites 2 and 3 were almost always greater than at the other sites.

The most numerous species of chironomid recorded during the survey were, B.longifurca, T.calvescens, R.fuscipes, O(O)rubicundus and E.clarripennis. C.bicinctus was also abundant but at only on one sampling occasion(Fig 20). Generally the numbers of B.longifurca, E.clarripennis and O(O)rubicundus were most abundant at Sites 2 and 3 and then showed marked reductions in numbers at Sites 4, 5 and 6. B.longifurca was most abundant at these sites in October and June(Fig 21). Workers including Learner et al.(1971) and Davies and Hawkes(1981) have also recorded this species in the polluted stretches of the Rivers Cynon and Cole respectively. Davies and Hawkes found however, that B.longifurca was most abundant in the winter and spring samples taken from the River Cole, and completely absent during the summer from the more polluted sites. The general reduction in numbers of B.longifurca at the lower sites on the Llynfi and Ogmore, particularly Site 4, is possibly due the fact that the substrate was being eroded and that plant species such as Helodea and Sparganum were not present. Lindegaard-Peterson(1972) has found that species such as B.longifurca are found on Helodea and Sparganum on which it grazes.

According to Cranston(1982) T.calvescens tends to be most abundant in the upper reaches of streams particularly among mosses, and in the middle reaches among macrophytes. However, this species according to Cranston is also regularly found in the slower flowing regions of deeper rivers. Indeed, the numbers of T.calvescens increased from the rapidly flowing Site 4 to the relatively deeper and somewhat slower flowing Site 5. However, this species was abundant at Sites 2 and 3 in October(Fig 12).

Gower and Buckland(1978) have recorded peak abundances for E.clarripennis in October in Moat Brook. This was found to be the case for the Llynfi where large populations(4416/m^2) were recorded at Site 2 in October. These large numbers at the polluted sites are in agreement with Cranston(1982) who concluded that this species is most frequently encountered in organically enriched areas. Davies(1971) has also noted that E.clarripennis was present in large numbers in the organically polluted River Cole. However, in the River Cole this species was present throughout the year but it was absent from the Llynfi in June.

According to Lindegaard-Peterson(1972) R.fuscipes is similar to B.longifurca in that it is usually associated with vegetation such as Helodea. This species was particularly abundant during October at Sites 2 and 3 and was generally ubiquitous throughout the survey. This agrees with Cranston(1982) who stated that R.fuscipes is one of the most frequent and abundant of running water Orthocladiinae.

O(O)rubicundus while never as abundant as B.longifurca was present at all sites in most collections. A peak abundance was reached in April at Site 6. Fig 22 shows that the numbers at this time were greater than at any other time.

Large populations of C.bicinctus were recorded in the summer collection and it can be seen in Fig 20 that in the June collection the numbers of this species were significantly greater than in the other collections, and that Sites 1 and 5 had the greatest populations. This is similar to that recorded by Davies and Hawkes(1981) who found that their Site 5, well below the effluent outfall exhibited the best conditions for C.bicinctus and that greatest numbers were recorded during the summer.

Many workers including Butcher(1955) have found that the chironomid, Chironomus riparius is a particularly common species below organic effluent outfalls, but it did not appear in any of the collections from the Llynfi. Although chironomids were abundant, particularly at Sites 2 and 3 for most of the year, they did not achieve the dominance observed by Nuttall and Purves(1974) in the Tamar where the chironomids were the dominant group immediately below an effluent outfall. The dominant group numerically in the Llynfi in almost every collection was the Oligochaeta.

Generally the dominant species of oligochaetes were Nais elinguis, Tubifex tubifex and Enchytraeidae. Nais elinguis although abundant, became particularly so in April, achieving a density of 3618/m^2 at Site 2. Many workers including Learner (1978) have found that naid worms respond to organic pollution with a large increase in numbers. Eyres et al(1978) has stated that N.elinguis appears to be particularly tolerant of pollution. Eyres found that this species was particularly abundant in his study of the River Irwell with recruitment occurring in April, which was similar to the situation in the Llynfi.

Many workers eg. Brinkhurst(1970) have noted that T.tubifex becomes particularly numerous below an organic effluent discharge. In these regions of low dissolved oxygen concentration, T.tubifex may become associated with the tubificid Limnodrilus hoffmeisteri. Brinkhurst has reported mono-cultures of tubificids in the order of $10^6/m^2$ below an effluent outfall. However, populations of this order were never recorded in the Llynfi even at Site 2. The largest population density of tubificids occurred in October and September where, $3440/m^2$ and $7550/m^2$ respectively were recorded. In general tubificid worms like naid worms and lumbriculid worms are adapted to life burrowing in sediments. The large populations recorded during October of a number of species of worm is probably due to the fact that competition is avoided and as Brinkhurst(1972) suggests, the worms present are able to select a specific food source thus not competing with other species for food.

Brinkhurst and Kennedy(1965) showed the co-existence of T.tubifex and L.hoffmeisteri in Ditton Brook. However with the exception of the October samples, L.hoffmeisteri was not collected in large numbers in the Llynfi. The populations of T.tubifex were always greater throughout the survey. Eyres et al(1978) has also observed the abundance of T.tubifex in the organically polluted River Irwell.

T.tubifex was most abundant at Site 2, the most polluted site. This is in agreement with the work of Aston(1973) who found that this species along with L.hoffmeisteri became the dominant organisms in conditions of low dissolved oxygen concentration. Indeed, Dausend(1931) has noted that tubificids could survive for four weeks in anaerobic conditions. It was certainly the case that when there were a large population of tubificids at Site 2, the dissolved oxygen concentration was below 2.5ppm, and this perhaps explains why they were the dominant organisms at this time. However, 98% of the tubificids at this time wereT.tubifex and the dominance of this species over L.hoffmeisteri may be explained by the fact that mixed species cultures are far less tolerant of anoxia than mono-cultures and, Chapman(1982), states that mixed species do not regulate their respiratory rates. Chua and Brinkhurst(1973) have also found that there is a lower respiration rate in mixed as opposed to pure cultures.

The Enchytraeidae were the most abundant taxonomic group in the Llynfi and Ogmore for much of the survey. The largest populations tended to be associated with Sites 2 and 3. For example in October, populations of $7116/m^2$ and $7590/m^2$ respecively were recorded. It appears that little work has been carried out on the aquatic ecology of this mainly terrestrial group and so comparisons are difficult to make. Eyres et al(1978) found quite a large populations in the Irwell, but in this stream the Tubificidae were the dominant group whereas in the Llynfi the Enchytraeidae was dominant at certain times.

The various pollution and diversity indices used to assess the results all gave broadly similar patterns. Overall the values obtained from Shannon's index, Trent biotic index, Chandler score, BMWP score and the Welsh Water Authority score indicated that from quite high values at Site 1 the values dropped at Site 2, and in some cases even further at Site 3, before rising again at Sites 4, 5 and 6. Kothe's species deficit and Czekanowski's coefficient and Jaccard's coefficient were also used to assess the general community structure of the Llynfi and Ogmore.

The patterns for October(Fig 33) indicated that Site 2 was certainly inferior in water quality when compared to the other sites. It can be seen that all the indices/scores recorded a significant drop in value from Site 1 to Site 2. This was due to the large populations of worms and chironomids, and lack of clean water fauna at this time. All the assessment methods showed Site 4 to be the cleanest and most diverse site. Indeed, the Chandler, BMWP and Welsh Water scores indicated a significant rise from Site 3 to Site 4. At Site 5 and 6 species diversity would seem to be poorer than at Site 4, almost certainly due to the numbers of worms and chironomids recorded at this time.

In January(Fig 34) a different pattern was observed. All the assessment methods indicated that Site 3 was inferior to the other sites. This low value can be attributed to the fact that only oligochaetes and chironomids were present at this time. Site 5 appeared to have the highest values and was the cleanest site at this time. This was probably due to the fact that thirty-eight species were present, more than at any other site. Sites 4 and 6 however, were very close in water quality to Site 5. Shannon's index gave the closest relationship between these three sites.

With the exception of the Trent biotic index the other methods indicated Site 3 to be the most polluted site in April(Fig 35). The Trent index gave this site an equal value to Site 2. Site 1 had the highest value in all cases and this was particularly so in the Chandler score. However, by June(Fig 36) this pattern had changed with Site 4 once again having the highest values and therefore being the cleanest site. Site 3 once again appeared to be the poorest in water quality, although Shannon's index gave a lower value for Site 2. Sites 4, 5 and 6 had much greater values thasn the other sites, this was particularly so with the BMWP and Welsh Water scores.

It was Site 6 that appeared to have the most diverse community in September (Fig 37). This may be attributable to the large numbers of Plecoptera and Ephemeroptera present in the samples. However, the qualitative indices eg. Trent biotic did not indicate such a marked difference as the quantitative indices such as the BMWP score. Site 3 again gave the lowest values.

This trend was again seen in the November samples(Fig 38) with most schemes giving Site 6 the highest and Site 3 the lowest values. However Chandler's score ascribed the lowest value to Site 2 indicating that this site had the poorest water quality.

Kothe's species deficit, Jaccard's coefficient of similarity and Czekanowski's coefficient were used to compare Site 2 with Sites 1, 4 and 6. The general trend was that there was little similarity or affinity between Site 2 and the other sites. The values obtained are listed in Tables 63 and 65. With both Kothe's species deficit and Jaccard's coefficient, Sites 1 and 2 and 2 and 6 had the greatest similarity values in June. Sites 2 and 4 showed the most similarity for both Kothe and Jaccard in November. Czekanowski's coefficient confirmed this overall trend but indicated that a very low correlation was obtained when Sites 2 and 4 were compared. The October samples gave a particularly low value and this may be expected when we consider the species composition at this time as Site 4 had relatively few oligochaetes and chironomids when compared to Site 2. A low correlation was also seen in September. Sites 1 and 2 and 2 and 6 had their lowest values in October and September. The highest correlation value was obtained for Sites 1 and 2 in April. At this time the worm population at Site 1 accounted for 87% of the benthic invertebrates present at this site. Generally Czekanowski's coefficient always gave quite low correlations between Sites 1 and 2, with the exception of the relatively high value seen in April. Sites 2 and 6 however, gave the best relationship in January and April when values of 0.77 and 0.73 were recorded. At these times the oligochaetes and chironomids were numerically important components of the benthic community.

In addition to the assessment methods and the block histograms, the computer analysis using ARTHUR 81 and SPSS-X can give valuable information into the clustering of the results at each sampling occasion. Clustering refers to the similarity between data points, thus sites with a similar composition when analysed by the computer will tend to be clustered together. Thus, generally, Sites 2 and 3 were clustered quite closely together in most of the data sets indicating that their community structure had fundamental similarities. This is very much as expected as these two sites were located closest to the effluent outfall and were therefore the most polluted.

It can be seen from the raw data(Tables 26 - 61) and the block histograms(Figs 27-32) that the faunal composition was broadly similar at the two sites, both sites usually having large worm and chironomid populations. Consequently this would have a large weighting in any clustering routines used eg. dendogram plots. From the computer print outs(Figs 46 - 87) we can see that Site 6 also appeared rather different from the other sites, with Sites 1, 4 and 5 being rather similar. Both ARTHUR and SPSS-X tended to give similar results from the clustering techniques used. The reason why Site 6 appeared to be separate is almost certainly due to the fact that in addition to large populations of worms and chironomids, there was a very diverse fauna present at this site. However, the other sites tended to have reasonably large worm populations at similar times eg. April and thus they would tend to be difficult to differentiate.

In the October print outs(Figs 46 - 52) we can see that Site 2 showed a definite autonomy from the other sites, and at this time Site 3 appeared to be the closest neighbour to Site 2. Because of the large worm populations present at Sites 5 and 6 it meant that they tended to become closely clustered together. The large worm populations at these sites also meant that they became much more closely associated and similar to Site 2 than Sites 1 and 4 where the oligochaete populations were very much less. Indeed, at Site 4, 918 Baetis rhodani/m^2 were recorded which gave a strong weighting away from the other sites including Site 1 where only 74/m^2 were recorded. Correlation and probability values for ARTHUR (Fig 50) showed that the presence of T.tubifex and L.hoffmeisteri were closely linked.

While the print outs for January(Figs 53 - 59) indicated that Sites 5 and 6 were again closely associated, the overall picture was less clear than for October. This is probably due to the fact that the overall species numbers were much reduced from those in the previous collection, thus tending to weight most features evenly and so the plots in both ARTHUR and SPSS-X lacked distinction.

However, by April a much clearer picture emerged with almost 92% of the data being assigned to the first orthogonal(Fig 61). This indicates that the sites tended to have a unique identity and thus better clustering was observed in the first principal component plot(Fig 62). After using the SELECT routine the clustering of the sites became very distinct(Fig 63), with Sites 2 and 3 showing a particular affinity for each other. This is no doubt due to the influence of the oligochaetes at this time, with Site 2 having a population of 6276/m^2 and Site 3, 5178/m^2 thus ascribing a heavy weighting to the results. Even though there was an even larger worm population at Site 6 (7476/m^2), the large chironomid opulation and the presence of many other species gave the data points for this site a particular identity particular in WARD's method(Fig 66).

The data appeared more widespread in the June samples with poor clustering being observed with ARTHUR(Fig 73). However Sites 1 and 4 appeared quite closely clustered together, although in the SPSS-X routines(Figs 74 - 78), Site 4 appeared quite distinct particularly in the COMPLETE LINKAGE method(Fig 76). However, two distinct groups emerged from SPSS-X, Sites 1 - 3 and Sites 4 - 6, although from the raw data this is not obvious.

Using the SELECT routine on the September samples revealed that once again there appeared to be a strong affinity between Sites 2 and 3(Fig 81).This no doubt resulting from the large worm populations found at this time. The other sites had much reduced numbers of Oligochaetes whe compared to these two sites. Sites 5 and 6 also appeared quite closely linked. WARD's method(Fig 82) and the SINGLE LINKAGE method(Fig 83) also indicated that Sites 2 and 3 were quite distinct from the other sites.

This pattern persisted in the November print outs where the distinct nature of Sites 2 and 3 was again confirmed, particularly after using the SELECT routine (Fig 86). Sites 1, 4 and 5 appeared quite closely aligned, also, with Site 6 being quite distinct. Although the SPSS-X routines generally gave a rather confused picture and , possibly, reflecting the general sparseness of the benthic community. The largest population was found at Site 6 where only 2206 animals/m^2 being recorded. Thus, the biological and chemical data indicate that the fauna was adversely affected at Sites 2 and 3, immediately below the effluent outfall. At these sites oligochaetes and chironomids dominated the benthic community for much of the period of the survey. Site 4 appeared to have the most diverse fauna and this is probably due to the fact that no appreciable effluent affects the River Ogmore at this point. Sites 5 and 6 showed that, as progress is made down the stream from the confluence of the Rivers Llynfi and Ogmore, then the oligochaetes and chironomids become less dominant and cleaner-water species such as stoneflies and mayflies become well established in the benthic community.

7. Conclusions.

The water quality of the Rivers Llynfi and Ogmore was assessed at six sites over a period extending from October 1985 to November 1986. It was found that the river was adversely affected by the organic discharge of a paper mill at Llangynwydd. As such marked pollution faunas were recorded from Sites 2 and 3, immediately below the outfall. The fauna at these sites was dominated by the Oligochaeta and Chironomidae. At other sites cleaner water forms such as members of the Plecoptera, Ephemeroptera and Trichoptera became present in large numbers. The most common species from these three taxonomic groups was B.rhodani which became very common in the September samples where a population of 3724/m^2 were recorded at Site 2.

The chemical data provided by the Welsh Water Authority helped to explain the patterns seen in the benthos present. The water quality in the Llynfi below the effluent outfall at Sites 2 and 3 generally appeared to be somewhat better than expected, although it was usually much inferior to that found at the other sites. This difference in water quality was best seen in October to December(Fig 6) when the dissolved oxygen concentration was particularly poor at Sites 2 and 3.

Site 1.

This site, above the effluent discharge, did not appear to be as diverse as one would expect, and this is probably due to the discharges from the nearby town of Maesteg. However, the dissolved oxygen content of the water at this site was generally quite good throughout the survey, with 8.9ppm being the lowest level recorded. BOD_5, ammoniacal nitrogen and particulate solids(Figs 7 - 9) were all present in low concentrations.

Plecoptera, Ephemeroptera, Trichoptera etc were all recorded at this site during the survey. In the case of the Ephemeroptera, B.rhodani became quite numerous in January(Fig 13) with 578/m^2 being recorded. The oligochaetes and chironomids were always present at this site, and, particularly so in October(Fig 12) where they were the dominant forms. Both E.ignita and C.bicinctus showed marked seasonal variations only appearing in any numbers during the summer collections.

Site 2.

This site was situated approximately 0.5Km below the outfall from the paper mill, and as such its fauna reflected the reduction in water quality one would expect.

However, the conditions present were never severe enough for either, all species to be eliminated, or to let the worms and chironomids to become the only groups present. The disssolved oxygen concentration(Fig 6) at this site was however, much inferior to that seen at the previous site, with a level of only 1.7ppm being recorded in October 1986. BOD_5 at this time was 18.2ppm. The levels of both ammoniacal nitrogen and particulate solids (Figs 7 and 8)were both much increased from those recorded at Site 1. The National Water Council has described the river at this point as Class 4, which describes it as 'grossly polluted.' This is a considerable reduction from the Class 1B state of the river at Site 1 where the river could be described as having 'water of high quality.'

These ambient conditions will obviously favour polluted water macro-invertebrates such as the Chironomidae and Oligochaeta. These two groups were at their greatest abundance in the October samples. The oligochaetes were particularly dominant at this time with 13616/m^2 being recorded. However after this time the oligochaetes were never as abundant. During the period of the survey other taxa became more abundant such that Plecopterans, Ephemeropterans and Trichopterans were present. In the case of the mayfly, B.rhodani, this species became very numerous in June with 1377/m^2 being recorded.

Site 3.

It was expected that Site 3 would show a significant increase in water quality from the previous site. However, this was not generally found to be the case, although the dissolved oxygen levels were never as low as at Site 2, they were below those found elsewhere on the river system. The National Water Council has classed Site 3 as a Class 3 river, which means this site is 'an area of poor quality requiring improvement as a matter of some urgency.'

Similarly to Site 2, the Oligochaeta and Chironomidae were recorded in large populations at certain times of the year, although the numbers were never as great as at Site 2. As at the previous site, other taxa became more numerous during the period of the survey. The similarities between Sites 2 and 3 were largely confirmed by the Computer Analysis(Figs 46 - 87) performed on the raw data. Quite close linkage was observed between these two sites such that generally they were distinct from the other sites. Thus the water quality at these sites must obviously have contributed greatly to this.

Site 4.

This site, from the chemical data, did not appear to have any pollutional problems during the survey and had the lowest levels for all the parameters recorded. This section of the Ogmore River has been given a Class 1A standard which indicates that the river at this point is unpolluted, is of sufficient quality to be potable, has a high amenity value and is suitable for game fishing.

The unpolluted state of the water was reflected in the benthic fauna present which was always the most diverse recorded from any site during the survey. This factor was highlighted by the biotic indices/scores used(Figs 33 - 38) which clearly placed Site 4 above the others at all sampling occasions. The Chironomidae and Oligochaeta were never dominant here as at other sites, not only due to the ambient water quality, but also by the fact that the substrate was an eroding one which would obviously favour other taxa such as the Plecoptera and Ephemeroptera which became very numerous during the survey.

Site 5.

The river at this point has been assigned a 1B classification. This slight drop from the previous site is almost certainly due to the mixing of the Llynfi and Ogmore Rivers. However this deterioration in water quality is quite small, and the levels of ammoniacal nitrogen and BOD_5(Figs 5 and 7) were always low, while dissolved oxygen concentration(Fig 6) was always well over the 60% level that the National Water Council assigns to water of 1B standard.

The water quality at this site was reflected in the benthic macroinvertebrates recorded. However, the Plecoptera and Ephemeroptera were never quite as dominant as at Site 4. This was probably due to the fact the river had somewhat slowed by this site and so some deposition was taking place, thus encouraging burrowing forms to become established. This was seen particularly in the October samples when 4932 worms/m^2 were recorded. However, after this time the numbers of Oligochaeta declined at this site although they, together with the Chironomidae, were always well represented here.

Site 6.

This site was very similar in water quality to Site 5, also being classed as 1B. The levels of all parameters recorded here were also very similar to those at the previous site. There was also appreciable deposition here as the river widened 2Km from the sea.

The similarity in water quality was also apparent in the similarity with the benthic fauna recorded, with quite a wide diversity being present encompassing Plecoptera to Oligochaeta. The Computer Analysis(Figs 46 - 87) tended to indicate that Sites 5 and 6 generally were well clustered together. The biotic indices/scores also confirmed the similarity of these two sites.

The water quality along the length of the river appeared to be much better than could initially have been expected. The pollution from the paper mill, while by no means negligble, was however less than that experienced by a number of workers including Gaufin(1958), Dines and Wharfe(1985, 1986) etc, and as such it appears that British Tissues Ltd have made an effort to amelorate their effluent before discharging into the receiving waters.

Norrstrom(1974) has stated that there are four ways in which a pulp bleaching plant such as the one at Llangynwydd can reduce the pollution in discharged waters

1) Lowering the amount of dissolved organic matter entering with the unbleached pulp
2) Lowering the lignin content of the unbleached pulp.
3) Changing the bleaching conditions.
4) Introducing oxygen bleaching.

Finally, it must be realised that although the paper mill is a major pollutant to the Llynfi, this has to be weighted against the fact that British Tissues is one of the few major employers in the area and thus any excess pressure to reduce effluent discharges may affect employment prospects in a depressed area.

Acknowledgements.

I would like to extend my grateful thanks to Dr L.J Davies for his considerable help and guidance during this project and Mr B Huxter, without whose cooperation the practical work would have been impossible. I would also like to thank Dr K.W Burton at the Polytechnic for his help with ARTHUR and SPSS-X and Dr M.J Learner at UWIST who gave me expert guidance in the intricacies of the oligochaetes and chironomids. Lastly, but by no means least I would like to acknowledge the contribution of Ms M.Alter, Mr K.J Grabham and Mrs B Grabham without whose support I would not have completed this work.

References.

Albrecht, M.L.(1953). 'Die Plane und andere Flamingbacke.' Z.Fisch.NFI. 389-476.

Ambuhl, H.(1959). 'Die Bedeutung der Stromung als Oklogischer Faktor.' Schweiz.Z.Hydrol. 21, 133-264.

Ander, P.(1977). 'Studies on the mutagenic properties of bleaching effluents.' Svensk Parestidning. 14, 454-58.

Aston, R.J.(1973). 'Tubificids and water quality: A reveiw.' Environ.Pollut. 5, 1-10.

Barber, W.E. and Kevern, N.R.(1973). 'Ecological factors influencing macro-invertebrate standing crop distribution.' Hydobiologia. 43, 53-75.

Bass, J.A.B.(1976). 'Studies on Ephemerella ignita in a chalk stream in Southern England.' Hydrobiologia. 49, 117-21.

Beck, W.M.(1975). 'Suggested methods for reporting biotic data.' Sewage and Ind. wastes. 27, 539-562.

Begon, M., Harper, C.L. and Townsend, C.R.(1986). Ecology: Individuals, Populations and Communities. Blackwell.

Bowker, D.W., Wareham, M.T. and Learner, M.A. (1983).'The selection and ingestion of epiphytic algae by Nais elinguis.'Hydrobiologia. 98, 171-178.

Bowker, D.W., Wareham, M.T. and Learner, M.A.(1985). 'A choice chamber experiment on the selection of algae as food and substrata by Nais elinguis.' Freshwat.Biol. 15, 547-57.

Boycott, A.E.(1936). 'The habitats of freshwater Mollusca in Britain.' J.Anim.Ecol. 5, 116-86.

Brinkhurst, R.O.(1970). 'Distribution and abundance of tubificid species in Toronto Harbour, Lake Ontario.' J.Fish.Res.Bd.Can. 27, 161-69.

Brinkhurst, R.O.(1971). 'A guide for the identification of British Aquatic Oligochaeta.' Freshwat.Biol.Assoc. Scientific publication. 22.

Brinkhurst, R.O., Chua, K.E. and Kaushik, N.(1972). 'Interspecific interactions and selective feeding by tubificid oligochaetes.' Limnol.Oceanogr. 17, 122-33.

Brinkhurst, R.O.and Kennedy, C.R.(1965). 'Studies on the biology of the Tubificidae in a polluted stream.' J.Anim.Ecol. 34, 429-43.

Bryce, D.(1960). 'Studies on the larvae of the British Chironomidae,with keys to the Chironomidae and Tanypodinae.' Trans.Soc.Br.Ent. 14, 19-62.

Bryce, D., Caffoor, I.M., Dale, C.R. and Jarret, A.F.(1978). 'Macro-invertebrates and the Bio-assay of water quality.' A report based upon a survey of the River Lee. Science series 1. Nelpress.

Butcher, R.W.(1937). 'Contribution to our knowledge of the ecology of sewage fungus.' Trans.Brit.Mycol.Soc. 17, 112.

Butcher, R.W.(1946). J.Inst.Sew.Purif. 2, 92.
Butcher, R.W.(1955). 'Relation between the biology and polluted condition of the Trent.' Verh.Int.Ver.Limnol. 12, 7-832.
Cairns, J.and Kaesler, R.L. 'Cluster Analysis of Potomac River survey stations based on protozoan presence-absence data.' Hydrobiologia. 34, 414-32.
Carpenter, K.E.(1928). Life in Inland Waters. Sidgwick and Jackson. London.
Cawley, W.A.(1959). 'Sewage fungus:its nature and effects.' Wat.Res. 3, 289-311.
Chandler, J.R.(1970). 'A biological approach to water quality management.' Wat.Pollut.Control. 69, 415-21.
Chapman, G.(1982). 'Effects of species interactions on the survival and respiration of Limnodrilus hoffmeisteri and Tubifex tubifex exposed to various pollutants and Environmental factors.' Water.Res. 16, 1405-8.
Chua, K.E.and Brinkhurst, R.O.(1973). 'Evidence of interspecific interactions in the respiration of tubificid oligochaetes.' J.Fish.Res.Bd.Can. 30, 617-22.
Cormack, J.F.and Amsberg, H.R.(1969). 'The effect of biological treatment of sulphite waste liquor on the growth of Sphaerotilus natans.' Proc.14th Ind.Waste.Conf. Purdue University, Lafayette, Indiana.
Cranston, P.S.(1982). A key to the larvae of the British Orthocladiinae. Freshwat.Biol. Assoc.Scientific publication. 45.
Curtis, E.J.(1969). 'Sewage fungus:its nature and effects.' Water.Res. 3, 289-311.
Czekanowski, J.(1913). 'Zarys metod Statystynych(Die Grundzuge der Statistichen metoden).' Warsaw.
Dale, C.R.(1980). 'The biotic indexing of water quality and its application to field work in schools and colleges.' J.Biol.Ed. 14, 205-12.
Dausend, F.(1931). 'Uber die atmung der tubificides.' Z.Vergl.Physiol. 14, 557-608.
Davies, L.J.(1971). Unpublished PhD thesis. University of Aston.
Davies, L.J.and Hawkes, H.A.(1981). 'Some effectes of organic pollution on the distribution and seasonal incidence of Chironomidae in the fiffles in the River Cole.' J.Freshwat.Biol. 11, 549-59.
Denning, R.(Ed).(1980). Glamorgan Historian. 5. Stewart Williams.
Department of the Environment.(1970). Report of a River Pollution Survey of England and Wales. HMSO. 1.
Department of the Environment.(1978). Methods of Biological Sampling: Handnet Sampling of Aquatic Benthic Macroinvertebrates. HMSO. 8.
Dimick, R.E.and Haydu, E.P.(1952). 'The effect of kraft mill waste liquors and certain of their components on certain salmonid fishes of the Pacific.' Nat.Council Stream Improvement. Tech.Bull. 51.

Dines, R.A.and Wharfe, J.R.(1985). 'The enviromental impact of paper mill waste discharges to the Swale.' Environ.Pollut.(A). 38, 245-60.

Dines, R.A.and Wharfe, J.R.(1986). 'The environmental impact of paper mill waste discharges to the upper Medway Estuary.' Environ.Pollut.(A). 40, 345-57.

Dittmar, H.(1955). 'Ein Sauterlandbach Untersuchungen an einen Weisen-Mittelgebirsbach.'Arch.Hydrobiol. 50, 305-552.

Dodds, G.S.and Hisaw, F.L.(1926). 'Ecological studies of aquatic insects. 2. Size of respiratory organs in relation to environmental conditions.' Ecology. 5, 262-71.

Dorier, A.and Vaillant, F.(1954). 'Observations et experiences relatives a la resistance au courant de rivers invertebres aquatiques.' Trav.Lab.Hydrobiol.Grenoble. 45 and 46, 9-31.

Drake, C.M.(1982). 'Spatial distribution of chironomid larvae on leaves of the Bulrush in a chalk stream. J.Anim.Ecol. 52, 421-37.

Edington, J.M.(1964). 'The taxonomy of British Polycentropid larvae.' Proc.Zool.Soc. Lond. 143, 281-300.

Edington, J.M.(1965). 'The effect of water flow on populations of net-spinning Trichoptera.' Mitt.int.theor.agnew.Limnol. 13, 40-48.

Edington, J.M.and Hildrew A.G.(1981). A key to the caseless caddis larvae of the British Isles with notes on their ecology. Freshwat.Biol.Assoc.Scientific publication. 43.

Egglishaw, H.J.(1964). 'The distributional relationship between the depositing substrates in the Irwell.Freshwat. Biol. 8, 25-32.

Elliott, J.M.(1967). 'The life histories and drifting of the Plecoptera and Ephemeroptera in a Dartmoor stream.' J.Anim.Ecol. 36, 343-62.

Elliott, J.M.(1977). Some methods for the Statistical Analysis of Samples of Benthic Invertebrates. Freshwat.Biol.Assoc.

Elliott, J.M.and Mann, K.H.(1979). A Key to the British freshwater Leeches. Freshwat.Biol.Assoc. 40.

Entz, B.(1947). 'Qualitative and quantitative studies in the coatings of Potamogeton perfoliatus and Myriphyllum spicatum in Lake Balaton.'Archiva biologica hungarica SeriesIII. 17, 17-37.

Eyres, J.P., Williams, N.V. and Pugh-Thomas, M.(1978). 'Ecological studies on Oligochaeta inhabiting depositing substrates in the Irwell.Freshwat.Biol. 8, 25-32.

Fahy, E.(1973). 'Observations on the growth of Ephemeroptera in fluctuating and constant temperature conditions.' Proc.R.Ir.Acsd. 73B, 133-49.

Fahy, E.(1975). 'Quantiative aspects of the distribution of invertebrates in the benthos of a small stream system in Western Ireland. Freshwat.' Biol. 5, 167-82.

Field, J.G.(1969). 'The use of information statistics in the numerical classification of heterogenous systems.' J.Ecol. 57, 565-569.

Fisher, R.A.and Yates, F.(1963). Statistical Tables for Biological, Agricultural and Medical Research. Edinburgh.

Gauch, H.G.(1982). Multivariate Analysis in Community Ecology. Cambridge University Press.

Gaufin, A.R.(1958). 'The effects of pollution on a Midwestern stream. Ohio.J.Sci. 58, 197-208.

Gaufin, A.R.and Tarzwell, C.M.(1955).'Aquatic macro-invertebrate communities as indicators of organic pollution in Lytle Creek.' Sewage and Ind wastes. 28, 906-24.

Gower, A.M.and Buckland, R.J.(1978). 'Water quality and Chironomus riparius.' Freshwat.Biol. 8, 153-64.

Graham,T.R.(1965). Annual Report Lothians Purification Board. 16-26.

Gray, J.S.(1981). The Ecology of Marine Sediments: An Introduction to the Structure and Function of Benthic Communities. Cambridge University Press.

Grenier, P.(1949). 'Contribution a l'etude biologique des simulides de France.' Physiol.Comp. 1, 165-330.

Greze, I.I.(1954). 'Hydrobiology of the lower part of the River Angara.' Trudy Vses. gidrobiol.obschch. 5, 11-203.

Hamer, A.D.and Soulsby, P.G.(1980). 'An approach to chemical and biological river monitoring systems.' Wat.Pollut.Control. 79, 56-69.

Hardell, H.L.and de Sousa, F.(1977). Sven Paperstidn. 80, 153-201.

Hargreaves, J.W.and Pomfret, I.R.(1979). 'A Simplified Biotic Index for the Assessment of Biologically-Oxidizable Pollution in Flowing Waters.' Wat.Pollut.Control.

Harrod, J.J.(1964). 'The distribution of invertebrates on submerged aquatic plants in a chalk stream.' J.Anim.Ecol. 33, 325-343.

Hawkes, H.A.(1956). 'The biological assessment of pollution in Birmingham streams.' J.Inst.Munic.Engrs. 82, 452-63.

Hawkes, H.A.(1962). 'Biological aspects of river pollution.' In River Pollution. Butterworths. 311-432.

Hawkes, H.A.(1967). 'Some Effects of Industrial Effluents on the Biology of Rivers.' Inst.Wat.Pollut.Control.Symposium. 5.

Hawkes, H.A.(1974). 'Water quality: biological considerations.' Chem and Ind. 990-1000

Hawkes, H.A.and Davies, L.J.(1971). 'Some effects of organic enrichment on benthic invertebrate communities in stream riffles.' In Scientific Management of Animal and Plant Communities for Conservation. Blackwell.

Howell, P.and Beazley, E.(1977). The Companion Guide to South Wales.Collins.
Hubault, E.(1927). 'Contribution a l'etude des invertebres torrenticoles.' Bull.Biol.Suppl. 9, 1-388.
Hynes, H.B.N.(1960). The Biology of Polluted Waters. Liverpool University Press.
Hynes, H.B.N.(1970). The Ecology of Running Waters. Liverpool University Press.
Hynes, H.B.N.(1984). A Key to the Adults and Nymphs of the British Stoneflies with notes on their Ecology and Distribution. Freshwat.Biol.Assoc.Scientific publication. 17.
Jollow, P.J.and Brodie, B.B.(1972). 'Mechanisms of drug absorption and of drug solution.' Pharmacology. 8, 21-32.
Jones, J.R.E.(1949). 'An ecological study of the River Rheidol, North Cardiganshire, Wales. J.Anim.Ecol. 18, 67.
Juul, R.B.and Shireman, J.V.(1972). 'A biological assessment of fish and benthic populations inhabiting a kraft mill effluent channel.' Wat.Res. 12, 691-701.
Keith, L.H.(1976). 'Identification of organic compounds in unbleached treated Kraft paper mill wastewaters.' Environ.Sci.Technol. 10,555-64.
Kennedy, C.R.(1966). 'The life history of Limnodrilus hoffmeisteri and its adaptive significance.' Oikos. 17, 158-168.
Kinne, O.(1953). 'Zur Biologie und Physiologie von Gammarus duebeni,uber die Hautungsfrequenz,ihre Abhangigkeit von Temperatur und Salzghalt,sowie uber ihr Verhalten bei isoliert gehalen und amputieren Versuchstieren.' Zool.Jb. 64, 183-206.
Kolkowitz, R.and Marsson, M.(1909). 'Okologie der Herischen Saprobien.' Int.Rev.Hydrobiol. 2, 126-52.
Kothe, P.(1962). Dtsch.Gewasserkundle.Mitt. 6, p60.
Kringstaad, K.P.and Lindstrom, K.(1984). 'Spent liquors from pulp bleaching.' Environ.Sci.Technol. 18, 236-48.
Ladd, J.M.(1969). 'Effects of pH on the acute toxicity of Kraft pulp mill effluent to juvenile Coho salmon. Msc thesis.
Lawton, J.H.and Price, P.W.(1979). 'Species richness of parasites on hosts:Agromyzid flies on the British Umbelliferiae.' J.Anim.Ecol. 48, 619-37.
Lazim, M.N.and Learner, M.A.(1986). 'The life-cycle and production of Limnodrilus hoffmeisteri and limnodrilus udekemianus in the organically enriched moat-feeder stream,Cardiff.' Arch.Hydrobiol. 2, 200-25.
Lazim, M.N.and Learner, M.A.(1986). 'The life-cycle and production of Tubifex tubifex in the organically enriched moat-feeder stream,Cardiff.' Holarctic Ecology. 9, 185-92.

Leach, J.M.and Thakore, A.N.(1974). 'Isolation of the toxic constituents of Kraft pulp mill effluent.' CPAR.Rep. 11-40.

Learner, M.A.and Edwards, R.W.E.(1963). 'The toxicity of some substances to Nais.' Proc.Soc.Wat.Treat.Exam. 12, 161-8.

Learner, M.A.and Edwards, R.W.E.(1966). 'The distribution of the midge Chironomus riparius in a polluted river system and its environs.' Int.J.Air and Wat.Pollut. 10 757-768.

Learner, M.A., Williams, R., Harcup, M. and Hughes, B.D.(1971). 'A survey of the macro-fauna of the River Cynon.'Freshwat.Biol. 1, 339-67.

Learner, M.A., Lochhead, G. and Hughes, B.D.(1978). 'A reveiw of the British Naididae.' Freshwat.Biol. 8,357-75.

Lindegaard-Peterson, C.(1972). 'An ecological investigation of the Chironomidae from a Danish lowland stream(Linding A).' Arch.Hydrobiol. 69, 405-507.

Lindstrom, K.(1984). J.High.Resol.Chromatogr.

Lindstrom, K.(1985). J.High.Resol.Chromatogr.

Lindstrom, K., Nordin, J. and Osterberg, F.(1981). In Advances in the Identification and Analysis of Organic Pollutants in Water. Ann Arbor Science. 2, 1039.

Macan, T.T.(1957). 'The Ephemeroptera of a sony stream.' J.Anim.Ecol. 26, 317-42.

Macan, T.T.(1958). 'Methods of sampling the bottom fauna in stony streams.' Mitt.Int.Ver.Limnol. 8, 21.

Macan, T.T.(1959). A guide to Freshwater Invertebrate Animals. Longmans.

Macan, T.T.(1962). 'Biotic factors in running waters.' Schweiz.Z.Hydrobiol. 24, 386-407.

Macan, T.T.(1963). Freshwater Ecology. Longman

Macan, T.T.(1965). 'Predation as a factor in the ecology of Water Bugs.' J.Anim.Ecol. 34, 691-98.

Mackey, A.P.(1979). 'Trophic dependencies of some larval Chironomidae and fish species in the River Thames.' Hydrobiologia. 62, 241-247.

Maitland, P.S.(1965). 'The distribution,life cycle and predators of Ephemerella ignita in the River Endrick.' Oikos. 16, 48-57.

Maitland, P.S.(1966). 'Studies on Loch Lomond. 2. The fauna of the River Endrick'. Blackie.

Maitland, P.S.(1978). Biology of Fresh Waters. Blackie.

Mann, K.H.(1955). 'The ecology of the British freshwater leeches.' J.Anim.Ecol. 24, 98-119.

Mason, C.F.(1980). Biology of Freshwater Pollution. Longman.

McClachan, A.J., Brennan, A.J. and Wotton, R.S.(1978). 'Particle size and chironomid food in an upland river.' Oikos. 31, 247-52.

McLeay, D.J., Walden, C.C. aqnd Munro, J.R.(1979). 'Influence of dilution water on the toxicity of kraft pulp and paper mill effluent, including mechanism of effect.' Wat.Res. 13, 151-158.

National Research Council.(1978). The troposphere transport of pollutants and other substances to the oceans. National Academy Press. Washington D.C .

Norrstrom, H.(1975). 'Pollution control in the Swedish pulp and paper industry.' Ambio. 4, 80-86.

Nuttall, P.M.and Purves, J.B.(1974). 'Numerical indices applied to the results of a survey of a macroivertebrate fauna of the Tamar catchment. ' Freshwat.Biol. 4, 213-22.

O'Connell, R.R.and Campbell, R.S.(1953). 'The benthos of the Black River and Clearwater Lake, Missourri.Univ.Mo.Stud. 26, 25-41.

Opalinski, K.W.(1971). 'Macrofauna communities of the littoral Mikolajskie Lake.' Polskie Archivum Hydrobiologii. 18, 275-85.

Palmer, M.F.(1968). 'Aspects of the respiratory physiology of Tubifex tubifex in relation to its ecology.' J.Zool. 154, 463-73.

Palmer, M.F.and Chapman, G.(1970). 'The state of oxygenation of haemoglobin in the blood of living Tubifex.' J.Zool. 161, 203-9.

Pantle, R.and Buck, H.(1955). 'Die biologische uber wachung der gwasser und die darstellung der ergebnisse. Gas und Wasserfuch. 96, 604.

Pearson, E.S.and Hartley, H.O.(1966). Biometrika Tables for Statisticians. Cambridge.

Pentelow, F.T.K. and Butcher, R.W.(1938). 'Observations on the condition of the Rivers Churnet and Dove in 1938.' Rep.Trent.Fish.Dist.App. 1.

Percival, E.and Whitehead, H.(1929). 'A quantitative study of the fauna of some types of stream bed.' J.Ecol. 17, 282-314.

Phillips, G.(1982). The Old Parish 100 Not Out, 1882-1982.

Pleskot, G.(1958). 'Die Periodizitat einger Ephemeropteran der Schwechat.' Wasser.U.Abwasser. 1-32.

Produbnaya, T.L.(1959). 'About seasonal distribution of populations of Tubificidae in Rybinsk resevoir.' Trud.Inst.Biol.Vodokhran. 5, 102-8.

Reynoldson, T.B.(1961). 'Observations on the occurrence of Asellus in some lakes in northern Britain.'Verh.Int.Limnol. 14, 988-94.

Roback, S.S.(1957). 'The immature Tenipedids of the Philadelphia area.' Acad.Nat.Sci. Philadelphia. Monograph 9.

Roberts, J.C.(1977). 'Sewage fungus growth in rivers receiving paper mill effluent.' Wat.Res. 11, 603-10.

Rydholm, S.A.(1965). Pulping Processes. Interscience. 764-835.

Scott, D.(1958). 'Ecological studies of the Trichoptera of the River Dean, Cheshire.' Arch.Hydrobiol. 54, 340-392.

Shapiro, A.M.(1975). 'The temporal component of butterfly species diversity.' Ecology and Evolution of Communities. Harvard Press. 181-95.

Shelly, E.(1979). 'The effect of rock size upon the distribution of species of Orthocladiinae and Baetis intercalaris.' Ecological Entymology. 4, 397-403.

Sjostrom, E.(1981).Wood Chemistry, Fundamentals and Applications. Academic Press. New York.

Smock, L.A.and Stoneburner, D.A.(1980). 'The response of macroinvertebrates to aquatic macrophyte decomposition.' Oikos. 35, 397-403.

Strong, D.R.and Levin, D.A.(1979). 'Species richness of plant parasites and growth form of their hosts.' American Naturalist. 114, 1-22.

Surber, E.W.(1937). 'Rainbow Trout and bottom fauna production in one mile of stream.' Trans.Am.Fish.Soc. 66, 193-202.

Taylor, L.R.and Taylor, R.A.J.(1977). 'Aggregation, migration and population mechanics.' Nature. 265, 415-421.

Thibault, M.(1917). 'Le developpment des Ephemeropteres d'un ruisseau a truites des Pyrenees Atlantiques, le Lissurga.' Annis.Limnol. 7, 53-120.

Thienemann, A.(1912). 'Aristotles und die Abwsserbilogie.' Festschrift medizinish-naturwissenschaftlichen Gessellschaft.

Tokeshi, M.(1986). 'Population dynamics, life histories and species richness in an epiphytic chironomid community.' Freshwat.Biol. 16, 431-41.

Tokeshi, M.and Pinder, L.C.V.(1985). 'Microhabitats of stream invertebrates on two submerged macrophytes with contrsting leaf morphology.' Holarctic Ecology.

Townsend, C.R., Hildrew, A.G. and Francis, J.E.(1983). 'Community structure in some Southern English streams: the influence of physiochemical factors.' Freshwat.Biol. 13, 521-544.

Van Horn, W.M.(1947). 'The toxicity of kraft pulping wastes to typical fish food organisms.' Tech.Bull. 10. Nat Council Stream Improvement, New York.

Voss, R.H., Wearing, J.T. and Wong, A.(1980). Pap.Puu. 62, 809.

Voss, R.H., Wearing, J.T. and Wong, A.(1981). Pulp.Pap.Can. 82, 97.

Voss, R.H.(1984). 'Neutral organic compounds in biologically treated kraft mill effluents.' Environ.Sci.Technol. 18, 938-46.

Walden, C.C.(1976). 'The toxicity of pulp and paper mill effluent and corresponding measurement procedures.' Wat.Res. 10, 639-664.

Wisdom, A.S.(1956). The Law on the Pollution of Waters. Shaw.

Woodiwiss, F.S.(1964). 'The biological system of stream classification used by the Trent River Authority.' Chem.Ind. 11, 7-443.

Appendix 1.

Fig 1: Photograph of saw sampler.

Fig 2: Photograph of the paper mill at Llangynwydd.

Fig 3: Ordinance survey map of area of study.

Fig 4: Map to show relative positions of sites in the Ogwr watershed.

The saw sampler.

Fig 1

The paper mill at Llangynwydd.

Fig 2

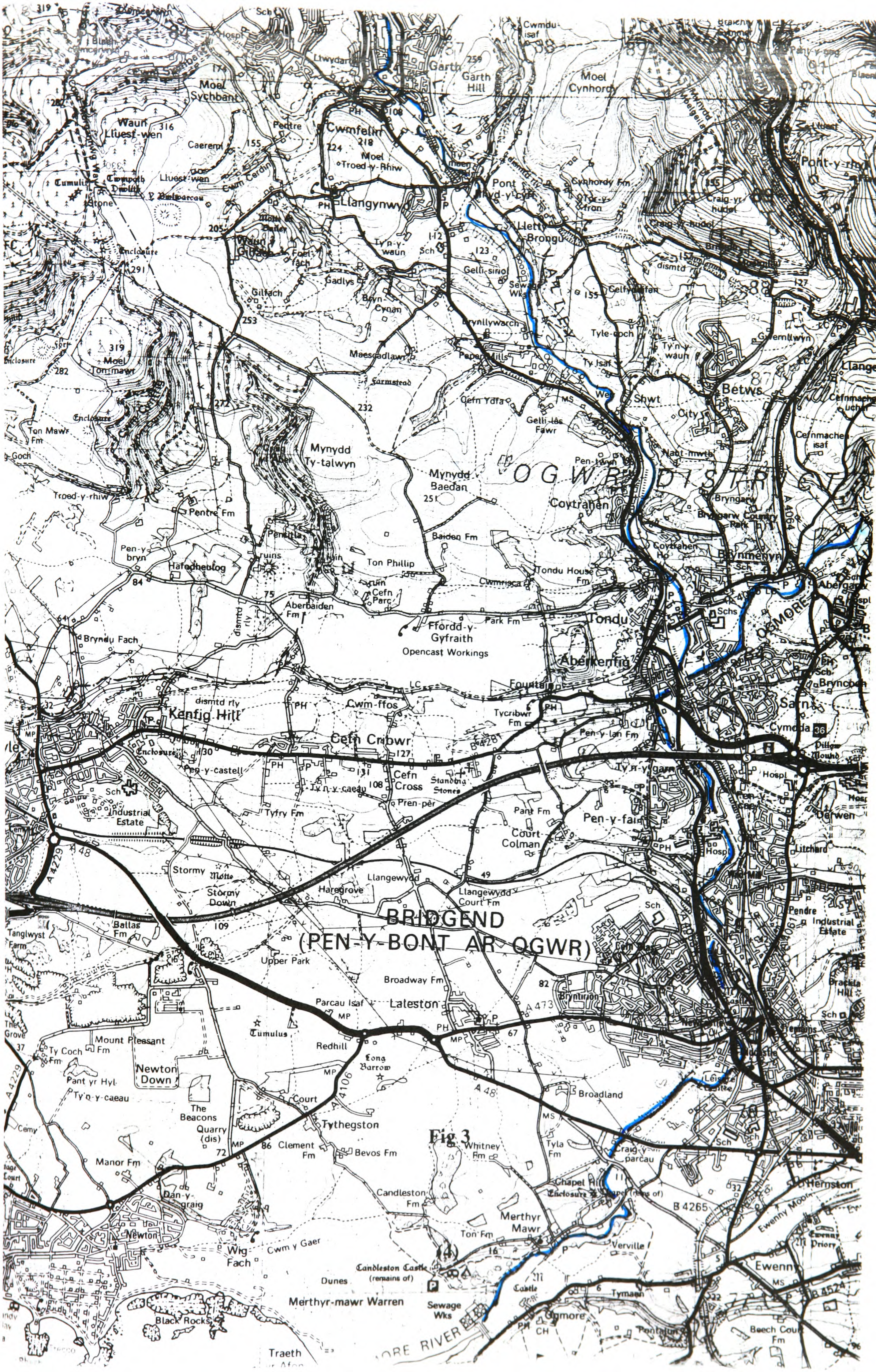

Moel Sychbant
Waun Lluest-wen
Garth
Garth Hill
Moel Cynhordy
Cwmfelin
Moel Troed-y-Rhiw
Llangynwyd
Pont Rhyd-y-cyff
Llettý Brongu
Cynhordy Fm
Craig-yr-hudol
Pont-y-rhyl
Waun Gilfach
Ty'n-y-waun
Gelli-siriol
Gadlys
Bryn-Cynan
Gilfach
Bryntlywarch
Maescadlawr
Paper Mill
Tyle-coch
Ty Isaf
Shwt
Betws
Llange
Moel Ton-mawr
Farmstead
Cefn Ydfa
Gelli-lâs Fawr
Ton Mawr Fm
Mynydd Ty-talwyn
Mynydd Baedan
OGWR DISTRICT
Pen-twyn
Nant-mwth
Cwm-macher isaf
Troed-y-rhiw
Pentre Fm
Coytrahen
Bryngarw
Bryngarw Country Park
Baiden Fm
Pen-y-bryn
Hafodheulog
Ton Phillip
Tondu House Fm
Coytrahen Ho
Brynmenyn
Abergarw
Aberbaiden Fm
Cefn Parc
Park Fm
Tondu
OGMORE
Bryndu Fach
Ffordd-y-Gyfraith
Opencast Workings
Aberkenfig
Fountain
Brynceth
Sarn
Kenfig Hill
Cwm-ffos
Tycribwr Fm
Cefn Cribwr
Pen-y-lan Fm
Cymdda
Pen-y-castell
Ty'n-y-caeau
Cefn Cross
Standing Stones
Pren-pêr
Tyn-y-garn
Hospl
Industrial Estate
Tyfry Fm
Pant Fm
Court Colman
Pen-y-fai
Derwen
Litchard
Stormy
Stormy Down
Llangewydd
Haregrove
Llangewydd Court Fm
BRIDGEND
(PEN-Y-BONT AR OGWR)
Pendre
Industrial Estate
Tanglwyst Farm
Ballas Fm
Upper Park
Broadway Fm
Bryntirion
Parcau Isaf
Laleston
Brackla Hill
Mount Pleasant Fm
Tumulus
Redhill
Long Barrow
Ty Coch Fm
Newton Down
Pant yr Hyl
Ty'n-y-caeau
Court
Broadland
The Beacons
Quarry (dis)
Tythegston
Clement Fm
Bevos Fm
Whitney Fm
Tyla Fm
Craig-y-parcau
Manor Fm
Chapel Hill
Hernston
Dan-y-graig
Candleston Fm
Merthyr Mawr
Newton
Ton Fm
Verville
Ewenny Priory
Wig Fach
Cwm y Gaer
Candleston Castle (remains of)
Ewenny
Dunes
Castle
Merthyr-mawr Warren
Sewage Wks
Ogmore
Tyrnaen
Black Rocks
Beech Court Fm
Traeth yr Afon
OGMORE RIVER

Fig 3

Map to show relative positions of sites.

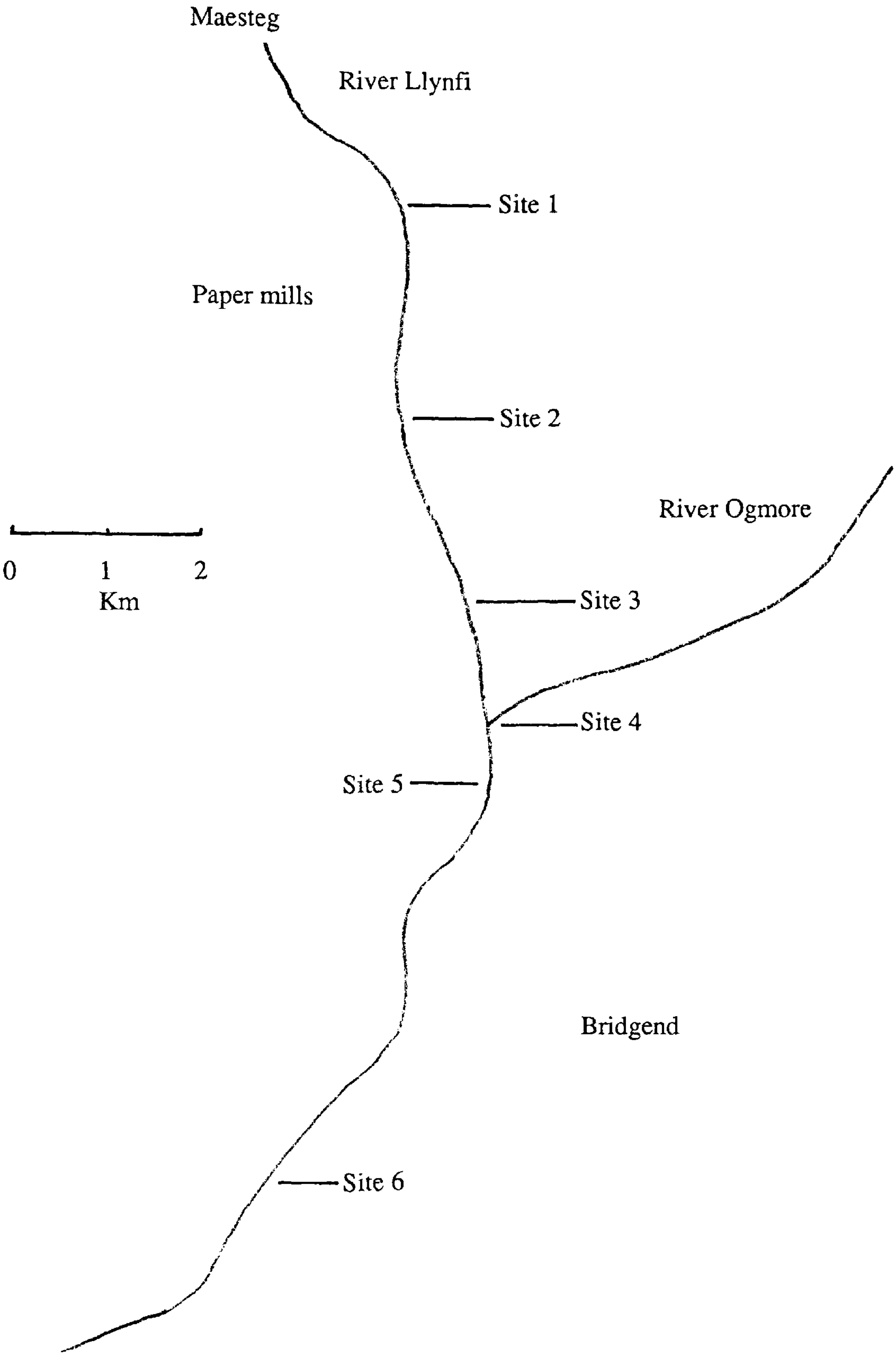


Fig 4

Appendix 2.

Chemical results from routine sampling by the WWA: Tables 1-24.
Chemical results from 24 hour survey, July 21-22 1986: Table 25.

Site 1: Pontrhyd-y-Cyff.

parameter date	pH	cond'ty (us/cm)	water temp(^oC)	D.O (% sat)	D.O (ppm)	BOD (ppm)
28.10.85	7.8	252	8.5	101.5	11.5	0.7
12.11.85	7.6	204	5	94.7	11.7	1.5
19.11.85	7.6	204	5.5	101	12.3	0.5
4.12.85	7.5	183	10.5	82.6	8.9	4.6
10.12.85	7.3	268	7	91.8	10.8	9.9
22.1.86	7.5	182	7	91.8	10.8	3.7
27.1.86	7.5	168	6	92	11.1	12.4
5.3.86	7.9	248	2	97	13	1
14.3.86	7.8	198	4	92.9	11.8	6.7
7.4.86	8	263.2	5	91.4	11.3	2.4
9.4.86	7.8	206	5	103	12.7	1.7
16.4.86	17.9	216	6	97	11.7	1.2
19.5.86	7.6	219	8	97.6	11.2	2.5
23.5.86	7.6	173	10.5	97.8	10.9	0.7
17.6.86	8	198	11	105.2	11.6	1.8
22.7.86	7.7	286	14	112	11.5	0.4
28.7.86	7.2		14	95.2	9.8	0.5
10.9.86	7.7	227	10	95.7	10.8	0.4
8.10.86	7.9	286	15	99.3	10	1
22.10.86	7.6	199	12	82.2	9.5	3.8
28.11.86	7.7	188	10	94.9	10.7	6.6

Table 1

Site 1.

parameter	am'ical N_2(ppm)	total ox N_2(ppm)	nitrite (ppm)	solids (ppm)	hardness (ppm)	chloride (ppm)
date						
28.10.85	0.02	0.6	0.008	2	98.3	11
12.11.85	0.03	0.7	0.004	4	67.7	11
19.11.85	0.02	0.7	0.004	3		12
4.12.85	0.17	0.7	0.028	59	52.6	11
10.12.85	1.04	0.8	0.026	19	64.5	37
22.1.86	0.11	0.8	0.01	3	59.7	12
27.1.86	0.26	0.6	0.082	239	65.9	16
11.2.86	0.03	0.6	0.007	5	94.6	13
14.3.86	0.4	1.4	0.024	30	57.8	18
7.4.86	0.12	1	0.022	5	77.8	30
9.4.86	0.05	0.7	0.007	3	71.4	11
16.4.86	0.02	0.7	0.004	2	70.9	13
19.5.86	0.03	0.8	0.006	5	65.9	14
23.5.86	0.05	0.9	0.012	6	61.5	12
17.6.86	0.07	0.8	0.013	6	61.5	11
22.7.86	0.02	0.6	0.007	10	68.5	11
28.7.86	0.02	0.5	0.015	6	97.6	13
10.9.86	0.02	0.7	0.008	3	88	10
8.10.86	0.02	0.7	0.025	4	106.2	13
22.10.86	0.07	1	0.017	21	68.6	11
28.11.86	0.97	0.9	0.11	12	63.3	11

Table 2

Site 1.

parameter	orthophos	copper	zinc	cadmium	aluminium	lead
	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)
date						
28.10.85	0.03	0.002	0.011	0.001	0.032	0.002
12.11.85	0.02	0.002	0.014	0.001	0.047	0.003
19.11.85	0.02	0.002	0.019	0.001	0.05	0.012
4.12.85	0.1					
10.12.85	0.18					
22.1.86	0.08	0.04	0.08	0.01	1.36	0.015
27.1.86	0.2					
11.2.86	0.04					
14.3.86	0.11					
7.4.86	0.02					
9.4.86	0.02					
16.4.86	0.02					
19.5.86	0.02					
23.5.86	0.06					
17.6.86	0.02					
22.7.86	0.05					
10.9.86	0.02					
8.10.86	0.02					
22.10.86	0.1					
28.11.86	0.18					

Table 3

Site 1.

parameter	chromium (ppm)	mang'ese (ppm)	iron (ppm)	nickel (ppm)
28.10.85	0.012	0.086	0.234	0.003
12.11.85	0.009	0.076	0.24	0.003
27.1.86	0.003	0.15	2.35	0.03

Table 4

Site 2: Shwt.

parameter date	pH	cond'ty (us/cm)	water (°C)	D.O (% sat)	D.O (ppm)	BOD (ppm)
28.10.85	7.2	276	12	68.2	7.1	11.1
19.11.85	7.2	209	7	88.4	10.4	4.7
4.12.85	7.3	171	12	90.3	9.4	3.8
27.1.86	7.3	182	7	88.4	10.4	5
11.2.86	7.6	291	3	79	10.3	7.1
5.3.86	7.6	190	3	89	11.6	6.2
16.4.86	7.3	227	8	80.2	9.2	8.1
19.5.86	7.2	198	12	87.3	9.4	2.5
17.6.86	7.2	245	16.5	70.7	6.9	5.5
10.7.86	7	354	18	52.9	5	5.1
22.7.86	7	339	18	41.2	3.9	6.4
8.10.86	7.3	378	16	17.2	1.7	18.2
28.11.86	7.4	182	8	86.1	10.2	3.2

Table 5

parameter date	am'ical N_2(ppm)	oxidised N_2(ppm)	nitrite (ppm)	solids (ppm)	hardness (ppm)	chloride (ppm)
28.10.85	0.09	1.5	0.064	22	76.3	23
19.11.85	0.05	1.4	0.023	25	73.3	16
4.12.85	0.21	0.8	0.091	498	5.5	15
27.1.86	0.21	0.8	0.062	246	51.3	21
11.2.86	0.11	1.5	0.04	26	742	26
5.3.86	0.38	1.5	0.028	51	52.2	20
16.4.86	0.02	1.2	0.022	22	63.7	19
19.5.86	0.02	1.3	0.02	12	61.6	17
17.6.86	0.25	1.8	0.062	9	71.9	23
22.7.86	1.1	1.3	0.127	23	90.1	28
8.10.86	0.62	0.4	0.079	17	128.6	33
28.11.86	0.1	1.3	0.008	6	64	12

Table 6

Site 2.

parameter	orthophos (ppm)	copper (ppm)	zinc (ppm)	cadmium (ppm)	aluminium (ppm)	lead (ppm)
date						
28.10.85	0.87	0.011	0.026	0.001	0.216	0.006
19.11.85	0.2					
4.12.85	0.32	0.002	0.005	0.001	0.26	0.025
27.1.86	0.17					
11.2.86	0.55	0.009	0.028	0.001	0.25	0.013
5.3.86	0.12					
16.4.86	0.19	0.007	0.024	0.001	0.2	0.025
19.5.86	0.56					
17.6.86	1.1					
10.7.86	1.3					
22.7.86	2.1					
8.10.86	0.53	0.007	0.018	0.001	0.157	0.017
28.11.86	0.19					

Table 7

parameter	chromium (ppm)	mang'ese (ppm)	iron (ppm)	nickel (ppm)
date				
28.10.85	0.01	0.147	0.049	0.003
4.12.85	0.003	0.022	0.465	0.003
11.2.86	0.008	0.17	0.79	0.003
16.4.86	0.009	0.144	0.479	0.003
8.10.86	0.003	0.219	0.724	0.003

Table 8

Site 3: Tondu.

parameter date	pH	cond'ty (us/cm)	water temp(°C)	D.O (% sat)	D.O (ppm)	BOD (ppm)
28.10.85	7.4	260	9	85.8	9.6	3.4
19.11.85	7.3	216	6	92.9	11.2	3.8
27.1.86	7.4	220	7	91.8	10.8	8
10.2.86	7.7	294	5	90.6	11.2	2.6
11.2.86	7.7	278	4	95.3	12.1	2.7
5.3.86	7.7	188	3	91.3	11.9	4.7
9.4.86	7.5	263	7	88.4	10.4	3.9
16.4.86	7.4	227	7	84.2	9.9	4.1
19.5.86	7.4	190	12	100	10.8	1.4
23.5.86	7.6	192	12.5	100.2	10.8	2.8
17.6.86	7.4	232	16	95.3	9.4	3.7
10.7.86	7	333	17	70.5	6.8	6.3
22.7.86	7.1	323	17	77.7	7.5	3.9
8.10.86	7.6	378	14	56.4	5.8	5.6
28.11.86	7.5	174	7	91.5	11.1	1.6

Table 9

Site 3

parameter	am'ical N_2(ppm)	oxidised N_2(ppm)	nitrite (ppm)	solids (ppm)	hardness (ppm)	chloride (ppm)
date						
28.10.85	0.27	1.6	0.07	5	80.3	18
19.11.85	0.05	1.5	0.026	6	78.4	16
4.12.85	0.22	0.9	0.07	321	6.6	14
27.1.86	0.23	0.9	0.041	204	58.6	27
10.2.86	0.06	1.6	0.038	8	69.6	25
11.2.86	0.19	1.5	0.031	13	73.3	20
9.4.86	0.2	1.4	0.034	7	66.5	27
16.4.86	0.03	1.3	0.022	14	66.5	22
19.5.86	0.02	1.4	0.017	10	63	16
23.5.86	0.009	1.5	0.018	9	62.7	15
17.6.86	0.17	1.8	0.068	4	69.5	21
10.7.86	0.74	2	0.29	18	86.6	35
22.7.86	0.43	1.7	0.22	14	81	26
8.10.86	0.79	0.3	0.075	12	120	31
28.11.86	0.04	1.5	0.008	9	64	13

Table 10

Site 3.

parameter	orthophos (ppm)	copper (ppm)	zinc (ppm)	cadmium (ppm)	aluminium (ppm)	lead (ppm)
date						
28.10.85	0.61	0.006	0.014	0,001	0,09	0.009
19.11.85	0.17					
4.12.85	0.24	0.002	0.005	0.001	0.19	0.025
27.1.86	0.15					
10.2.86	0.62	0.005	0.015	0.001	0.07	0.008
5.3.86	0.1					
9.4.86	0.78					
16.4.86	0.18	0.005	0.022	0.001	0.197	0.025
19.5.86	0.4					
23.5.86	0.17					
17.6.86	0.73					
10.7.86	1.3					
22.3.86	1.7					
8.10.86	0.66	0.003	0.018	0.001	0.106	0.015
28.11.86	0.13					

Table 11

parameter	chromium (ppm)	mang'ese (ppm)	iron (ppm)	nickel (ppm)
date				
28.10.85	0.01	0.138	0.501	0.004
4.12.85	0.003	0.026	1.980	0.003
10.2.86	0.007	0.139	0.354	0.003
11.2.86	0.006	0.142	0.334	0.003
16.4.86	0.007	0.15	0.527	0.003
8.10.86	0.003	0.388	0.795	0.004

Table 12

Site 4: Abergarw.

parameter date	pH	cond'ty (us/cm)	water temp(^oC)	D.O (% sat)	D.O (ppm)	BOD (ppm)
28.10.85	7.6	171	10.5	107.6	11.6	1
19.11.85	7.5	167	5	104	12.8	0.1
4.12.85	7.6	157	10	93.4	10.2	1
27.1.86	7.3	146	5	86.6	10.7	1.2
5.3.86	7.6	169	4	95.3	12.1	2
10.3.86	7.5	167	8	89.8	10.3	1
16.4.86	7.8	182	7	91.8	10.8	2.2
19.5.86	7.5	126	14	100	10.3	1
17.6.86	6.8	144	14	100	10.3	0.6
10.7.86	7.4	187	15	100	10.1	1.5
22.7.86	7.6	198	14	100	10.3	0.7
8.10.86	7.8	199	11.5	96.4	10.5	0.8

Table 13

parameter date	am'ical N_2(ppm)	oxidised N_2(ppm)	nitrite (ppm)	solids (ppm)	hardness (ppm)	chloride (ppm)
28.10.86	0.003	0.9	0.005	2	63	11
19.11.85	0.05	0.9	0.004	1	56.7	11
4.12.85	0.005	0.8	0.02	63	4.3	10
27.1.86	0.05	1	0.009	14	43	13
5.3.86	0.23	1.3	0.024	35	43.5	20
10.3.86	0.02	1.2	0.006	5	54.5	15
16.4.86	0.002	0.7	0.009	7	55.1	13
19.5.86	0.02	1.2	0.011	11	42.4	11
17.6.86	0.003	2.2	0.085	9	53.2	11
10.7.86	0.02	0.7	0.004	7	68	11
22.7.86	0.03	0.7	0.004	2	65.4	11
8.10.86	0.02	0.8	0.005	3	76.8	11

Table 14

Site 4.

parameter	orthophos (ppm)	copper (ppm)	zinc (ppm)	cadmium (ppm)	aluminium (ppm)	lead (ppm)
date						
28.10.85	0.02	0.002	0.01	0.001	0.039	0.002
19.11.85	0.02					
4.12.85	0.05	0.002	0.004	0.001	0.054	0.25
5.3.86	0.03					
10.3.86	0.02					
16.4.86	0.02	0.002	0.01	0.001	0.061	0.025
19.5.86	0.02					
17.6.86	0.02					
22.7.86	0.02					
8.10.86	0.02	0.003	0.007	0.001	0.017	0.009

Table 15

parameter	chromium (ppm)	mang'ese (ppm)	iron (ppm)	nickel (ppm)
date				
28.10.85	0.007	0.033	0.127	0.004
4.12.85	0.003	0.007	0.62	0.003
16.4.86	0.007	0.054	1.44	0.003
8.10.86	0.003	0.044	0.14	0.003

Table16

Site 5: Penycae.

parameter date	pH	cond'ty (us/cm)	water temp(^oC)	DO (% sat)	DO (ppm)	BOD (ppm)
28.10.85	7.5	249	10	99.8	10.9	2
19.11.85	7.5	200	6	100	12.1	2.6
4.12.85	7.4	177	12	89.3	9.3	3.6
27.1.86	7.3	182	7	96.1	11.3	3.4
11.2.86	7.7	246	3	95.9	12.5	2.3
5.3.86	7.6	190	3	90.5	11.8	4.7
16.4.86	7.6	212	7	91.8	10.8	3.1
19.5.86	7.4	158	13	92.1	9.7	1.2
10.7.86	7.2	278	16	90.3	8.9	2.3
22.7.86	7.4	272	16	90.3	8.9	2.6
8.10.86	7.7	293	15	90.4	9.1	3.3

Table 17

parameter date	am'ical N_2(ppm)	oxidised N_2(ppm)	nitrite	solids (ppm)	hardness (ppm)	chloride (ppm)
28.10.85	0.02	2.6	0.009	6	83.7	23
19.11.85	0.04	1.1	0.015	6	73.2	13
4.12.85	0.15	0.8	0.059	182	6	13
27.1.86	0.15	0.9	0.041	114	54.1	22
11.2.86	0.07	1.1	0.013	5	72.8	16
5.3.86	0.33	1.4	0.037	96	52.5	20
16.4.86	0.02	1.1	0.012	10	63.9	16
19.5.86	0.02	1.2	0.017	14	54.1	14
17.6.86	0.04	1.1	0.025	10	63.4	14
17.6.86	0.04	1.1	0.025	10	63.4	14
10.7.86	0.02	1.3	0.106	11	87.9	22
22.7.86	0.15	1.1	0.090	18	85.9	18
8.10.86	0.3	0.7	0.052	13	103	20

Table 18

Site 5.

parameter	orthophos (ppm)	copper (ppm)	zinc (ppm)	cadmium (ppm)	aluminium (ppm)	lead (ppm)
date						
28.10.85	0.12	0.003	0.01	0.001	0.068	0.005
19.11.85	0.11					
4.12.85	0.16	0.002	0.004	0.001	0.13	0.025
27.1.86	0.12					
11.2.86	0.15	0.003	0.011	0.001	0.04	0.007
5.3.86	0.09					
16.4.86	0.09	0.003	0.014	0.001	0.11	0.025
19.5.86	0.14					
17.6.86	0.23					
10.7.86	0.46					
22.7.86	0.71					
8.10.86	0.29	0.003	0.011	0.001	0.088	0.012

Table 19

parameter	chromium (ppm)	mang'ese (ppm)	iron (ppm)	nickel (ppm)
date				
28.10.85	0.01	0.085	0.27	0.004
4.12.85	0.003	0.018	0.29	0.003
11.2.86	0.006	0.104	0.232	0.003
16.4.86	0.009	0.077	0.32	0.003
8.10.86	0.003	0.128	0.469	0.003

Table 20

Site 6: Merthyr Mawr dipping bridge.

parameter	pH	cond'ty (us/cm)	water temp(°C)	DO (% sat)	DO (ppm)	BOD (ppm)
date						
28.10.85	7.9	251	10	109.9	12	1.4
19.11.85	7.7	216	5	99	12.4	2.5
4.12.85	7.6	186	12	92.2	9.6	3
10.1.86	7.3	153				
27.1.86	7.5	200	7	98.6	11.6	2.7
11.2.86	7.9	250	3	102	13.3	2.5
5.3.86	7.7	209	4	91.3	11.6	3.6
16.4.86	7.9	220	8	95	10.9	2.8
7.5.86			8			
19.5.86	7.8	166	13			1.2
6.6.86			11			
17.6.86	7.4	199	16.5	103	10	1.8
10.7.86	7.3	288	17	86	8.3	2.2
22.7.86	7.6	279	17	107	10.3	3.4
1.8.86			14			
3.9.86	7.7	199	15	91.4	9.2	0.7
8.9.86	7.6	227	14	82.6	8.5	2
8.10.86	7.9	307	15	94.3	9.5	2.7

Table 21

Site 6.

parameter date	am'ical N_2(ppm)	oxidised N_2(ppm)	nitrite (ppm)	solids (ppm)	hardness (ppm)	chloride (ppm)
28.10.85	0.08	1.4	0.037	2	89.8	18
19.11.86	0.04	1.2	0.018	3	75.9	15
4.12.85	0.15	0.9	0.069	203	59.6	13
10.1.86	0.08	1.1	0.027		4.9	13
27.1.86	0.17	1	0.038	84	59.4	20
11.2.86	0.13	1.3	0.016	5	74.5	17
5.3.86	0.32	1.6	0.045	110	61.5	22
16.4.86	0.02	1.2	0.015	11	68.8	17
19.5.86	0.02	1.2	0.012	15	55.9	13
17.6.86	0.05	1.2	0.039	63	71.9	15
10.7.86	0.12	1.7	0.177	75	93.3	22
22.7.86	0.1	1.4	0.099	5	87.9	18
3.9.86	0.08	1.1	0.02	17	69.8	13
8.9.86	0.05	1.3	0.027	40	75.5	16
8.10.86	0.13	0.9	0.077	7	114.1	20

Table 22

Site 6.

parameter	orthophos (ppm)	copper (ppm)	zinc (ppm)	cadmium (ppm)	aluminium (ppm)	lead (ppm)
date						
28.10.85	0.23	0.003	0.012	0.001	0.059	0.002
19.11.86	0.1					
4.12.85	0.15					
10.1.86	0.07	0.002	0.007		0.530	0.005
27.1.86	0.11					
11.2.86	0.18	0.002	0.008	0.001	0.039	0.002
5.3.86	0.09					
16.4.86	0.09	0.004	0.016	0.001	0.175	0.025
19.5.86	0.16					
17.6.86	0.24					
10.7.86	0.46					
22.7.86	0.73					
3.9.86	0.06	0.006	0.056	0.001	0.145	0.01
8.9.86	0.18	0.003	0.05	0.001	0.034	0.009
8.10.86	0.34	0.003	0.012	0.001	0.068	0.011

Table 23

Parameter	chromium (ppm)	mang'ese (ppm)	iron (ppm)	nickel (ppm)
date				
28.10.85	0.01	0.057	0.205	0.003
10.1.86	0.005	0.04	8.7	
11.2.86	0.006	0.08	0.17	0.003
16.4.86	0.006	0.066	0.407	0.003
3.9.86	0.003	0.06	0.507	0.015
8.9.86	0.003	0.04	0.056	0.003
8.10.86	0.003	0.043	0.336	0.003

Table 24

24 hour survey.

Dissolved oxygen(ppm)

time site	7 am	11 am	3 pm	7 pm	11 pm	3 am	7 am
1	7.3	8.7	10.1	8.3	7.7	2.9	3.9
2	2	2.5	2.9	2.6	2.6	2.6	2.5
3	4.4	6.2	6.4	6.1	3	2.4	5.1
4	6.8	8.8	9.3	8.6	3.1	2.6	5.6
5	7.9	8.3	8.9	8.3	2.6	2.3	6.4
6	7.4	8.1	8.4	8	2.5	2.1	5.8

Temperature(°C).

time site	7 am	11 am	3 pm	7 pm	11 pm	3 am	7 am
1	11.5	13	14.5	14	12	11.5	11.5
2	16.5	18	20	17.5	17	17	17
3	15	17	18.5	17.5	16	15	15
4	13	15	17.5	16.5	15	13.5	13
5	13	16	18.5	16.5	15.5	14	13.5
6	15	20.5	20	18	15.5	14.5	15

Table 25

Appendix 3.

Biological results from routine sampling by the WWA: Tables 26-61.
Biological results from initial survey: Table 62.

Site 1 October 1985.

Species	1	2	3	4	5	6	7	8	9	10
Leuctra sp								1		
Baetis rhodani	5	5	1	4		1	6	5	5	5
Glossosoma conformis		1					1			
Hydropsyche instabilis								1		1
Rhyacophila dorsalis					1					
Limnius volkmari			1							
Hemerodroma sp										1
Hydrobia jenkinsii	33						127			
Ancylus fluviatile		1								
Limnaea pereger			1							
Conchapelopia melanops		2		1	3			2	1	
Prodiamesa olivacea		1			2			1		1
Brillia longifurca							1			
Brillia modesta		1			1		2	2		1
Tvetania calvescens	1	14	4	9	16	6	6	17	9	15
Eukiefferiella clarripennis		1	1				1	1	1	1
O(O)rubicundus		2	1	1	2	1		2	2	2
Rheocricotopus fuscipes		5		9	2	3	1	6	3	5
Metrocnemius sp				2						1
Nais alpina						2				1
Nais elinguis	5		4		10	32	18	37		38
Stylaria lacustris				3	1	1		3		5
Tubifex tubifex	1			3	26			16	20	
Rhyacodrilus coccineus		3				7	3	7		9
Limnodrilus hoffmeisteri						2			1	
Enchytraeidae		21	6	18	31	3	16	52	56	51
Lumbriculus variegatus	1									1
Stylodrilus herringianus		3	2	3		1	10	11		13
Eclipidrilus lacustris					10	1	2	7	9	

Table 26

Site 2 October 1986.

species	1	2	3	4	5	6	7	8	9	10
Dytiscus sp							1			
Asellus aquaticus								3		
Conchapelopia melanops	4			3						
Prodiamesa olivacea	4		5	5			4			
Brillia longifurca	7	21	29	33	12	20	45	35	8	22
Brillia modesta		3		12						3
Tvetania calvescens	26	27	38	43	21	11	36	46	23	29
Eukiefferiella clarripennis	126	11	156	179	129	84	102	190	49	120
O(O)rubicundus		16	22	25	16	23	9	27	29	17
Rheocricotopus fuscipes	18	19	27	31	12	20	27	32	8	20
Nais elinguis	39	40	43		68	44	25		6	35
Tubifex tubifex	241	244	266	300	14	72	377	72	215	39
Limnodrilus hoffmeisteri	115	116	127	60	82	101	151	6	19	103
Enchytraeidae	464	470	512	540	41	360	628	54	75	414
Lumbriculis variegatus	5	6	6			14		6		5
Stylodrilus herringianus	21	20	24			43	25	6		19
Eclipidrilus lacustris	40	42	44			86	50		4	36

Table 27

Site 3 October 1985.

Species	1	2	3	4	5	6	7	8	9	10
Leuctra sp										1
Baetis rhodani										1
Tabanus sp							1			
Asellus aquaticus										1
Ceratopogonid sp	10				1	1				
Conchapelopia melanops			3		1		4		1	
Brillia longifurca	20	23	20	7	9	7	21	28	22	17
Brillia modesta		12	3		2	2		18	7	5
Tvetania calvescens		33	37	38	12	10	34	25	37	24
Eukiefferiella clarripennis	30	26	10	52	10	7	25	4	15	19
O(O)rubicundus	31	11	7	3	4	3	10	4		8
Rheocricotopus fuscipes	30	25	20	4	9	7	26	25	26	18
Naiselinguis	17	30	107	357	27		87	20	144	
Tubifex tubifex	17	10	29	36	27		26	12	43	37
Rhyacodrilus coccineus	8									4
Limnodrilus hoffmeisteri	8		4	71	26		23	11	38	
Enchytraeidae	322	454	509	293	328	413	190	681	533	72
Lumbriculis variegatus	8							4		
Eclipidrilus lacustris	42		36		27	23	29	13	48	49
Eiseniella tetrahedra		2								

Table 28

Site 4 October 1985.

Species	1	2	3	4	5	6	7	8	9	10
Rhithrogena semicolorata									2	2
Ecdyonurus sp	2	1	5	1			1	1	3	2
Baetis rhodani	61	43	73	48	45	17	10	49	60	53
Ephemerella ignita			2							
Glossosoma conformis			1	1						
Rhyacophila dorsalis			1				1	2		1
Hydropsyche silitalai	1						1	2		1
Philopotamus montanus				1						
Limnius volkmari		2	1	1	1		3	2		1
Simulium ornatum								2		
Dicranota sp		1	3		2	1		2	1	1
Gammarus pulex										1
Hydrobia jenkinsii				2		1			4	1
Erpobdella octoculata								1	1	
Ceratopogonid sp				1				1		
Cochapelopia melanops	1	1			2	2	2			1
Brillia longifurca	3				2					
Brillia modesta	1				1	1	1			
Tvetania calvescens	8	10	14	9	32	22	10	19	14	15
Eukieferiella gracei					1		1			
O(O) rubicundus	1		3		2		1	1	1	1
Rheocricotopus fuscipes	2	4	3	1	6	4	2	4	1	2
Nematoda	1			1	1					
Nais alpina		5					1		1	
Nais elinguis	2	2	4	5	1	5	3	3	2	8
Tubifex tubifex	1			1	4			2		
Rhyacodrilus coccineus				2					1	
Enchytraeidae	2	1	1	1	3	1		2		3
Stylodrilus herringianus				2	3		1		3	
Eiseniella tetrahedra			1					1		1

Table 29

Site 5 October 1985.

species	1	2	3	4	5	6	7	8	9	10
Rhithrogena semicolorata						2				
Baetis rhodani	10	5	15	14	11	22	18	9	5	5
Glossosoma conformis							1			
Hydropsyche silitalai					1					
Limnius volkmari	1		1	2	1		1		1	
Dicranota sp				1						
Asellus aquaticus									1	
Hydrobia jenkinsii	1	1	1	1						
Ancylus fluviatile			1	1						
Ceratopogonid sp	1		1		1					
Conchapelopia melanops	1	1	1		1	2	1	1	1	
Brillia longifurca		1	2	1	1	1	1		1	
Brillia modesta					1				1	
Tvetania calvescens	27	19	30	43	41	35	41	20	38	25
Eukiefferiella clarripennis	2		3	4	6	2	4	1		
O(Eu)thienemanni							1			
O(E)thienemanni										2
O(O)rubicundus	2		3	4	6	3	4	3		5
Rheocricotpus fuscipes	8	9	14	13	9	11	13	7	12	3
Nematoda	5						1		2	
Ophinodais serpentia	4						1			
Nais alpina	5							2		
Nais elinguis	15	10	42	124	96	70	54	57	33	32
Stylaria lacustris	9	5	16		16	13	10	10		6
Tubifex tubifex					16	4		4		
Rhyacodrlus coccineus			5				1			
Enchytraeidae	205	232	185	186	104	224	171	182	95	101
Stylodrilus herringianus		5	16	21	16	16	12	13		7
Eclipidrilus lacustris		4						1		2

Table 30

Site 6 October 1985.

Species	1	2	3	4	5	6	7	8	9	10
Rhithrogena semicolorata	1									
Baetis rhodani	27	30	17	6	27	25	63	5	64	4
Glossosoma conformis		1	3	1	1		2			
Limnius volkmari							1			
Simulium ornatum									3	
Gammarus pulex					1	1			1	
Asellus aquaticus						1	1			
Ancylus fluviatile	1		1							
Erpobdella octoculata		2	2			1				
Ceratopogonid sp		1					1			
Conchapelopia melanops		1	1			1			1	
Brillia longifurca	1		1			1	2		1	
Brillia modesta	3		1			1				1
Tvetania calvescens	16	5	7	9	3	26	24	2	30	2
Eukiefferiella clarripennis		1							1	
Eukiefferiella gracei		1								
O(E)thienemanni			1							
O(O)rubicundus	2		3	2		1	1	1	3	1
Rheocricotopus fuscipes	22	7	9	8	1	31	23	1	25	2
Nais elingius	7	11	16		2	3	28	3	8	12
Stylaria lacustris	1		2	1	2		4			
Tubifex tubifex	9	15		28	2	13	38	6	11	
Rhyacodrilus coccineus	11	18	2	14		19	45	24	13	
Limnodrilus hoffmeisteri			2						1	
Enchytraeidae	24	39	6	28	40	29	98	21	29	6
Lumbriculis variegatus		1						3		
Eclipidrilus lacustris	1							3		

Table 31

Site 1 January 1986.

Species	1	2	3	4	5	6	7	8	9	10
Perlodes microcephala						1			2	
Nemoura sp			1							
Rhithrogena semicolorata	1				1	1			3	
Ecdyonurus dispar				1	2			1		3
Baetis rhodani	25	18	31	62	18	36	3	26	64	6
Rhyacophila dorsalis								1		
Hydropsyche instabilis			1				1			
Hydropsyche silitalai									3	
Philapotamus montanus	1									
Tipula sp		1								
Gammarus pulex										1
Hydrobia jenkinsii						1	1	9	2	
Ancylus fluviatile								2		
Glossiphonia complanata						1				
Erpobdella octoculata								1		
Conchapelopia melanops	1						1			
Brillia longifurca			1					1		
Brillia modesta	1	1		2	1		1		1	1
Tvetania calvescens		1			2	3		1	1	3
Rheocricotopus fuscipes			1		1					2
Nais alpina		1								1
Nais elinguis	2	2	1			1	1			3
Enchytraeidae	8	2	4	7	2	4		3	2	15
Ecilpidrilus lacustris		3				1		1		2

Table 32

Site 2 January 1986.

Species	1	2	3	4	5	6	7	8	9	10
Rhithrogena semicolorata								2		
Baetis rhodani		10	25	2	2	5	10	8	5	7
Sericostoma personatum		1								
Rhyacophila dorsalis			2							1
Limnius volkmari										1
Asellus aquaticus		1	2						1	
Brillia longifurca	1			1	1		2		1	1
Brillia modesta			1			1				
Tvetania calvescens	4	1	5	3	4	4	3	5	4	2
Eukiefferiella clarripennis		1	2	1			2	3	2	1
Eukiefferiella gracei		1								
O(O)rubicundus	1				1					1
Tubifex tubifex		4		2		1	4		6	1
Enchytraeidae	18	37	17	4	3	4	14	26	27	9

Table 33

Site 3 January 1986.

Species	1	2	3	4	5	6	7	8	9	10
Conchapelopia melanops		1	1	1		1	1		1	2
Brillia longifurca	3	3		2	2	1				3
Brillia modesta	2							1		
Tvetania calvescens	8	7	3	4	5	5	2		2	3
Eukiefferiella clarripennis	1	7	8	1	6	6	3		1	8
O(O)rubicundus								1		
O(E)thienemanni			1							
Rheocricotopus fuscipes	1							1		
Enchytraeidae	137	27	125	231	126	84	253	134	127	10

Table 34

Site 4 January 1986.

Species	1	2	3	4	5	6	7	8	9	10
Perlodes microcephala					1					
Rhithrogena semicolorata		1					2			
Baetis rhodani	12	30	22	40	35	2	6	2	30	15
Sericostoma personatum							1	1	1	
Glossosoma conformis				2						2
Rhyacophila dorsalis	1	1							3	1
Hydropsyche instabilis				1	1		3	2		5
Hydropsyche silitalai		3	1	3	6	1				
Philopotamus montanus				2						
Gyrinus sp		1								
Tabanus sp							3			
Clinocera	1									
Limnius volkmari		1		1	1	2	2	2		3
Dicranota sp						2		1	1	3
Gamarus pulex				1						
Hydrobia jenkinsii		1		2				2		
Ancylus fluviatile	6					1		2		1
Glossiphonia complanata				1						
Conchapelopia melanops		1			1		1	1		
Brillia longifurca							1			1
Tvetania calvescens	2	6	4	14	6	2	4	2	5	4
O(Eu)thienemanni			1							
O(O)rubicundus							1			1
Rheocricotopus fuscipes				1						1
Polypedilum pedestre							1			
Nais elinguis	2									
Enchytraeidae	2		2	1	5	2			1	
Lumbriculis variegatus				2						
Eiseniella tetrahedra							1			

Table 35

Site 5 January 1986.

Species	1	2	3	4	5	6	7	8	9	10
Perlodes microcephala	2			1						
Isoperla grammatica	1					1	2			
Rhithrogena semicolorata					1	1		1	1	3
Ecdyonurus dispar	17	6	5	4	16	5	13	8	9	9
Baetis rhodani	25	14	14	12	23	17	17	18	12	14
Ephemerella ignita				1		2			1	
Caenis moesta						1				
Sericostoma personatum					1			1		
Glossosoma conformis	2		2		2		1			1
Rhyacophila dorsalis	1									
Hydropsyche instabilis	3			1	1		1			1
Hydropsyche silitalai	3	1	1		4	1	3	2	1	2
Elmis sp								1		
Tabanus sp	1									
Clinocera sp							2			
Hemerodroma sp										1
Dicranota sp	1	2	2			2	1	1	1	1
Limnius volkmari	1	1	7	4	2	2	1		3	
Gammarus pulex	2									
Asellus aquaticus	1									
Hydrobia jenkinsii	2	1								1
Ancylus fluviatile	1		3				1			1
Erpobdella octoculata	1	1	1		1		1			1
Ceratopogonid sp	1		3			1	1		1	1
Conchapelopia melanops	1		1	1	2				1	2
Prodiamesa olivacea			1				1		1	1
Brillia longifurca	3	2	2	2	2	1	3	1	3	6
Brillia modesta		1					1			
Tvetania calvescens	15	5	15	8	16	14	12	3	13	15
Eukiefferiella clarripennis	2		3		1	2	1		1	1
O(O)rubicundus				1	1				1	1
Rheocricotopus fuscipes	3	2	3	2	1	1	2	1	3	3

Table 36

Species	1	2	3	4	5	6	7	8	9	10
Nematoda	1		1	4	3					6
Nais elinguis	4				1					3
Enchytraeidae	42	20	99	67	73	48	26	118	6	15
Eclipidrilus lacustris	3	2			2		2			4
Eiseniella tetrahedra		1								

Table 36(cont)

Site 6 January 1986.

Species	1	2	3	4	5	6	7	8	9	10
Isoperla grammatica								1		
Rhithrogena semicolorata			1		1		3	2	3	2
Ecdyonurus dispar	6	4	3		4	5	3	2	8	10
Baetis rhodani	17	15	12	4	15	9	10	16	22	
Sericostoma personatum								1		
Glossosoma conformis	1						1			
Rhyacophila dorsalis			1				2			
hydropsyche instabilis		1								
Hydropsyche silitalai	2							1		1
P.flavomaculatus									1	
Dicranota sp										2
Hemerodroma sp						1				
Limnius volkmari			1					1	1	
Gammarus pulex	1	2				1	1			2
Asellus aquaticus	2		1	1	1			1	2	
Hydrobia jenkinsii	1									
Ancylus fluviatile	2			1	1		3			1
Erpobdella octoculata	1	4		1			1			1
Glossiphonia complanata	1				1					
Ceratopogonid sp		1				1				
Conchapelopia melanops		1	1				1			
Brillia longifurca	6	4	4	2	2	2	4	1	3	8
Brillia modesta	1	1			1		1		1	2
Tvetania calvescens	12	8	17	3	3	4	7	2	6	9
Eukiefferiella clarripennis	1	4	1		2	1		1	1	
O(O)rubicundus						1				2
Rheocricotopus fuscipes	5	2	4	2	5	2	3	1	3	4

Table 37

Species	1	2	3	4	5	6	7	8	9	10
Nais elinguis	13	45	65	2	16	14	85	24	87	10
Tubifex tubifex	5	4				1		2	7	5
Rhyacodrilus coccineus	3	2					3	2	4	
Enchytraeidae	26	25	36		8	8	14	2	49	33
Stylodrilus herringianus						1				2
Eclipidrilus lacustris	5		1						1	
Eiseniella tetrahedra					2					

Table 37(cont)

Site 1 April 1986.

Species	1	2	3	4	5	6	7	8	9	10
Isoperla grammatica	1		1							
Nemoura avicularis					1					
Rhithrogena semicolorata								1		
Ecdyonurus dispar	3						1	2		
Baetis rhodani	5	2	1		3	3	1	3	6	3
Glossosoma conformis		2								
Rhyacophila dorsalis	1		1							
Hydropsyche instabilis										1
Diplectrona felix									1	
Tabanus sp										1
Hemerodroma sp				1						
Limnius volkmari			1						1	
Tipula sp			1							
Asellus aquaticus			1							
Hydrobia jenkinsii		2						2	1	1
Ancylus fluviatile			1					1		
Ceratopogonid sp	1		1			1	1			
Conchapelopia melanops		1		1		1	2			
Brillia longifurca		1	1					1		
Cricotopus bicinctus			1	1						2
O(E)thienemanni							1			
O(O)rubicundus			1			2				
Rheocricotopus fuscipes	3	1	1			4		2	3	1
Nais elinguis	20	29	60	19	20	58	22	29	30	18
Tubifex tubifex			2						10	
Enchytraeidae	2	25	50	6	1	145		27	5	1
Stylodrilus herringianus						15		2		
Eclipidrilus lacustris								1	5	

Table 38

Site 2 April 1986.

Species	1	2	3	4	5	6	7	8	9	10
Ecdyonurus dispar						1	1			
Rhithrogena semicolorata				1	4					
Baetis rhodani	1	8	2		13	3	5	7	5	8
Gammarus pulex							1			
Rhyacophila dorsalis					1					
Ceratopogonid sp			1							1
Conchapelopia melanops								1	1	
Brillia longifurca			1		1		1	1		2
Brillia modesta						1	1	1		
O(O)rubicundus	1	1	1	1	5	8	3	6	4	3
Rheocricotopus fuscipes			1	1					1	
Nais elinguis	221	37	115	283	249	271	273	234	114	12
Tubifex tubifex	9	18	72		58	32	55	57	47	23
Rhyacodrlius coccineus			6					2		
Limnodrilus hoffmeisteri			18		14	13	14	15	12	6
Enchytraeidae	10	37	150	57	125	26	120	124	103	50
Eclipidrilus lacustris			42		3			4		7

Table 39

Site 3 April 1986.

Species	1	2	3	4	5	6	7	8	9	10
Leuctra moselyi		1								
Baetis rhodani	5	4	4	7	6		1	1	3	1
Asellus aquaticus									1	
Brillia longifurca		1	1	1			1	1		1
Tvetania calvescens					1		1		1	
O(O)rubicundus	1	3	2	4	1		1		3	1
O(E)thienemanni		1								
Rheocricotopus fuscipes	1	2		2	2		1			2
Nais elinguis	320	339	189	164	191	113	299	64	120	40
Tubifex tubifex	7	14	4	23			5	3		13
Limnodrilus hoffmeisteri		10		23			4		3	9
Enchytraidae	115	121	26	141	31	16	40	23	107	42

Table 40

Site 4 April 1986.

Species	1	2	3	4	5	6	7	8	9	10
Leuctra moselyi							1			
Rhithrogena semicolorata									1	
Ecdyonurus dispar					1		2			
Baetis rhodani	4	3	5	12	8	3	1	9	4	7
Ephemerella ignita		1								
Rhyacophila dorsalis									1	
Hydropsyche silitalai		1								
Diplectrona felix								1		
Elmis aena				1						
Tabanus sp										1
Limnius volkmari									2	4
Dicranota sp		2	1							
Glossiphonia complanata							1			
Ceratopogonid sp	1		1		1	2		2	2	3
Conchapelopia melanops				1	2		1	2	1	1
Pothastia longimiana		1								
Cricotopus bicinctus		4		1	1			1		6
Tvetania calvescens			1	1				2		3
O(O)rubicundus	3		8	4	8	4	7	15	7	28
Rheocricotopus fuscipes		1	1		1	1	1	1		7
Nais elinguis	69	104	113	294	132	48	158	213	127	54
Tubifex tubifex	2		1					2		
Enchytraeidae			6	17	16	12				7
Stylodrilus herringianus		6			6			12	5	

Table 41

Site 5 April 1986.

Species	1	2	3	4	5	6	7	8	9	10
Perlodes microcephala										1
Nemoura avicularis						1				
Ecdyonurus dispar	1	4		1	1	1	6	5	2	1
Baetis rhodani	1	4	6	2	3	6	3	6	5	7
Ephemera danica								1		
Caenis moesta				1						
Rhyacophila dorsalis										1
Hydropsyche instabilis								1		
Hydropsyche silitalai		1					1			
P.flavomaculatus			1		1					
Plectrocnemia geniculata									1	
Gammarus pulex					1					
Asellus aquaticus						2	2	2		
Ceratopogonid sp			1			1		1	1	2
Conchapelopia melanops		1					1			
Prodiamesa olivacea							1	1		
Brillia longifurca	1	2	2			3	1	3	2	3
O(E)thienemanni	2	11	7	3	2	15	5	19	13	17
O(O)rubicundus	1	5	1	3	1	7	6	9	3	8
Rheocricotopus fuscipes	3	8	5	2	1	12	4	14	9	10
Polypedilum pedestre							1			
Nematoda		2						1		
Nais elinguis	40	55	33	10	20	53	19	84	86	23
Tubifex tubifex	1	38	35	15		52	16	41	83	92
Rhyacodrilus coccineus		3								
Limnodrilus hoffmeisteri				5	1	1		2	2	
Enchytraeidae		12	11	46		36	12	43	58	57
Stylodrilus herringianus		3							1	

Table 42

Site 6 April 1986.

Species	1	2	3	4	5	6	7	8	9	10
Rhithrogena semicolorata	1			3			1	4		1
Ecdyonurus dispar	5	2	5			4	2	4		1
Baetis rhodani	15	1	4	3	6	3	3	14	5	6
Glossosoma conformis			1		1					
Clinocera sp								2		
Hemerodroma sp										1
Limnius volkmari								1		
Gammarus pulex		1	1		1	2	1	1		1
Asellus aquaticus	1		1			2	1	1		1
Hydrobia jenkinsii								1		
Glossiphonia complanata										1
Erpobdella octoculata								1	1	1
Ceratopogonid sp			1		1	1	3			
Conchapelopia melanops	1			2	3	1		1	1	2
Prodiamesa olivacea			2	3		1			2	1
Brillia longifurca		2	4	6	5	3	5	3		3
Brillia modesta	1	1	2	3	1	1	4		1	
O(E)thienemanni	2	5	7	11	8	3	9	8	8	3
O(O)rubicundus	29	17	74	115	70	51	109	76	80	43
Rheocricotopus fuscipes	3	3	11	17	9	4	18	15	13	7
Nais elinguis	154	184	178	152	268	602	281	259	188	32
Tubifex tubifex	2		6		9	20			7	15
Limnodrilus hoffmeisteri				25		30		13	9	
Enchytraeidae	8	16	99	203	150	336	156	144	105	69
Stylodrilus herringianus			2			2		4		5
Eiseniella tetrahedra		4			1					

Table 43

Site 1 June 1986.

Species	1	2	3	4	5	6	7	8	9	10
Perlodes microcephala	1					1			1	
Ecdyonurus dispar								1		
Baetis rhodani	3	1	7	1	2	4	2	4		
Ephemerella ignita			2	2	3	3	2	4	2	3
Rhyacophila dorsalis					1					1
Elmis aena			1							
Limnius volkmari					2	1	1	1		4
Conchapelopia melanops	2			2	3	7	9		1	1
Prodiamesa olivacea				4	1	6			4	
Brillia longifurca	2	2	2			6		6	4	
Brillia modesta					1		2		1	1
O(O)rubicundus		4		4	2	11	14	9		5
Rheocricotopus fuscipes	4		5	4	2	18	22	14		21
Metrocnemius calvicola	2							1		
Ophinodais serpentia			1						1	
Nais elinguis			2		1	2		1		2
Stylaria lacustris							7	1		1
Tubifex tubifex	4			4	1	8		4	4	6
Rhyacodrilus coccineus			4						1	
Limnodrilus hoffmeisteri				2		1			1	1
Enchytraeidae	34	18	4	8	21	109	61	63	57	80
Lumbriculis variegatus			8						1	1
Stylodrilus herringianus	4	2			1	5		2	3	4
Eiseniella tetrahedra						1	7			1

Table 44

Site 2 June 1986.

Species	1	2	3	4	5	6	7	8	9	10
Ecdyonurus dispar	1									
Baetis rhodani	1	4	3	6	2	3	1	2	2	40
Baetis scambus	1	1		6	2	1	4	5	4	7
Ephemerella ignita	6	1	2	8	9	3	6	3	2	
Asellus aquaticus		1		2	1				2	1
Limnius volkmari					1					
Conchapelopia melanops	1				1				1	
Prodiamesa olivacea			1		2		1	1		
Brillia longifurca	38	56	23	58	41	50	13	24	32	4
Brillia modesta									1	
Cricotopus bicinctus	26	19	4	20	14	17	5	8	2	
O(O)rubicundus		9	2	10	7	8	3	4	3	9
Rheocricotopus fuscipes	10	13	2	12	10	12	5	6	2	6
Metrocnemiuscavicola							1			
Nais elinguis					2					1
Stylaria lacustris	3	5			2	2	1		6	2
Tubifex tubifex	33	22	1	8	34	22	12	6	87	20
Rhyacodrilus coccineus		3			6					
Limnodrilus hoffmeisteri	5	9			4	3	2	1	6	3
Enchytraidae	55	84	56	42	33	37	21	11	38	34
Lumbriculis vareigatus	6	9	3	4		3	2	1	5	3
Stylodrilus herringianus		6				1			3	2
Eclipidrilus lacustris	5	19			2	2	1			2

Table 45

Site 3 June 1986.

Species	1	2	3	4	5	6	7	8	9	10
Ecdyonurus dispar			1	1	2			1		
Baetis rhodani	24	68	24	38	56	100	24	68	48	8
Baetis scambus		1		1		1	1			
Ephemerella ignita	4	1	1		2					1
Asellus aquaticus		1		1		4			2	
Conchapelopia melanops						1	1			
Prodiamesa olivacea				1		1			1	
Brillia longifurca	19	14	21	7	59	44	49	46	49	4
Brillia modesta	1	1	3		3			2		
Cricotopus bicinctus	4	7	10	7	21	16	11	17	18	1
O(O)rubicundus	2	2	5	3	9	7	6	8	8	
Rheocricotopus fuscipes	2	1		2	3	3			2	
Ophinodais serpentia						1				
Nais elinguis		5				11	3		4	
Stylaria lacustris	3	14	26	2	13		11	2		1
Tubifex tubifex		15		2	21		13	17	13	1
Limnodrilus hoffmeisteri	4				2		1			
Enchytraeidae	25	62	60	8	81	2	59	27	26	4
Lumbriculis variegatus		1			2			3		
Stylodrilus herringianus	3	4	5	1			1	3		
Eclipidrilus lacustris		8	14	1	10		6			

Table 46

Site 4 June 1986.

Species	1	2	3	4	5	6	7	8	9	10
Perlodes microcephala		3	6	3	2	3	5			
Isoperla grammatica							2			
Leuctra moselyi	3						1	3	5	1
Rhithrogena semicolorata							2			
Ecdyonurus dispar	2	2	2				1	2	1	1
Baetis rhodani	50	70	104	19	38	26	88	64	148	45
Baetis scambus								1	5	4
Ephemerella ignita	27	37	49	16	9	25	40	60	64	33
Caenis moesta		2	2	1						
Glossosoma conformis				1			1	1	1	
Rhyacophila dorsalis		1						1		
Hydropsyche silitalai								1		
Simulium ornatum									1	
Hemerodroma sp							1	1		1
Limnius volkmari					1		1		1	
Dicranota sp								1		
Conchapelopia melanops	4	8	5	5	1	4	3	10	5	6
Brillia longifurca					4			1		1
Brillia modesta		1	1	1	1			1	2	2
Cricotopus bicinctus	6	10	6	2	4	5	4	13	4	8
O(Eudactylocladius) sp					1					
Rheocricotopus fuscipes	3	4	3	2	2	2	2	4	2	1
Ophinodais serpentia				1				1		
Nais alpina		2		5		1				
Nais elinguis	1	4	4	2	3	1	6	1		2
Stylaria lacustris	1									
Tubifex tubifex	3	1	1		2	1	3	2		1
Limnodrilus hoffmeisteri		1	1				3			
Enchytraeidae	6	1	2	1	5	3	17	5		2
Eclipidrilus lacustris	1	1								

Table 47

Site 5 June 1986.

Species	1	2	3	4	5	6	7	8	9	10
Perlodes microcephala		2								
Leuctra moselyi										1
Ecdyonurus dispar	3	6	3	6	7	1	4	2	2	5
Baetis rhodani	35	4	5	64	11	5	7	36	12	8
Baetis scambus				2	2		2	4	1	8
Ephemerella ignita	26	38	16	48	41	22	15	100	19	22
Caenis moesta		1								
Glossosoma conformis			1	2						
Rhyacophila dorsalis				1	1		1			
Hydropsyche instabilis				1					1	
Philopotamus montanus	1									
Limnius volkmari				1				2		
Dicranota sp	1	4		3	1			4	1	1
Asellus aquaticus	1						1			
Hydrobia jenkinsii	1									
Erpobdella octoculata									1	
Conchapelopia melanops		2	1			1		1	2	
Brillia longifurca	1	1	2	2		2		5	2	3
Brillia modesta				2	1				1	1
Cricotopus bicinctus	36	49	30	26	38	57	16	137	47	55
Eukiefferiella clarripennis		1						1		
O(O)rubicundus	1	4	2	1		1	2	6	1	
Rheocricotopus fuscipes	3		3	2	1	1	1	5		1

Table48

Species	1	2	3	4	5	6	7	8	9	10
Ophinodais serpentia			1					1		
Nais elinguis	2				1			6	1	
Tubifex tubifex	7	9	1		8	7	1	58	4	3
Rhyacodrilus coccineus		1				2			1	
Enchytraeidae	5	6	3	18	4	4	1	70	4	4
Lumbriculis variegatus			1	2		2		8		
Stylodrilus herringianus			2			2				1
Eclipidrilus lacustris	2	6			1	4	1	21		1
Eiseniella tetrahedra	2									

Table 48(Cont)

Site 6 June 1986.

Species	1	2	3	4	5	6	7	8	9	10
Leuctra moselyi	1							3	1	
Ecdyonurus dispar	8	1	2	8	12	8	6	10	8	1
Baetis rhodani	15	8		20	6	7	13	24	36	5
Baetis scambus		11		1	3	7	2	1	4	6
Ephemerella ignita	25	19	9	31	29	17	24	30	89	11
Glossosoma conformis					1	1				
Rhyacophila dorsalis							1	1		
Philopotamus montanus								1		
Hemerodroma sp									1	
Limnius volkmari					2	1		1		
Dicranota sp					1					1
Gammarus pulex	2			1	1				2	
Asellus aquaticus	1	1		1	3					
Hydrobia jenkinsii						1				
Ancylus fluviatile									1	
Erpobdella octoculata			3	1					1	
Conchapelopia melanops	2		1					1		1
Brillia longifurca	2	1	1		2	2	2		3	
Brillia modesta	1			2	1	2		1		2
Cricotopus bicinctus	22	12	11	19	16	21	28	17	35	10
Eukiefferiella clypeata				1						
O(O)rubicundus	1		5	4	2	3	4	4		
Rheocricotopus fuscipes	7	5	5	3	2	6	8	5	10	3
Polypedilum pedestre		1								

Table 49

Site 1 September 1986.

Species	1	2	3	4	5	6	7	8	9	10
Perlodes microcephala										1
Leuctra moselyi		1				1	1	1	2	1
Ecdyonurus dispar	1				1				2	
Baetis rhodani	16	10	18	11	25	13	20	8	21	27
Ephemerella ignita					2		3	1		6
Rhyacophila dorsalis			1	1			1		1	
hydropsyche silitalai							1		1	
Tabanus sp		1								
Hemerodroma sp	1									
Limnius volkmari				2			1		1	
Hydrobia jenkinsii		1								
Brillia longifurca	1		1			3		1		1
Rheocricotopus fuscipes			1	2	1	1	1	1		2
Nais alpina			2					2		
Nais elinguis			2	1		1	1	2	1	
Stylaria lacustris			1							
Limnodrilus hoffmeisteri			2							
Enchytraeidae	2		1	7	1	2		3	1	1
Lumbriculis variegatus	1					3				
Stylodrilus herringianus		2		1				2		1
Eclipidrilus lacustris				1		1				
Eiseniella tetrahedra				3						

Table 50

Site 2 September 1986.

Species	1	2	3	4	5	6	7	8	9	10
Leuctra moselyi	1	2				1	1			
Ecdyonurus dispar			1							
Baetis rhodani	240	104	256	96	168	120	148	5	184	56
Ephemerella ignita		1	2						6	
Caenis moesta								1		
Sericostoma personatum						1				
Hydropsyche silitalai							1			
Simulium ornatum										1
Limnius volkmari									1	
Asellus aquaticus		1	4	1			6		1	
Conchapelopia melanops				1			1			
Prodiamesa olivacea						1			2	
Brillia longifurca	7	6	48	7	3	7	7	7	30	20
Brillia modesta		2	3					3		1
Cricotopus bicinctus						1				
O(O)rubicundus	11	12	70	13	5	16	11	18	20	30
Rheocricotopus fuscipes	5	12	37	5	3	4	5	7	16	15
Polypedilum pedestre		1				1		1		1
Nais elinguis		10	3				2			2
Nais variablis									7	
Stylaria lacustris			7				4	3	21	4
Tubifex tubifex	639	265	716	294	338	372	360	327	415	94
Limnodrilus hoffmeisteri			12	21			6	6	14	
Enchytraidae	86		88		26		44	40	142	51
Lumbriculis variegatus		10	11				6	5	21	1
Stylodrilus herringianus			2						7	
Eclipidrilus lacustris	69		35		26		18	16	7	20
Eiseniella tetrahedra	4									

Table 51

Site 3 September 1986.

Species	1	2	3	4	5	6	7	8	9	10
Leuctra moselyi					2		1			
Ecdyonurus dispar	1	2	2		1					
Baetis rhodani	51	48	56	46	126	40	64	80	100	44
Baetis scambus			4	8		4		2	2	4
Ephemerella ignita										1
Dytiscus sp									1	
Limnius volkmari		1	1							
Dicranota sp				1			1			
Asellus aquaticus		2		1	1					2
Conchapelopia melanops				1				1		
Brillia longifurca	5	2	3	4	3	1	3	4	2	9
Brillia modesta						1				1
Tvetania calvescens		1		2						
O(O)rubicundus	2	1	7	4	4	5	2	5	3	12
Rheocricotopus fuscipes	3	1	2	1	2	2	5	3	1	8
Nais alpina				2						
Nais elinguis		42		23		10	7	39	71	29
Nais variablis				2						
Tubifex tubifex	19	261	158	62	60	128	241	198	179	72
Limnodrilus hoffmeisteri		15		4		3	7	14	28	11
Enchytraeidae	33	69	58	4	36	16	13	64	28	47
Lumbriculis variegatus	14	7			2		3	7		5
Stylodrilus herringianus				2						1
Eclipidrilus lacustris		11		2	3		7	11	21	8

Table 52

Site 4 September 1986.

Species	1	2	3	4	5	6	7	8	9	10
Perlodes microcephala									1	
Leuctra moselyi	2	3	1	1	2	1	2	3	4	4
Rhithrogena semicolorata						1				
Ecdyonurus dispar		1		1	1		5	2	4	
Baetis rhodani	17	49	43	25	31	14	37	32	34	24
Ephemerella ignita		5	2		7		9	2	3	4
Glossosoma conformis			2	3	2					
Rhyacophila dorsalis			1	1					1	1
P.flavomaculatus					1					
Elmis aena					1					
Gyrinus sp								1	1	
Simulium ornatum							1			
Hemerodroma sp	1						1			
Tipula sp	1									
Limnius volkmari					1				1	
Dicranota sp							1		5	
Asellus aquaticus			1							
Hydrobia jenkinsii								1		
Glossiphonia complanta								1		
Conchapelopia melanops		1		1			1	1	1	
Brillia modesta		1					1			2
O(O)rubicundus	2	2	1						1	1
Rheocricotopus effusus			2	2	2	1	1	3		2
Nais elinguis										1
Tubifex tubifex	10		1	1					2	1
Limnodrilus hoffmeisteri	4	2								
Enchytraeidae	4		1	1		1	1	4	1	1
Stylodrilus herringianus								1		
Eiseniella tetrahedra	1		3				1	1	1	

Table 53

Site 5 September 1986.

Species	1	2	3	4	5	6	7	8	9	10
Perlodes microcephala	1								2	
Nemoura sp								1		
Leuctra moselyi		1	1		2	2	1	4	3	6
Ecdyonurus dispar		1	2	3		4	4		1	8
Baetis rhodani	18	9	6	19	17	26	63	13	24	43
Ephemerella ignita						2	2	1	4	6
Glossosoms conformis	1							1		1
Rhyacophila dorsalis	1							1		
Hydropsyche instabilis					1	2		1	1	1
Philopotamus montanus									1	1
Gyrinus sp							1			
Gammarus pulex								1		1
Asellus aquaticus					1					1
Conchapelopia melanops						1			1	
Brillia longifurca								1	1	
Tvetania calvescens		1			1	2	1		1	2
O(O)rubicudus	2			1			1		2	2
Rheocricotopus fuscipes				1	1	1			1	1
Nais alpina	1			2						
Nais elinguis	1	3	5	4	1	4	11	1	2	6
Stylaria lacustris	1								2	
Tubifex tubifex		1		2		2	3	1		6
Limnodrilus hoffmeisteri				1			3		1	
Enchytraeidae	1	1	1	1		1	10	2	2	2
Lumbriculis variegatus			2							
Stylodrilus herringianus						2		1		2
Eiseniella tetrahedra										4

Table 54

Site 6 September 1986.

Species	1	2	3	4	5	6	7	8	9	10
Perlodes microcephala									1	
Isoperla grammatica		3		1			1			6
Leuctra moselyi			1	1	5	5		4		9
Ecdyonurus dispar		1	3	1	3	2	2		3	2
Baetis rhodani	8	5	39	33	18	46	24	71	30	49
Ephemerella ignita		3		1	1	3		2	5	1
Glossosoma conformis					3		1		1	
Hydropsyche instabilis		1	1						1	
Hydropsyche silitalai										1
Elmis aena		1								
Gyrinus sp									1	
Simulium ornatum							1			
Tabanus sp								1		
Limnius volkmari									1	1
Dicranota sp	1						1			
Gammarus pulex										1
Asellus aquaticus		2								1
Ancylus fluviatile						1		1		
Glossiphonia complanata									2	
Brillia longifurca	1		1		3	1				1
Tvetania calvescens		1		2	2				3	
O(O)rubicundus	1				5		5		1	2
Rheocricotopus fuscipes		2		1	3		1	1	2	1

Table 55

Species	1	2	3	4	5	6	7	8	9	10
Ophinodais serpentia			1							
Nais alpina	5				1			4		
Nais elinguis	5	2	3		4	4		4	2	6
Stylaria lacustris		1		2		3		2		1
Tubifex tubifex			1			1				1
Limnodrilus hoffmeisteri		1			3					
Enchytraeidae		1	1	4		1	1	9	1	
Eclipidrilus lacustris			1	1			1			
Eiseniella tetrahedra				1				2		

Table 55(cont)

Site 1 November 1986.

Species	1	2	3	4	5	6	7	8	9	10
Rhithrogena semicolorata					1		1			
Ecdyonurus dispar			1							3
Heptagenia lateralis					1					1
Baetis rhodani		2	3		5	2	1	1	5	3
Ephemerella ignita										1
Sericostoma personatum	1									1
Hydropsyche instabilis										1
Tipula sp										1
Hemerodroma sp									1	
Limnius volkmari										1
Gammarus pulex									1	
Ceratopogonid sp										1
Conchapelopia melanops										1
Brillia longifurca										1
O(O)rubicundus										2
Rheocricotopus fuscipes										3
Nais alpina			1							
Nais elinguis		1	1	2	1		2	1		2
Tubifex tubifex										10
Rhyacodrilus coccineus		1								
Limnodrilus hoffmeisteri			1							
Enchytraeidae					1		1	1	1	2
Lumbriculis variegatus										4
Stylodrilus herrinianus							1			
Eclipidrilus lacustris									1	
Eiseniella tetrahedra										1

Table 56

<u>Site 2 November 1986.</u>

Species	1	2	3	4	5	6	7	8	9	10
Leuctra sp									1	
Baetis rhodani	3	3		10	7	6	1	1	3	7
Glossosoma conformis			1							
P.flavomaculatus								1		
Hemerodroma sp									1	
Gammarus pulex			1							
Brillia longifurca	1			1	1					
Eukiefferiella clarripennis		1				1				
O(O)rubicudus	1		1	3	1		1			1
Rheocricotopus fuscipes	2	3	1		4					2
Nais elinguis		4	8			10	1	14	8	
Tubifex tubifex	2	2	25	56	29	2	3	4	6	10
Rhyacodrilus coccineus									6	12
Limnodrilus hoffmeisteri					4	4		2		
Enchytraeidae	2	4	49	14	11	2	3	4	4	2
Stylodrilus herringianus	2									2
Eclipidrilus lacustris	2	10			7		1		8	2
Eiseniella tetrahedra					3					

Table 57

Site 3 November 1986.

Species	1	2	3	4	5	6	7	8	9	10
Nemoura sp						1				
Ecdyonurus dispar					1					
Baetis rhodani	3		1	3	5	8	9	4	3	1
Gammarus pulex							1			
Asellus aquaticus	1			1	1	2	1			
Conchapelopia melanops			1	1		1		1	1	2
Brillia longifurca	1			2	1	1	2		2	3
Brillia modesta			1	1		1		1	1	2
Eukiefferiella clypeata							2			
O(O)rubicundus		1	3	2			1		2	3
Rheocricotopus fuscipes	1	1	4	10	4	6		2	7	9
Nais elinguis	6	10		2	4		1	2	2	2
Tubifex tubifex	2	2	8		4	11	1	3	3	2
Limnodrilus hoffmeisteri				1		3				4
Enchytraaeidae	6	10	8	14	4	5	2	5	6	10
Lumbriculis variegatus			6		4		1	1	1	
Stylodrilus herringianus			4			2				
Eclipidrilus lacustris		2		2		5	1	1		
Eiseniella tetrahedra	2					1				2

Table 58

Site 4 November 1986.

Species	1	2	3	4	5	6	7	8	9	10
Rhithrogena semicolorata		1		1	1			1		1
Ecdyonurus dispar		1		1	2		1			
Heptagenia lateralis		1			2		1			
Baetis rhodani		1	2	1	2	1	2	7	5	1
Ephemerella ignita							1		1	
Sericostoma personatum				1						
Glossosoma conformis							1	4		1
Elmis aena	1									
Dicranota sp									1	
Gammarus pulex		1								
Asellus aquaticus									1	
Ceratopogonid sp			1		1		1			1
Conchapelopia melanops				1			1			
Brillia modesta			1				1			2
Eukiefferiella clarripennis		1				1				
O(O)rubicundus	1			2	1		1	1		2
Rheocricotopus fuscipes	2	3			2		2		1	1
Nais elinguis		4	2	1	5		2	1	1	2
Stylaria lacustris										1
Tubifex tubifex								3		
Limnodrilus hoffmeisteri		1			1					
Enchytraeidae		1		1			1	1	3	
Eclipidrilus lacustris		1	2							

Table 59

Site 5 November 1986.

Species	1	2	3	4	5	6	7	8	9	10
Leuctra sp			1							1
Nemoura avicularis							1			
Rhithrogena semicolorata	2		1					2		
Ecdyonurus dispar	2		4	1	2	2		3		2
Baetis rhodani	9	1	10	2	4	6	3	8	5	4
Rhyacophila dorsalis						1		1		
Hydropsyche silitalai						1	1			1
Hydropsyche instabilis				1						
Hemerodroma sp			1							
Dicranota sp				1	1		3			
Asellus aquaticus						1	2			
Erpobdella octoculata					1			1		
Glossiphonia complanata						1				
Ceratopogonid sp								1		1
Conchapelopia melanops						1		2	1	
Prodiamesa olivacea		1		2		1		1		
Brillia modesta				1						
Tvetania calvescens								1		1
O(O)rubicundus		2			1	1	1	2		
Rheocricotopus fuscipes		3		2	3	2	5	6	1	
Nais elinguis	3	8	1	9	1	5	13	6	5	6
Stylaria lacustris				1	1	2				1
tubifex tubifex				1	4	7			2	
Rhyacodrilus coccineus					4					
Limnodrilus hoffmeisteri		1	1				2	4		1
Enchytraeidae		2		2	2	2		12		2
Stylodrilus herringianus						5		2		
Eclipidrilus lacustris						2	2	4		1

Table 60

Site 6 November 1986.

Species	1	2	3	4	5	6	7	8	9	10
Leuctra sp					1					
Nemoura avicularis			1		1	1				
Rhithrogena semicolorata	2	1	4	1	2	3		2	1	7
Ecdyonurus dispar	2	2	4	3	7	2	1	1	6	
Baetis rhodani	15	17	10	14	26	9	8	9	8	17
Ephemerella ignita		1								
Rhyacophila dorsalis	1				1				1	
Hydropsyche instabilis										1
Elmis aena			1							
Gyrinus sp				1						
Tipula sp					1					1
Tabanus sp								1		
Limnius volkmari	1	1						1		
Dicranota sp	2			2	2					3
Gammarus pulex	1			5	3	2		4		3
Asellus aquaticus				4		2				1
Erpobdella octoculata					1			2		
Conchapelopia melanops			1	2		1	2		1	
Brillia longifurca			1	3	3	1		5		2
Brillia modesta		1	2	3	2	2		1		2
Eukiefferiella clypeata	4			3	1				1	1
O(O)rubicundus	3				3	3		2		4
Rheocricotopus fuscipes	3	3	5	11	10	12	4	13	5	4
Nais elinguis	29	35	5		9	3	24	15		27
Tubifex tubifex	4				3		4		4	
Rhyacodrilus coccineus			2		3		4	1		
Limnodrilus hoffmeisteri			2				4			
Enchytraeidae	99	15	36	70	36	48	4	52	54	93
Lumbriculis variegatus	1					2				1
Stylodrilus herringianus	1			3						
Eclipidrilus lacustris	4			5	7			2		4

Table 61

Initial survey results.

The numbers at each sampling time are expressed as a percntage of the total numbers.

	Time(seconds)								
species	30	60	90	120	150	180	210	240	Total
Perlodes microcephala	1								1
Ecdyonurus dispar	2		1						3
Rhithrogena semicolorata	1			1					2
Baetis rhodani	10	8	5	3		1		1	20
Glossosoma conformis	1								1
Hydropsyche instabilis			1						1
Tabanus sp		1							1
Hemerodroma sp	1								1
Dicranota sp			1						1
Gammarus pulex	1	1							2
Asellus aquaticus			1						1
Ceratopogonid	1								1
Chironomidae	25	20	15	6	3	2		2	73
Oligochaeta	31	21	17	9	6	3		1	88
Totals	74	44	35	27	10	8	0	1	204
% of total	36	61	81	91	95	98	98	100	

Table 62

thus, since >90% of the organisms in this initial survey were recorded at 120s it was decided that this was to be the sampling time for the biological sampling programme.

Appendix 4.

Graphs representing chemical results against sampling time: Figs 5-11

Fig 5: pH.

Fig 6: Dissolved oxygen(ppm) and Temperature(^oC).

Fig 7: Ammoniacal nitrogen(ppm).

Fig 8: Particulate solids(ppm).

Fig 9: BOD(ppm).

Fig 10: Oxidised nitrogen(ppm).

Fig 11: 24 hour survey.

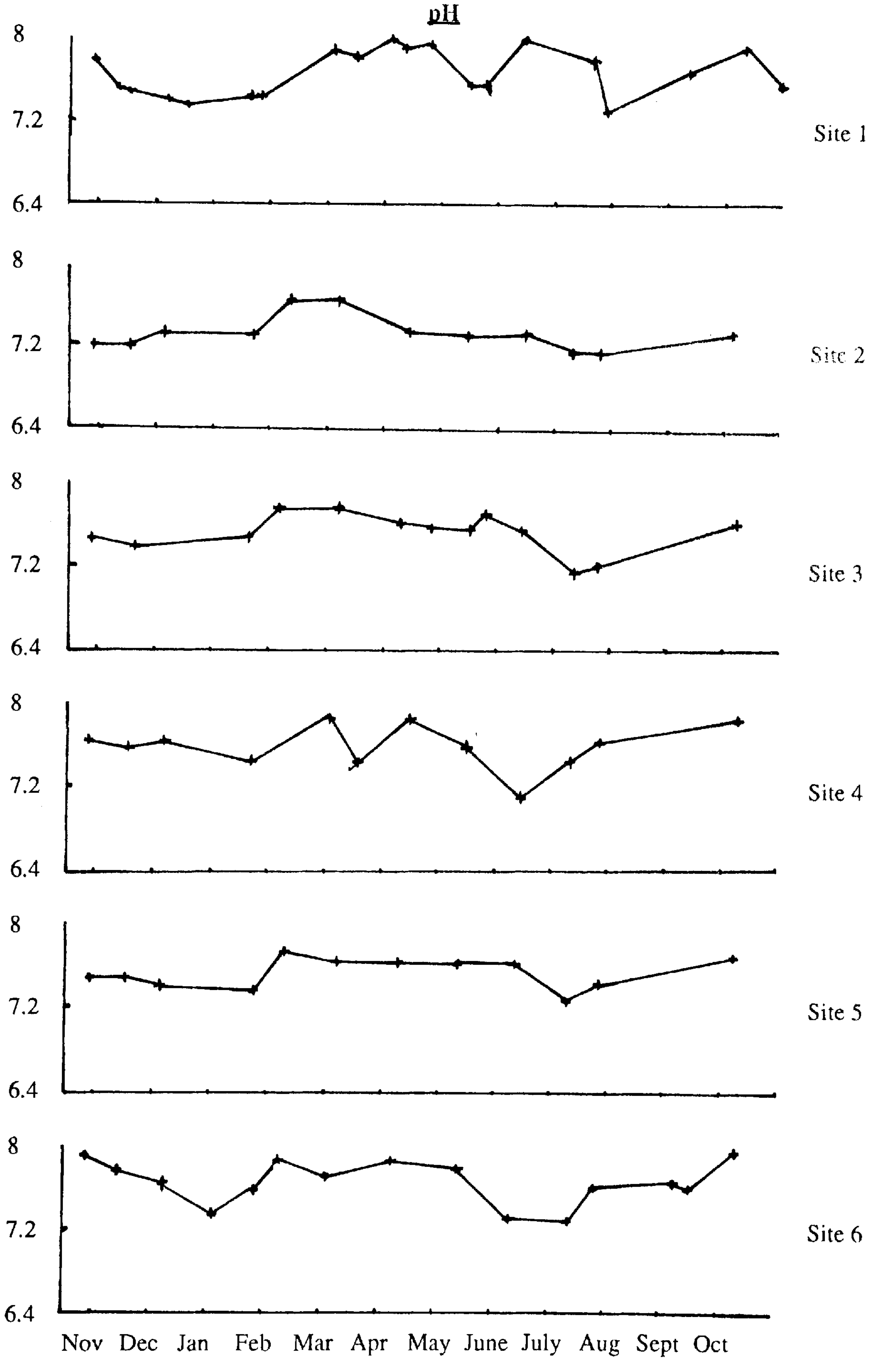

pH
8
7.2
6.4
Site 1
8
7.2
6.4
Site 2
8
7.2
6.4
Site 3
8
7.2
6.4
Site 4
8
7.2
6.4
Site 5
8
7.2
6.4
Site 6
Nov Dec Jan Feb Mar Apr May June July Aug Sept Oct

Fig 5

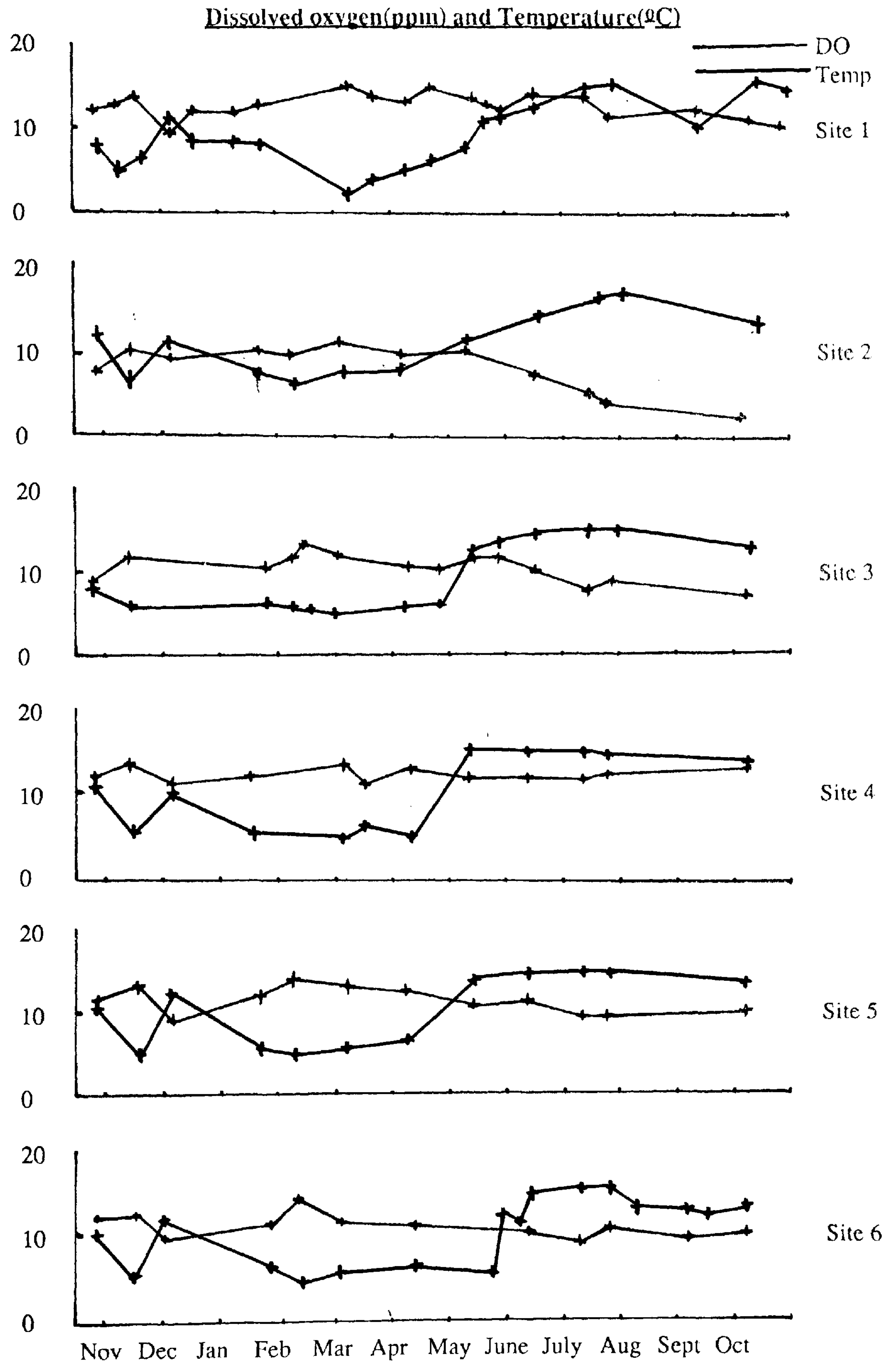

Dissolved oxygen(ppm) and Temperature(ºC)
DO
Temp
20
10
0
Site 1
Site 2
Site 3
Site 4
Site 5
Site 6
Nov Dec Jan Feb Mar Apr May June July Aug Sept Oct

Fig 6

Ammoniacal nitrogen(ppm)

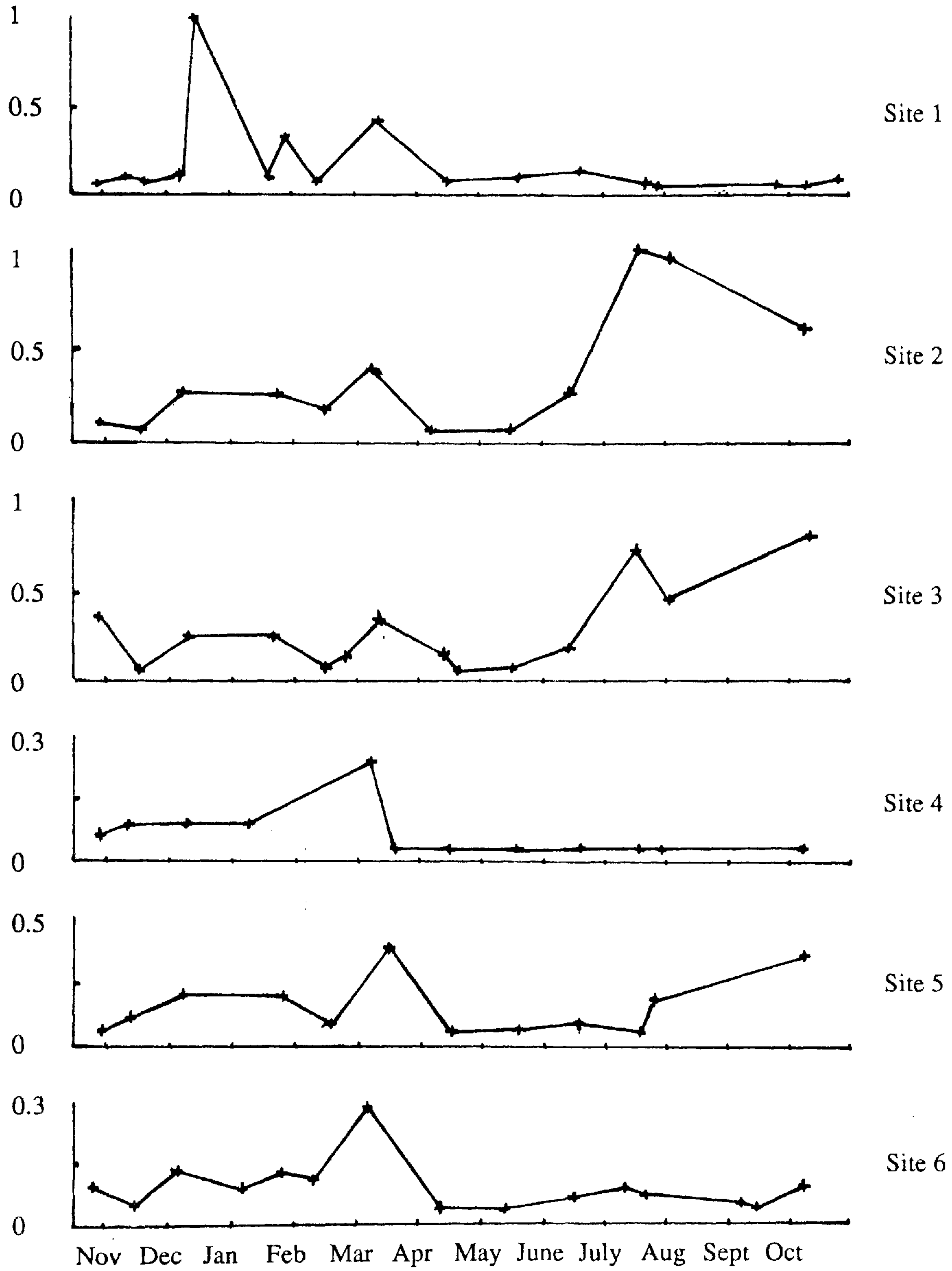


Fig 7

Particulate solids(ppm)

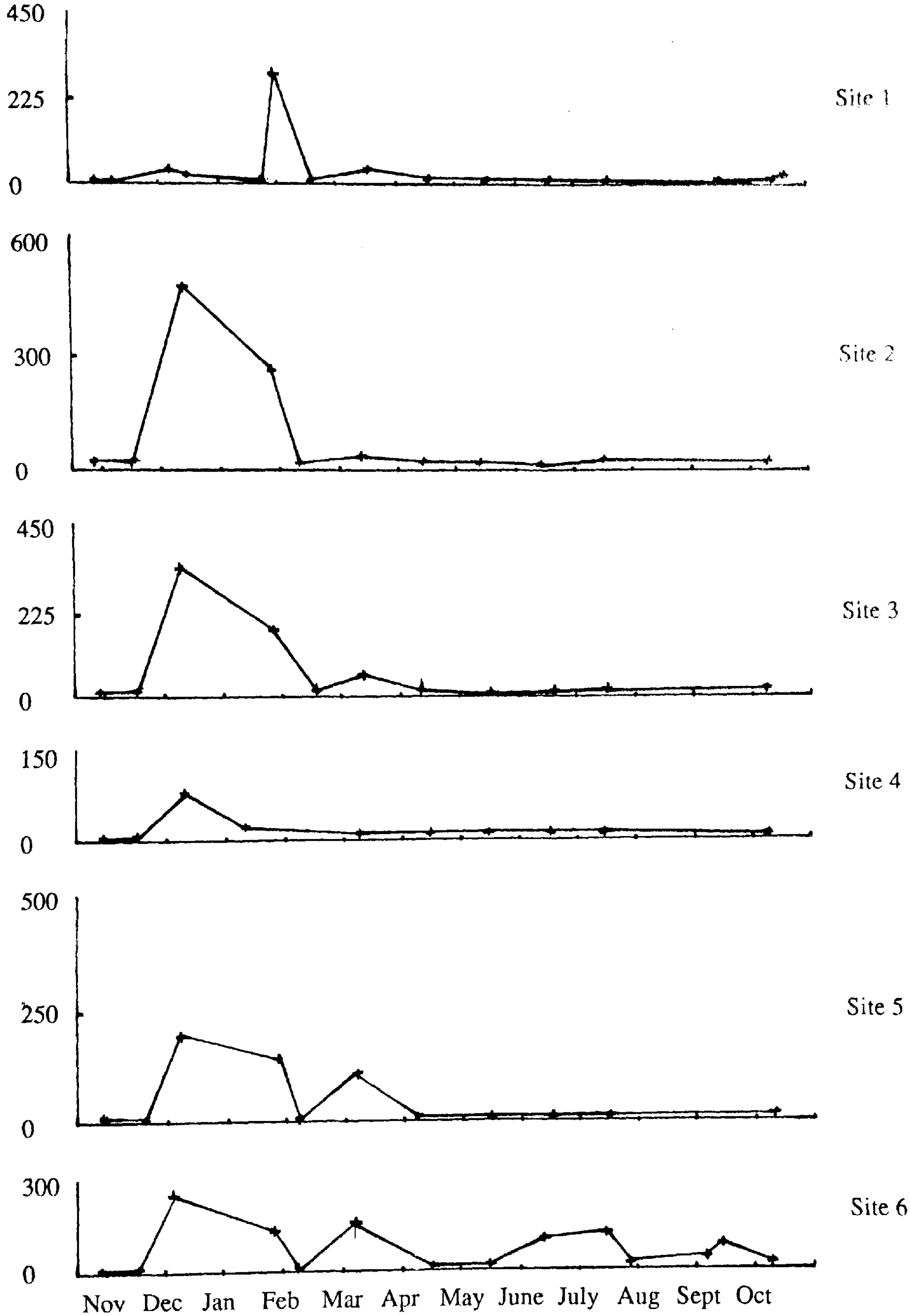


Fig 8

BOD(ppm)

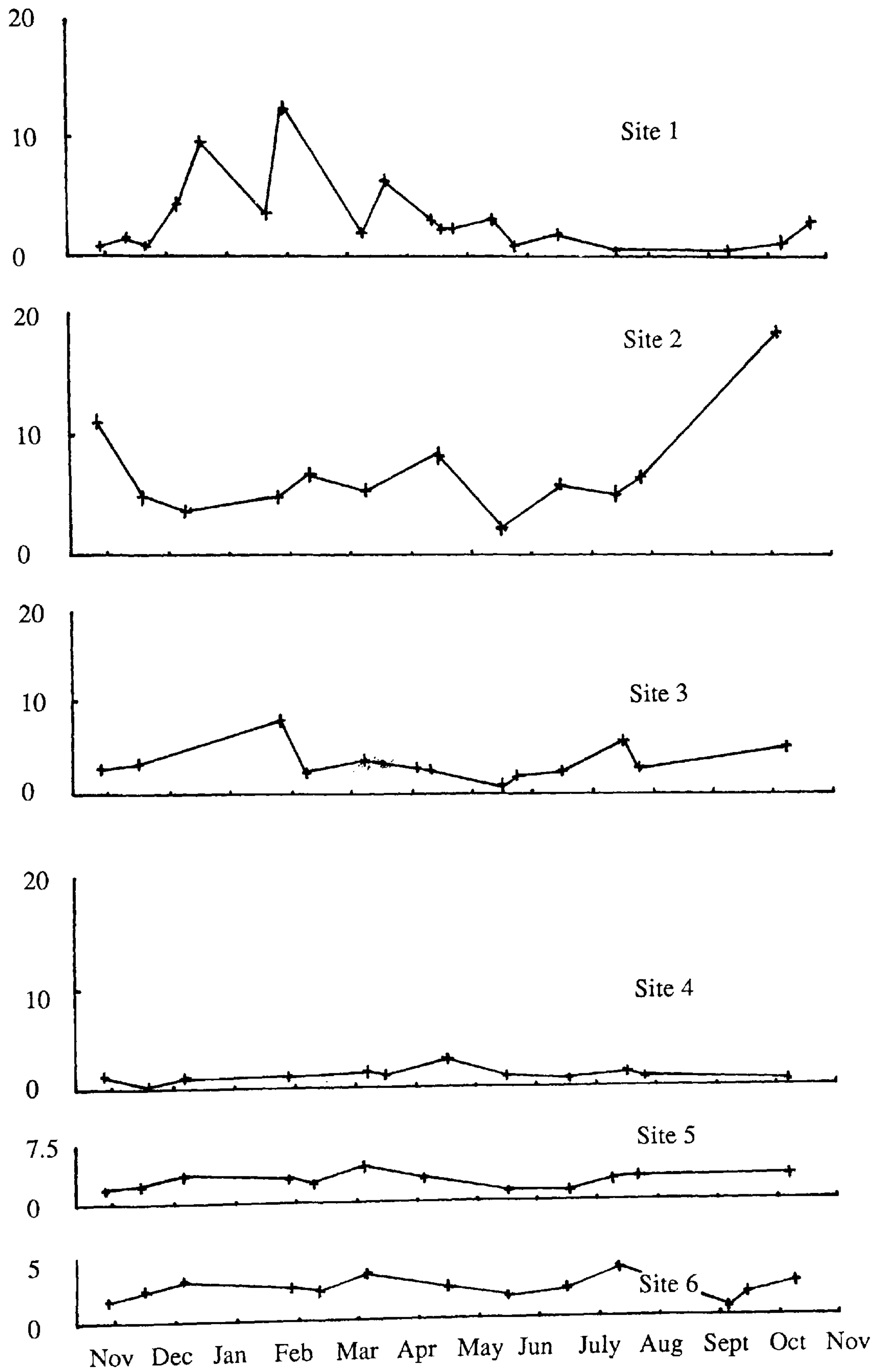

20
10
0
Site 1
20
10
0
Site 2
20
10
0
Site 3
20
10
0
Site 4
7.5
0
Site 5
5
0
Site 6
Nov Dec Jan Feb Mar Apr May Jun July Aug Sept Oct Nov

Fig 9

Oxidised nitrogen(ppm).

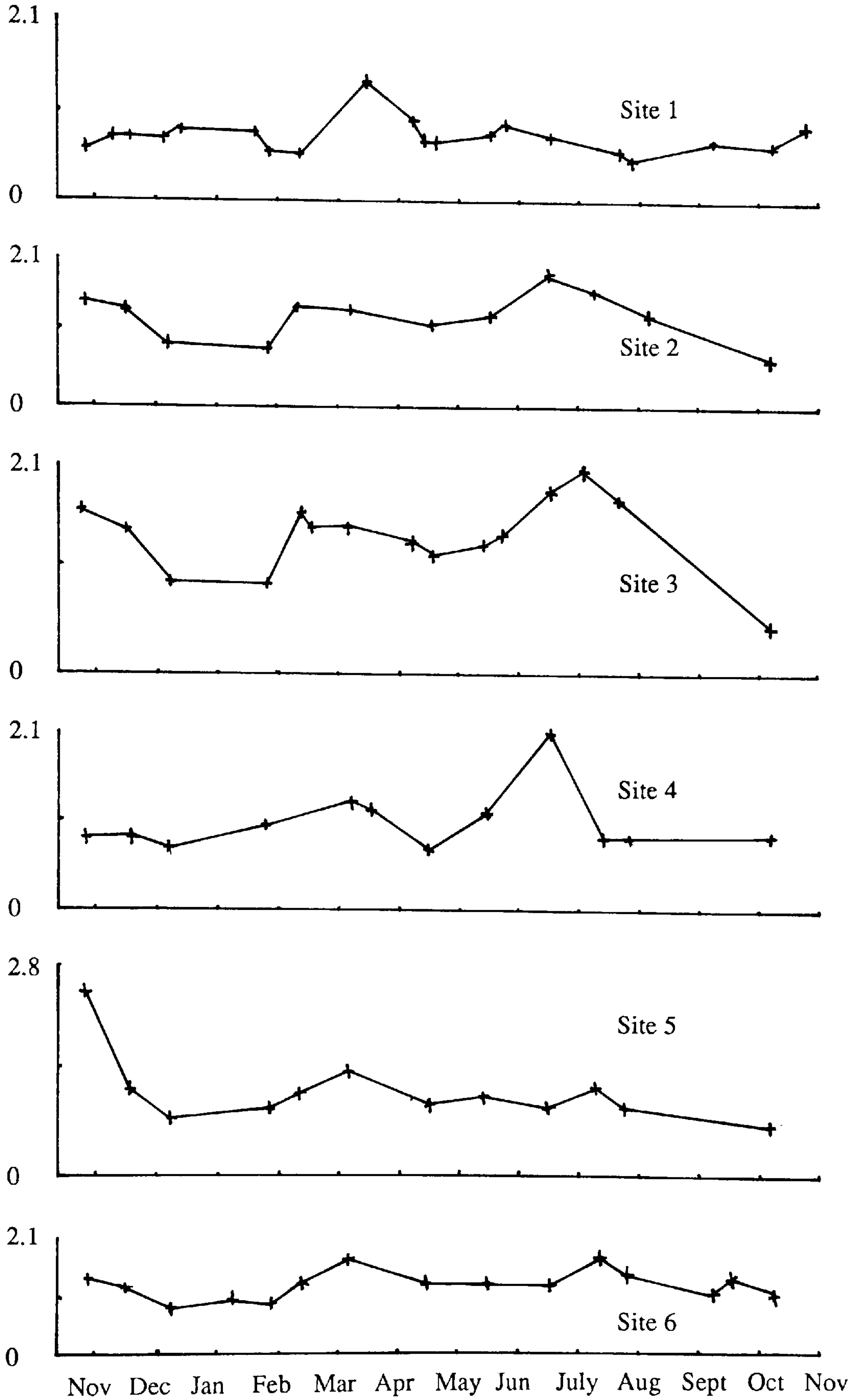
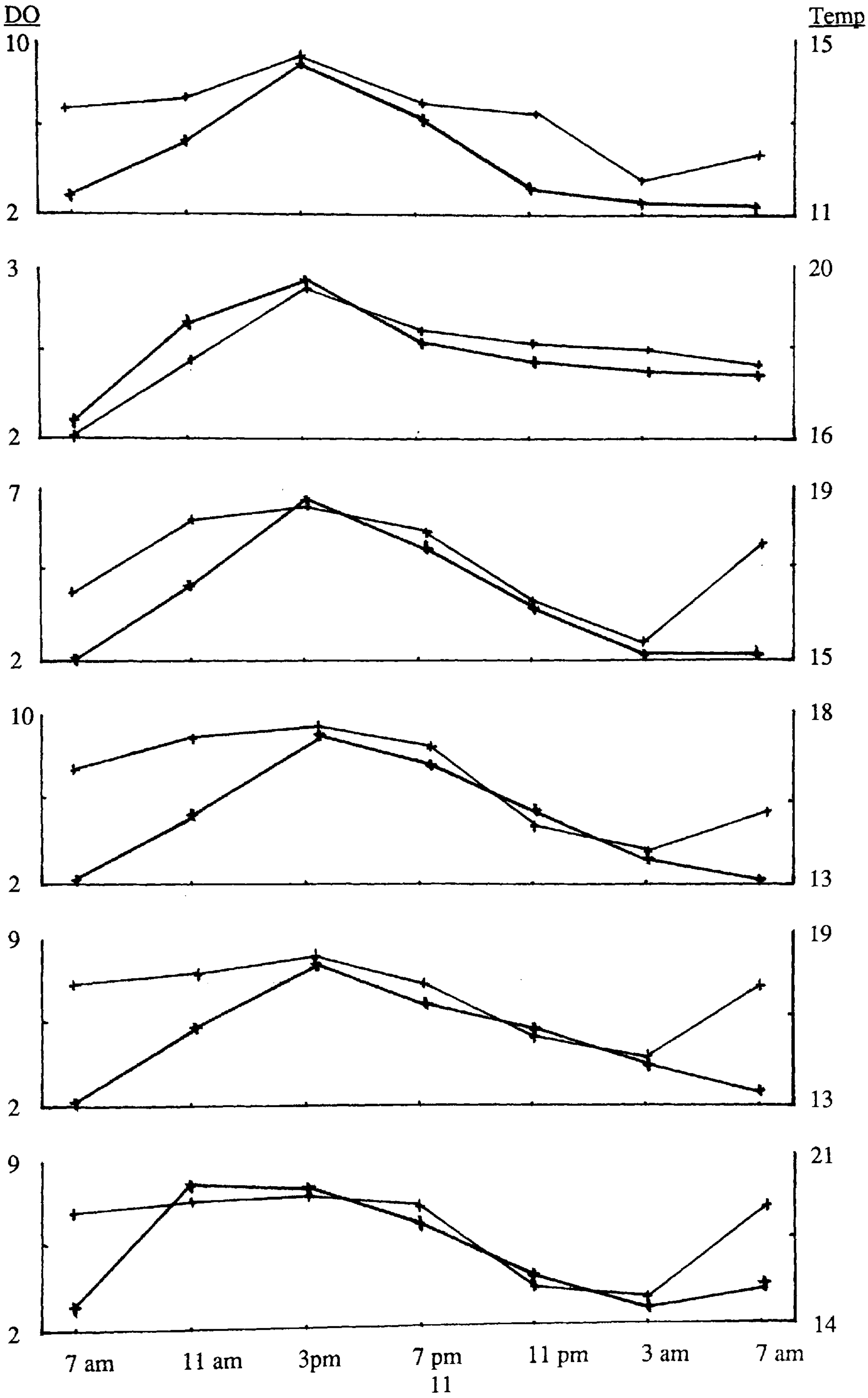


Fig 10

24 hour survey: Dissolved oxygen(ppm) and Temperature(ºC).



Appendix 5.

Graphs of 95% confidence limits (All graphs show animals/m^2 against site number):

1) Most common species:
Fig 12: October 1985.
Fig 13: January 1986.
Fig 14: April 1986.
Fig 15: June 1986.
Fig 16: September 1986.
Fig 17: November 1986.

2) Seasonal variation of selected species:
Fig 18: Baetis rhodani.
Fig 19: Ephemerella ignita.
Fig 20: Cricotopus bicinctus.
Fig 21: Brillia longifurca.
Fig 22: Orthocladius(O) rubicundus.
Fig 23: Rheocricotopus fuscipes.
Fig 24: Tubifex tubifex.
Fig 25: Nais elinguis.
Fig 26: Enchytraeidae.

Most common species: October 1985

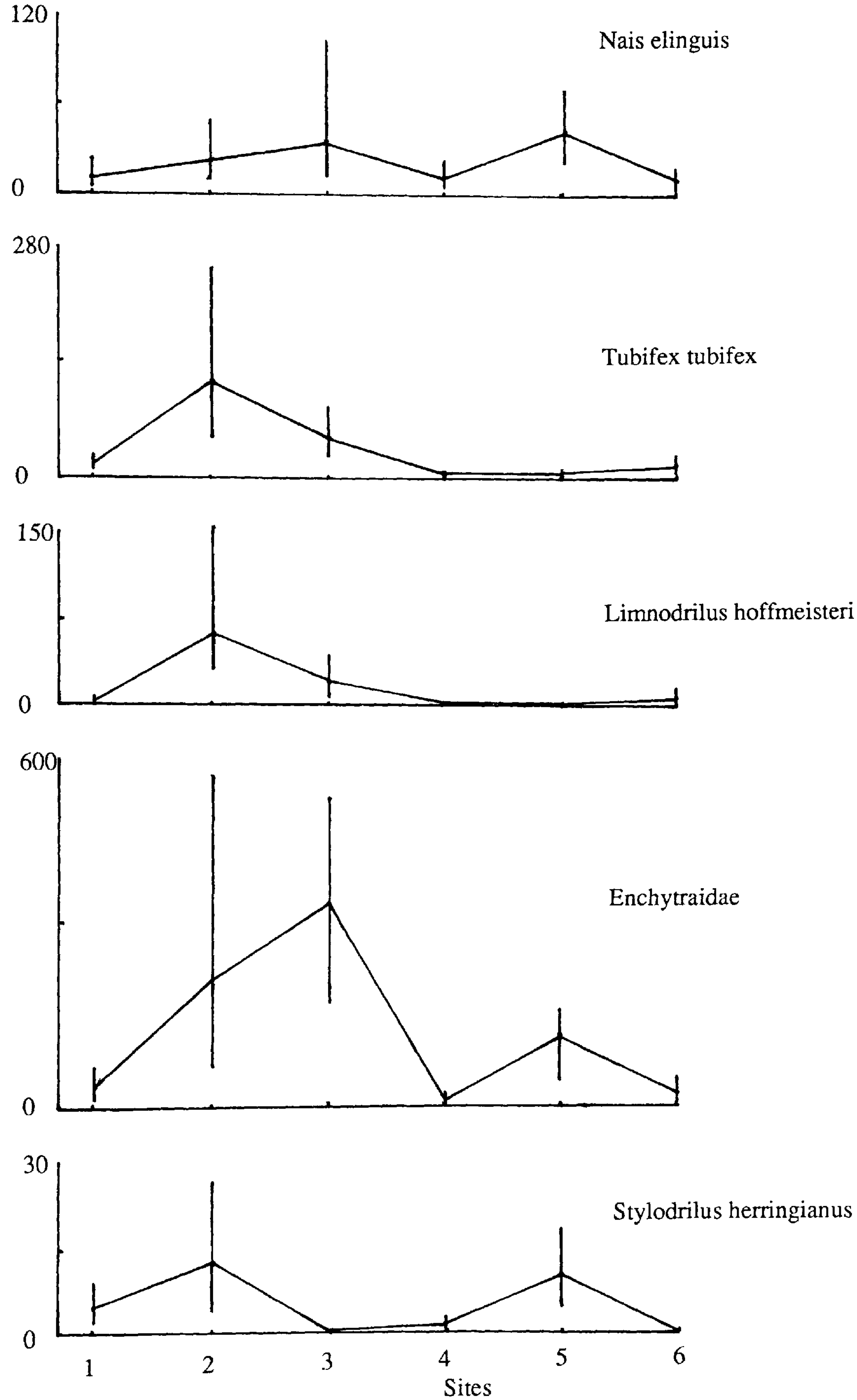


Fig 12

Most common species: October 1985.

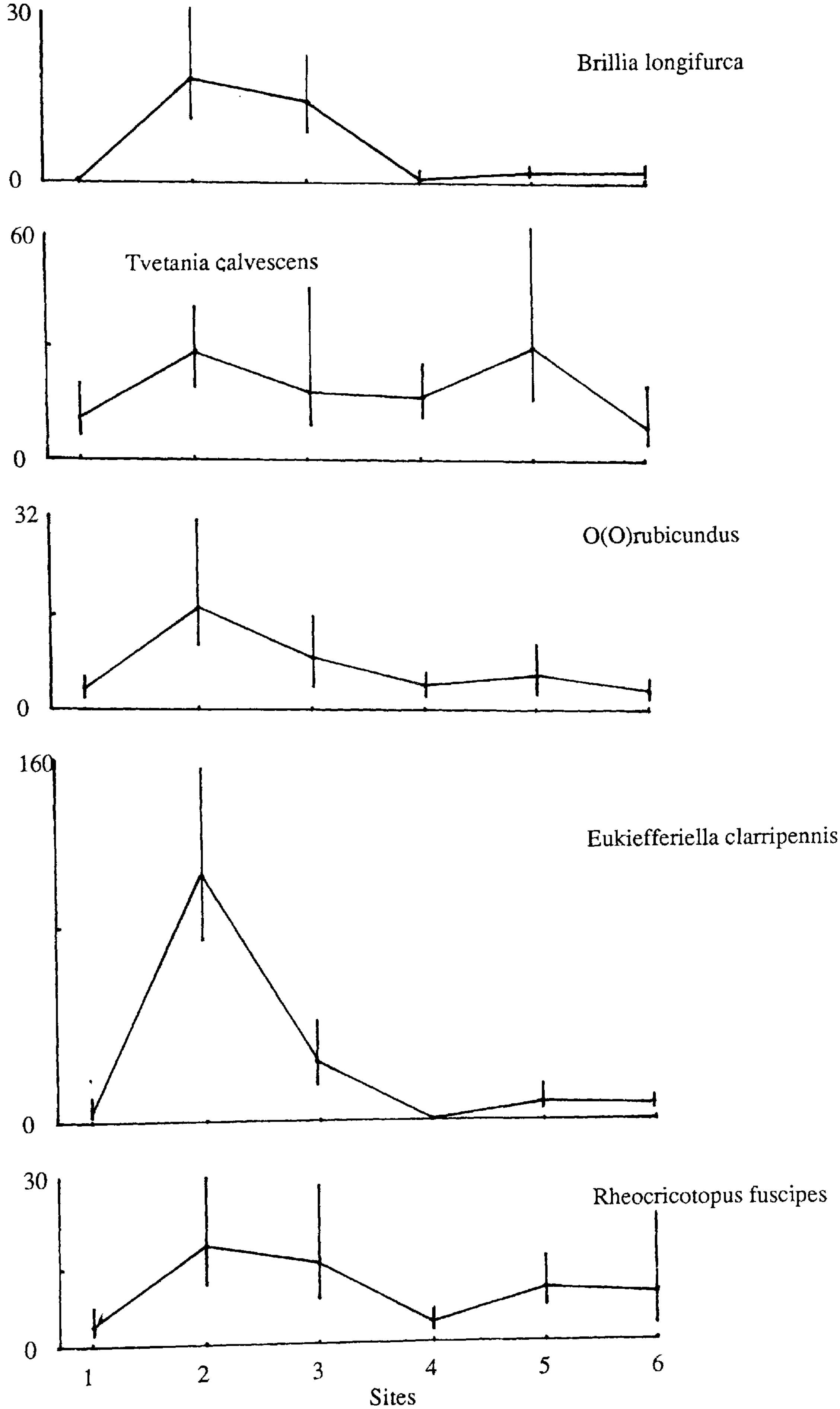


Fig 12(cont)

Most common species: January 1986.

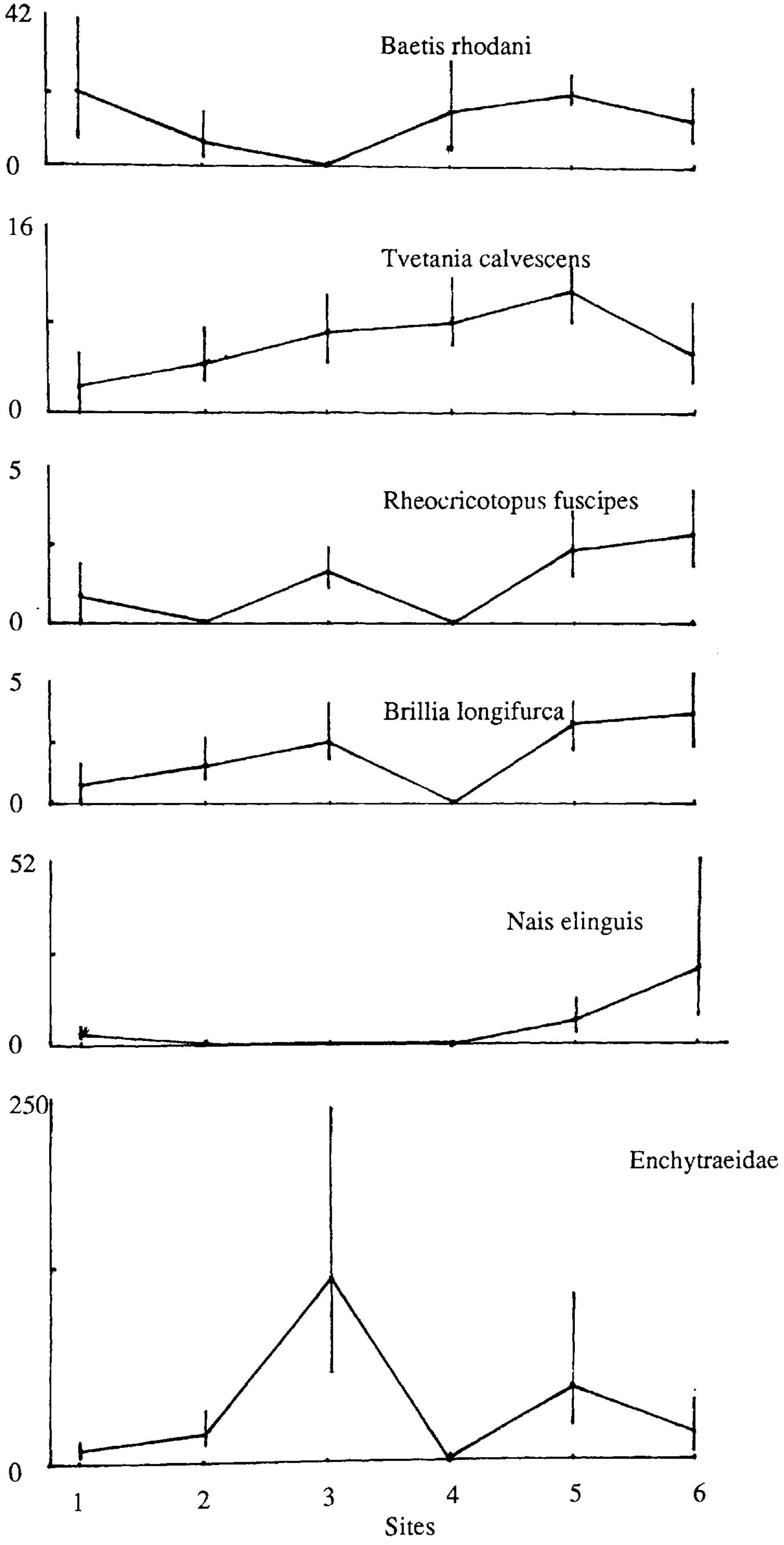


Fig 13

Most common species: April 1986.

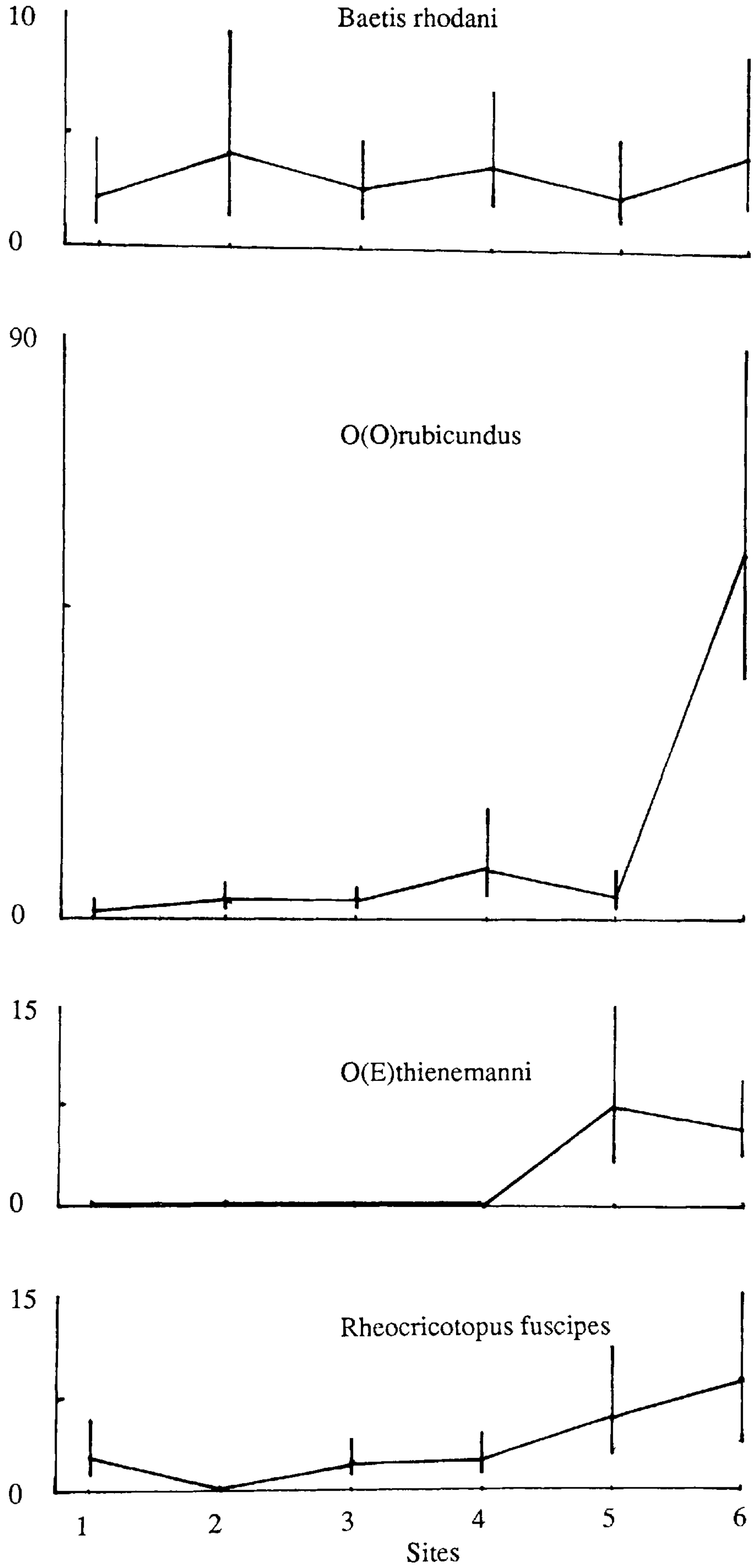


Fig 14

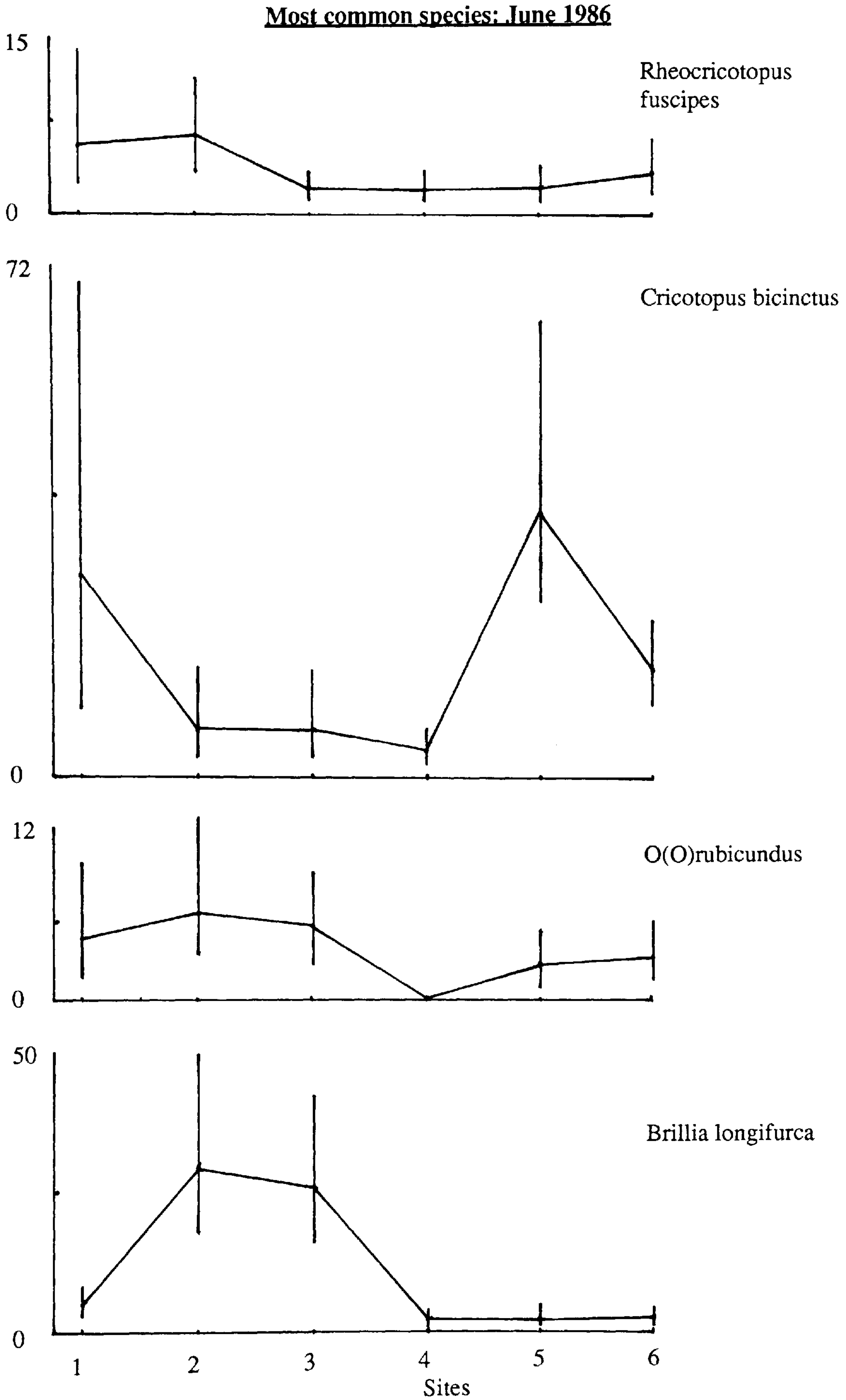

Most common species: June 1986
15
0
Rheocricotopus fuscipes
72
0
Cricotopus bicinctus
12
0
O(O)rubicundus
50
0
Brillia longifurca
1
2
3
4
5
6
Sites

Fig 15

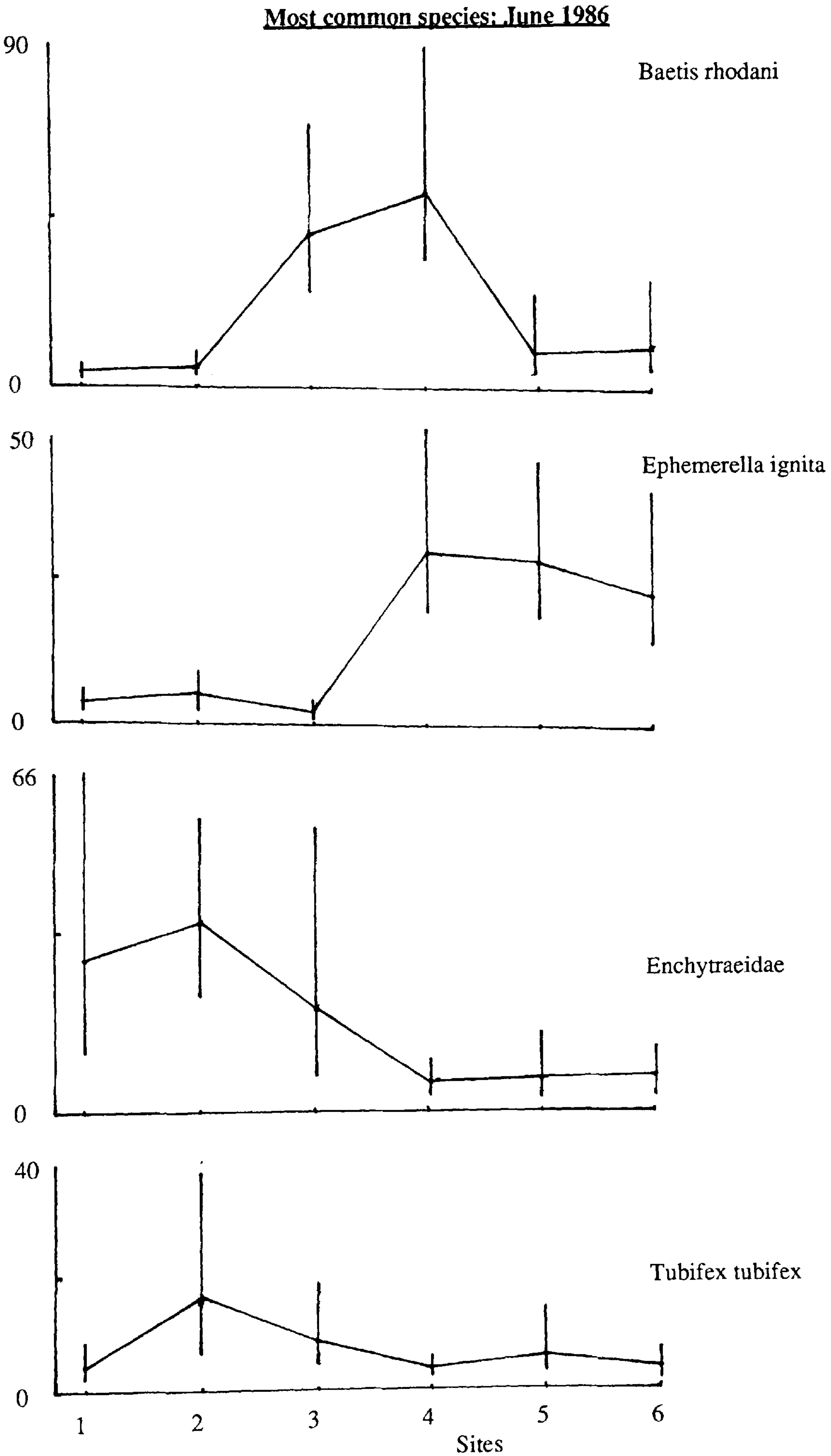

Most common species: June 1986
90
0
Baetis rhodani
50
0
Ephemerella ignita
66
0
Enchytraeidae
40
0
Tubifex tubifex
1
2
3
4
5
6
Sites

Fig 15(cont)

Most common species: September 1986.

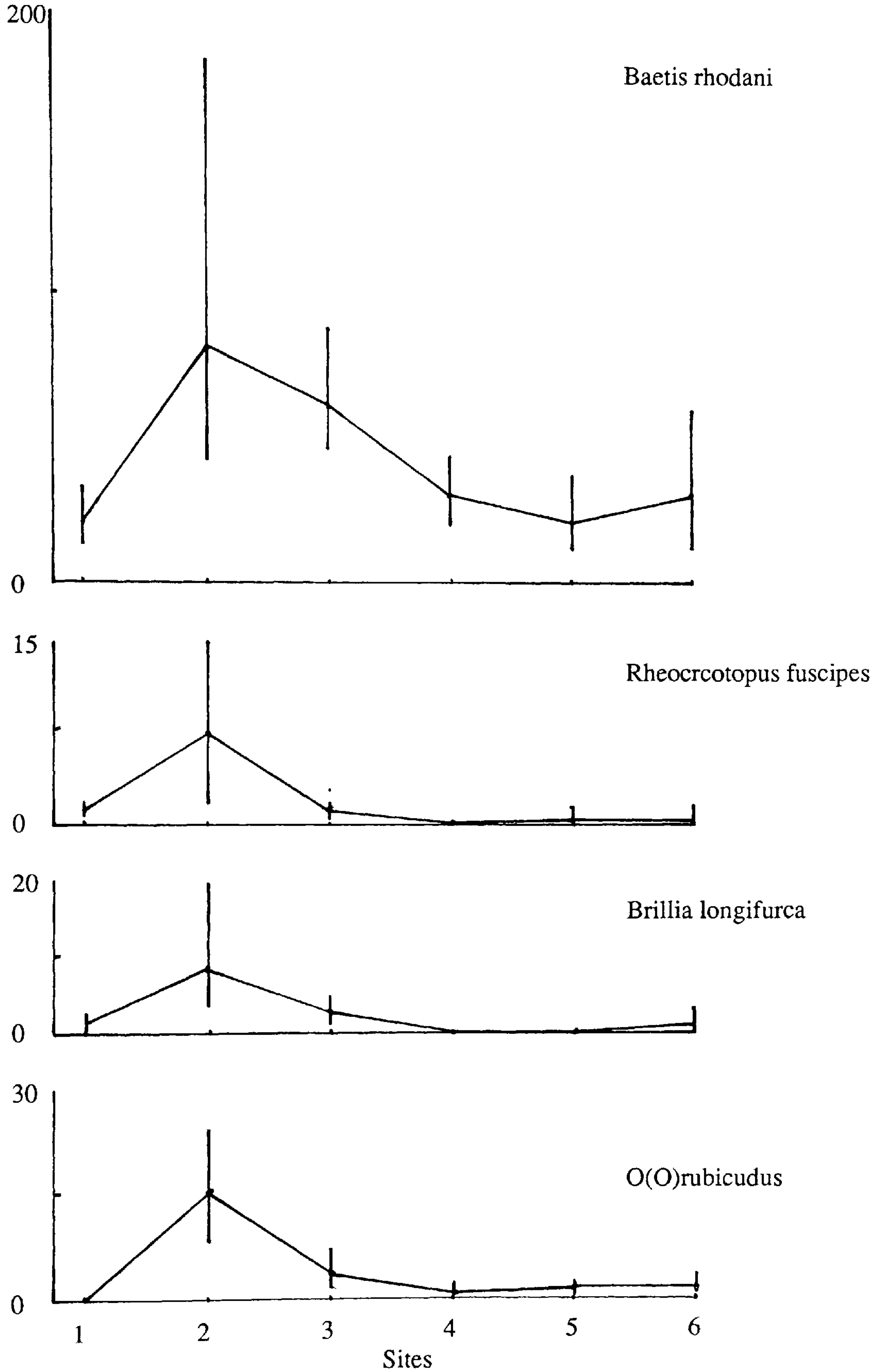


Fig 16

Most common species: September 1986.

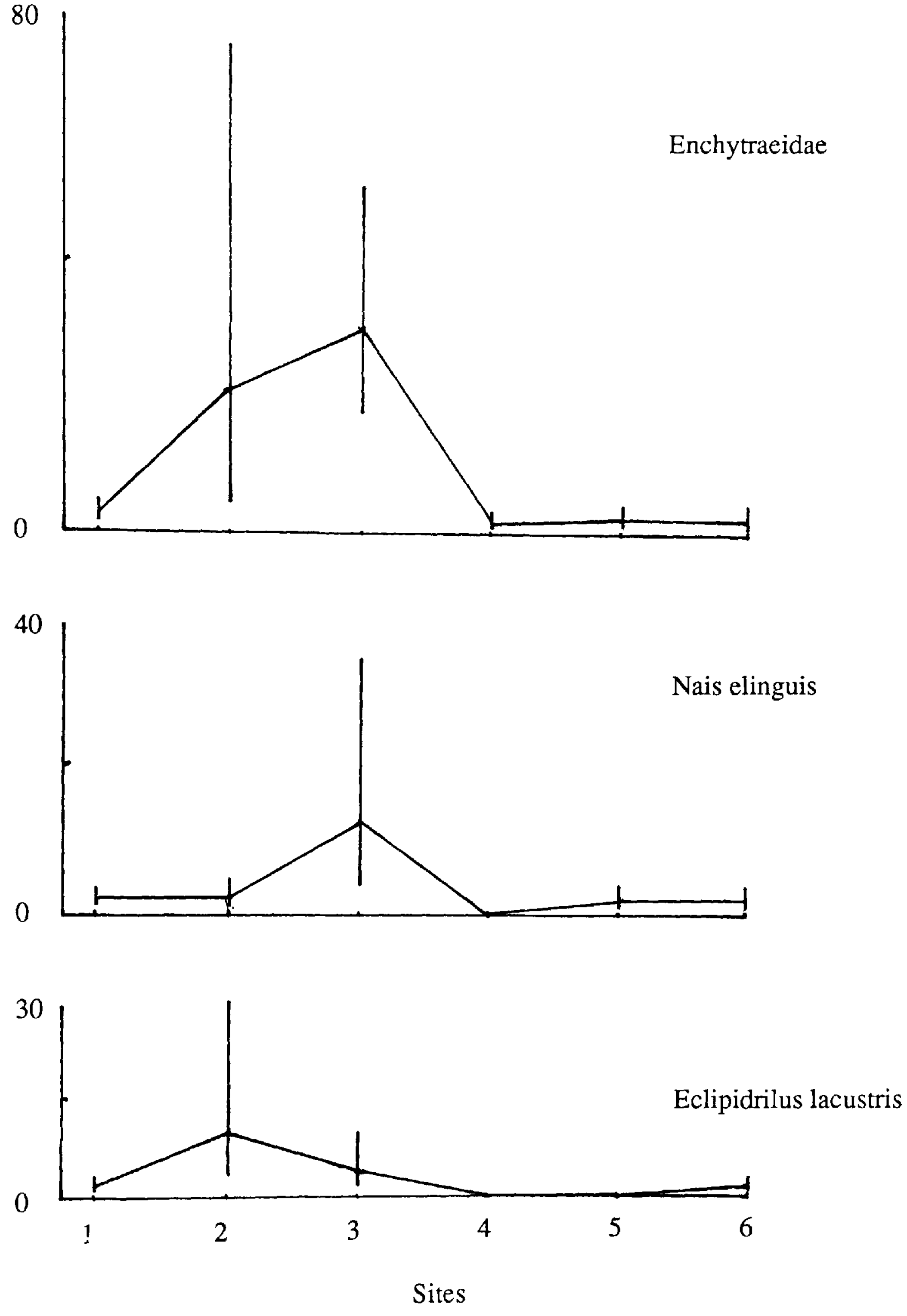


Fig 16(cont)

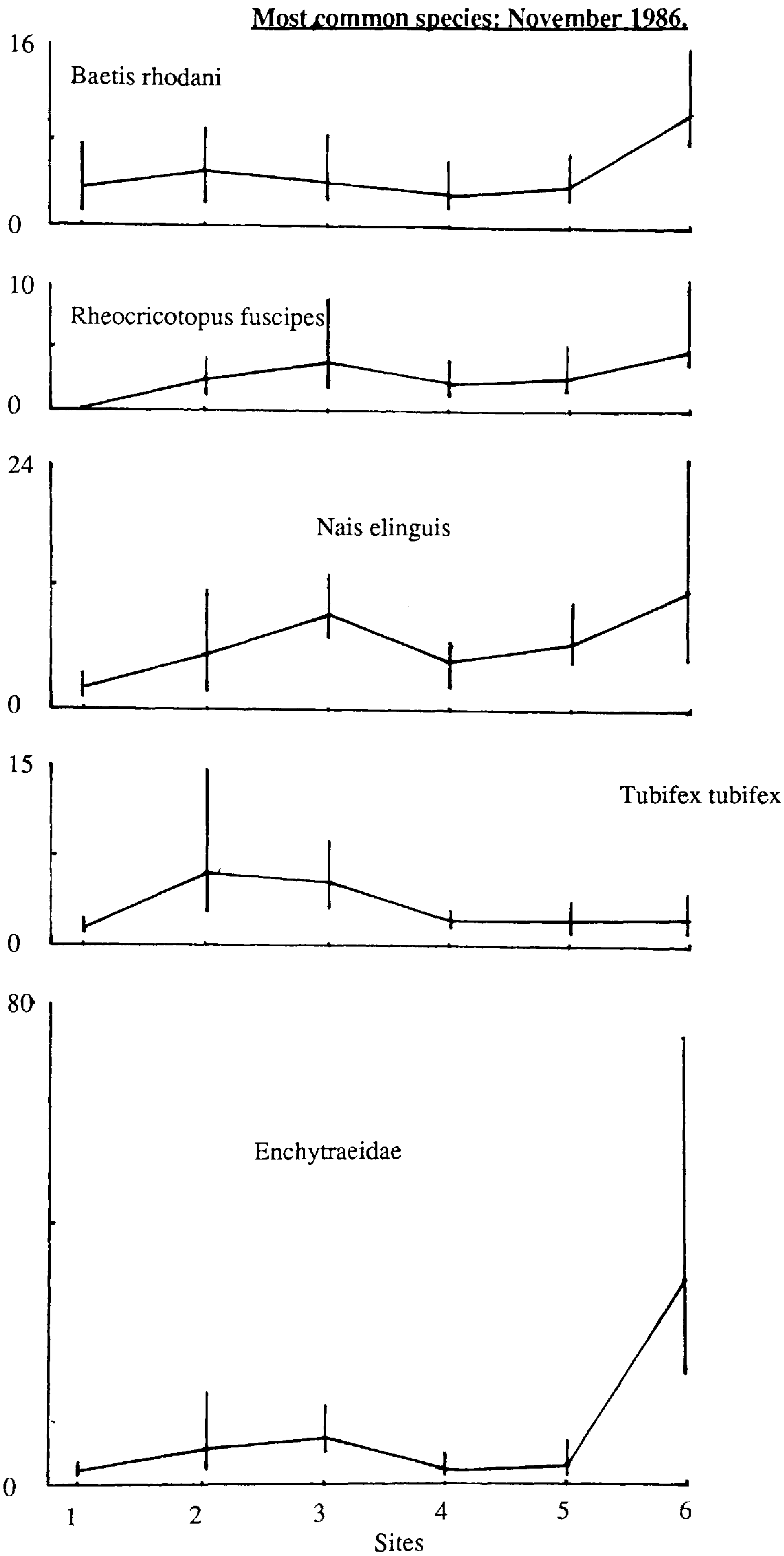

Most common species: November 1986.
16
Baetis rhodani
0
10
Rheocricotopus fuscipes
0
24
Nais elinguis
0
15
Tubifex tubifex
0
80
Enchytraeidae
0
1
2
3
4
5
6
Sites

Fig 17

Baetis rhodani.

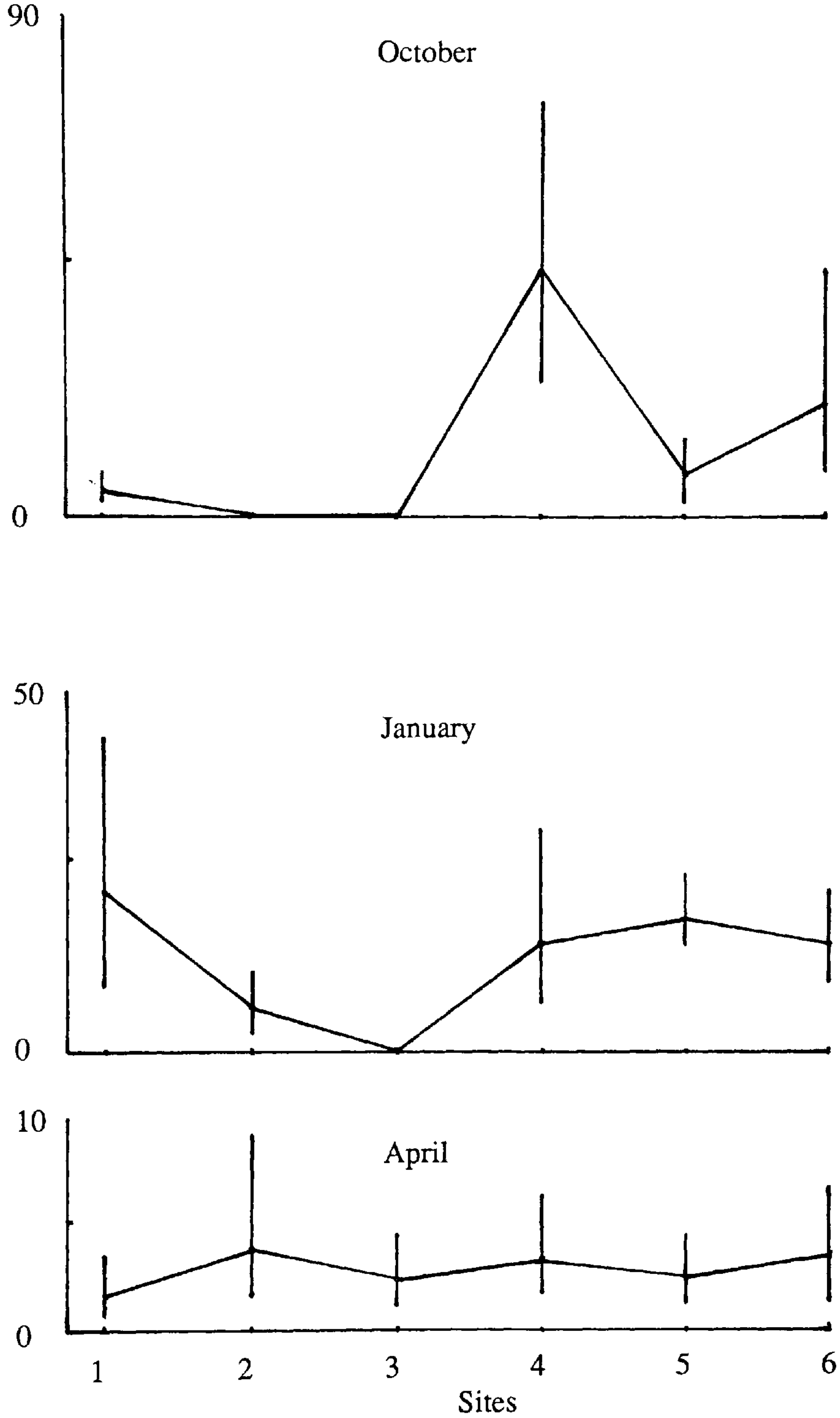


Fig 18

Baetis rhodani.

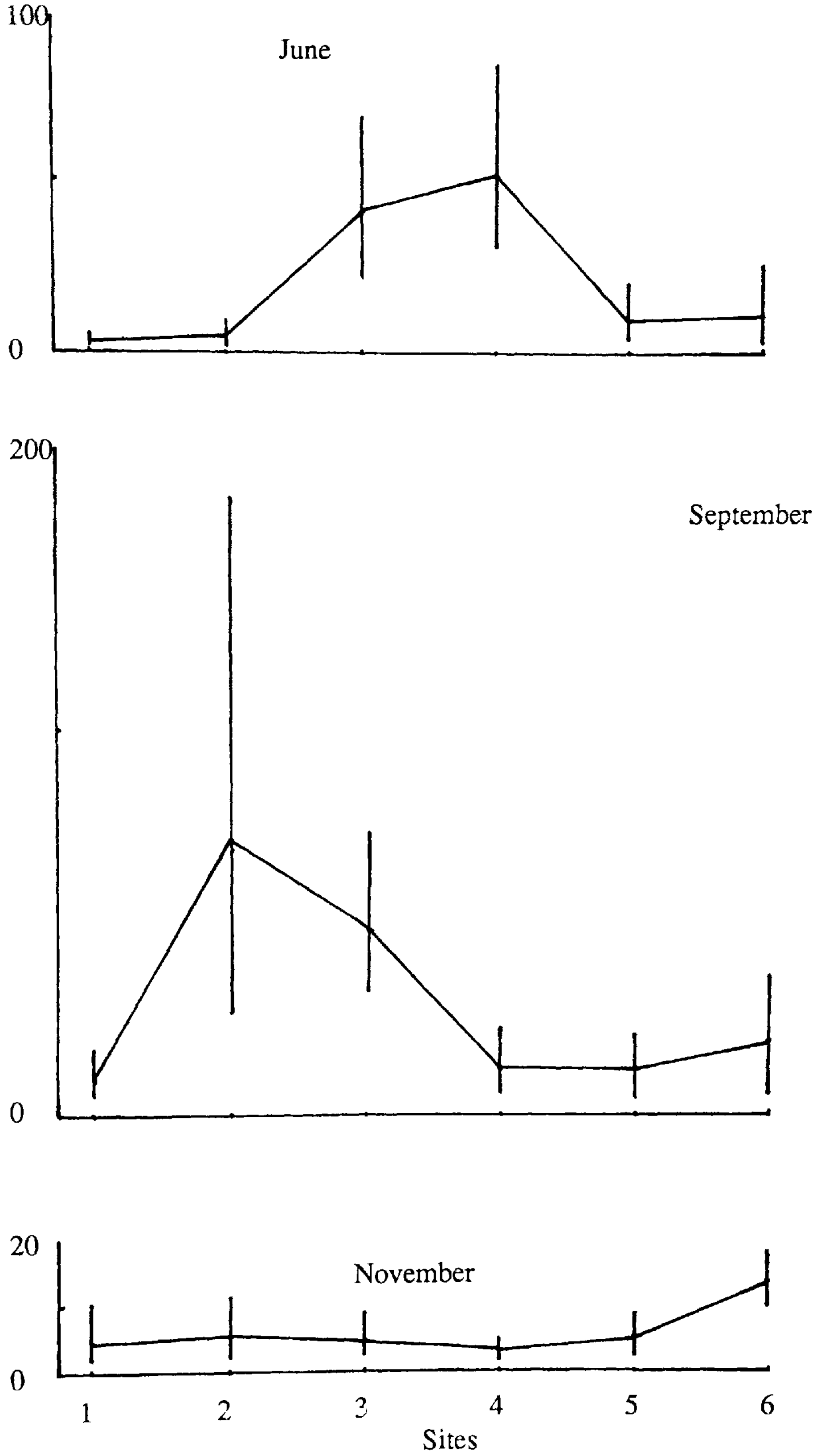


Fig 18(cont)

Ephemerella ignita.

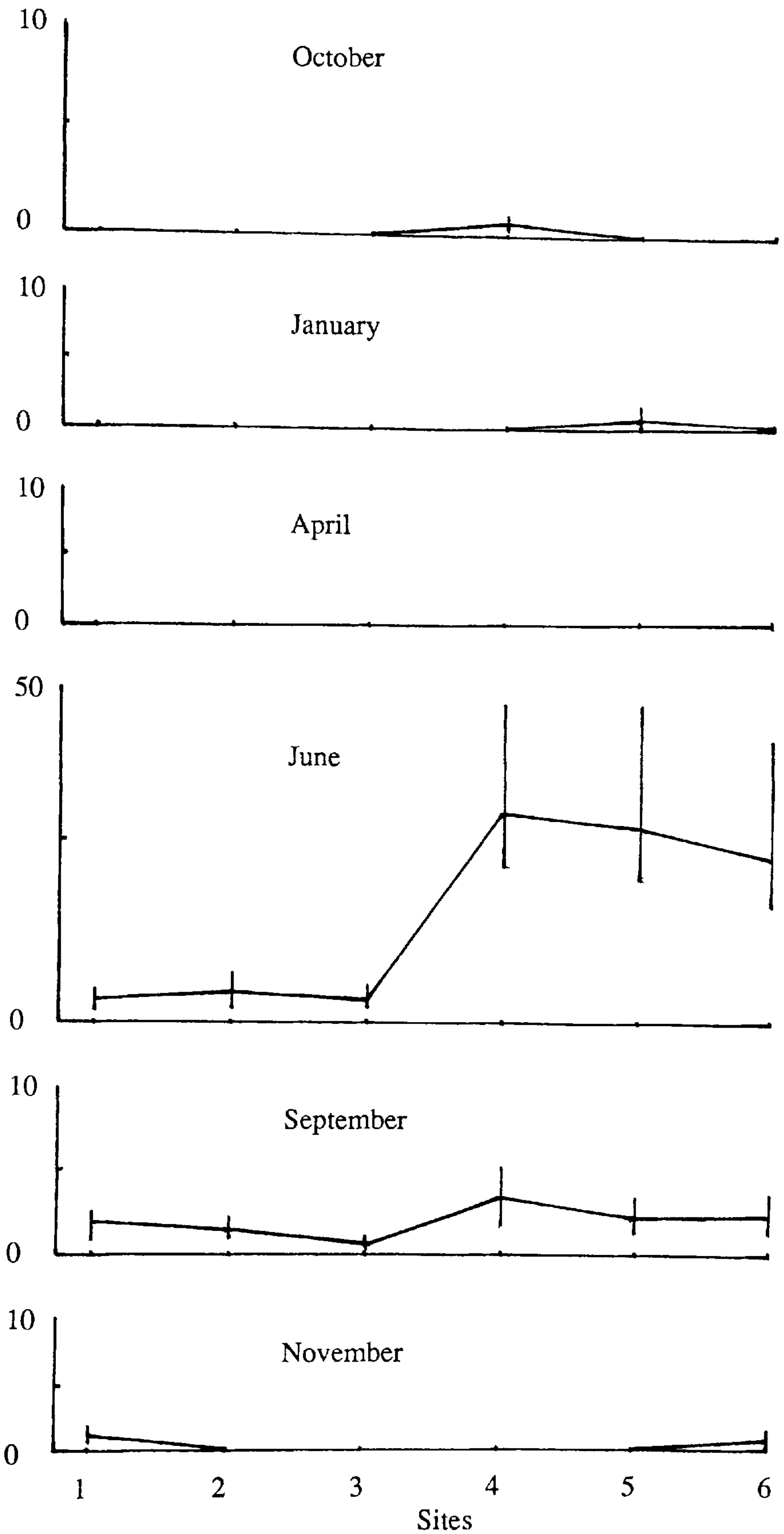


Fig 19

Cricotopus bicinctus.

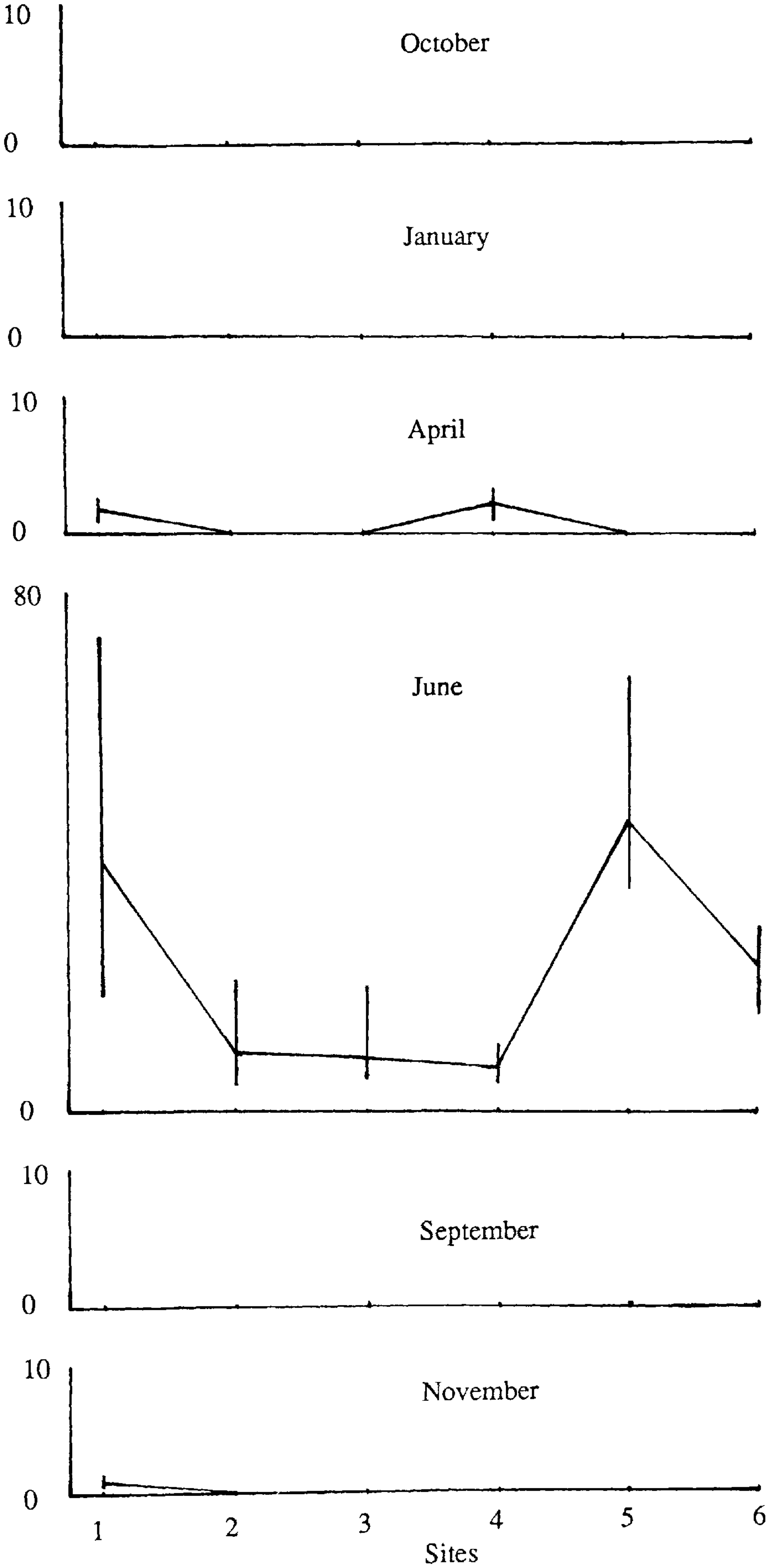


Fig 20

Brillia longifurca.

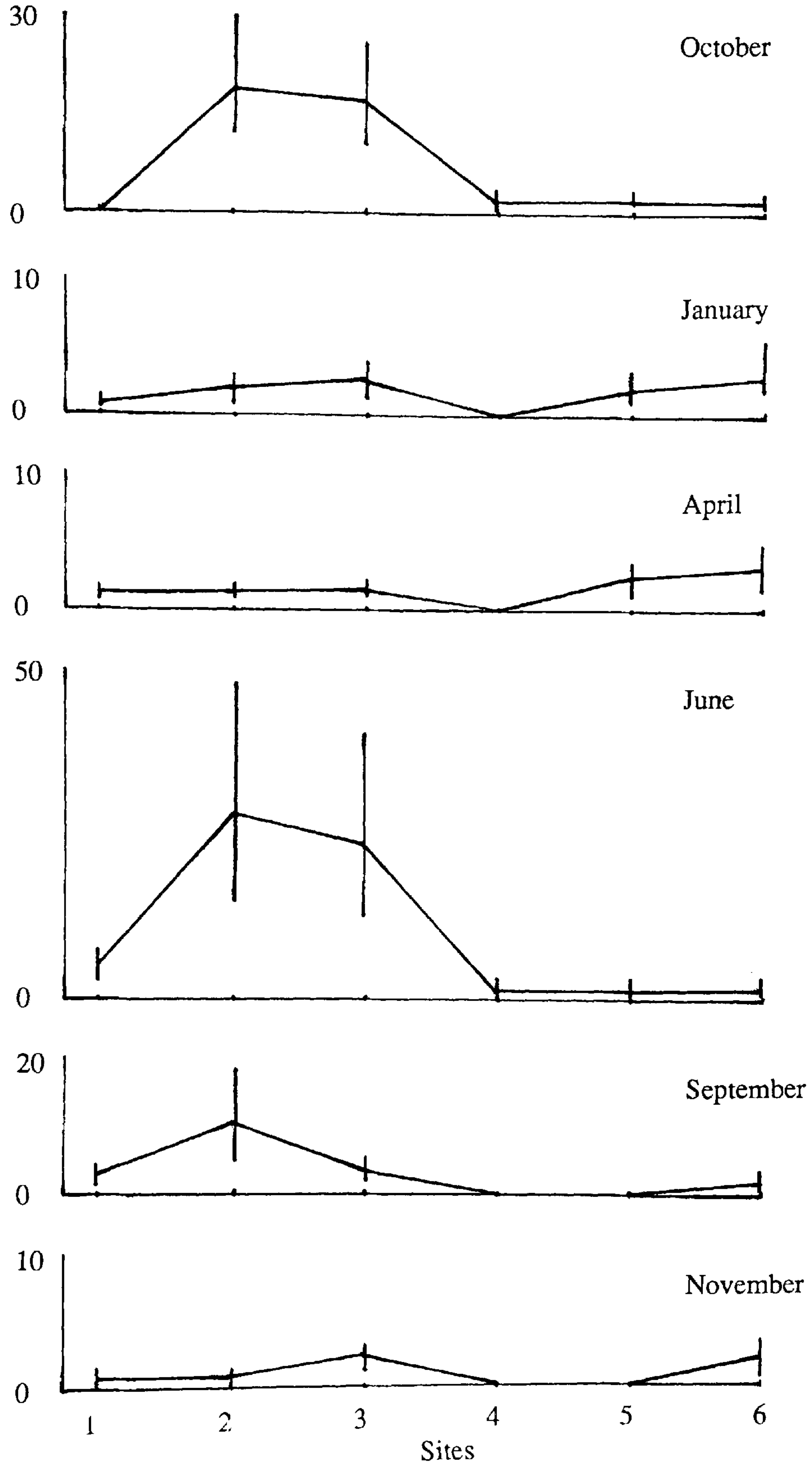


Fig 21

Orthocladius(O)rubicundus.

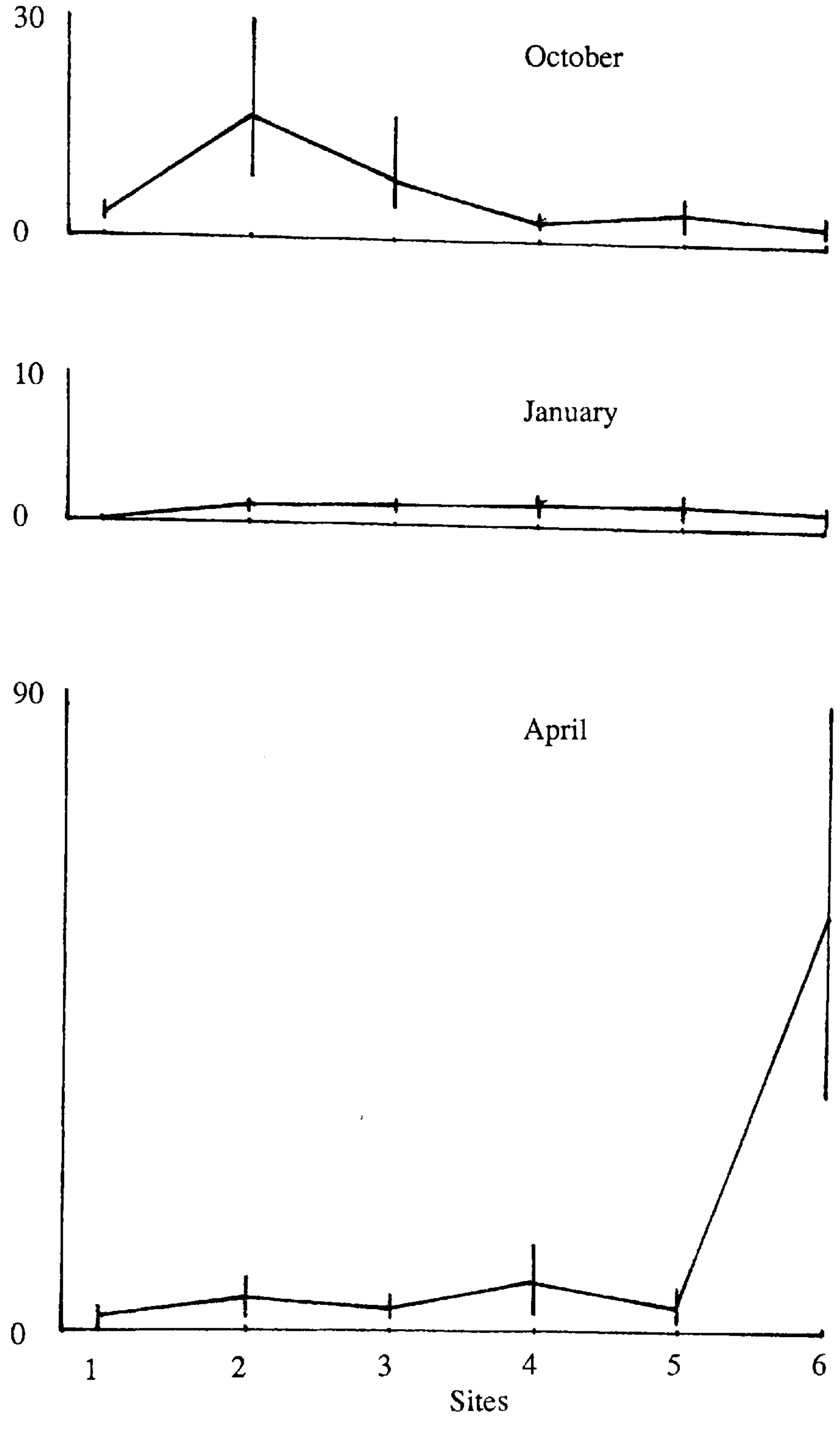


Fig 22

Orthocladius(O)rubicundus.

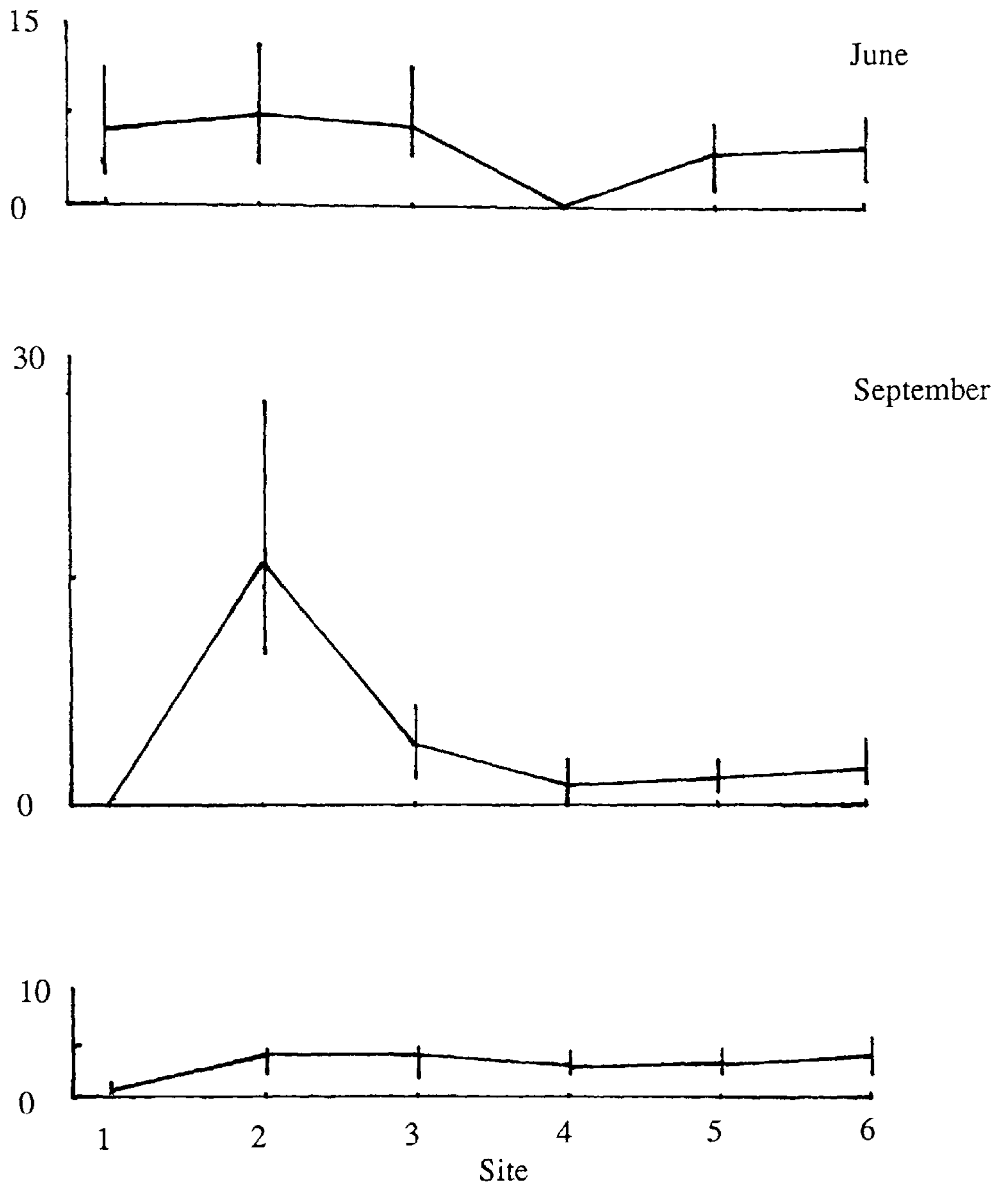


Fig 22(cont)

Rheocricotopus fuscipes.

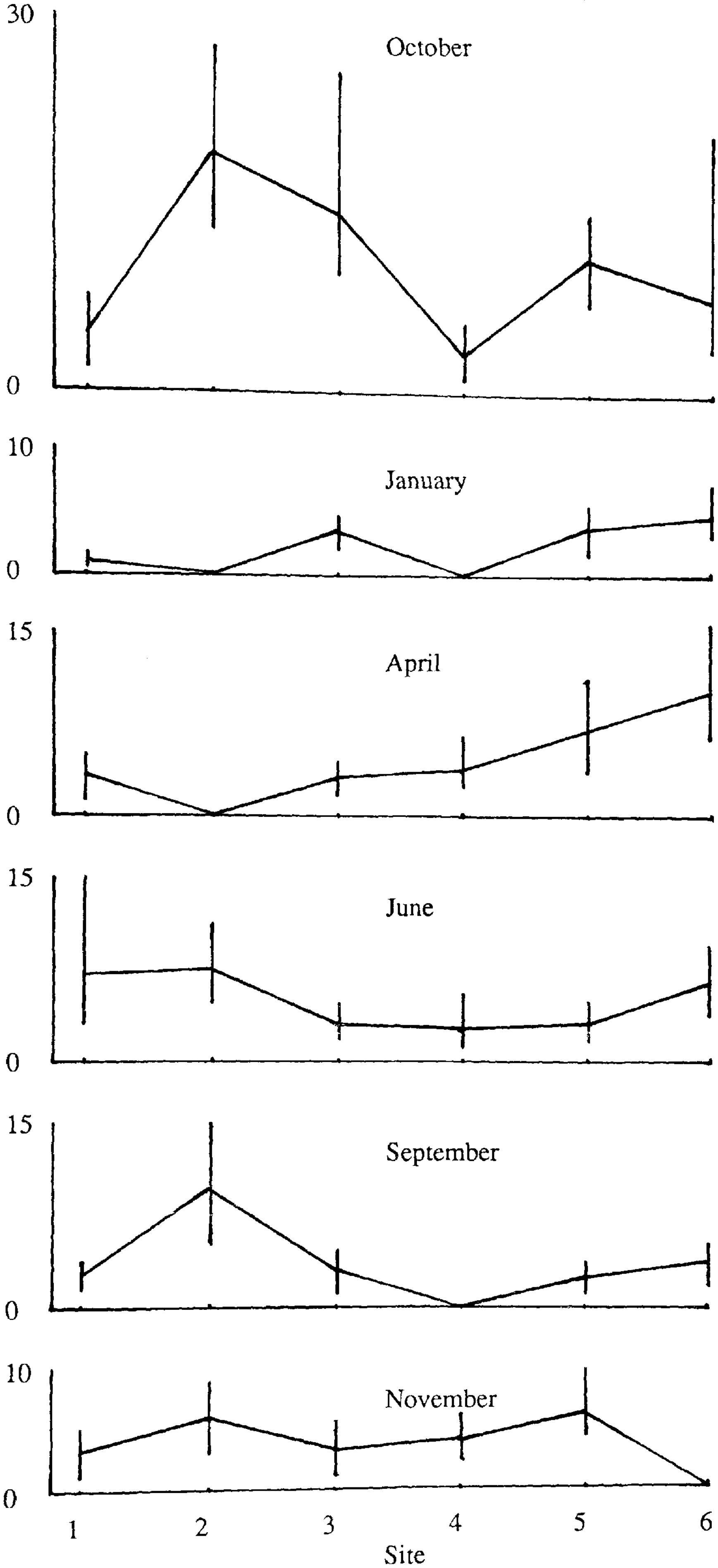


Fig 23

Tubifex tubifex.

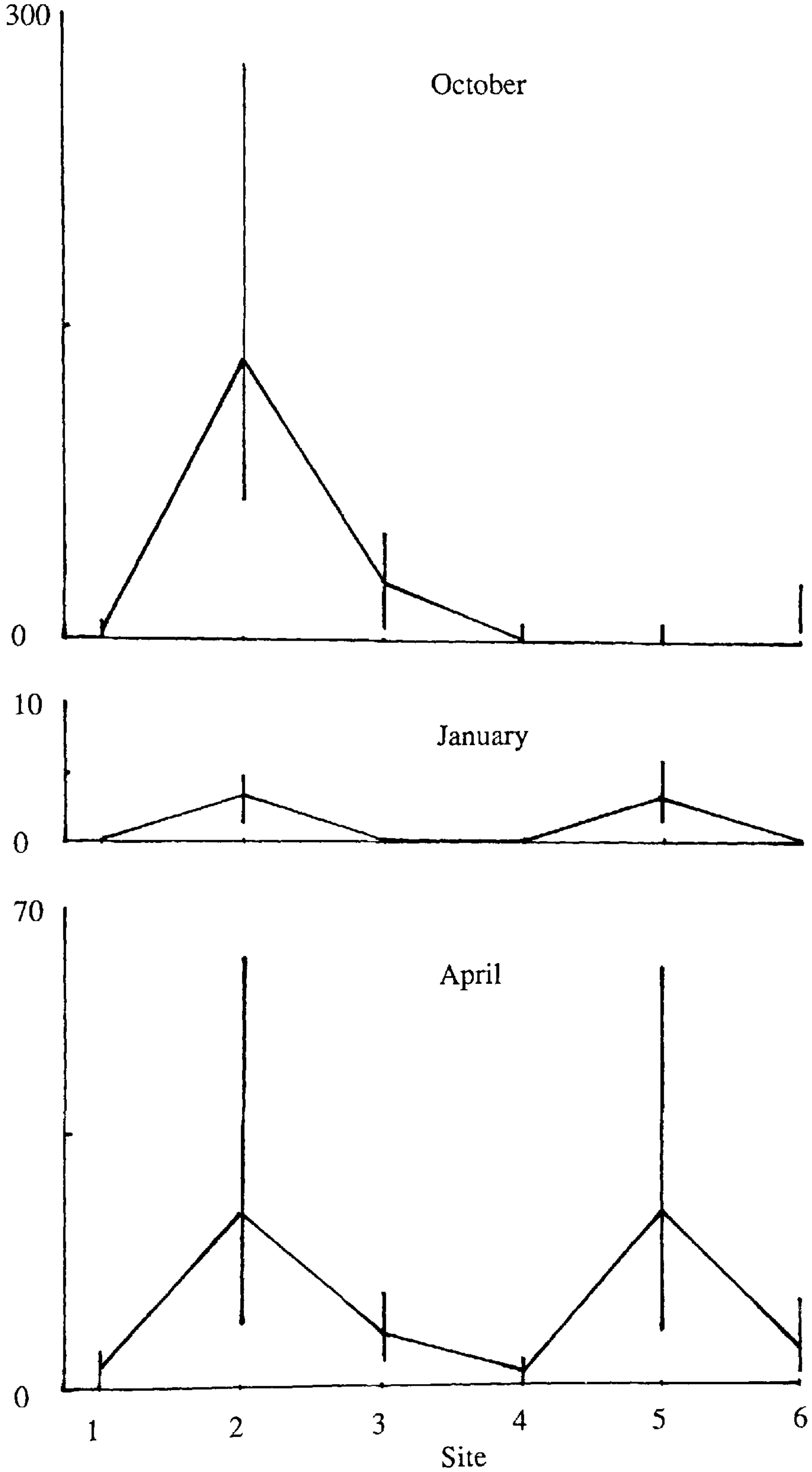


Fig 24

Tubifex tubifex.

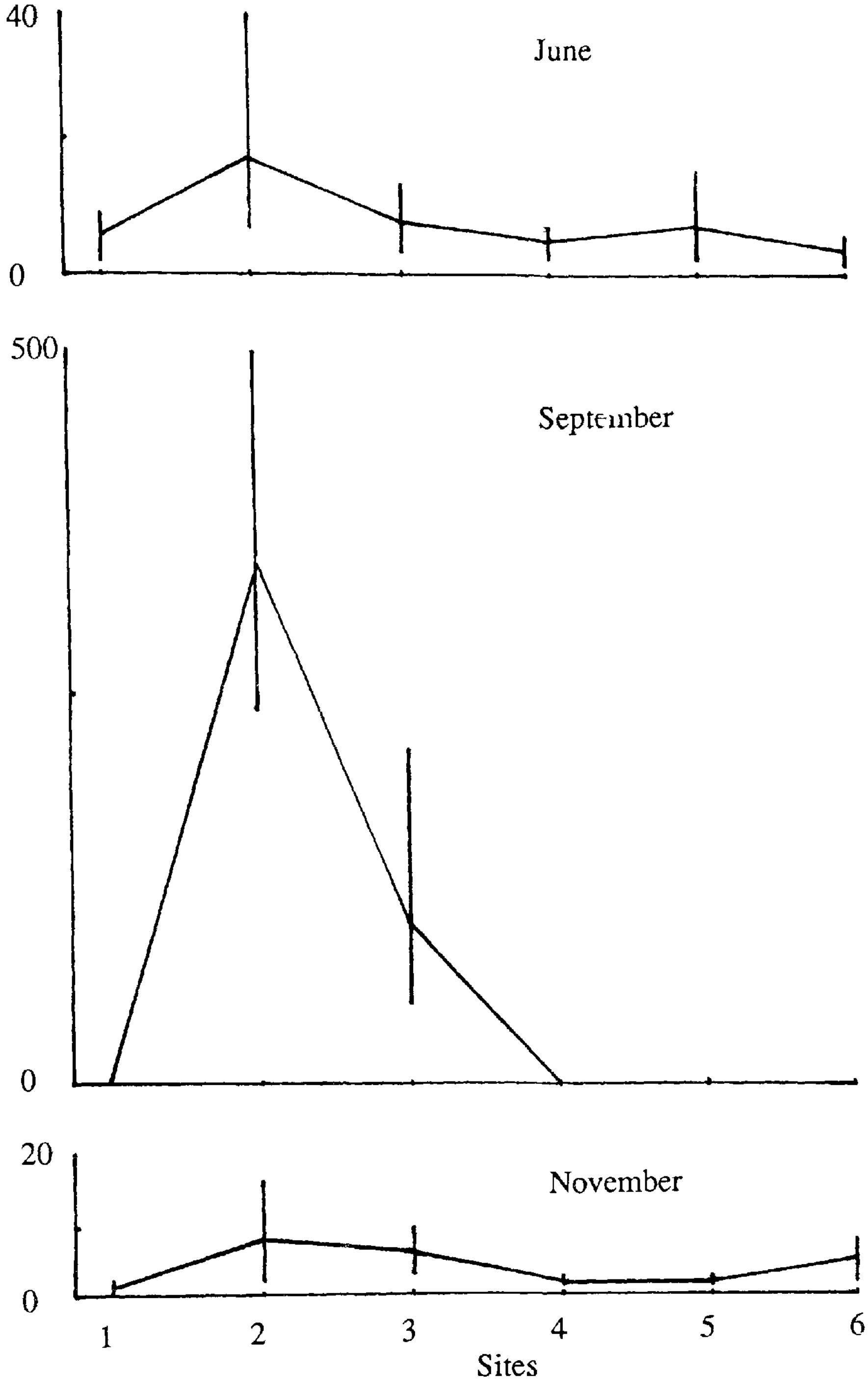


Fig 24(cont)

Nais elinguis.

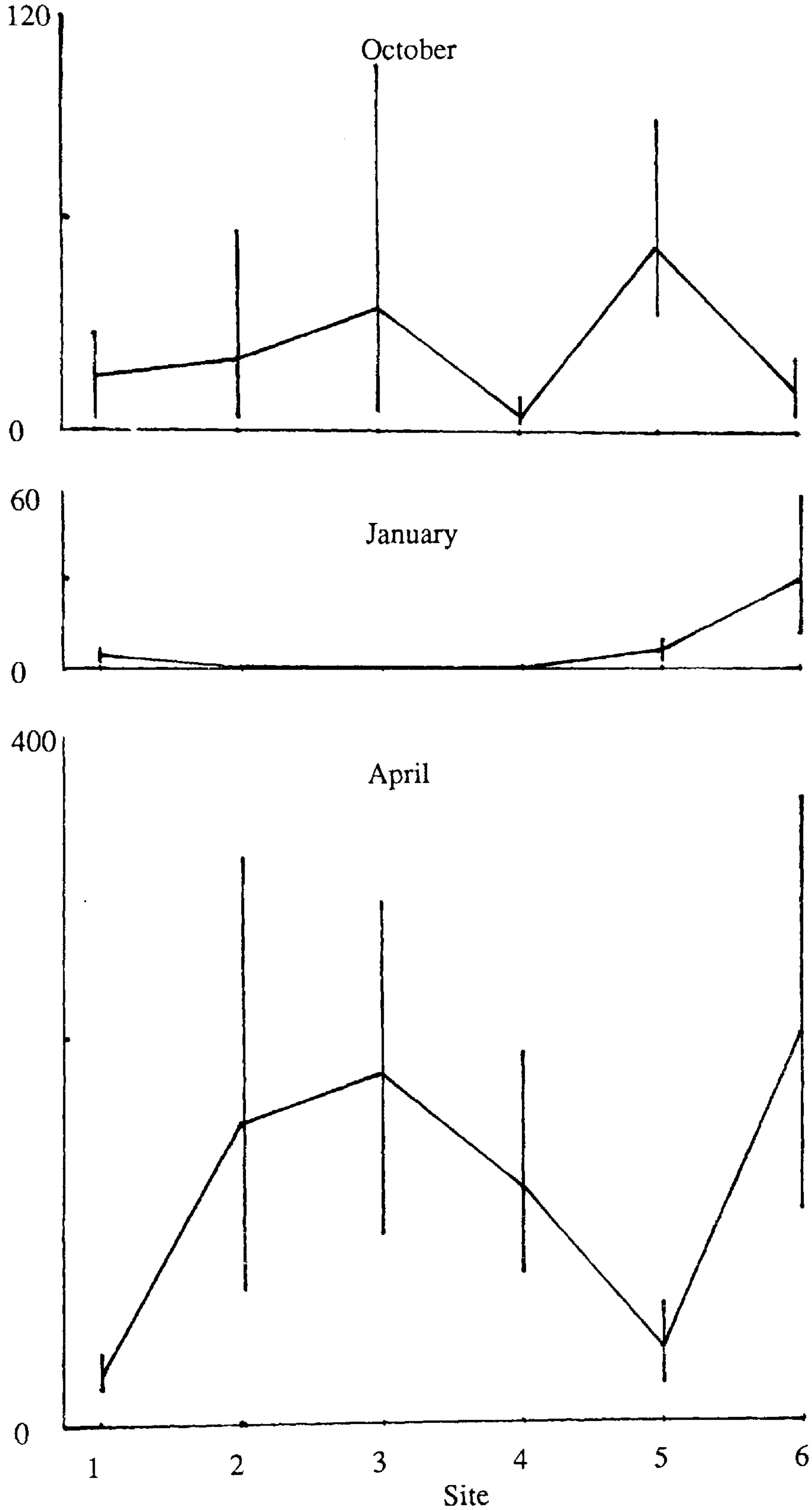


Fig 25

Nais elinguis.

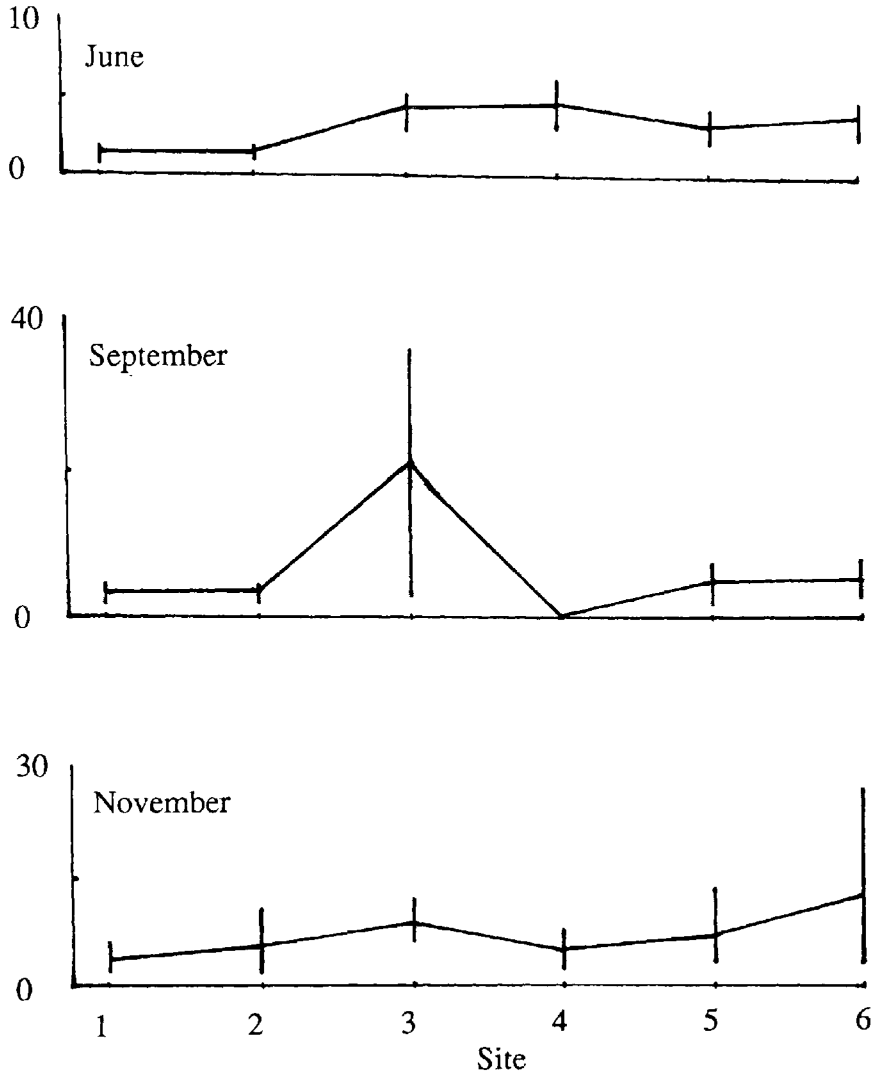


Fig 25(cont)

Enchytraeidae.

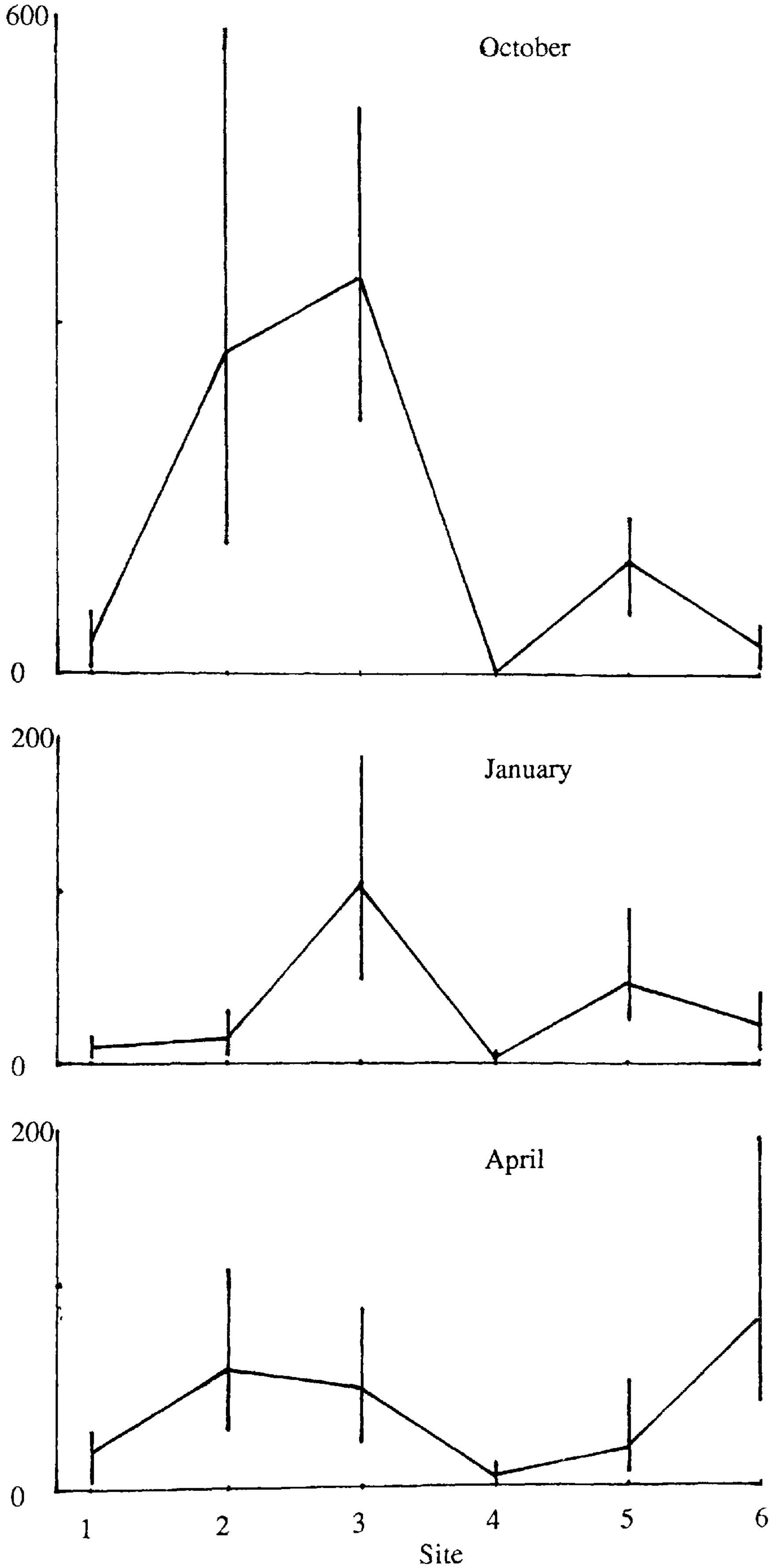


Fig 26

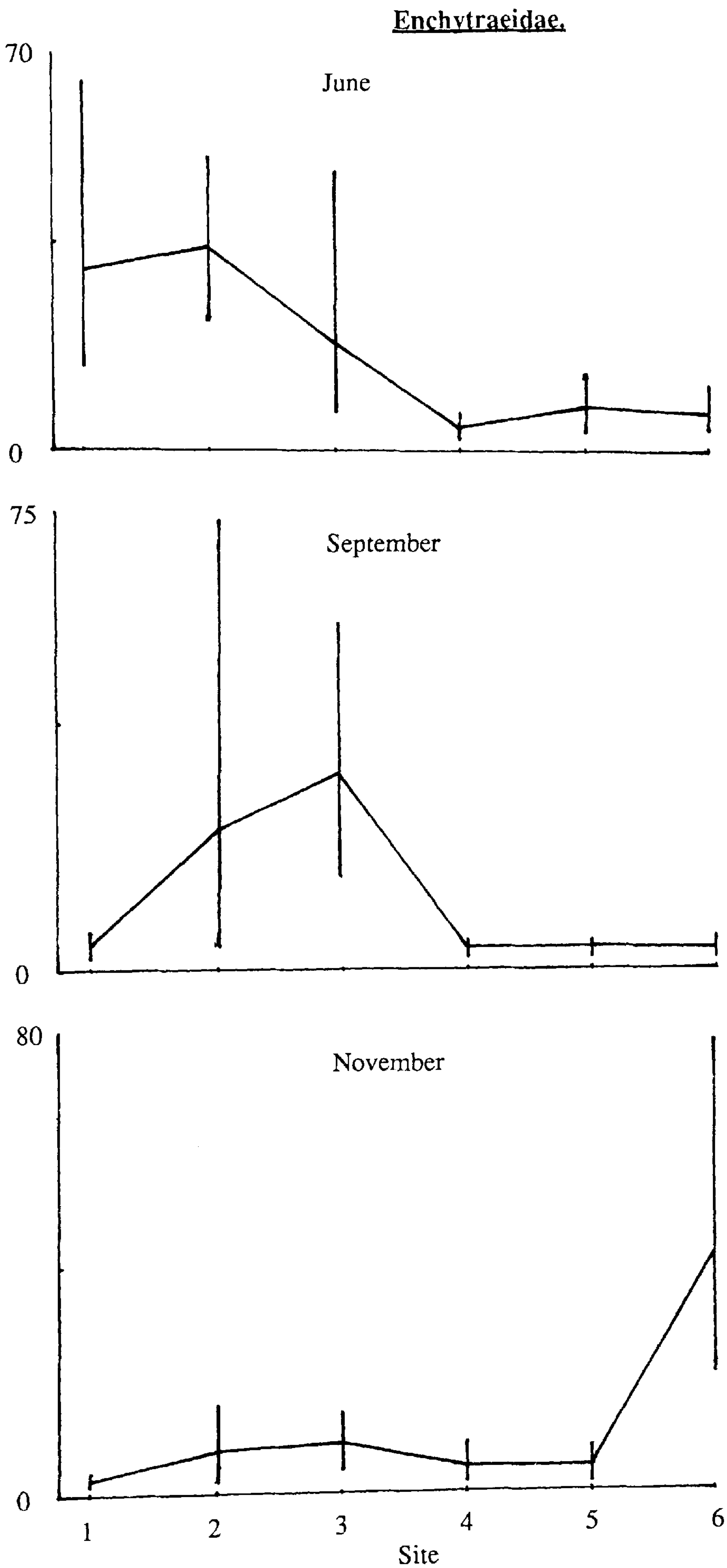

Enchytraeidae.
70
June
0
75
September
0
80
November
0
1
2
3
4
5
6
Site

Fig 26(cont)

Appendix 6.

Block histograms and diversity indices: Figs 27 - 38, results from indices Tables 63 - 69

1) Graphs of block histograms for each sampling occasion:

Fig 27: October 1985.

Fig 28: January 1986.

Fig 29: April 1986.

Fig 30: June 1986.

Fig 31: September 1986.

Fig 32: November 1986.

2) Graphs of diversity indices for each sampling occasion:

Fig 33: October 1985.

Fig 34: January 1986.

Fig 35: April 1986.

Fig 36: June 1986.

Fig 37: September 1986.

Fig 38: November 1986.

3) Results for indices used:

Table 63: Kothe's speciesdeficit

Table 64: Shannon's diversity index.

Table 65: Czekanowski's coefficient.

Table 66: Trent biotic index.

Table 67: Chandler score.

Table 68: BMWP score.

Table 69: WWA score.

Block histogram: October 1985.

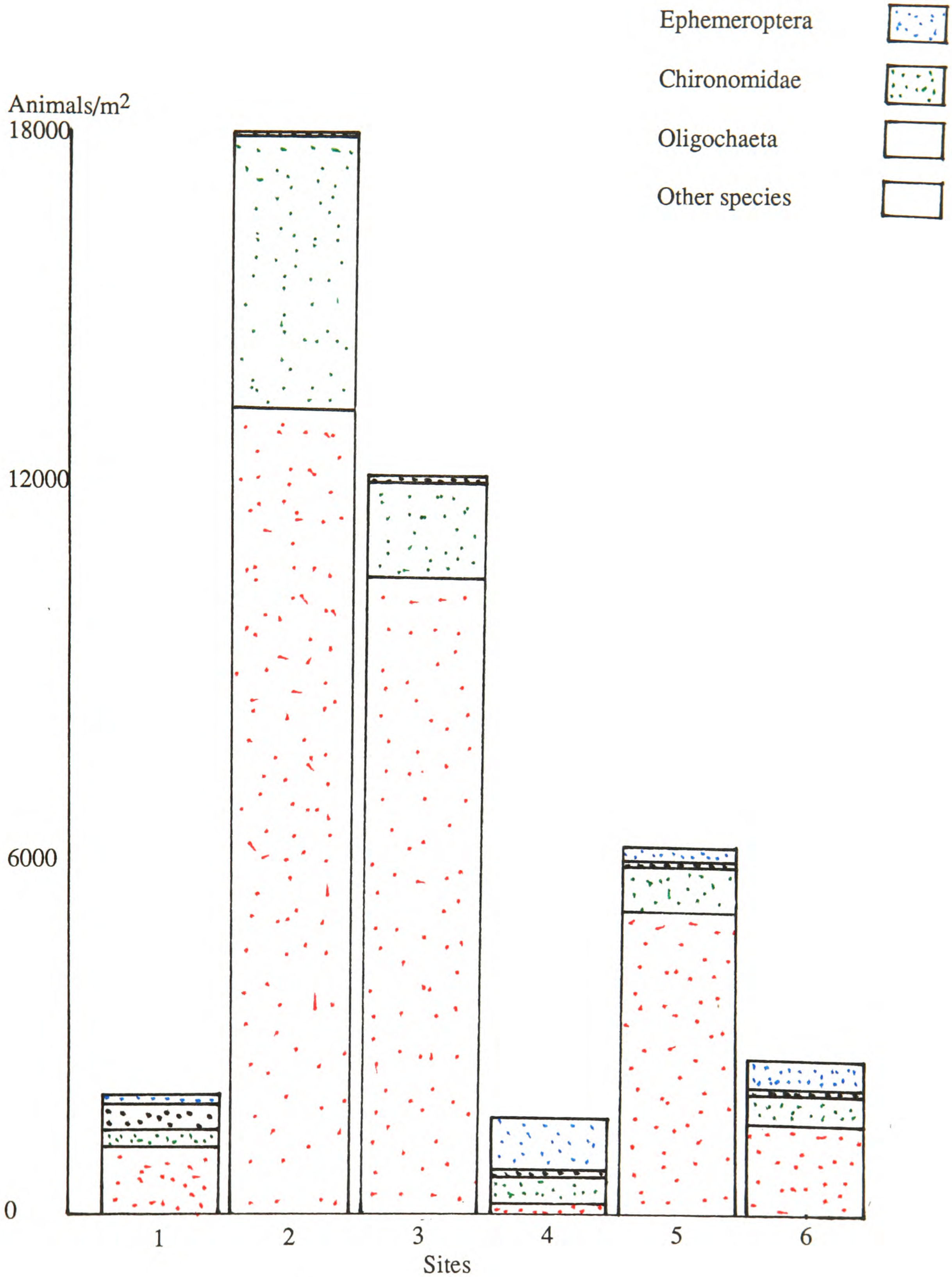


Fig 27

Block histogram: January 1986.

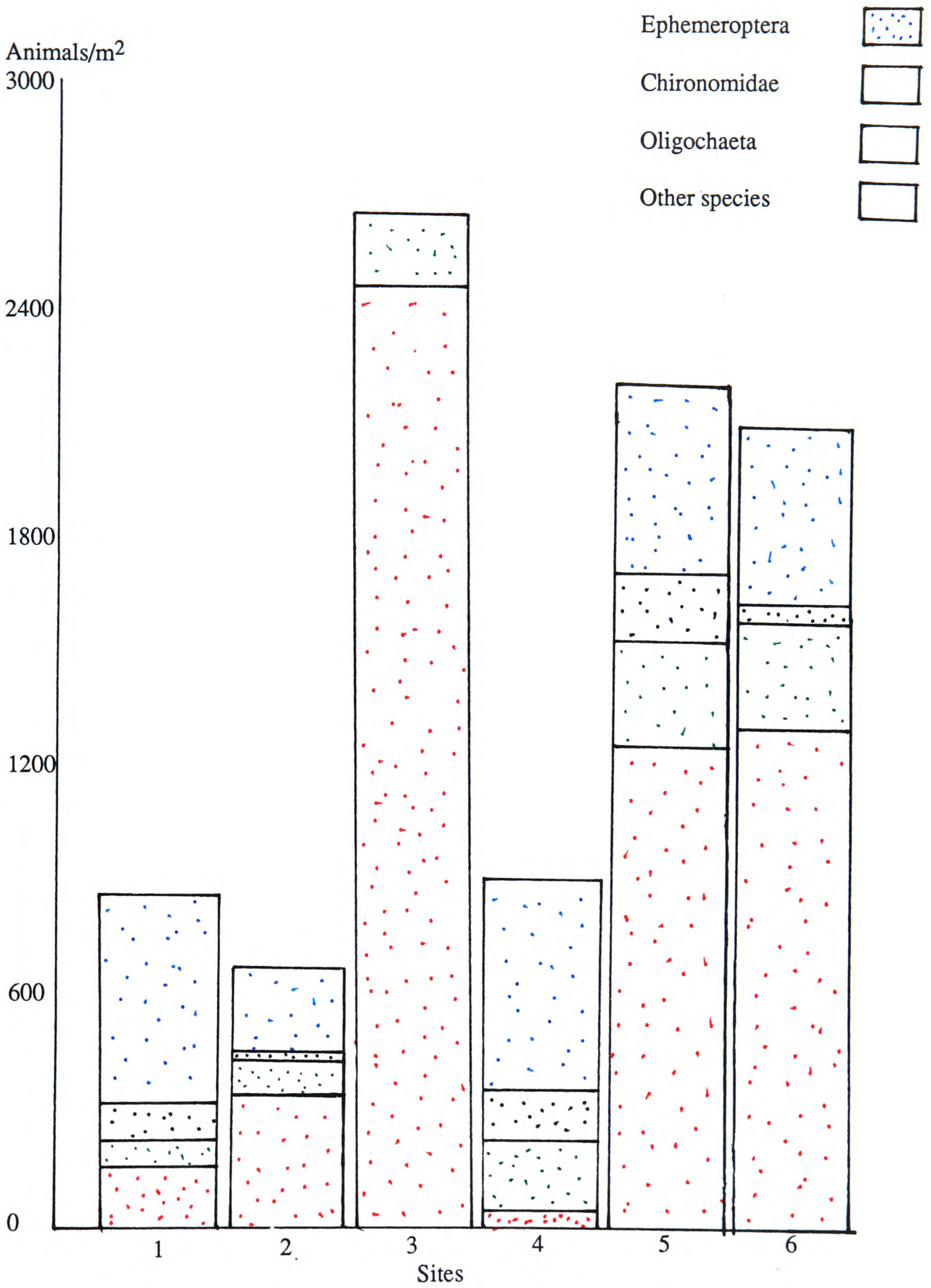


Fig 28

Block histogram: April 1986.

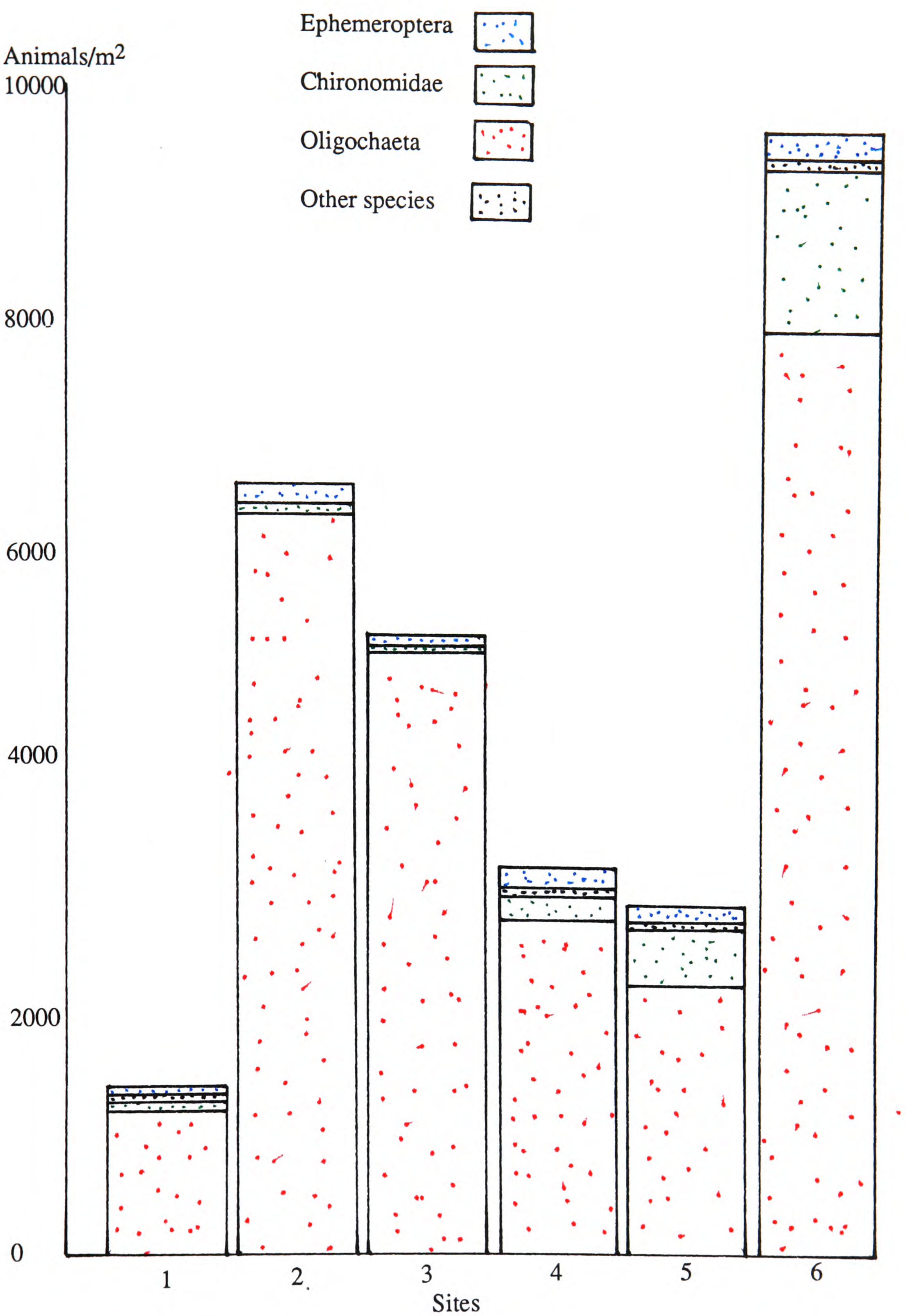


Fig 29

Block histogram: June 1986.

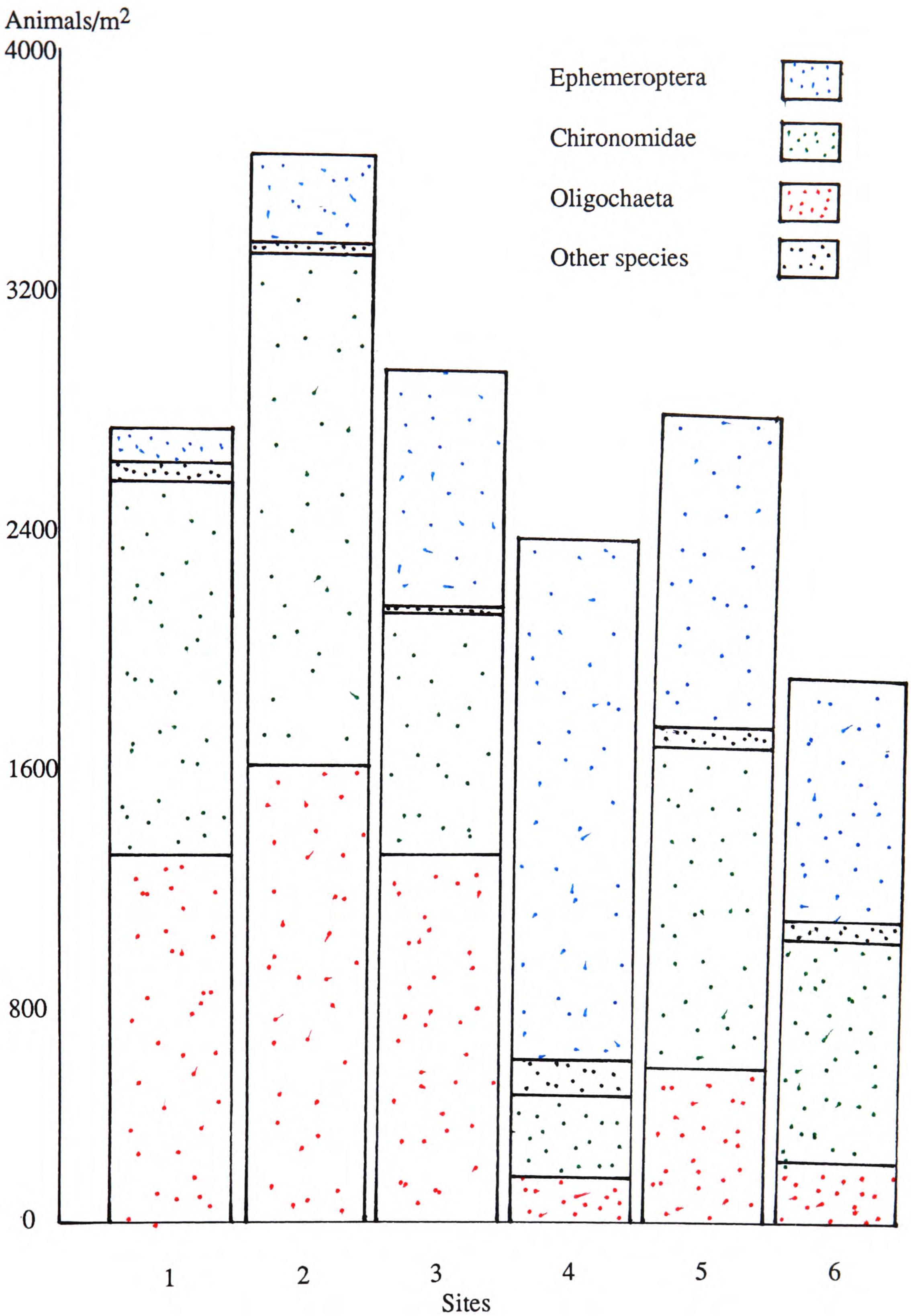


Fig 30

Block histogram: September 1986.

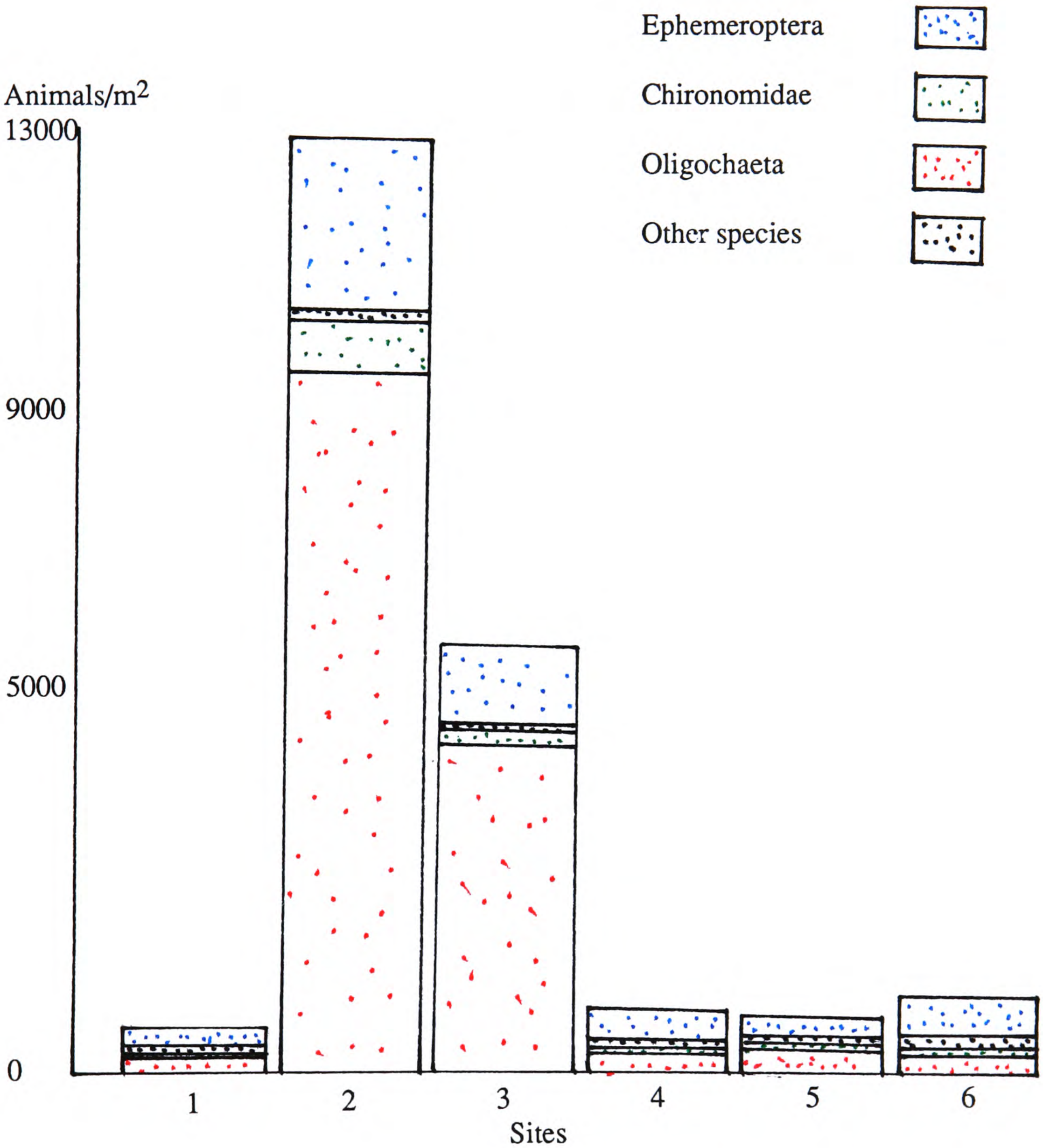


Fig 31

Block histogram: November 1986.

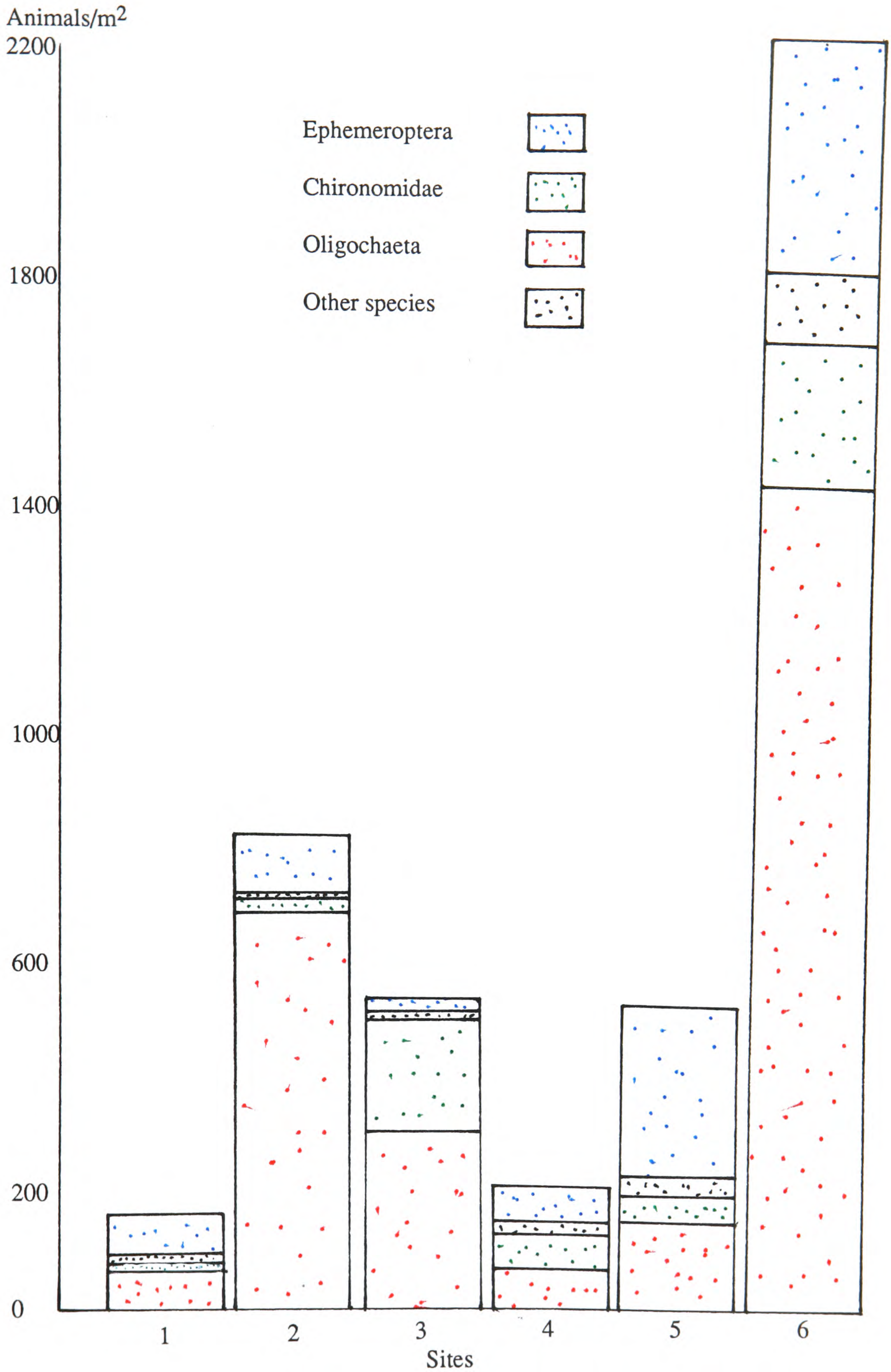


Fig 32

Indices for October 1985.

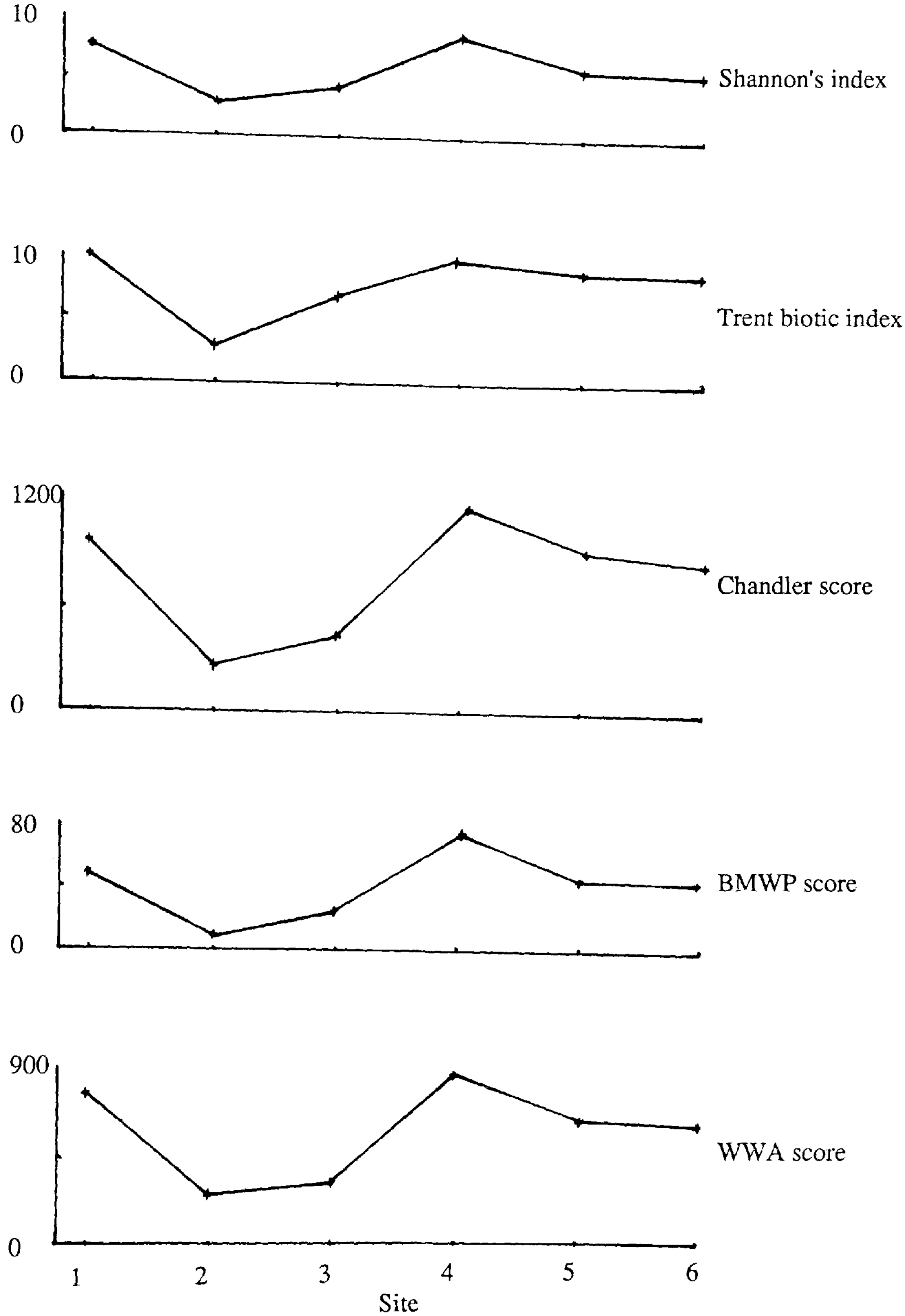


Fig 33

Indices for January 1986.

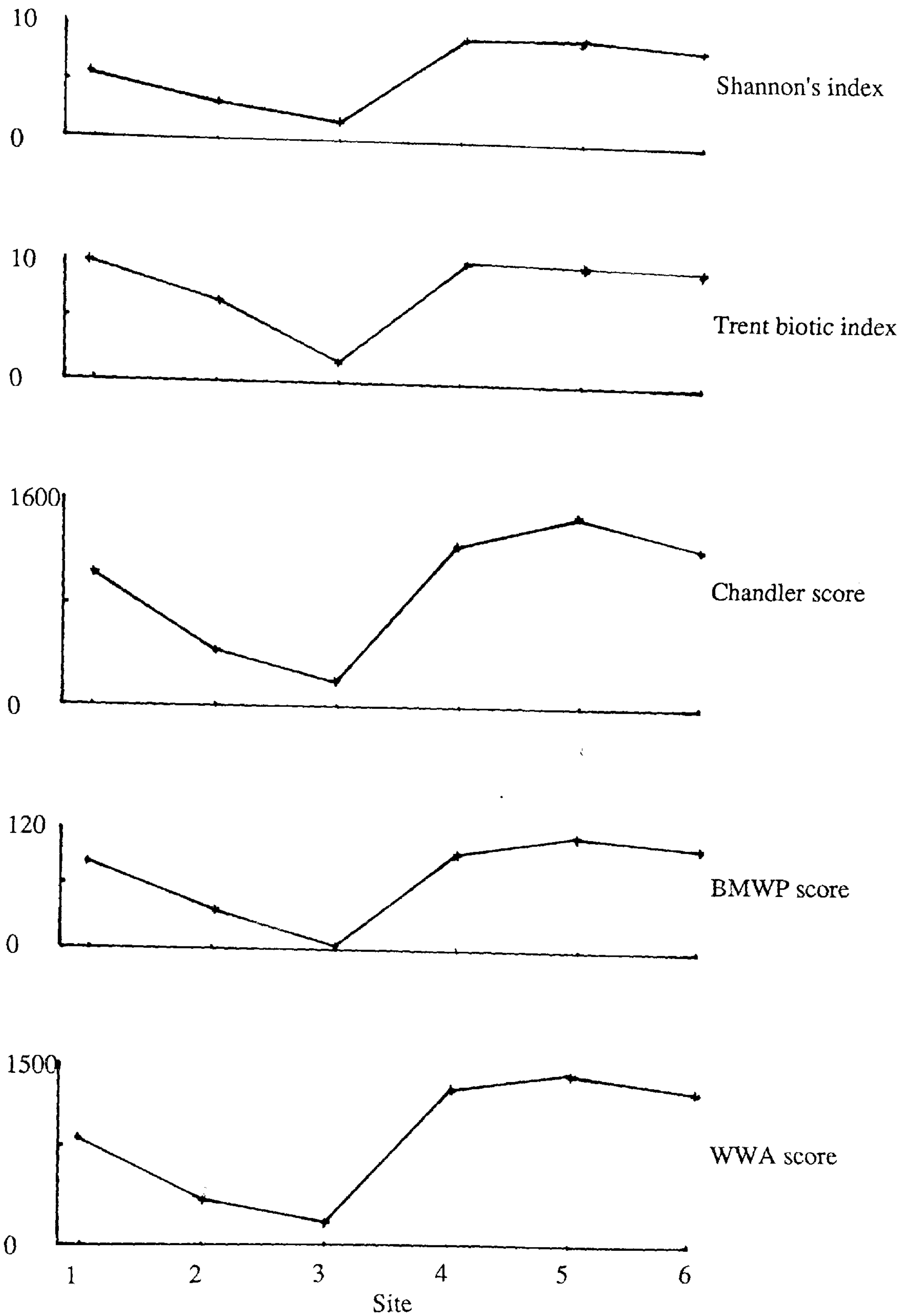


Fig 34

Indices for April 1986.

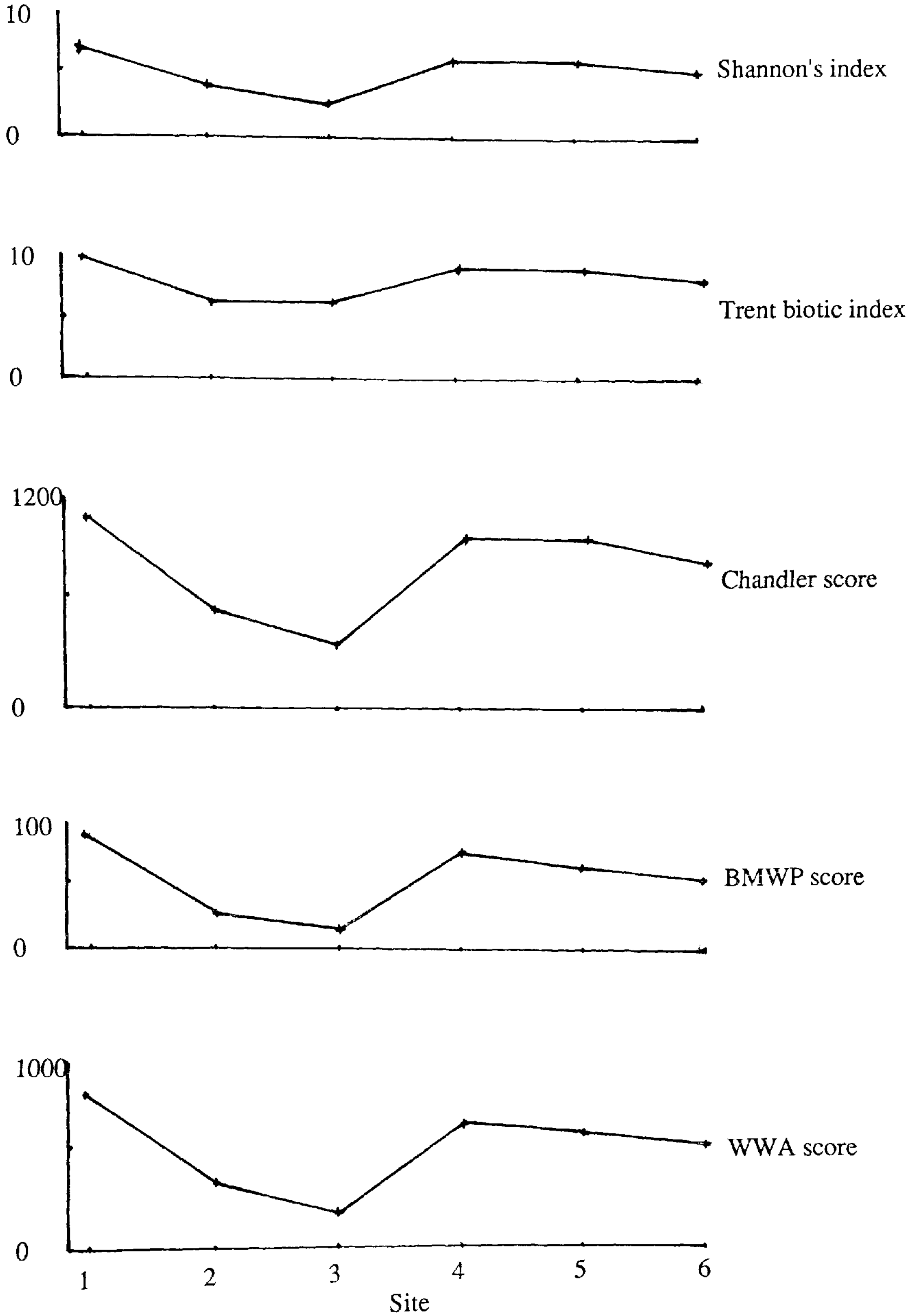


Fig 35

Indices for June 1986.

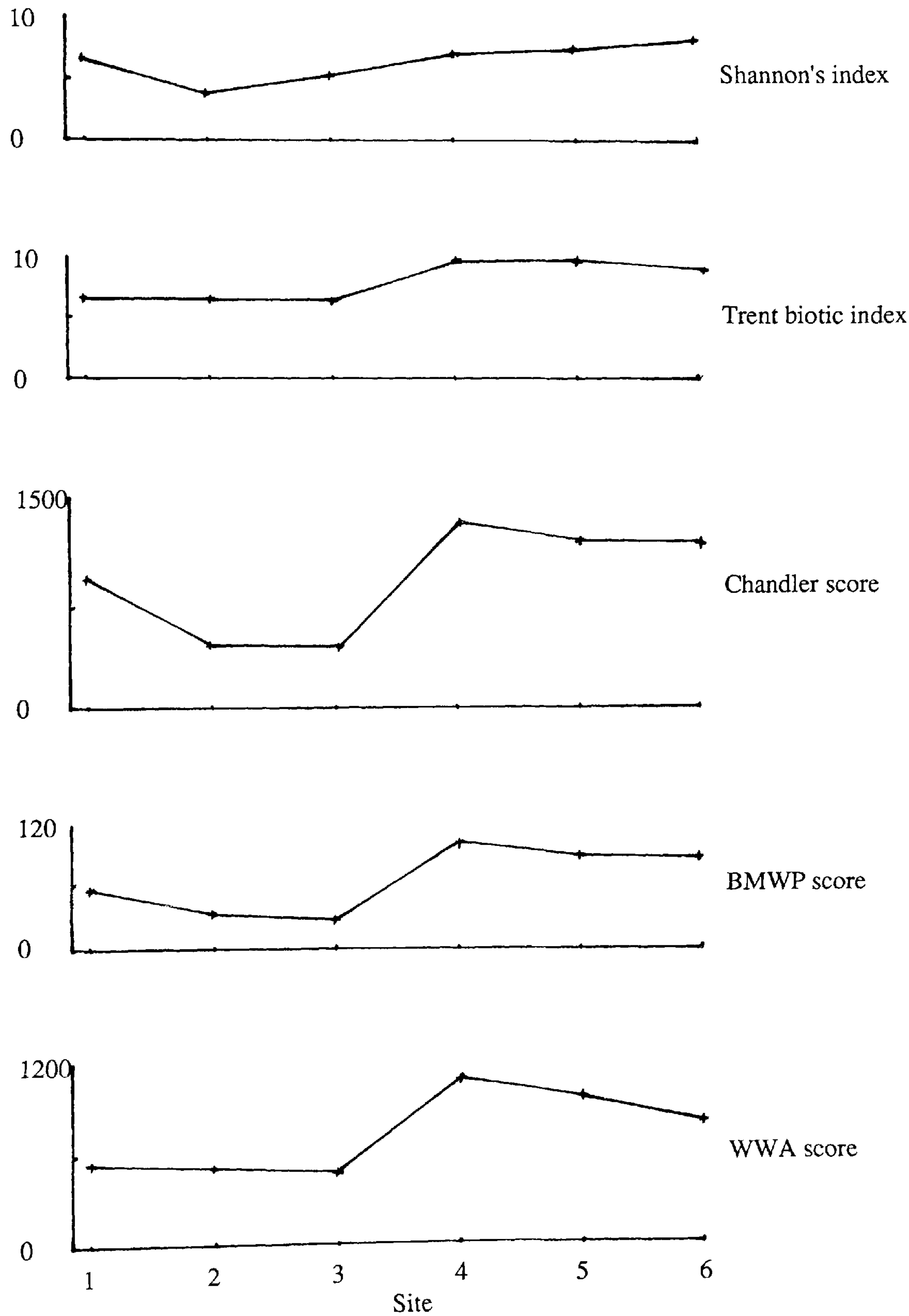


Fig 36

Indices for September 1986.

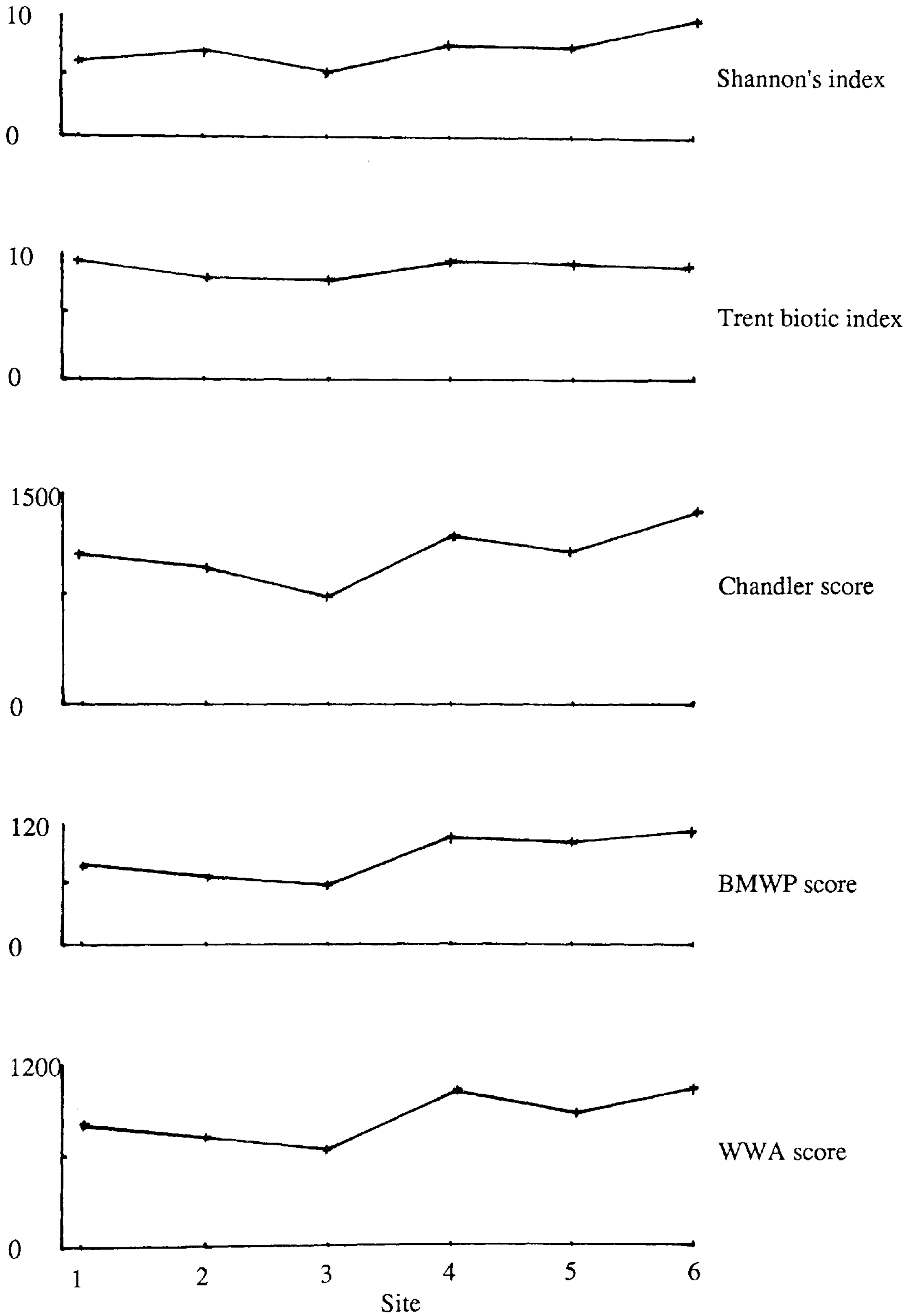


Fig 37

Indices for November 1986.

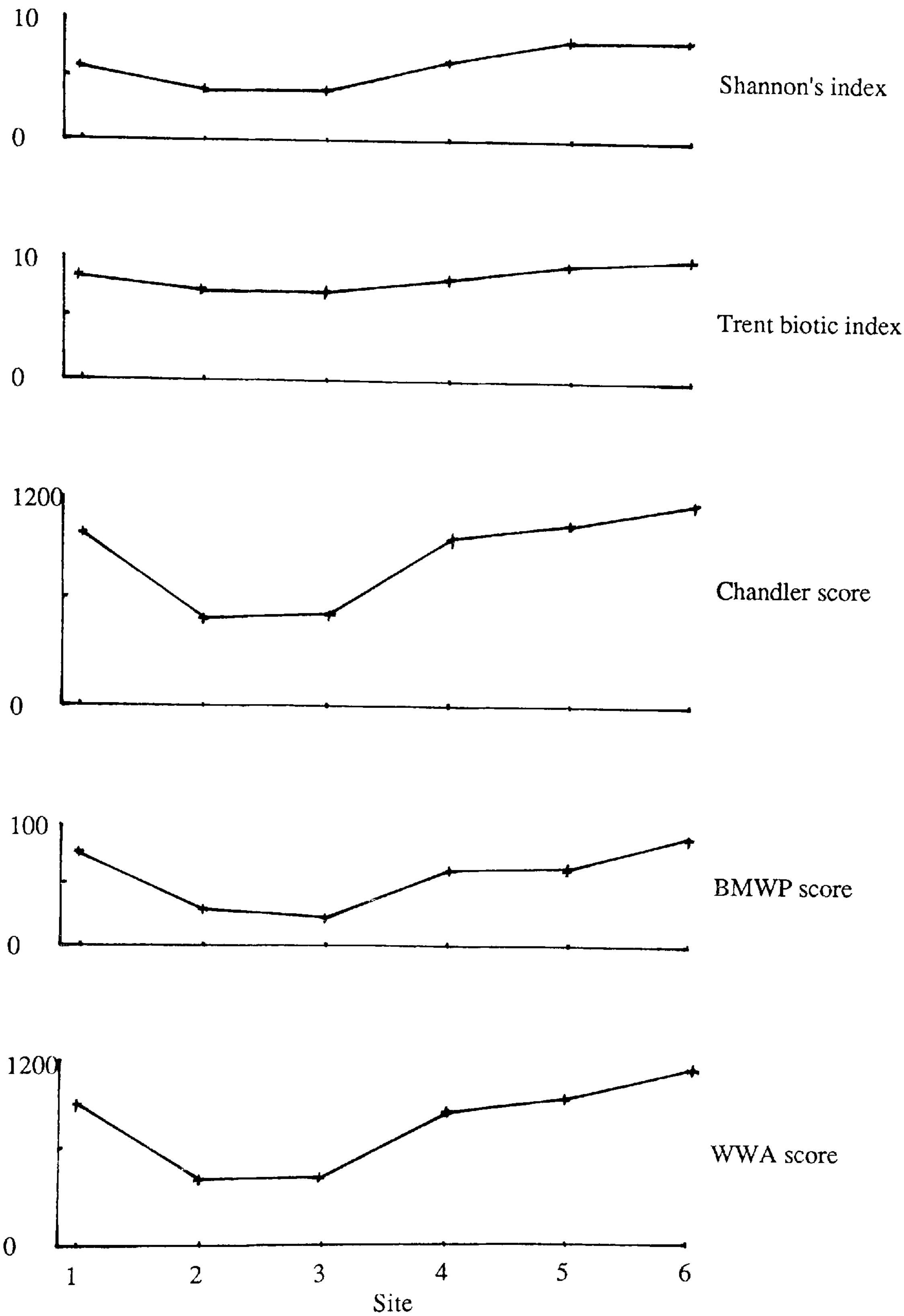


Fig 38

Kothe's species deficit and Jaccard's coefficient.

A table of comparisons for sites 1 and 2, 2 and 4, and 2 and 6 can be seen below:

D_m = Kothe's species deficit, J = Jaccard's coefficient

Sampling date.

Sites 1 and 2	D_m(%)	J
October 1985	50	0.47
January 1986	29.2	0.2
April 1986	46.4	0.41
June 1986	80.8	0.75
September 1986	72.7	0.47
November 1986	57.5	0.52
Sites 2 and 4.		
October 1985	34.4	0.26
January 1986	32.3	0.29
April 1986	45.8	0.37
June 1986	53	0.47
September 1986	55.2	0.39
November 1986	56.5	0.46
Sites 2 and 6.		
October 1985	52	0.47
January 1986	38.2	0.37
April 1986	53.8	0.48
June 1986	57.1	0.53
September 1986	51.5	0.39
November 1986	30.4	0.32

Table 63

Shannon's diversity index.

The results obtained from the raw biological data are given below:

Site	October 1985	January 1986	April 1986
1	8.13	5.62	7.47
2	2.59	3.23	3.93
3	3.81	1.84	2.51
4	8.29	8.46	5.73
5	6.41	8.63	5.86
6	6.39	8.28	5.37

	June 1986	September 1986	November 1986
1	6.67	6.12	5.74
2	4.18	6.73	4.43
3	5.3	5.31	6.62
4	7.11	7.47	6.62
5	7.55	7.13	8.11
6	8.32	9	8.2

Table 64

Czekanowski's coefficient.

A table of comparisons for Site 1 and 2, 2 and 4, and 2 and 6 can be seen below:

C_z = Czekanowski's coefficient.

Sites 1 and 2	C_z
October 1985	0.07
January 1986	0.46
April 1986	0.63
June 1986	0.2
September 1986	0.12
November 1986	0.35
Sites 2 and 4	
October 1986	0.14
January 1986	0.43
April 1986	0.33
June 1986	0.52
September 1986	0.17
November 1986	0.27
Sites 2 and 6	
October 1986	0.17
January 1986	0.77
April 1986	0.73
June 1986	0.34
September 1986	0.12
November1986	0.38

Table 65

Trent biotic index.

The results obtained from the Trent biotic scoring system as follows:

Site 1	October 1985	January 1986	April 1986
1	10	10	10
2	3	7	7
3	7	2	7
4	9	10	9
5	8	11	9
6	8	10	8

	June 1986	September 1986	November 1986
1	7	9	8
2	7	8	7
3	7	8	7
4	10	11	8
5	10	10	9
6	9	11	10

Table 66

Chandler score.

The results obtained from the Chandler score are as follows:

Site	October 1985	January 1986	April 1986
1	795	1045	1140
2	240	465	535
3	440	185	310
4	1160	1255	975
5	795	1585	975
6	725	1265	795

	June 1986	September 1986	November 1986
1	815	900	980
2	560	827	510
3	550	750	535
4	1335	1205	940
5	1230	1130	1005
6	1235	1412	1190

Table 67

BMWP score.

The results obtained from the BMWP score are as follows:

Site	October 1985	January 1986	April 1986
1	50	77	93
2	11	42	30
3	25	3	20
4	79	101	82
5	51	121	72
6	52	112	60

	June 1986	September 1986	November 1986
1	54	77	73
2	35	65	42
3	30	60	36
4	107	108	66
5	96	101	65
6	95	114	98

Table 68

Welsh Water Authority score.

The results obtained from the Welsh Water Authority scoring system are as follows:

Site	October 1985	January 1986	April 1986
1	698	773	888
2	248	299	377
3	319	95	186
4	890	1116	760
5	593	1362	742
6	592	1074	652

	June 1986	September 1986	November 1986
1	534	783	730
2	520	683	425
3	461	625	439
4	1171	1028	715
5	1051	874	790
6	994	1098	1038

Table 69

Appendix 7.

Data analysis and line listings for ARTHUR and SPSS-X: Figs 39-90.

1) 95% confidence limits:

Fig 39: Sample calculation for 95% confidence limits.

2) Species lists used for input of data to ARTHUR and SPSS-X.

Fig 40: October 1985.

Fig 41: January 1986.

Fig 42: April 1986.

Fig 43: June 1986.

Fig 44: September 1986.

Fig 45: November 1986.

3) Line listings for ARTHUR and SPSS-X

Figs 46-90.

Sample calculation for 95% confidence limits.

Suppose we have a list of five species which have relative abundances/m^2 of, 98, 22, 72, 214 and 67.

In order to find 95% confidence limits we firstly need to find the Logs of these values:

	x		Log x
	98		1.991
	22		1.342
	72		1.857
	214		2.330
	67		1.826
x =	94.6	y =	1.869

then, we must find the values of x - x and also the sum of the squares;

x	x	x -x	$(x - x)^2$
1.991	1.869	0.122	0.015
1.342	1.869	-0.527	0.278
1.857	1.869	-0.012	1.44×10^{-4}
2.330	1.869	0.461	0.212
1.826	1.869	-0.043	1.9×10^{-3}
			0.507

this value must the be divided by n - 1(ie number of factors is 5). thus giving a value of 0.127.

To find 95% confidence limits where t = 2.262 then;

$$1.869 \pm 2.262 \quad \frac{0.127}{5}$$

and so 95% limits for the data are;

1.869 - 0.362 = 1.507 and 1.869 + 0.362 = 2.231

which gives us values of;

32.1 to 170.2, y = 74

Fig 39

Species list for October 1985.

1. Conchapelopia
2. Brillia longifurca
3. Brillia modesta
4. Tvetania calvescens
5. Eukiefferiella clarripennis
6. O(O)rubicundus
7. Rheocricotopus fuscipes
8. Nais elinguis
9. Tubifex tubifex
10. Rhyacodrilus coccineus
11. Limnodrilus hoffmeisteri
12. Enchytraeidae
13. Stylodrilus herringianus
14. Eclipidrilus lacustris

Fig 40

Species list for January 1986.

1. Stoneflies:	a)Perlodes microcephala
	b) Isoperla grammatica
2. Other mayflies	a) Rhithrogena semicolorata
	b) Ecdyonurus dispar
	c) Ephemerella ignita
3.Baetis rhodani	
4. Cased caddis:	a) Sericostoma personatum
	b) Glossosoma conformis
5. Hydropsychids :	a) Hydropsyche instabilis
	b) Hydropsyche silitalai
6. Dipterans:	a)Tabanus
	b)Dicranota
	c)Clinocera
	d) Hemerodroma
7. Limnius volkmari	
8. Molluscs:	a) Hydrobia jenkinsii
	b) Ancylus fluviatile
9. Leeches:	a) Erpobdella octoculata
	b) Glossiphonia complanata
10. Conchapelopia melanops	
11. Brillia longifurca	
12. Brillia modesta	
13. Tvetania calvescens	
14. Eukiefferiella clarripennis	
15. Rheocricotopus fuscipes	
16. Tubifex tubifex	
17. Nais elinguis	
18. Enchytraeidae	

Fig 41

Species list for April 1986.

1. Stoneflies:	a) Perlodes microcephala
	b) Isoperla grammatica
2. Other mayflies	a) Rhithrogena semicolorata
	b) Ecdyonurus dispar
3.Baetis rhodani	
4.Caddis	a) Rhyacophila dorsalis
	b) Hydropsyche instabilis
	c) Hydropsyche silitalai
	d) Polycentropus flavomaculatus
	e) Plectrocnemia geniculata
	f) Diplectrona felix
5. Dipterans	a)Clinocera
	b) Hemerodroma
	c) Tabanus
	d) Tipula
	e) Dicranota

6. Ceratopogonid
7. Conchapelopia melanops
8. Brillia longifurca
9. Brillia modesta
10. O(E)thienemanni
11.O(O)rubicundus
12. Rheocricotopus fuscipes
13. Nais elinguis
14. Tubifex tubifex
15. Limnodrilus hoffmeisteri
16. Enchytraeidae
17. Stylodrilus herringianus
18. Eclipidrilus lacustris

Fig 42

Species list for June 1986.

1. Stoneflies: a) Perlodes microcephala
   b) Isoperla grammatica
   c) Leuctra moselyi
2. Other mayflies a) Rhithrogena semicolorata
   b) Ecdyonurus dispar
3. Baetid mayflies a) Baetis rhodani
   b) Baetis scambus
4. Ephemerella ignita
5. Conchapelopia
6. Brillia longifurca
7. Cricotopus bicinctus
8. O(O)rubicundus
9. Rheocricotopus fuscipes
10. Nais elinguis
11. Stylaria lacustris
12. Tubifex tubifex
13. Limnodrilus hoffmeisteri
14. Enchytraeidae

Fig 43

Species list for September 1986.

1. Stoneflies: a) Perlodes microcephala
   b) Isoperla grammatica
   c) Nemoura avicularis
2. Ecdyonurus dispar
3. Baetid mayflies: a) Baetis rhodani
   b) Baetis scambus
4. Ephemerella ignita
5. Caddis
6. Brillia longifurca
7. Brillia modesta
8. Tvetania calvescens
9. O(O)rubicundus
10. Rheocricotopus fuscipes
11. Nais elinguis
12. Tubifex tubifex
13. Limnodrilus hoffmeisteri
14. Enchytraeidae
15. Lumbriculis variegatus
16. Eclipidrlus lacustris
17. Stylaria lacustris

Fig 44

Species list for November 1986.

1. Other mayflies: a) Rhithrogena semicolorata
   b) Ecdyonurus dispar
   c) Ephemerella ignita
2. Baetis rhodani
3. Brillia longifurca
4. Brillia modesta
5. O(O)rubicundus
6. Rheocricotopus fuscipes
7. Nais elinguis
8. Tubifex tubifex
9. Limnodrilus hoffmeisteri
10. Enchytraeidae
11. Eclipidrilus lacustris

Fig 45

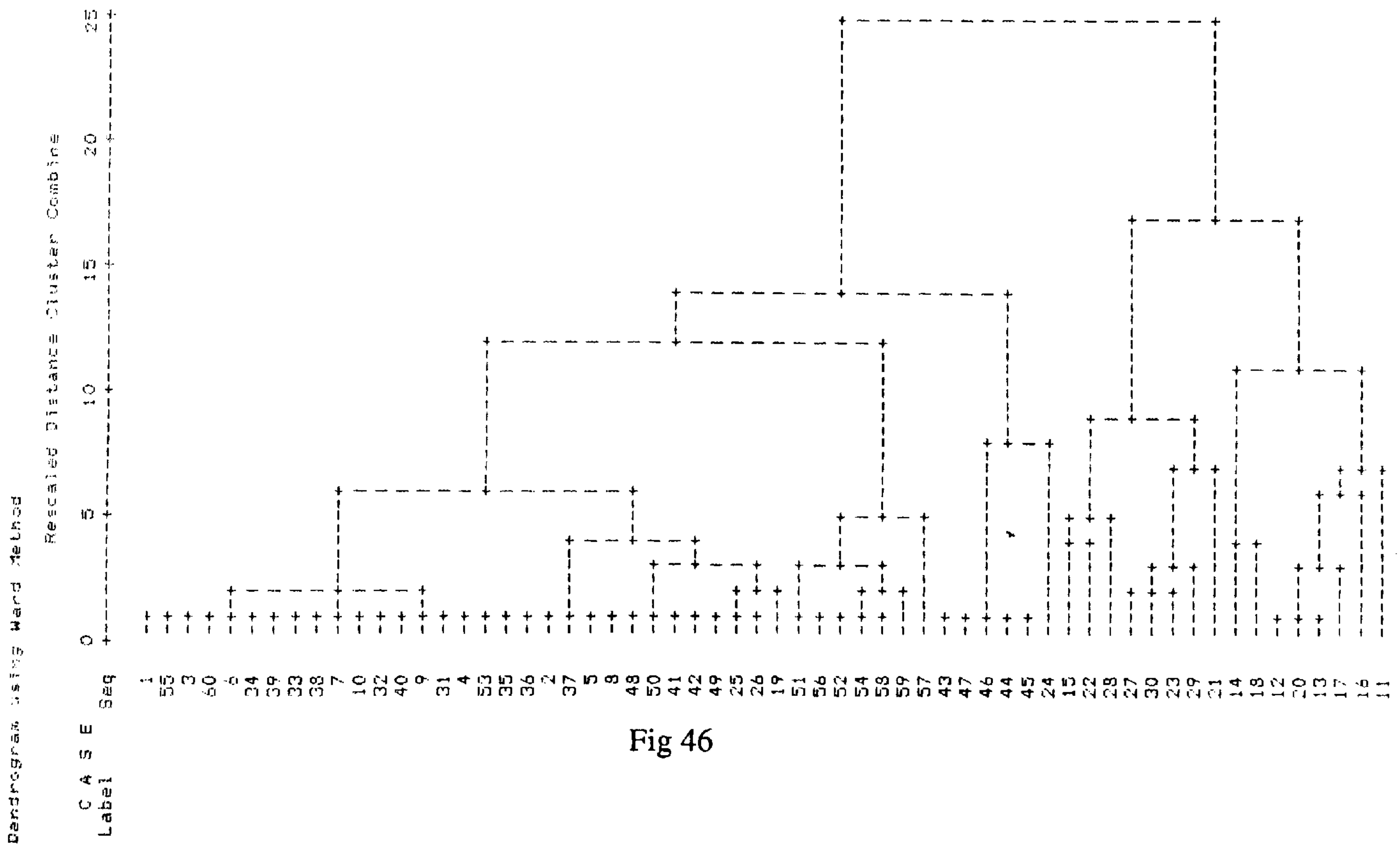
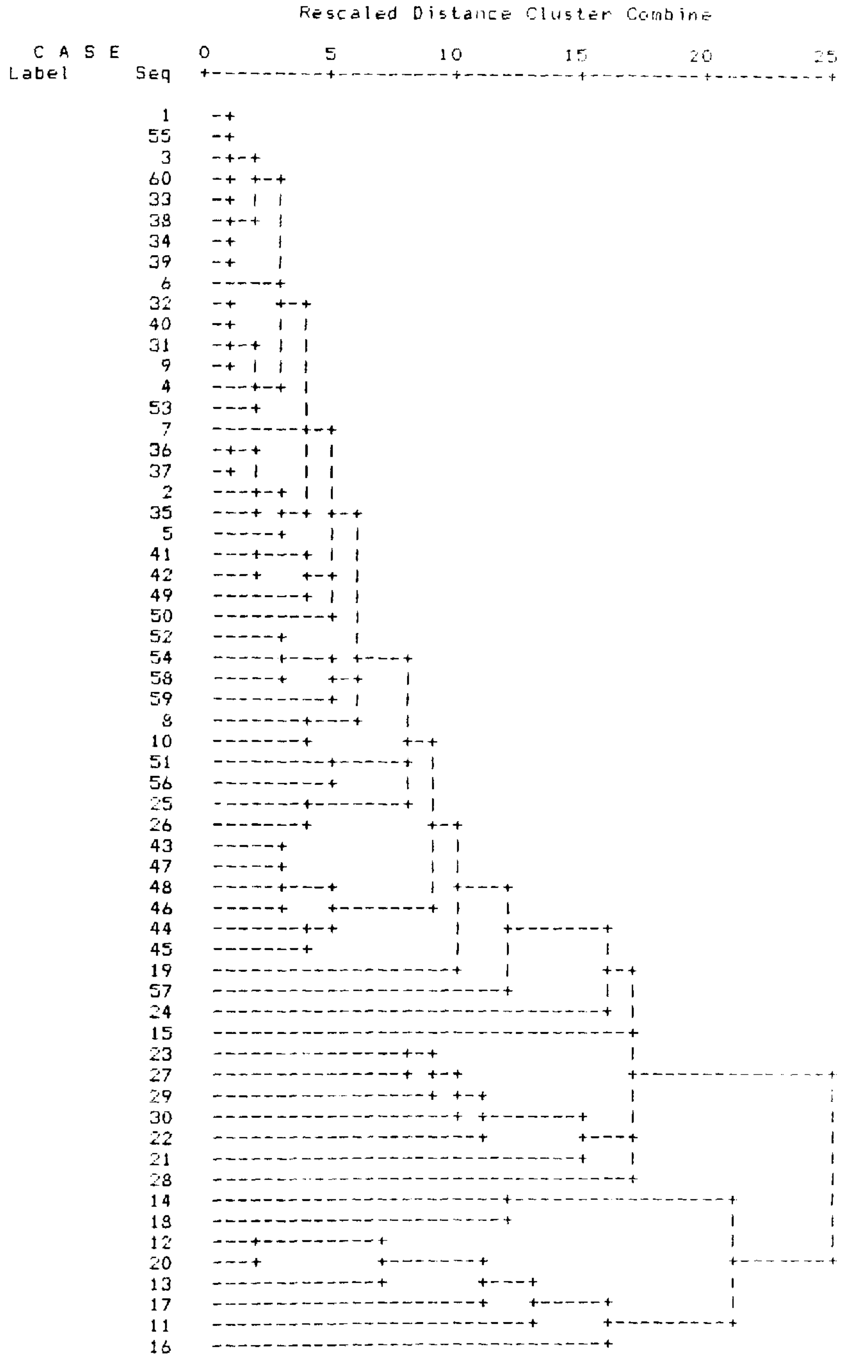

Dendrogram using Ward Method
Rescaled Distance Cluster Combine
C A S E
Label
Seq
0
5
10
15
20
25

Fig 46

* * * * * * * * * * * * * * * * * * * H I E R A R C H I C A L   C L U S

Dendrogram using Average Linkage (Between Groups)



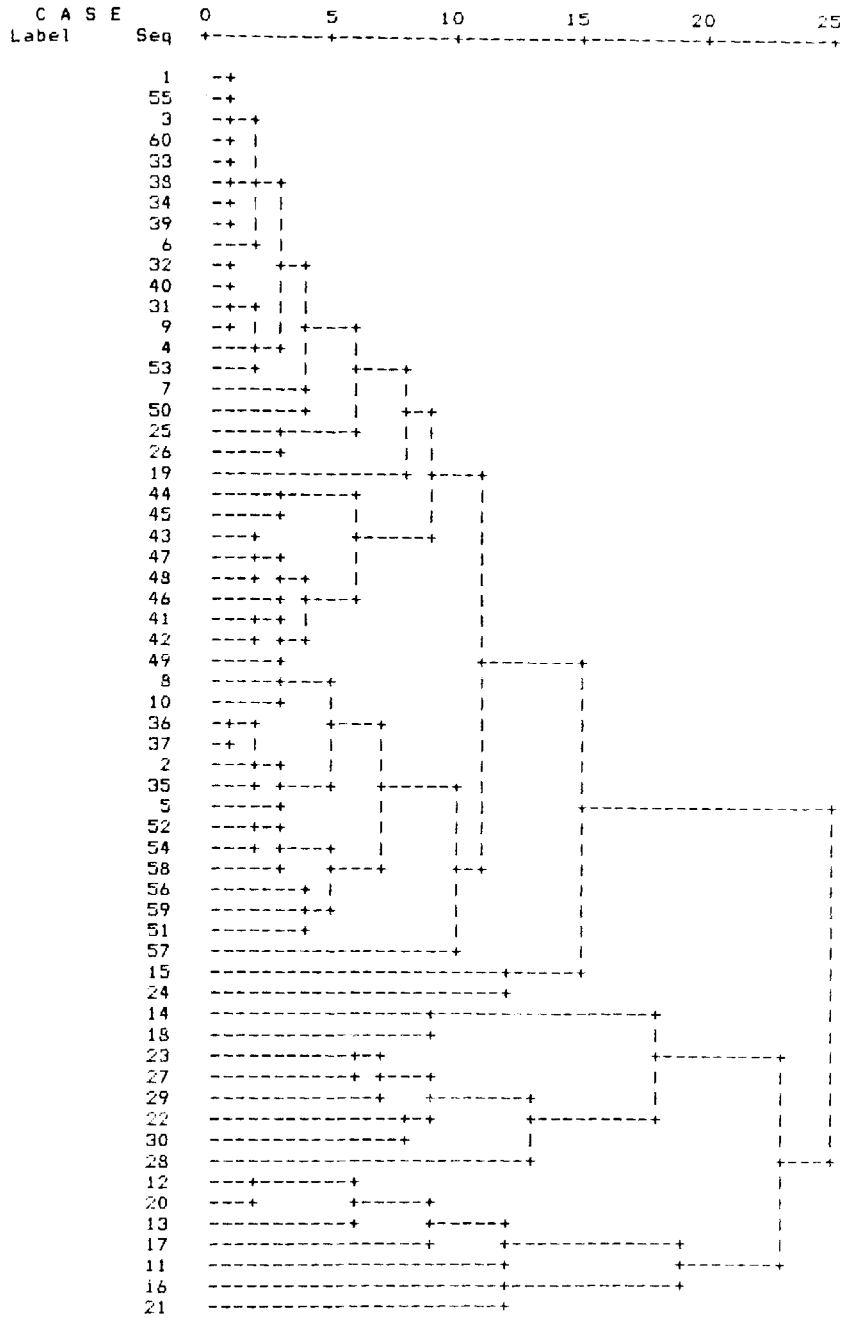
11-JUL-87   SPSS-X RELEASE 2.2+ FOR VAX/VMS

Fig 47

* * * * * * * * * * * * * * * * * * H I E R A R C H I C A L   C L U S

Dendrogram using Complete Linkage

Rescaled Distance Cluster Combine



31-JUL-87   SPSS-X RELEASE 2.2+ FOR VAX/VMS
10:07:55   THE POLYTECHNIC OF WALES   DEC VAX-8600   VMS V4.5

Fig 48

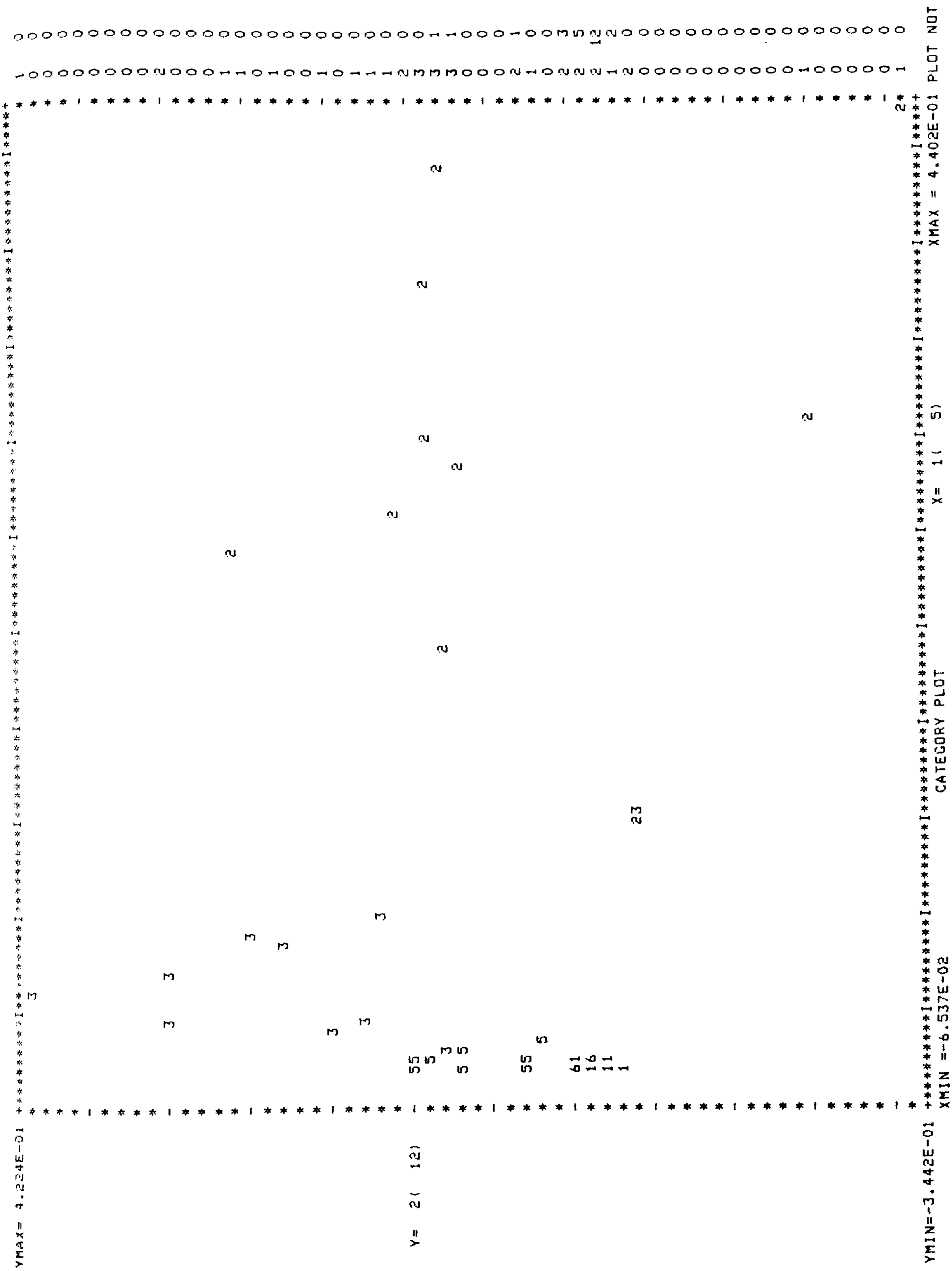

CATEGORY PLOT
PLOT NOT
YMAX= 4.224E-01
YMIN=-3.442E-01
XMIN =-6.537E-02
XMAX = 4.402E-01
X= 1(5)
Y= 2(12)

Fig 49

CORRELATION MATRIX

FEATURE		PROPERTY CORRELATION LO----COR----HI OPROB	J	LO----COR----HI OPROB	J	LO----COR----HI OPROB	J	LO----COR----HI OPROB
1	1	-0.341-0.090 0.173(0.496(						
2	2	-0.567-0.362-0.113(0.005(	1	-0.249 0.011 0.269(0.935)				
3	3	-0.392-0.148 0.115(0.259(	1	-0.065 0.198 0.434(0.130)	2	0.122 0.369 0.573(0.004)		
4	4	-0.225 0.036 0.293(0.782(	1	-0.076 0.187 0.425(0.153)	2	0.255 0.482 0.659(0.000)	3	-0.125 0.139 0.384(0.291)
5	5	-0.590-0.391-0.147(0.002(	1	-0.259-0.005 0.259(1.000)	2	0.603 0.745 0.842(0.000)	3	-0.179 0.084 0.335(0.524)
			4	0.203 0.439 0.626(0.000)				
6	6	-0.536-0.322-0.069(0.012(	1	-0.400-0.157 0.106(0.230)	2	0.574 0.725 0.828(0.000)	3	-0.169 0.094 0.344(0.476)
			4	0.051 0.306 0.523(0.017)	5	0.627 0.762 0.853(0.000)		
7	7	-0.329-0.077 0.186(0.561(	1	-0.198 0.064 0.318(0.626)	2	0.669 0.791 0.871(0.000)	3	0.053 0.308 0.525(0.017)
			4	0.350 0.558 0.714(0.000)	5	0.382 0.583 0.732(0.000)	6	0.442 0.629 0.764(0.000)
8	8	-0.287-0.030 0.231(0.821(	1	-0.343-0.093 0.170(0.481)	2	-0.131 0.132 0.378(0.315)	3	-0.184 0.079 0.331(0.551)
			4	0.228 0.460 0.642(0.000)	5	-0.157 0.107 0.356(0.418)	6	-0.238 0.022 0.279(0.866)
			7	-0.146 0.117 0.365(0.372)				
9	9	-0.536-0.321-0.068(0.012(	1	-0.175 0.088 0.339(0.505)	2	0.554 0.711 0.819(0.000)	3	-0.296-0.040 0.221(0.760)
			4	0.142 0.387 0.587(0.002)	5	0.674 0.794 0.873(0.000)	6	0.277 0.500 0.672(0.000)
			7	0.319 0.534 0.697(0.000)	8	-0.223 0.038 0.294(0.775)		
10	10	0.137 0.383 0.584(0.003(	1	-0.395-0.152 0.111(0.246)	2	-0.439-0.203 0.059(0.120)	3	-0.351-0.101 0.162(0.441)
			4	-0.409-0.168 0.096(0.201)	5	-0.437-0.201 0.061(0.124)	6	-0.396-0.153 0.110(0.243)
			7	-0.151 0.112 0.361(0.393)	8	-0.374-0.128 0.135(0.330)	9	-0.359-0.110 0.153(0.402)
11	11	-0.569-0.363-0.115(0.004(	1	-0.312-0.058 0.204(0.661)	2	0.475 0.654 0.780(0.000)	3	-0.175 0.087 0.339(0.507)
			4	0.060 0.314 0.530(0.014)	5	0.653 0.780 0.865(0.000)	6	0.274 0.497 0.670(0.000)
			7	0.216 0.450 0.635(0.000)	8	0.015 0.273 0.496(0.035)	9	0.785 0.868 0.920(0.000)
			10	-0.434-0.197 0.065(0.132)				
12	12	-0.462-0.231 0.030(0.076(	1	-0.168 0.095 0.346(0.470)	2	0.634 0.767 0.856(0.000)	3	-0.017 0.243 0.472(0.061)
			4	0.273 0.497 0.669(0.000)	5	0.289 0.510 0.679(0.000)	6	0.235 0.466 0.647(0.000)
			7	0.534 0.697 0.810(0.000)	8	-0.022 0.238 0.468(0.067)	9	0.487 0.663 0.787(0.000)
			10	-0.437-0.200 0.062(0.125)	11	0.423 0.615 0.754(0.000)		
13	13	-0.437-0.201 0.062(0.124(	1	-0.310-0.056 0.206(0.672)	2	0.045 0.301 0.519(0.020)	3	-0.394-0.151 0.112(0.249)
			4	0.036 0.292 0.512(0.023)	5	0.181 0.420 0.613(0.001)	6	0.075 0.328 0.541(0.011)
			7	0.001 0.259 0.486(0.045)	8	-0.099 0.164 0.406(0.210)	9	0.282 0.504 0.675(0.000)
			10	-0.413-0.173 0.090(0.186)	11	0.421 0.613 0.753(0.000)	12	0.150 0.394 0.592(0.002)
14	14	-0.545-0.333-0.081(0.009(	1	-0.299-0.043 0.218(0.744)	2	0.446 0.632 0.765(0.000)	3	-0.146 0.117 0.365(0.373)
			4	-0.134 0.130 0.376(0.323)	5	0.186 0.424 0.616(0.001)	6	0.244 0.473 0.652(0.000)
			7	0.306 0.524 0.689(0.000)	8	-0.128 0.135 0.381(0.304)	9	0.321 0.535 0.697(0.000)
			10	-0.382-0.137 0.127(0.298)	11	0.492 0.666 0.789(0.000)	12	0.632 0.766 0.855(0.000)
			13	0.336 0.547 0.706(0.000)				

METHOD CORR REQUIRED 224 WORDS OF BLANK COMMON.

Fig 50

```
ARTHUR, VER 7-1-79  KAPR                                                              26-A UG-8     15:2 4:42         8.363

                                  SPECIES DATA FROM R.OGMORE

I-M PRIN... YOU WANT COMPONENTS, WELL I-M THEIR PRINCIPAL.

NIN      31  CREATED IN WEIG     NPAT   60    NTEST    0    NVAR  14   NCAT  6   IFER 0   N -999   XLF 0.000  XHF 0.000

NOUTV    32  OUTPUT UNIT FOR PRINCIPAL COMPONENTS.

NPNT      1
NPCH      0

NVEC     14  MAXIMUM NUMBER OF EIGENVALUES/VECTORS EXTRACTED.

    EIGENVALUE  VAR. PRESERVED *******************************************FACTORS*******************************************
                  EACH  TOTAL

  1  5.026E+07   94.2   94.2 -1.432E-01 -9.703E-01 -3.439E-02 -3.200E-02 -1.597E-01 -1.417E-02 -6.642E-02 -3.812E-02 -1.278E-02
                             -3.536E-02 -5.336E-02 -1.489E-03 -2.034E-03 -6.734E-04

  2  2.079E+06    3.9   98.0  7.258E-01 -2.229E-01  5.508E-02  1.731E-02  5.963E-01  3.794E-02  2.438E-01  1.090E-02  2.597E-02
                              3.095E-03 -5.376E-02 -4.082E-03 -3.614E-03 -3.575E-04

  3  5.400E+05    1.0   99.1 -3.255E-01  4.675E-02 -1.648E-02 -5.406E-02  3.723E-01 -3.673E-02 -6.187E-02 -1.812E-01 -2.015E-02
                              2.497E-02 -8.432E-01 -3.157E-03 -8.252E-03 -5.764E-04

  4  3.224E+05    0.6   99.7  5.587E-01  5.509E-02  7.954E-02  8.411E-02 -5.971E-01  9.718E-02 -2.902E-01  8.955E-03 -4.564E-02
                             -1.274E-02 -4.675E-01 -1.181E-02  1.435E-02  1.576E-04

  5  8.850E+04    0.2   99.8 -3.010E-02 -1.170E-02  2.560E-02  1.953E-01  2.920E-01 -1.279E-05 -6.473E-01  4.863E-01 -8.834E-02
                             -4.462E-01  5.849E-02  9.418E-02 -5.615E-03  1.284E-02

  6  3.625E+04    0.1   99.9 -1.212E-01 -4.349E-02  7.771E-02  4.498E-01 -6.348E-02  1.348E-01  3.055E-01  6.024E-01  3.305E-01
                              3.383E-01 -1.707E-01  2.072E-01  2.558E-02  1.209E-02

  7  2.051E+04    0.0   99.9 -6.855E-02 -3.265E-02  6.242E-01  3.871E-01  1.104E-01  1.992E-01 -2.210E-01 -3.556E-01 -2.767E-01
                              3.229E-01  1.357E-01  1.657E-01  2.823E-02 -1.140E-02

  8  1.274E+04    0.0  100.0 -7.630E-02  7.788E-03  3.740E-01  1.109E-01 -1.290E-01 -1.363E-01  5.022E-01  1.592E-01 -4.539E-01
                             -5.173E-01 -1.123E-01 -1.225E-01  1.671E-01  3.791E-04

  9  1.007E+04    0.0  100.0  4.828E-02  1.499E-02 -5.042E-01  3.724E-01 -3.626E-02 -1.123E-01  1.159E-01 -2.413E-01 -2.707E-01
                             -1.328E-01  5.218E-04  6.542E-01 -2.291E-03 -3.499E-03

 10  5.216E+03    0.0  100.0  3.587E-02 -1.283E-02 -1.169E-01 -2.900E-01  2.760E-02 -2.205E-01 -6.227E-02  3.792E-01 -6.567E-01.
                              5.193E-01 -1.749E-02  2.095E-02 -3.432E-02  2.891E-02

 11  3.395E+03    0.0  100.0  6.789E-02 -4.576E-03  1.493E-01  2.153E-01 -1.216E-02 -9.142E-01 -1.031E-01 -7.391E-02  2.305E-01
                              1.017E-01  1.164E-02 -6.256E-02  8.199E-02  2.331E-02

 12  2.947E+03    0.0  100.0 -1.510E-02 -7.224E-03 -3.799E-01  5.623E-01  4.083E-02  7.659E-02 -1.264E-02 -7.635E-02 -1.971E-01
                              8.595E-02  1.946E-02 -6.864E-01 -8.450E-02  2.742E-02

 13  4.050E+02    0.0  100.0  3.513E-03 -3.089E-03 -1.295E-01 -2.381E-02  3.982E-02  9.117E-02 -7.767E-02 -2.431E-02  1.913E-02
                              7.973E-02  1.961E-02 -3.518E-02  9.550E-01  2.141E-01

 14  4.469E+01    0.0  100.0 -1.849E-03  9.998E-04  4.300E-02 -9.521E-03 -1.183E-02  6.501E-03  2.414E-02 -2.107E-02  8.334E-03
                             -3.256E-02 -2.112E-03  2.841E-02 -2.081E-01  9.755E-01

FEATURE   NAME    COMMUNALITY
    1       5      1.000E+00
    2      12      1.000E+00
    3       2      1.000E+00
    4       7      1.000E+00
    5       9      1.000E+00
```

Fig 51

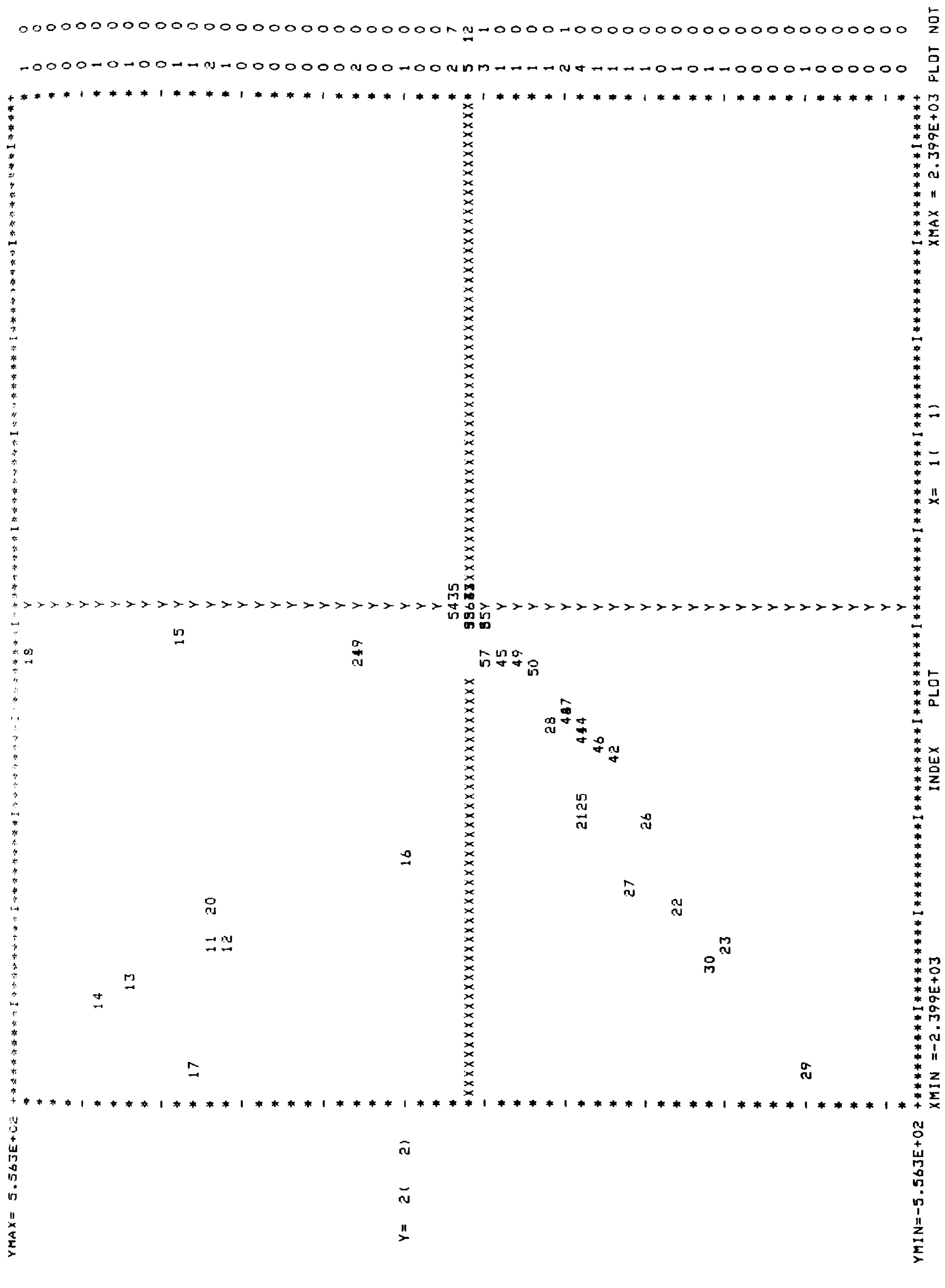

YMAX= 5.563E+02
YMIN=-5.563E+02
XMIN =-2.399E+03
XMAX = 2.399E+03
INDEX PLOT
PLOT NOT
X= 1(1)
Y= 2(2)

Fig 52

```
NOUTV      32  OUTPUT UNIT FOR PRINCIPAL COMPONENTS.

NPNT        1
NPCH        0

NVEC       18  MAXIMUM NUMBER OF EIGENVALUES/VECTORS EXTRACTED.
```

	EIGENVALUE	VAR. PRESERVED EACH	TOTAL	FACTORS								
1	2.773E+05	63.9	63.9	-4.337E-02	-1.355E-01	-3.972E-01	-1.829E-01	-8.611E-01	-4.538E-02	3.878E-02	-2.347E-02	-1.026E-02
				-2.046E-01	-1.833E-02	-7.172E-03	-8.893E-03	-9.643E-03	-1.487E-02	-6.633E-03	-1.097E-02	-4.230E-03
2	9.254E+04	21.3	85.2	1.740E-02	8.260E-02	8.759E-01	4.502E-02	-4.554E-01	6.505E-03	-3.172E-02	3.334E-02	6.772E-03
				1.161E-01	-1.521E-03	4.486E-03	3.728E-03	-1.844E-03	3.189E-03	1.137E-02	1.669E-02	6.355E-03
3	5.225E+04	12.0	97.3	5.561E-02	6.757E-02	-2.158E-01	4.197E-02	-1.522E-01	4.786E-02	-9.865E-03	-1.833E-02	-5.945E-03
				9.577E-01	-1.056E-02	7.994E-03	2.123E-04	2.078E-03	2.594E-02	1.612E-03	7.118E-04	-4.396E-03
4	7.441E+03	1.7	99.0	-1.543E-01	-6.959E-01	1.653E-01	-6.062E-01	1.460E-01	-1.446E-01	5.209E-02	-1.422E-01	-7.136E-02
				1.492E-01	-4.003E-02	-2.539E-02	-3.825E-02	-1.469E-02	9.413E-03	1.139E-02	-1.602E-02	-1.451E-02
5	2.033E+03	0.5	99.5	-1.565E-02	6.580E-01	3.016E-03	-7.253E-01	6.232E-02	-8.111E-02	-1.551E-01	5.824E-03	-7.345E-03
				-2.026E-03	-4.851E-02	-1.434E-02	-1.853E-04	-1.541E-02	4.169E-02	1.313E-02	-2.798E-02	2.530E-02
6	6.488E+02	0.1	99.6	-3.906E-01	-4.549E-04	-1.068E-02	1.482E-01	2.681E-02	-6.185E-01	-4.520E-01	2.312E-01	1.979E-02
				6.084E-02	2.223E-01	-9.670E-02	9.939E-02	2.403E-02	-3.133E-01	-8.304E-02	-7.441E-02	2.154E-02
7	5.429E+02	0.1	99.7	-4.935E-01	1.608E-01	-1.726E-03	1.797E-02	-3.430E-02	-1.567E-01	7.680E-01	1.720E-01	-3.445E-02
				3.080E-02	-1.856E-01	-2.830E-02	-3.823E-03	1.046E-01	-1.096E-01	-7.277E-02	-1.360E-01	2.994E-02
8	2.787E+02	0.1	99.8	2.913E-01	-3.752E-02	-9.950E-03	-1.635E-01	-4.454E-04	4.236E-02	2.169E-01	2.874E-01	1.917E-01
				1.411E-02	2.415E-01	7.386E-02	7.929E-02	1.044E-01	-5.574E-01	-9.586E-03	5.696E-01	4.846E-02
9	2.607E+02	0.1	99.9	2.156E-01	1.081E-01	1.674E-02	8.251E-02	-4.640E-03	-2.081E-01	7.173E-02	-6.704E-01	-2.518E-01
				-1.023E-02	-1.733E-01	-6.835E-02	-1.291E-01	-2.617E-02	-5.561E-01	-8.640E-03	-1.042E-01	-3.213E-02
10	2.066E+02	0.0	99.9	-4.294E-01	6.633E-02	-8.358E-03	8.870E-02	4.026E-03	3.915E-02	-1.441E-01	-2.522E-01	-2.174E-01
				-2.627E-03	-2.479E-01	7.239E-02	1.380E-02	-1.395E-02	1.570E-01	-9.634E-02	7.534E-01	-3.785E-02
11	1.438E+02	0.0	99.9	-3.292E-01	-5.177E-02	5.779E-03	-3.681E-02	2.099E-02	6.040E-01	-3.005E-01	1.442E-01	6.369E-02
				7.747E-03	-3.426E-01	-4.276E-02	-3.336E-02	1.455E-01	-4.638E-01	1.107E-01	-1.948E-01	1.448E-02
12	1.153E+02	0.0	100.0	3.484E-01	-7.249E-02	-8.303E-03	1.200E-02	1.526E-02	-2.111E-01	-7.355E-02	4.678E-01	-4.867E-01
				-6.421E-03	-5.768E-01	1.428E-01	4.662E-02	-7.185E-03	-2.617E-03	-9.149E-02	3.746E-03	5.848E-02
13	5.494E+01	0.0	100.0	-5.899E-02	2.380E-02	7.070E-03	-4.899E-02	-9.566E-03	2.546E-01	7.466E-03	4.138E-02	-6.726E-01
				-7.073E-03	5.071E-01	4.211E-02	-2.798E-03	3.378E-01	-1.553E-02	-2.856E-01	-9.129E-02	-1.058E-01
14	3.548E+01	0.0	100.0	6.766E-02	-1.532E-02	2.980E-03	4.756E-04	2.740E-03	7.048E-02	-1.394E-02	9.155E-02	3.579E-02
				3.443E-03	-3.187E-02	-6.805E-01	-4.209E-01	-1.068E-01	3.657E-02	-4.560E-01	8.598E-02	3.332E-01
15	2.505E+01	0.0	100.0	-8.383E-02	1.442E-02	-1.334E-02	3.346E-02	-1.859E-03	-5.741E-02	-9.645E-03	7.624E-02	-1.708E-01
				2.934E-03	1.550E-01	2.608E-01	-6.375E-01	-7.868E-03	6.060E-03	5.047E-01	4.736E-02	4.445E-01
16	2.410E+01	0.0	100.0	4.545E-02	1.149E-02	-1.107E-02	1.782E-02	-6.321E-03	-3.845E-02	4.764E-02	7.250E-02	-2.210E-01
				-3.961E-03	1.104E-02	-6.454E-01	1.763E-01	1.646E-01	6.229E-02	6.373E-01	1.182E-01	-2.014E-01
17	1.946E+01	0.0	100.0	9.121E-02	-7.019E-04	2.042E-03	1.008E-02	2.190E-03	-1.654E-01	-6.415E-02	7.160E-03	2.545E-01
				-3.574E-03	-1.507E-01	4.221E-02	-4.548E-01	6.758E-01	1.016E-01	-8.196E-02	3.670E-02	-4.345E-01
18	9.378E+00	0.0	100.0	-5.955E-02	2.462E-02	2.167E-04	-9.758E-03	4.549E-03	5.481E-02	3.339E-02	1.952E-01	-9.112E-02
				5.742E-03	8.222E-02	6.398E-03	-3.750E-01	-5.879E-01	-1.074E-01	8.831E-03	2.024E-02	-6.634E-01

Fig 53

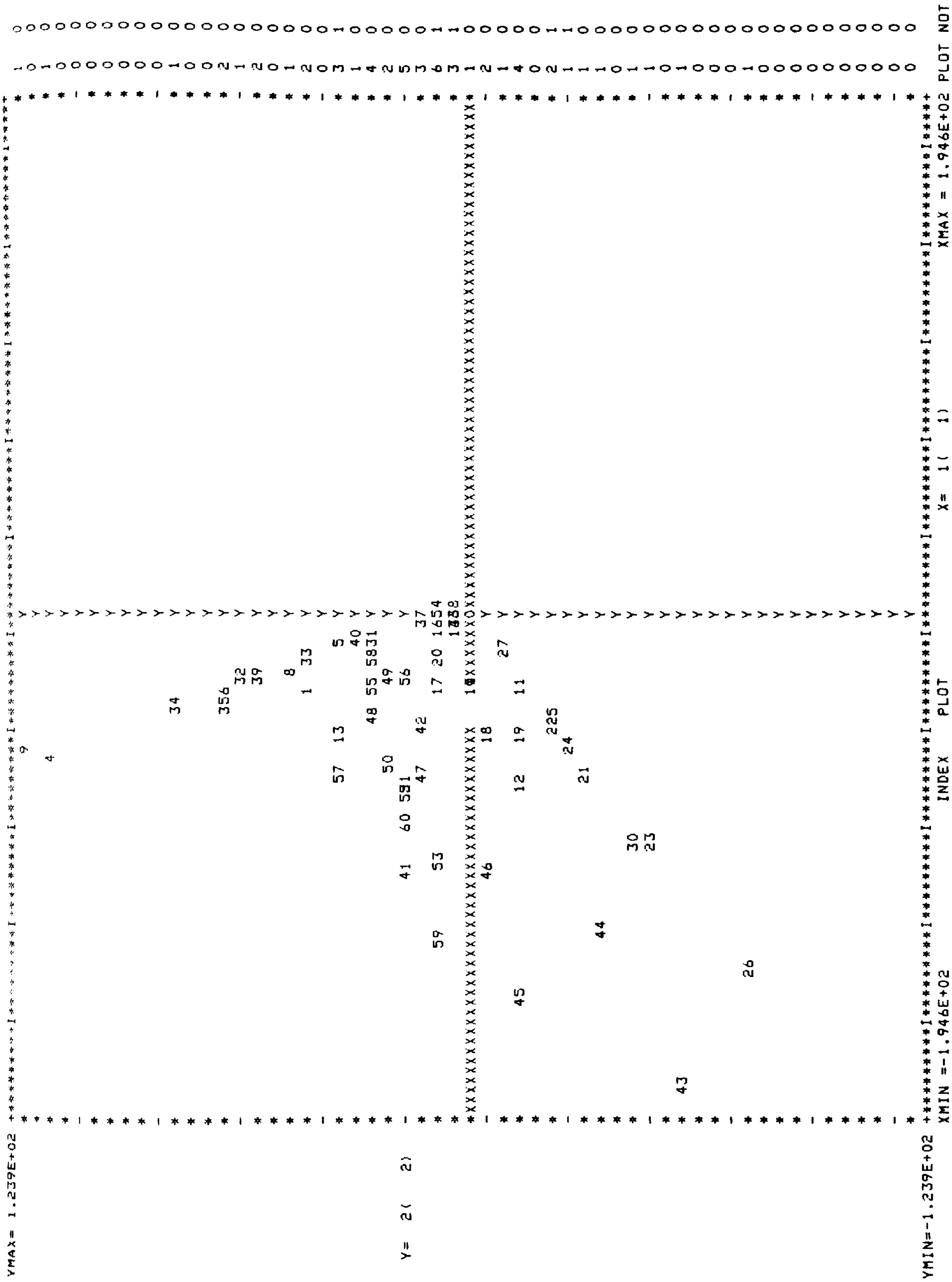

YMAX= 1.239E+02
YMIN=-1.239E+02
XMIN =-1.946E+02
XMAX = 1.946E+02
INDEX PLOT
X= 1(1)
Y= 2(2)
PLOT NOT

Fig 54

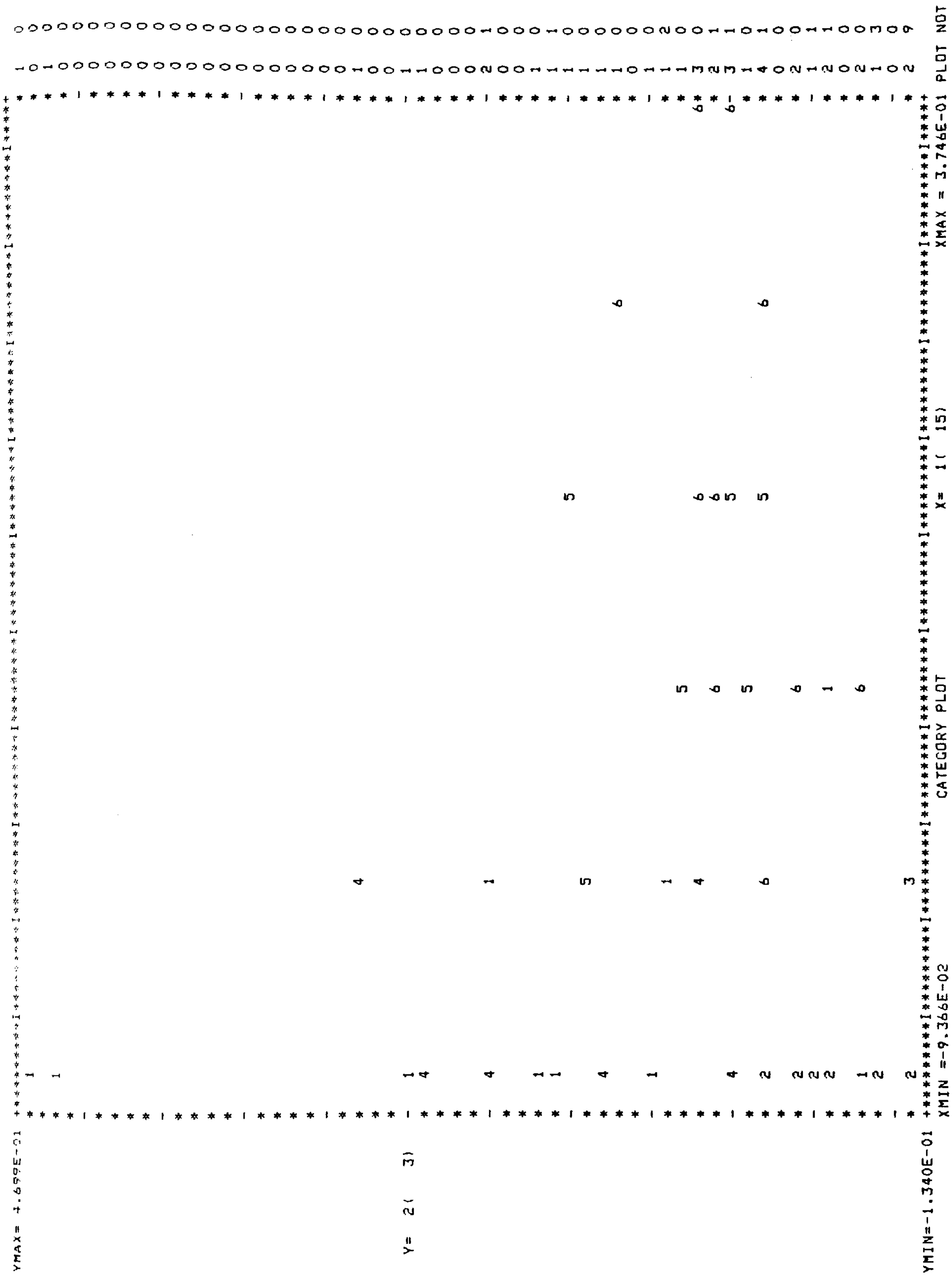
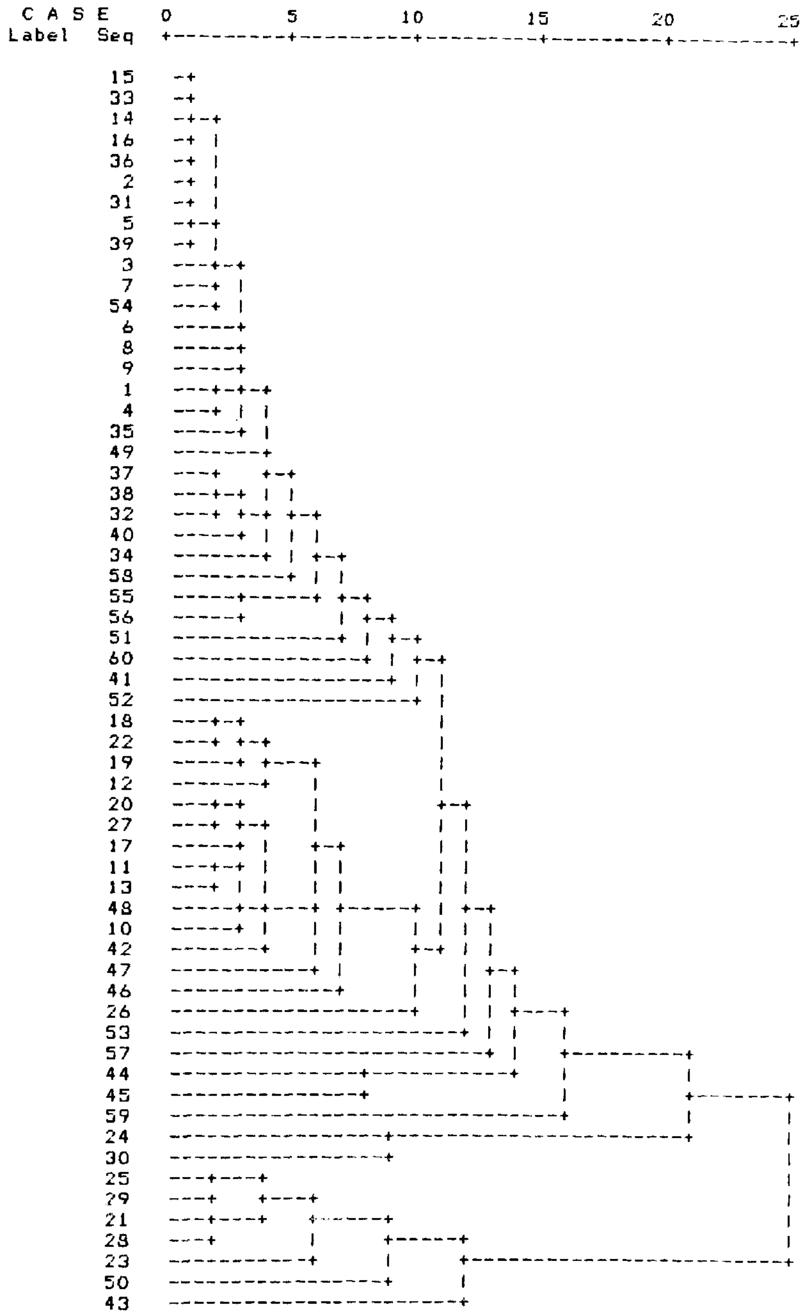

CATEGORY PLOT
XMIN =-9.366E-02
XMAX = 3.746E-01
YMIN=-1.340E-01
X= 1(15)
Y= 2(3)
PLOT NOT

Fig 55

Dendrogram using Average Linkage (Within Group)

Rescaled Distance Cluster Combine

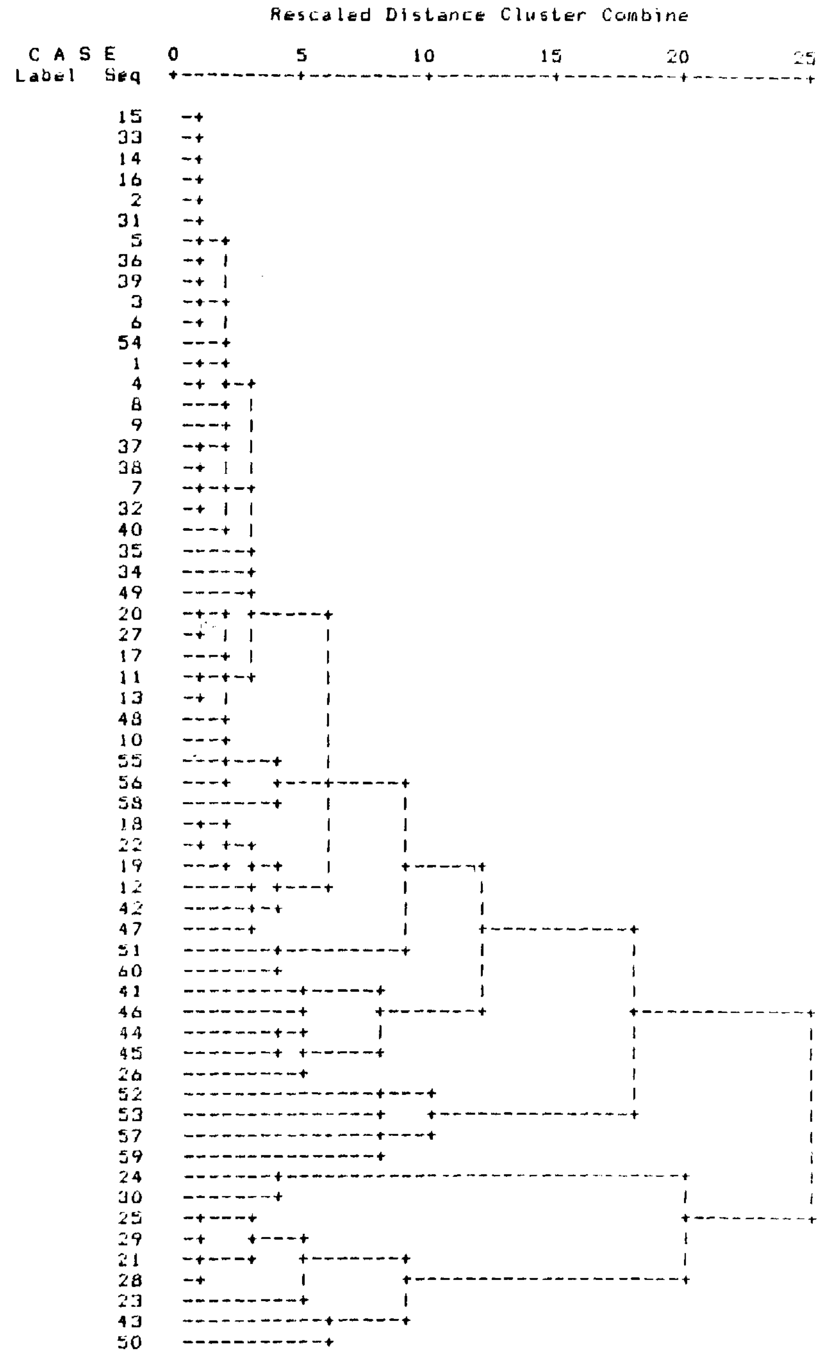


31-JUL-87 SPSS-X RELEASE 2.2+ FOR VAX/VMS
10:27:26 THE POLYTECHNIC OF WALES DEC VAX-8600 VMS V4.5

* H I E R A R C H I C A L   C L U S T E R   A N A L Y S I S * * * *

Fig 56

Dendrogram using Average Linkage (Between Groups)



31-JUL-87 SPSS-X RELEASE 2.2+ FOR VAX/VMS
10:27:26 THE POLYTECHNIC OF WALES DEC VAX-8600 VMS V4.5

Fig 57

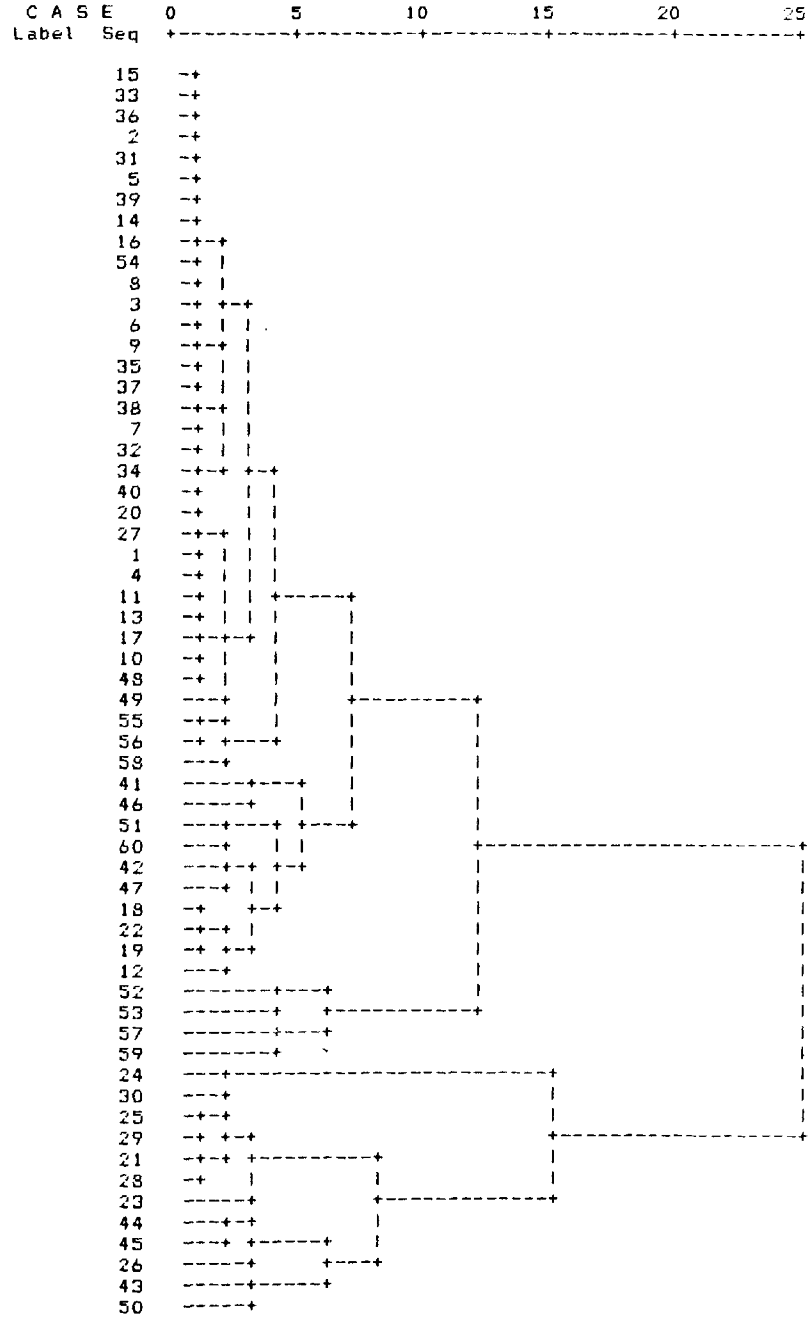
```
Dendrogram using Single Linkage

                         Rescaled Distance Cluster Combine

  C A S E    0         5        10        15        20        25
  Label  Seq +---------+---------+---------+---------+---------+

          15  -+
          33  -+
          14  -+
          16  -+
           2  -+
          31  -+
           5  -+-+
          39  -+ |
          36  -+ |
          20  -+-+
          27  -+ |
           3  ---+
          37  ---+
          38  ---+
          40  ---+
           7  ---+
           6  ---+
          54  ---+-+
          32  ---+ |
           1  ---+ |
           4  ---+ |
          17  -----+
           8  -----+
           9  -----+
          11  ---+-+
          13  ---+ |
          48  -----+
          10  -----+
          35  -----+
          34  -----+-+
          18  ---+ | |
          22  ---+-+ |
          19  ---+   +-+
          12  -------+ |
          42  -------+ +-+
          49  ---------+ +-+
          47  ---------+ | |
          55  -----+-----+ +---+
          56  -----+       |   |
          58  -------------+   |
          46  -----------------+
          44  ---------------+-+
          45  ---------------+ +---+
          26  -----------------+   +-+
          41  -----------------+   | |
          51  -------------+-------+ |
          60  -------------+         |
          25  ---+-+                 +-----+
          29  ---+ +-----------+     |     |
          21  ---+-+           +---+ |     |
          28  ---+             |   | |     +-+
          23  -----------------+   +-+     | |
          50  ---------------------+       | |
          43  ---------------------+       | +-----------------+
          52  -----------------------------+ |                 |
          53  -----------------------------+ |                 |
          57  -------------------------------+                 |
          59  -------------------------------+                 |
          24  ---------------+---------------------------------+
          30  ---------------+


31-JUL-87    SPSS-X RELEASE 2.2+ FOR VAX/VMS
10:27:26     THE POLYTECHNIC OF WALES            DEC VAX-8600    VMS V4.5
```

Fig 58

* H I E R A R C H I C A L   C L U S T E R   A N A L Y S I S

Dendrogram using Complete Linkage

Rescaled Distance Cluster Combine



31-JUL-87 SPSS-X RELEASE 2.2+ FOR VAX/VMS
10:27:27 THE POLYTECHNIC OF WALES DEC VAX-8600 VMS V4.5

Fig 59

NOUTV 32 OUTPUT UNIT FOR PRINCIPAL COMPONENTS.

NPNT 1
NPCH 0

NVEC 18 MAXIMUM NUMBER OF EIGENVALUES/VECTORS EXTRACTED.

	EIGENVALUE	VAR. PRESERVED EACH	TOTAL	*************************				FACTORS				*************************
1	7.656E+06	91.5	91.5	-1.309E-01	-1.350E-02	-1.830E-02	-6.180E-03	-6.788E-02	-9.186E-01	-3.648E-01	-4.791E-03	-2.436E-02
				-1.650E-03	-1.774E-03	-1.590E-03	-5.765E-04	-3.153E-03	-1.278E-02	-3.517E-04	-1.535E-04	-1.621E-03
2	4.195E+05	5.0	96.5	-4.612E-01	-5.818E-02	-6.854E-02	-2.004E-02	-1.129E-01	3.885E-01	-7.822E-01	-1.001E-02	-5.179E-02
				-5.783E-03	-1.883E-03	-8.088E-04	1.057E-04	-3.864E-04	8.560E-05	-1.267E-04	2.302E-05	-2.312E-02
3	1.995E+05	2.4	98.8	7.506E-01	4.329E-03	5.831E-02	9.386E-03	-5.611E-01	6.573E-02	-3.300E-01	9.568E-03	-5.402E-02
				8.324E-03	5.485E-03	2.219E-03	-6.219E-04	2.781E-03	-3.996E-03	1.909E-03	-8.226E-04	-4.279E-02
4	8.577E+04	1.0	99.9	-4.084E-01	-2.144E-01	-1.489E-01	-3.211E-02	-7.873E-01	-2.431E-02	3.708E-01	-2.735E-02	3.154E-02
				-5.383E-03	-3.903E-03	-1.148E-02	-6.014E-03	7.191E-03	-6.367E-02	-1.036E-03	-9.324E-04	-1.082E-02
5	4.987E+03	0.1	99.9	1.753E-01	-6.647E-01	-4.361E-01	-8.675E-02	1.593E-01	1.930E-04	-7.352E-02	-7.829E-02	4.456E-01
				1.603E-02	-1.185E-03	-2.064E-02	-2.006E-02	-8.831E-02	-2.169E-02	-2.090E-03	-5.978E-03	2.912E-01
6	2.049E+03	0.0	100.0	3.914E-02	-3.296E-01	-9.969E-02	-1.137E-02	6.358E-02	-2.407E-03	4.426E-02	-7.023E-02	-8.179E-01
				-7.008E-04	2.943E-02	6.821E-02	1.670E-02	2.093E-01	1.415E-01	5.904E-03	2.168E-03	3.608E-01
7	1.412E+03	0.0	100.0	6.470E-02	-8.447E-02	-3.096E-01	2.490E-02	1.094E-01	2.984E-03	1.725E-02	-2.450E-01	-2.933E-01
				4.958E-02	-4.663E-02	-3.064E-02	-3.622E-02	-2.483E-01	-6.494E-01	-3.792E-02	-1.783E-03	-4.922E-01
8	1.183E+03	0.0	100.0	2.947E-02	-2.796E-01	-1.380E-01	-7.780E-02	6.437E-02	-1.711E-02	2.204E-02	9.756E-02	-3.391E-02
				-1.410E-02	5.434E-02	-2.011E-02	1.580E-02	2.372E-01	5.439E-01	1.839E-02	3.793E-03	-7.239E-01
9	5.453E+02	0.0	100.0	-1.088E-02	1.741E-02	-8.302E-02	6.712E-02	-2.590E-02	-2.802E-03	2.225E-02	1.628E-01	-1.709E-01
				1.082E-02	-8.267E-02	-6.511E-02	-6.459E-03	-8.797E-01	3.811E-01	-1.766E-02	1.448E-02	2.278E-02
10	3.178E+02	0.0	100.0	-3.265E-02	-2.969E-01	6.155E-01	-1.581E-01	3.957E-03	-2.292E-04	-1.186E-03	-6.666E-01	4.553E-02
				-1.984E-02	-7.667E-02	9.015E-02	-4.242E-02	-1.710E-01	8.972E-02	3.465E-02	1.077E-02	-7.512E-02
11	2.564E+02	0.0	100.0	-2.285E-02	-4.342E-01	4.897E-01	-7.909E-02	4.079E-02	1.302E-03	-3.059E-03	6.569E-01	-4.777E-02
				3.324E-02	-1.412E-01	-2.445E-02	1.753E-02	-5.245E-02	-3.092E-01	4.639E-02	1.168E-02	-8.227E-02
12	1.105E+02	0.0	100.0	-2.231E-02	-1.753E-01	9.496E-02	9.564E-01	-1.189E-03	-6.743E-04	-9.289E-03	-6.062E-02	5.491E-02
				7.940E-02	4.917E-02	8.455E-02	1.321E-01	3.277E-02	1.524E-02	4.470E-02	1.329E-02	-3.912E-02
13	4.464E+01	0.0	100.0	-2.661E-04	4.720E-02	-8.919E-02	-6.726E-02	-7.958E-03	-1.640E-03	2.113E-03	6.781E-02	3.754E-02
				2.285E-01	-2.625E-01	9.170E-01	2.498E-02	-2.032E-02	1.882E-02	-1.037E-01	6.403E-02	-3.113E-02
14	3.955E+01	0.0	100.0	-5.297E-03	-4.216E-02	5.663E-02	-9.149E-02	3.389E-03	-7.421E-04	1.942E-03	5.956E-02	4.598E-03
				-2.481E-01	8.579E-01	2.968E-01	2.452E-01	-1.488E-01	-8.699E-02	5.594E-02	6.219E-02	-2.275E-02
15	2.172E+01	0.0	100.0	6.013E-03	2.834E-02	-3.453E-02	-1.188E-01	-1.548E-03	-1.910E-05	1.091E-03	-6.251E-02	4.395E-03
				9.057E-02	-2.220E-01	-1.077E-01	9.451E-01	7.248E-04	-5.860E-03	1.301E-01	2.547E-02	4.382E-03
16	1.947E+01	0.0	100.0	1.524E-02	2.674E-02	-8.480E-02	4.615E-02	3.913E-03	-8.368E-06	3.586E-04	8.440E-03	-3.465E-03
				-6.533E-01	-2.627E-01	1.543E-01	-7.439E-02	-3.482E-03	-2.443E-02	6.769E-01	7.455E-02	-1.165E-02
17	8.692E+00	0.0	100.0	1.070E-02	-3.777E-02	1.508E-02	6.764E-02	3.962E-03	2.216E-04	-1.720E-03	1.088E-02	5.160E-03
				-6.635E-01	-1.874E-01	4.237E-02	1.339E-01	1.789E-02	-8.115E-03	-7.005E-01	-8.515E-02	-1.147E-02
18	6.362E+00	0.0	100.0	2.260E-03	1.486E-03	-4.298E-03	4.156E-03	-1.841E-04	1.678E-04	-1.172E-03	-9.448E-03	3.775E-03
				-1.056E-02	-2.488E-02	-8.439E-02	-2.595E-02	2.504E-02	-1.326E-03	-1.129E-01	9.889E-01	8.019E-03

FEATURE NAME COMMUNALITY

Fig 60

```
ON MATRIX

ROPERTY CORRELATION          *******************************INTER-FEATURE CORRELATIONS*****************************

   LO----COR----HI  OPROB    J   LO----COR----HI  OPROB   J   LO----COR----HI  OPROB   J   LO----COR----HI  OPROB

 -0.432-0.195 0.067(0.135(

  0.239 0.469 0.649(0.000(    1 -0.295-0.039 0.222(0.769)

 -0.020 0.240 0.470(0.064(    1 -0.351-0.101 0.162(0.441)   2  0.103 0.352 0.560(0.006)

 -0.277-0.020 0.240(0.881(    1 -0.238 0.023 0.280(0.864)   2 -0.098 0.165 0.407(0.208)   3 -0.220 0.041 0.297(0.75

 -0.218 0.043 0.299(0.744(    1 -0.259 0.000 0.259(1.000)   2 -0.148 0.115 0.363(0.381)   3 -0.140 0.123 0.370(0.34
       4 -0.188 0.075 0.327(0.571)

 -0.044 0.217 0.451(0.095(    1 -0.190 0.073 0.325(0.581)   2 -0.275-0.018 0.242(0.894)   3 -0.170 0.093 0.344(0.48
       4 -0.174 0.088 0.340(0.501)   5 -0.259 0.000 0.259(1.000)

 -0.001 0.258 0.485(0.046(    1 -0.384-0.139 0.124(0.289)   2 -0.127 0.136 0.382(0.299)   3 -0.042 0.219 0.452(0.09
       4 -0.187 0.075 0.328(0.568)   5 -0.194 0.068 0.321(0.604)   6 -0.142 0.122 0.369(0.355)

  0.358 0.565 0.719(0.000(    1 -0.305-0.050 0.212(0.704)   2  0.200 0.436 0.625(0.000)   3 -0.177 0.086 0.337(0.51
       4 -0.167 0.096 0.346(0.465)   5 -0.271-0.013 0.247(0.923)   6 -0.026 0.234 0.465(0.071)
       7 -0.025 0.235 0.466(0.071)

  0.165 0.406 0.602(0.001(    1 -0.375-0.129 0.134(0.326)   2  0.041 0.297 0.516(0.021)   3 -0.275-0.017 0.243(0.89
       4 -0.347-0.097 0.166(0.462)   5 -0.387-0.142 0.121(0.278)   6 -0.038 0.223 0.456(0.086)
       7 -0.103 0.161 0.403(0.220)   8  0.448 0.633 0.767(0.000)

  0.430 0.620 0.757(0.000(    1 -0.237 0.024 0.281(0.857)   2  0.224 0.456 0.640(0.000)   3 -0.114 0.149 0.393(0.25
       4 -0.090 0.173 0.413(0.187)   5 -0.314-0.060 0.202(0.649)   6 -0.008 0.251 0.479(0.053)
       7 -0.182 0.081 0.333(0.539)   8  0.545 0.704 0.815(0.000)   9  0.054 0.309 0.526(0.016)

  0.430 0.620 0.757(0.000(    1 -0.381-0.136 0.128(0.302)   2  0.201 0.437 0.625(0.000)   3 -0.082 0.181 0.420(0.1
       4 -0.324-0.071 0.192(0.591)   5 -0.138 0.125 0.372(0.340)   6 -0.017 0.243 0.472(0.062)
       7  0.179 0.418 0.611(0.001)   8  0.566 0.719 0.825(0.000)   9  0.697 0.810 0.883(0.000)
      10  0.202 0.438 0.626(0.000)

  0.467 0.648 0.777(0.000(    1 -0.301-0.046 0.215(0.726)   2  0.297 0.516 0.684(0.000)   3 -0.070 0.193 0.430(0.14
       4 -0.188 0.074 0.327(0.573)   5 -0.152 0.111 0.360(0.399)   6  0.070 0.323 0.537(0.012)
       7 -0.052 0.210 0.445(0.107)   8  0.652 0.779 0.864(0.000)   9  0.367 0.571 0.723(0.000)
      10  0.744 0.841 0.903(0.000)  11  0.658 0.783 0.867(0.000)

 -0.036 0.225 0.457(0.084(    1 -0.385-0.140 0.123(0.286)   2 -0.151 0.112 0.360(0.395)   3 -0.091 0.172 0.412(0.1
       4 -0.456-0.224 0.037(0.085)   5 -0.324-0.072 0.191(0.587)   6 -0.197 0.065 0.318(0.623)
       7 -0.079 0.184 0.423(0.160)   8  0.008 0.266 0.491(0.040)   9  0.096 0.346 0.555(0.007)
      10 -0.303-0.048 0.214(0.718)  11  0.129 0.375 0.578(0.003)  12 -0.160 0.103 0.353(0.433)

 -0.223 0.038 0.294(0.772(    1 -0.215 0.047 0.302(0.721)   2 -0.196 0.067 0.320(0.613)   3 -0.043 0.218 0.452(0.0
       4 -0.212 0.050 0.305(0.705)   5 -0.446-0.212 0.050(0.104)   6 -0.176 0.086 0.338(0.511)
       7 -0.412-0.171 0.091(0.190)   8 -0.016 0.244 0.473(0.061)   9 -0.312-0.058 0.204(0.658)
      10  0.226 0.458 0.641(0.000)  11 -0.393-0.150 0.114(0.253)  12 -0.100 0.163 0.405(0.212)
      13 -0.203 0.059 0.313(0.653)

 -0.198 0.065 0.318(0.624(    1 -0.352-0.102 0.161(0.438)   2 -0.105 0.158 0.401(0.227)   3 -0.144 0.119 0.367(0.3
       4 -0.469-0.239 0.021(0.066)   5 -0.317-0.064 0.198(0.629)   6 -0.413-0.172 0.091(0.188)
       7 -0.189 0.073 0.326(0.579)   8  0.023 0.281 0.503(0.030)   9  0.039 0.295 0.515(0.022)
      10 -0.242 0.018 0.276(0.889)  11  0.053 0.307 0.524(0.017)  12 -0.139 0.125 0.371(0.343)
      13  0.335 0.547 0.706(0.000)  14  0.097 0.347 0.556(0.007)

 -0.043 0.218 0.452(0.094(    1 -0.341-0.090 0.173(0.494)   2 -0.037 0.224 0.457(0.085)   3 -0.169 0.094 0.345(0.4
       4 -0.436-0.200 0.062(0.126)   5 -0.331-0.079 0.183(0.547)   6 -0.226 0.035 0.292(0.788)
       7 -0.074 0.189 0.427(0.149)   8  0.338 0.549 0.707(0.000)   9  0.255 0.482 0.659(0.000)
      10 -0.069 0.193 0.430(0.140)  11  0.343 0.553 0.710(0.000)  12  0.133 0.379 0.581(0.003)
      13  0.513 0.682 0.799(0.000)  14  0.006 0.265 0.490(0.041)  15  0.653 0.780 0.864(0.000)

 -0.224 0.037 0.293(0.780(    1 -0.373-0.126 0.137(0.337)   2 -0.215 0.046 0.301(0.726)   3 -0.120 0.143 0.388(0.2
       4 -0.140 0.123 0.370(0.350)   5 -0.070 0.192 0.429(0.142)   6 -0.037 0.224 0.456(0.085)
       7  0.136 0.381 0.583(0.003)   8 -0.317-0.063 0.199([illegible])   9 -0.347-0.097 0.166(0.461)
      10 -0.323-0.070 0.192(0.593)  11 -0.218 0.043 0.299(0.742)  12 -0.227 0.034 0.290(0.797)
      13 -0.199 0.063 0.317(0.630)  14 -0.398-0.156 0.108(0.235)  15 -0.357-0.108 0.155(0.411)
      16 -0.195 0.067 0.321(0.610)

 -0.416-0.176 0.086(0.178(    1 -0.317-0.063 0.199(0.633) [illegible] 0.349-0.099 0.164(0.453)   3 -0.292-0.036 0.225(0.
       4 -0.319-0.065 0.197(0.620)   5 -0.322-0.069 0.193(0.599)   6 -0.191 0.072 0.325(0.586)
       7 -0.355-0.106 0.158(0.422)   8 -0.259-0.002 0.259(1.000)   9 -0.311-0.056 0.206(0.669)
      10 -0.356-0.107 0.156(0.415)  11 -0.339-0.087 0.175(0.507)  12 -0.351-0.102 0.161(0.439)
      13 -0.375-0.128 0.135(0.328)  14  0.119 0.366 0.571(0.004)  15  0.031 0.287 0.508(0.026)
      16 -0.069 0.194 0.431(0.138)  17 -0.322-0.069 0.193(0.600)
```

Fig 61

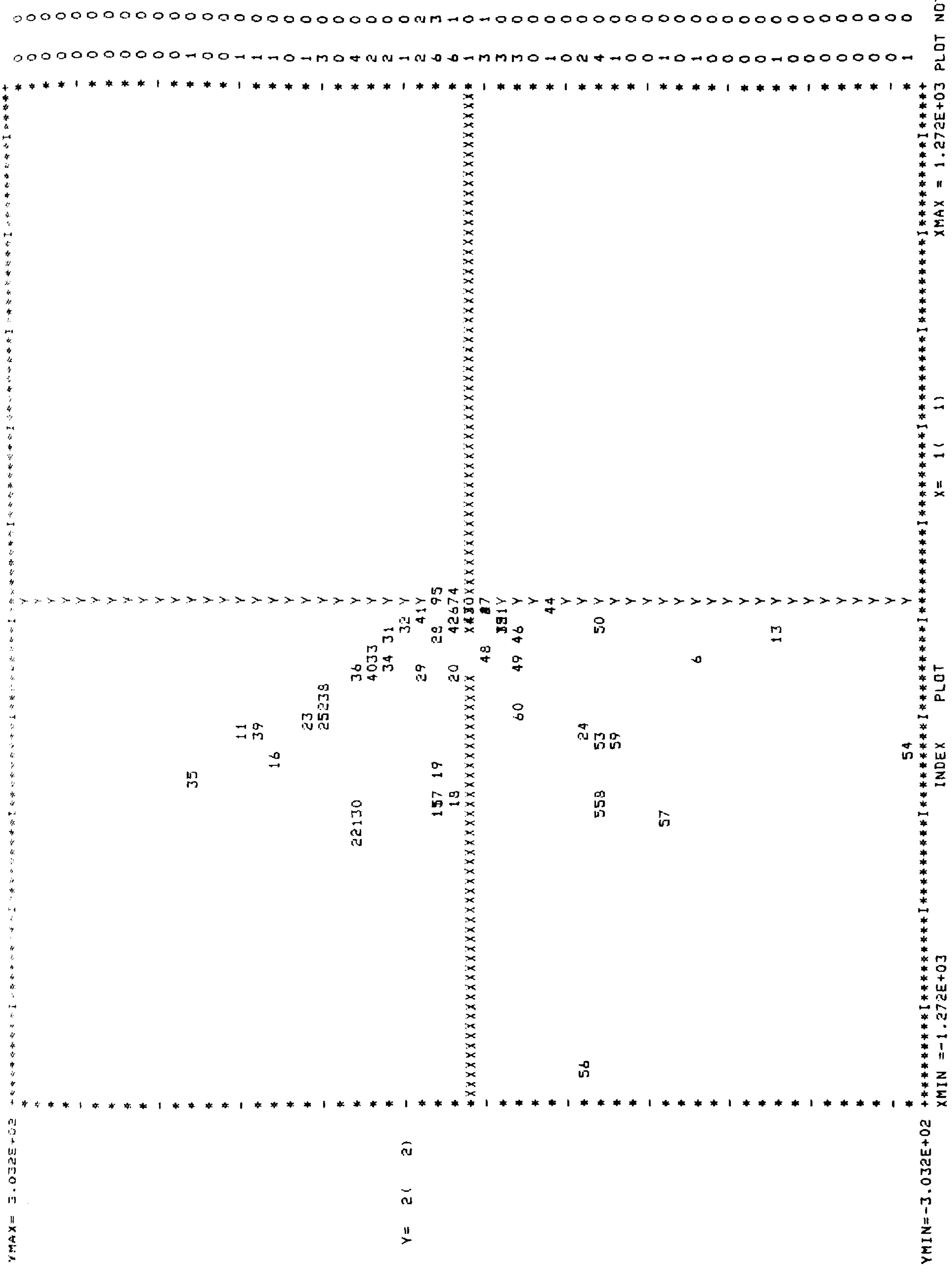
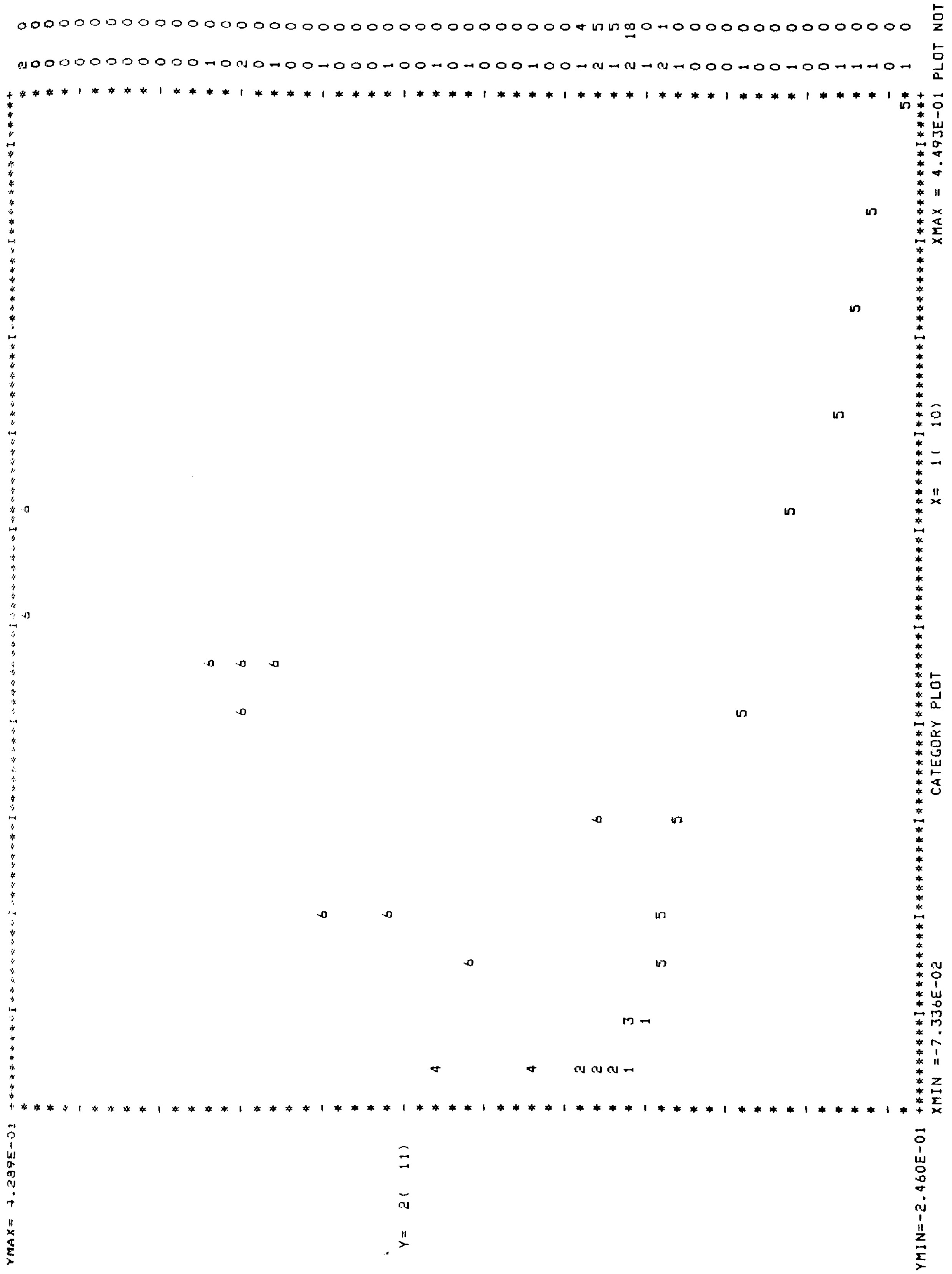

YMAX= 3.032E+02
Y= 2(2)
YMIN=-3.032E+02
XMIN =-1.272E+03
INDEX PLOT
X= 1(1)
XMAX = 1.272E+03
PLOT NOT

Fig 62



YMAX= 4.289E-01
YMIN=-2.460E-01
Y= 2(11)
XMIN =-7.336E-02
CATEGORY PLOT
X= 1(10)
XMAX = 4.493E-01
PLOT NOT

Fig 63

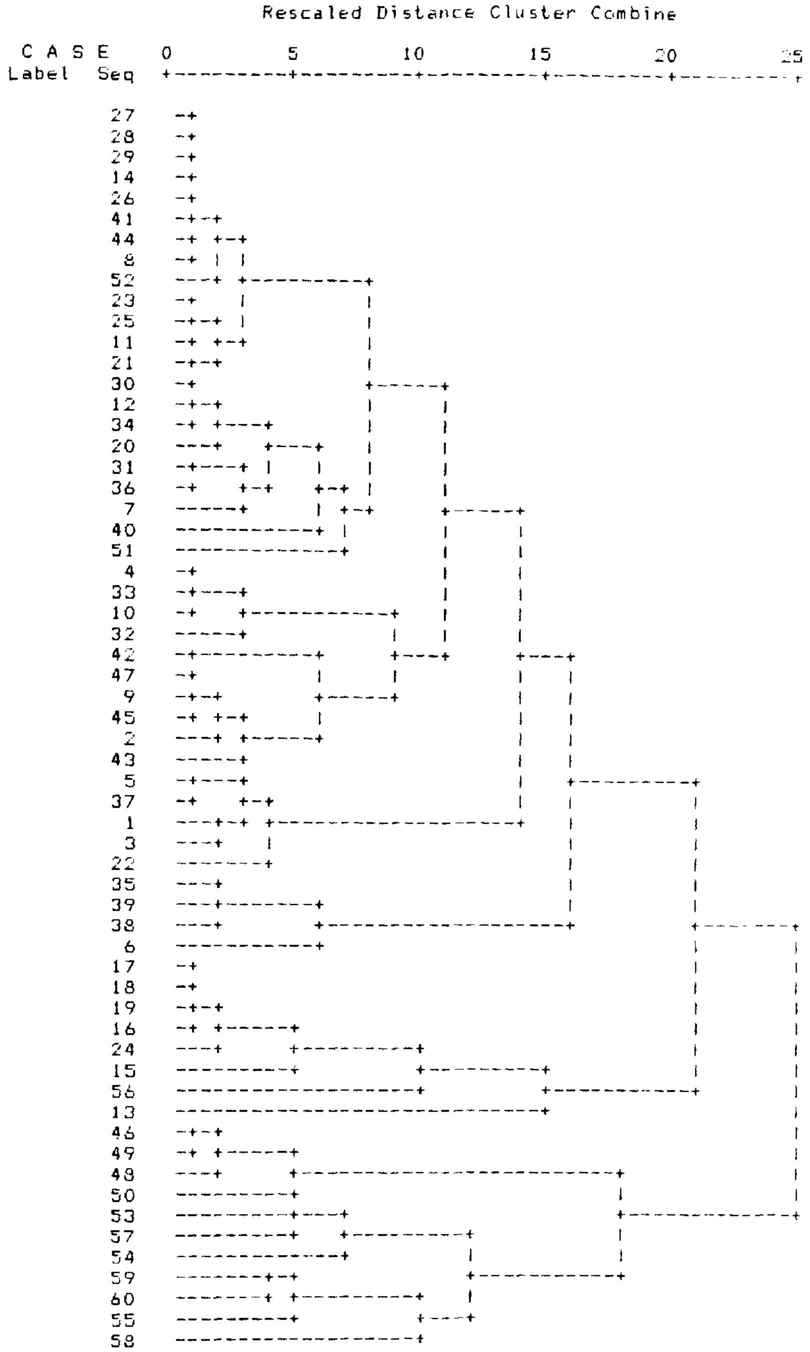
```
* * * * * * * * * * * * * * * * * * * H I E R A R C H I C A L   C L U S T E R   A N A L Y S I S *

 Dendrogram using Centroid Method

                         Rescaled Distance Cluster Combine

    C A S E      0         5        10        15        20        25
  Label  Seq     +---------+---------+---------+---------+---------+

           27     -+
           28     -+
           26     -+
           14     -+
           29     -+
           41     -+
           44     -+
           23     -+
           25     -+-+
           11     -+ |
            8     -+ |
           12     ---+
           31     -+-+
           36     -+ |
            9     -+-+
           45     -+ |
           21     ---+-+
           30     ---+ |
           52     ---+ |
            4     -----+
           33     -----+-+
           10     -----+ |
           20     -----+ |
           34     -------+
            7     -------+
           17     -+-+   +-+
           18     -+ |   | |
           19     ---+   | |
           16     ---+---+ +-+
           24     ---+     | |
            5     -+---+   | |
           37     -+   +-+ | |
            1     -----+ +-+ |
            3     -------+   |
           22     -----------+
            2     -----------+-+
           42     ---+---+   | |
           47     ---+   |   | |
           46     -----+ +---+ |
           49     -----+-+     |
           48     -----+ |     |
           43     -------+     |
           35     -------+     |
           39     -------+-----+
           38     -------+     |
            6     -------------+
           60     -------------+-+
           40     -------------+ |
           59     -------------+ +-+
           51     ---------------+ +-----------+
           15     ---------------+ |           |
           32     -----------------+           |
           50     -----------------------------+-----------+
           53     -----------------+---+       |           |
           57     -----------------+   |       |           |
           54     ---------------------+-------+           |
           55     ---------------------+                   +-------+
           56     -----------------------------------------+       |
           58     -----------------------------------------+       |
           13     -------------------------------------------------+

29-JUL-87   SPSS-X RELEASE 2.2+ FOR VAX/VMS
11:01:57    THE POLYTECHNIC OF WALES            DEC VAX-8600    VMS V4.5
* * * * * * * * * * * * * * * * * * * H I E R A R C H I C A L   C L U S T E R   A N A L Y S I S
```

Fig 64

```
* * * * * * * * * * * * * * * * * * * H I E R A R C H I C A L   C L U S T E R   A N A L Y S I S

Dendrogram using Median Method

                         Rescaled Distance Cluster Combine

  C A S E   0         5         10        15        20        25
Label  Seq  +---------+---------+---------+---------+---------+

        27   -+
        28   -+
        26   -+
        14   -+
        29   -+
        11   -+
        23   -+
        25   -+
        41   -+
        44   -+-+
         8   -+ |
        12   -+ |
        31   -+-+
        36   -+ |
        33   ---+
         9   -+-+
        45   -+ +-+
        10   ---+ +-+
         4   ---+ | |
         7   -----+ |
        21   -+-+   |
        30   -+ |   |
        17   -+ |   |
        18   -+-+   |
        19   -+ +-+ |
        16   ---+ +-+
        24   ---+ | |
        20   -----+ |
        34   -------+-+
        52   -------+ |
        42   ---+---+ |
        47   ---+   | |
        46   -----+ | |
        49   -----+-+ |
        48   -----+ | |
        43   -------+ +-+
         2   ---------+ |
         5   -+---+   | |
        37   -+   |   | +---+
         1   -----+---+ |   |
         3   -----+     |   |
        22   -----------+   |
        15   ---------------+
        51   ---------------+-+
        59   -------------+ | |
        60   -------------+ | |
        55   -------------+-+ |
        53   -------------+   |
        35   -----+           |
        39   -----+-----+     |
        38   -----+     +-----+
         6   -----------+     +---------------+
        40   -----------------+               |
        32   -----------------+               |
        58   ---------------------------------+-+
        54   -----------------------+---------+ |
        57   -----------------------+         | +-------------+
        56   ---------------------------------+ |             |
        50   -----------------------------------+             |
        13   -------------------------------------------------+

29-JUL-87   SPSS-X RELEASE 2.2+ FOR VAX/VMS
11:01:57    THE POLYTECHNIC OF WALES            DEC VAX-8600   VMS V4.5
```

Fig 65

Dendrogram using Ward Method



29-JUL-87 SPSS-X RELEASE 2.2+ FOR VAX/VMS
11:01:58 THE POLYTECHNIC OF WALES DEC VAX-8600 VMS V4.5

Fig 66

lrogram using Average Linkage (Within Group)

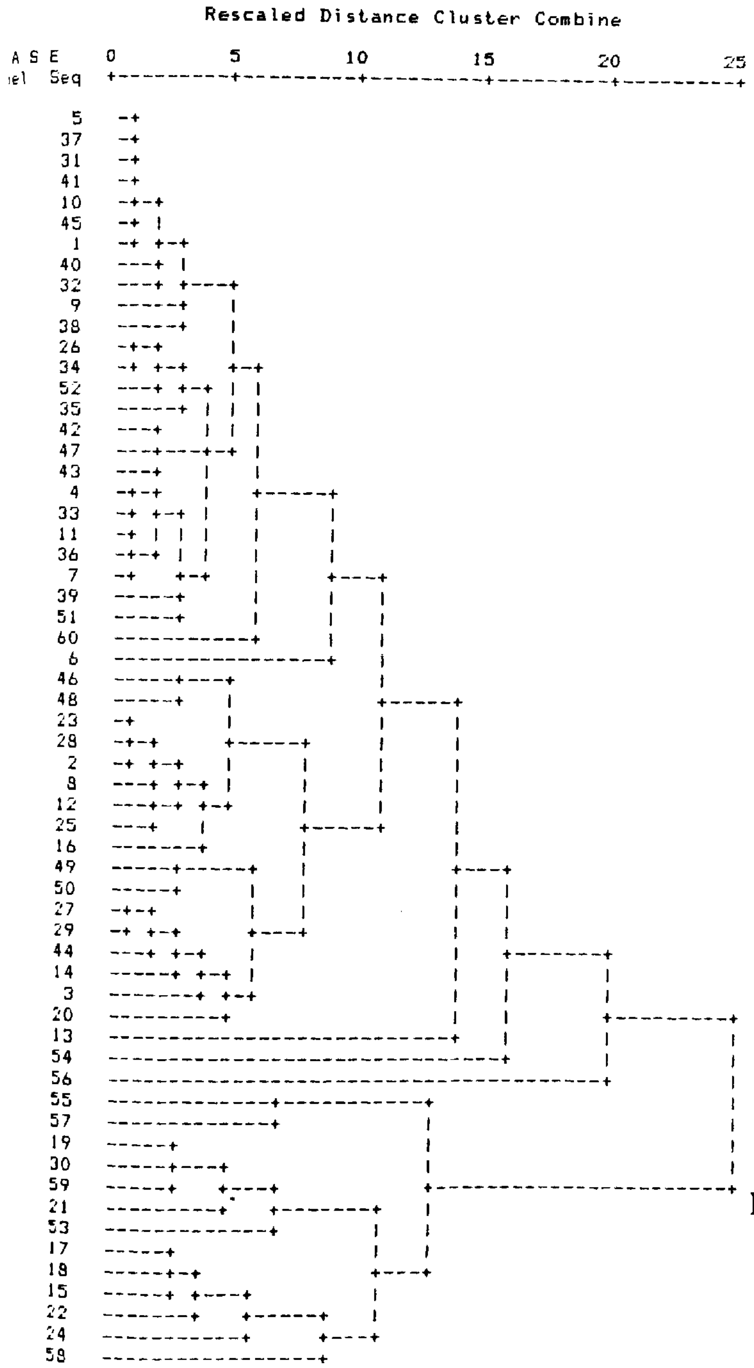


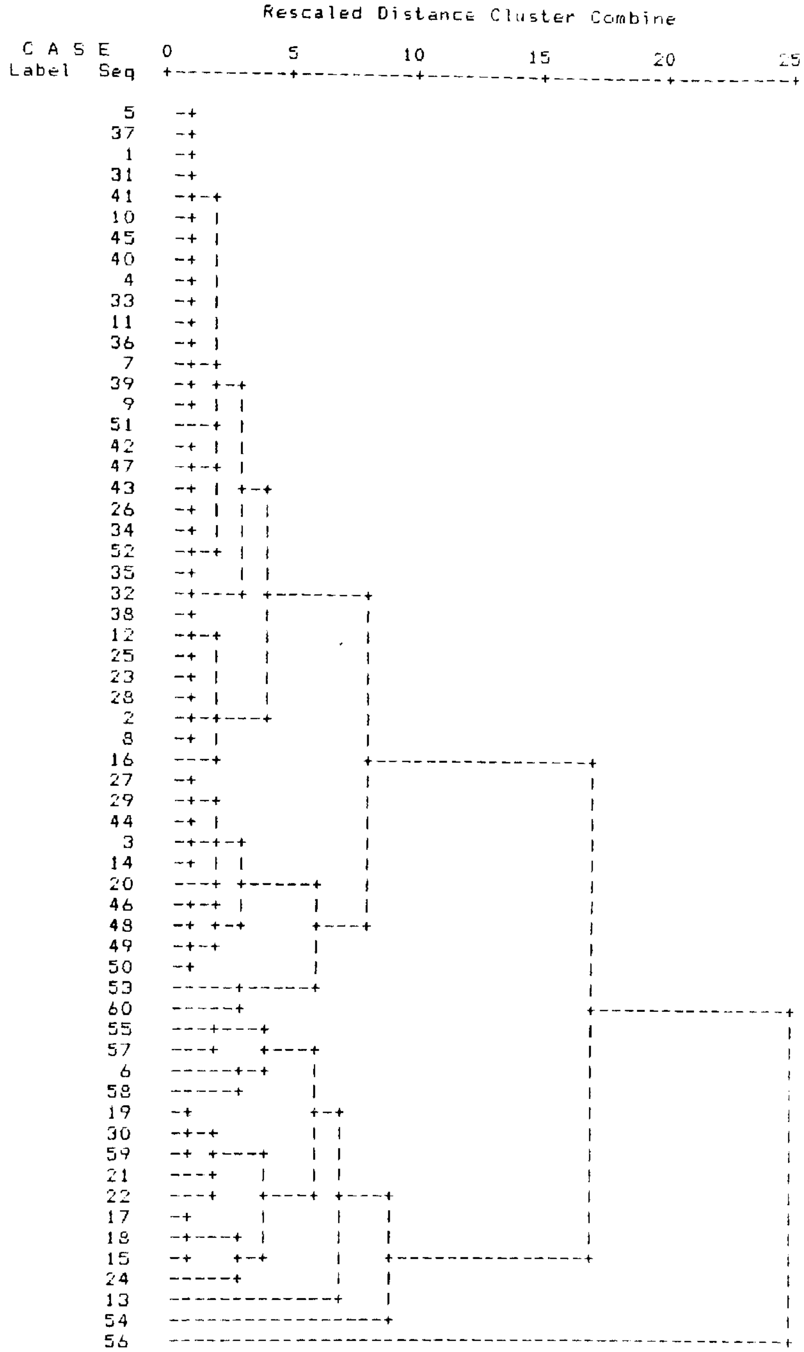
Fig 67

(149)

L-87 SPSS-X RELEASE 2.2+ FOR VAX/VMS
:28 THE POLYTECHNIC OF WALES DEC VAX-8600 VMS V4.5

* HIERARCHICAL CLUSTER ANALYSIS * * *

Dendrogram using Complete Linkage



31-JUL-87 SPSS-X RELEASE 2.2+ FOR VAX/VMS
10:24:29 THE POLYTECHNIC OF WALES DEC VAX-8600 VMS V4.5

Fig 68

* * * * * * * * * H I E R A R C H I C A L   C L U S T E R   A N A L Y S I S * * *

ram using Average Linkage (Between Groups)

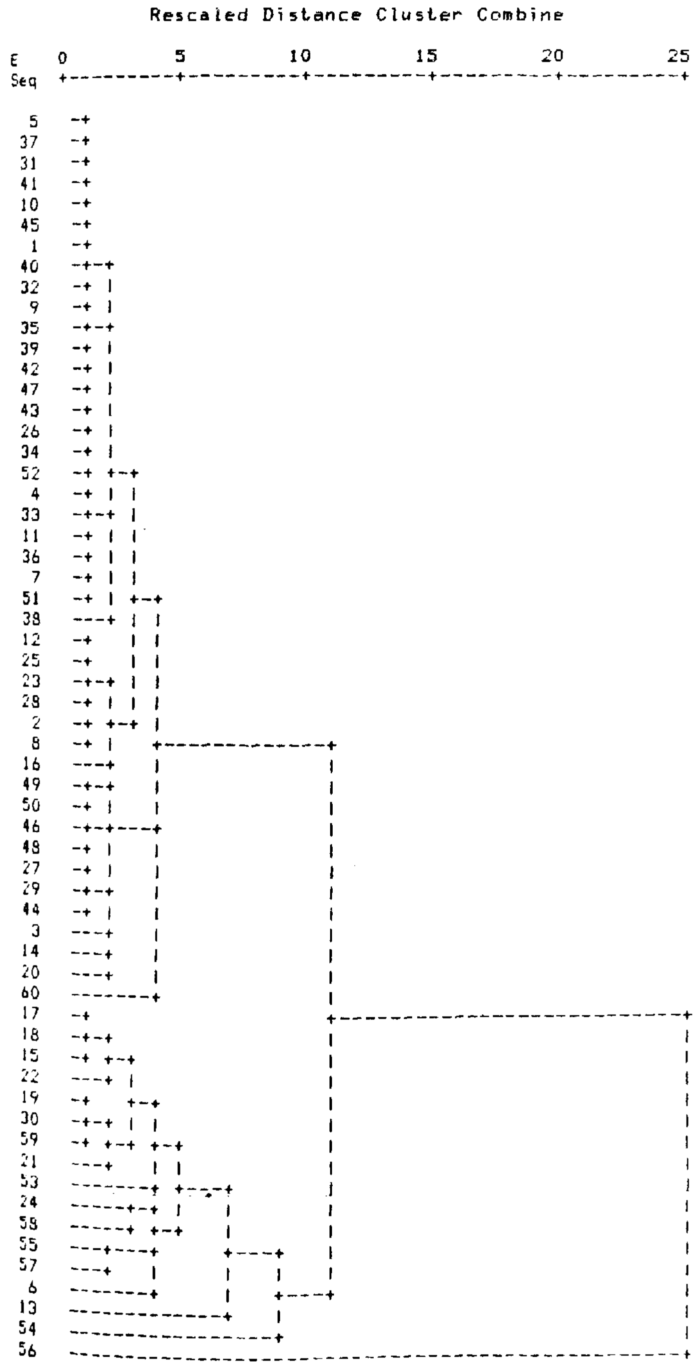


Fig 69

(151)

7 SPSS-X RELEASE 2.2+ FOR VAX/VMS
THE POLYTECHNIC OF WALES DEC VAX-8600 VMS V4.5

```
* * * * * * * * * * * * * * * * * * * H I E R A R C H I C A L   C L U S T E R   A N A L Y S I S * * *

 Dendrogram using Single Linkage

                        Rescaled Distance Cluster Combine

   C A S E     0         5        10        15        20        25
  Label  Seq   +---------+---------+---------+---------+---------+

           5    -+
          37    -+
          31    -+
          41    -+
          45    -+
          10    -+
           1    -+
           4    -+
          33    -+
          32    -+
          23    -+
          28    -+
          25    -+
           8    -+
          11    -+
          36    -+
           7    -+
          26    -+-+
          34    -+ |
          52    -+ |
           2    -+ |
          12    -+ |
          40    -+ |
          27    -+ |
          29    -+-+
          44    -+ |
          42    -+ |
          47    -+-+
          43    -+ |
           9    ---+
          35    ---+
          46    ---+
          51    ---+-+
          48    ---+ |
          39    ---+ |
          16    -----+
          38    -----+
           3    -----+
          14    -----+
          49    ---+-+---+
          50    ---+ |   +-----+
          20    -----+   |     |
          60    ---------+     |
          55    -------+---+   |
          57    -------+   +-+ +----+
           6    -----------+ | |    |
          17    ---+         | |    |
          18    ---+         | |    |
          15    ---+-+       | |    |
          22    ---+ |       +-+    |
          19    ---+ +---+   |      +-----+
          30    ---+-+   |   |      |     |
          59    ---+ |   |   |      |     |
          21    -----+   +-+ |      |     |
          53    ---------+ +-+      |     +-----------------------+
          24    ---------+ |        |     |                       |
          58    -----------+        |     |                       |
          13    --------------------+     |                       |
          54    --------------------------+                       |
          56    --------------------------------------------------+


31-JUL-87    SPSS-X RELEASE 2.2+ FOR VAX/VMS
10:24:29     THE POLYTECHNIC OF WALES             DEC VAX-8600    VMS V4.5

* * * * * * * * * * * * * * * * * * * H I E R A R C H I C A L   C L U S T E R   A N A L Y S I S *
```

Fig 70

```
ARTHUR, VER 7-1-79  KAPR                                                              26-A UG-8     16:1 5:51          8.500

                        JUNE DATA

I-M PRIN... YOU WANT COMPONENTS, WELL I-M THEIR PRINCIPAL.

NIN        31  CREATED IN WEIG      NPAT   60     NTEST     0     NVAR  14    NCAT  6    IFER 0    N -999    XLF 0.000  XHF 0.000

NOUTV      32  OUTPUT UNIT FOR PRINCIPAL COMPONENTS.

NPNT        1
NPCH        0

NVEC       14  MAXIMUM NUMBER OF EIGENVALUES/VECTORS EXTRACTED.

   EIGENVALUE   VAR. PRESERVED ********************************************FACTORS*********************************************
                  EACH  TOTAL

    1  7.327E+05   55.4    55.4 -4.097E-02 -4.400E-01 -2.276E-01 -5.871E-01 -7.596E-02 -4.641E-01 -2.724E-02 -1.509E-02 -4.121E-01
                                -4.941E-02 -2.639E-02 -1.049E-02 -1.129E-01 -1.650E-02

    2  2.963E+05   22.4    77.8 -2.112E-02 -2.879E-01  1.890E-01 -6.177E-01  8.353E-02  4.684E-01 -1.068E-02 -2.326E-02  5.094E-01
                                 5.244E-02  2.048E-02  9.268E-03  9.850E-02 -7.138E-03

    3  1.854E+05   14.0    91.8  5.643E-02  4.788E-01 -6.085E-01 -2.922E-01  7.397E-03  4.760E-01  1.482E-02  3.949E-03 -2.712E-01
                                -4.083E-02 -4.820E-02 -1.849E-02 -8.426E-02 -5.670E-03

    4  5.321E+04    4.0    95.8  8.310E-02  6.283E-01  4.635E-01 -4.103E-01 -2.983E-02 -2.968E-01 -3.462E-02 -9.872E-03 -9.859E-02
                                -1.613E-02 -2.664E-03  3.069E-02  3.372E-01 -1.667E-02

    5  3.119E+04    2.4    98.1  1.914E-02 -2.121E-01  4.872E-01  5.926E-02  1.592E-02  4.831E-01 -1.720E-02 -2.584E-02 -6.841E-01
                                 6.861E-02 -7.281E-02 -1.286E-02  2.188E-02  2.385E-02

    6  1.485E+04    1.1    99.3 -1.342E-01 -1.918E-01 -2.742E-01  1.144E-01 -1.153E-01  4.796E-02 -6.186E-03 -5.082E-03 -7.118E-02
                                -3.979E-02 -1.736E-02  3.688E-02  9.125E-01  1.826E-02

    7  3.471E+03    0.3    99.5  3.279E-02 -1.422E-02 -6.446E-02  7.834E-04  8.892E-01 -1.074E-01  2.208E-01  7.614E-02 -5.528E-02
                                 2.228E-01 -2.420E-01  1.303E-01  9.777E-02 -6.386E-08

    8  3.180E+03    0.2    99.8  7.684E-01 -9.424E-02 -7.423E-02  1.814E-02  7.644E-02 -8.913E-03 -1.028E-01 -3.385E-02 -4.191E-02
                                 1.919E-01  5.699E-01  6.826E-02  9.160E-02 -2.637E-02

    9  1.205E+03    0.1    99.9  4.774E-01 -6.210E-02 -2.354E-02  4.087E-02 -6.191E-02 -1.054E-02 -4.845E-01 -5.695E-02  8.562E-02
                                -1.239E-01 -7.046E-01  5.368E-02  2.062E-02 -4.066E-02

   10  6.490E+02    0.0    99.9 -3.497E-01  6.358E-02 -4.813E-02  1.390E-02  1.988E-01 -2.380E-02 -7.251E-01 -3.557E-01 -2.496E-02
                                 3.545E-01  1.931E-01 -1.164E-01 -1.371E-02  3.925E-02

   11  6.210E+02    0.0   100.0 -5.609E-02 -2.300E-02  4.660E-02  1.988E-02  3.424E-01  4.161E-02 -2.509E-01  2.436E-03 -3.242E-02
                                -8.565E-01  2.607E-01  9.098E-02 -1.732E-04 -3.133E-02

   12  3.122E+02    0.0   100.0 -4.582E-02 -4.142E-03  3.690E-03  2.600E-02 -5.617E-03  1.619E-02  4.478E-02 -1.343E-01 -1.183E-02
                                 2.791E-02  2.965E-03  1.393E-02  7.786E-03 -9.878E-01

   13  2.107E+02    0.0   100.0  1.473E-01 -1.023E-02  3.194E-03  1.097E-02  8.661E-02 -2.580E-02  2.864E-01 -6.580E-01  2.055E-02
                                -1.556E-01 -7.234E-02 -6.451E-01  4.755E-02  8.147E-02

   14  1.120E+02    0.0   100.0  2.578E-02 -8.953E-03  8.672E-03 -8.606E-03  9.012E-02 -6.681E-03 -1.751E-01  6.409E-01 -2.364E-03
                                 2.189E-02  2.609E-02 -7.309E-01  5.264E-02 -1.062E-01

 FEATURE    NAME      COMMUNALITY
```

Fig 71

```
CORRELATION MATRIX

       PROPERTY CORRELATION        ******************************INTER-FEATURE CORRELATIONS*******************************

FEATURE      LO----COR----HI  OPROB   J    LO----COR----HI  OPROB   J    LO----COR----HI  OPROB   J    LO----COR----HI  OPROB

 1   1     -0.093 0.170 0.411(0.195(

 2   2      0.582 0.731 0.832(0.000(    1 -0.173 0.089 0.340(0.497)

 3   3     -0.065 0.197 0.434(0.132(    1  0.394 0.593 0.738(0.000)   2 -0.259 0.010 0.259(1.000)

 4   4      0.383 0.584 0.732(0.000(    1  0.216 0.449 0.635(0.000)   2  0.279 0.501 0.673(0.000)   3  0.199 0.436 0.624(0.001)

 5   5     -0.331-0.079 0.183(0.547(    1  0.324 0.538 0.699(0.000)   2 -0.395-0.152 0.112(0.247)   3  0.043 0.299 0.518(0.020)
                 4  0.018 0.276 0.499(0.033)

 6   6     -0.562-0.354-0.105(0.005(    1 -0.521-0.303-0.048(0.019)   2 -0.552-0.342-0.091(0.007)   3 -0.237 0.023 0.280(0.860)
                 4 -0.593-0.395-0.152(0.002)   5 -0.526-0.309-0.054(0.016)

 7   7     -0.343-0.092 0.171(0.484(    1 -0.440-0.205 0.057(0.116)   2 -0.211 0.050 0.305(0.702)   3 -0.474-0.245 0.015(0.059)
                 4 -0.036 0.225 0.457(0.084)   5 -0.124 0.140 0.385(0.287)   6 -0.407-0.165 0.098(0.207)

 8   8     -0.603-0.408-0.167(0.001(    1 -0.573-0.369-0.122(0.004)   2 -0.446-0.211 0.050(0.105)   3 -0.396-0.153 0.111(0.245)
                 4 -0.567-0.361-0.112(0.005)   5 -0.309-0.054 0.207(0.679)   6  0.333 0.545 0.705(0.000)
                 7  0.127 0.373 0.577(0.003)

 9   9     -0.554-0.344-0.094(0.007(    1 -0.407-0.165 0.098(0.206)   2 -0.362-0.114 0.149(0.386)   3 -0.504-0.281-0.024(0.029)
                 4 -0.357-0.108 0.155(0.409)   5 -0.070 0.193 0.430(0.141)   6 -0.131 0.132 0.378(0.315)
                 7  0.342 0.552 0.710(0.000)   8  0.378 0.580 0.729(0.000)

10  10     -0.157 0.107 0.356(0.418(    1 -0.049 0.213 0.447(0.103)   2 -0.411-0.171 0.092(0.192)   3  0.171 0.412 0.606(0.001)
                 4 -0.158 0.106 0.355(0.422)   5 -0.129 0.134 0.380(0.308)   6 -0.215 0.047 0.302(0.723)
                 7 -0.216 0.045 0.300(0.733)   8 -0.215 0.046 0.302(0.726)   9 -0.321-0.068 0.195(0.607)

11  11     -0.303-0.048 0.213(0.714(    1 -0.421-0.182 0.081(0.165)   2 -0.235 0.025 0.282(0.849)   3 -0.259 0.002 0.259(1.000)
                 4 -0.477-0.248 0.011(0.056)   5 -0.393-0.149 0.114(0.255)   6  0.056 0.310 0.527(0.016)
                 7 -0.345-0.095 0.168(0.472)   8  0.009 0.267 0.492(0.039)   9 -0.306-0.051 0.211(0.698)
                10 -0.311-0.057 0.205(0.667)

12  12     -0.425-0.186 0.076(0.154(    1 -0.441-0.206 0.056(0.114)   2 -0.425-0.186 0.076(0.154)   3 -0.343-0.092 0.171(0.484)
                 4 -0.224 0.037 0.293(0.781)   5 -0.408-0.167 0.096(0.203)   6  0.195 0.432 0.622(0.001)
                 7 -0.105 0.159 0.401(0.226)   8 -0.005 0.254 0.481(0.050)   9 -0.169 0.094 0.344(0.475)
                10 -0.235 0.025 0.282(0.850)  11 -0.123 0.141 0.385(0.284)

13  13     -0.445-0.211 0.051(0.106(    1 -0.259-0.006 0.259(1.000)   2 -0.341-0.090 0.173(0.493)   3 -0.384-0.139 0.124(0.288)
                 4 -0.432-0.195 0.067(0.135)   5 -0.394-0.150 0.113(0.253)   6  0.187 0.425 0.616(0.001)
                 7 -0.403-0.161 0.102(0.218)   8 -0.032 0.229 0.460(0.079)   9  0.001 0.260 0.486(0.045)
                10 -0.393-0.150 0.114(0.254)  11 -0.108 0.155 0.398(0.236)  12  0.309 0.526 0.691(0.000)

14  14     -0.716-0.561-0.353(0.000(    1 -0.488-0.262-0.003(0.043)   2 -0.555-0.346-0.096(0.007)   3 -0.425-0.187 0.075(0.152)
                 4 -0.462-0.231 0.029(0.076)   5 -0.300-0.045 0.216(0.732)   6  0.222 0.455 0.639(0.000)
                 7  0.248 0.476 0.655(0.000)   8  0.397 0.594 0.740(0.000)   9  0.331 0.543 0.703(0.000)
                10 -0.299-0.043 0.218(0.744)  11  0.151 0.395 0.593(0.002)  12  0.147 0.391 0.590(0.002)
                13  0.047 0.302 0.520(0.019)

METHOD CORR REQUIRED     224 WORDS OF BLANK COMMON.
```

Fig 72

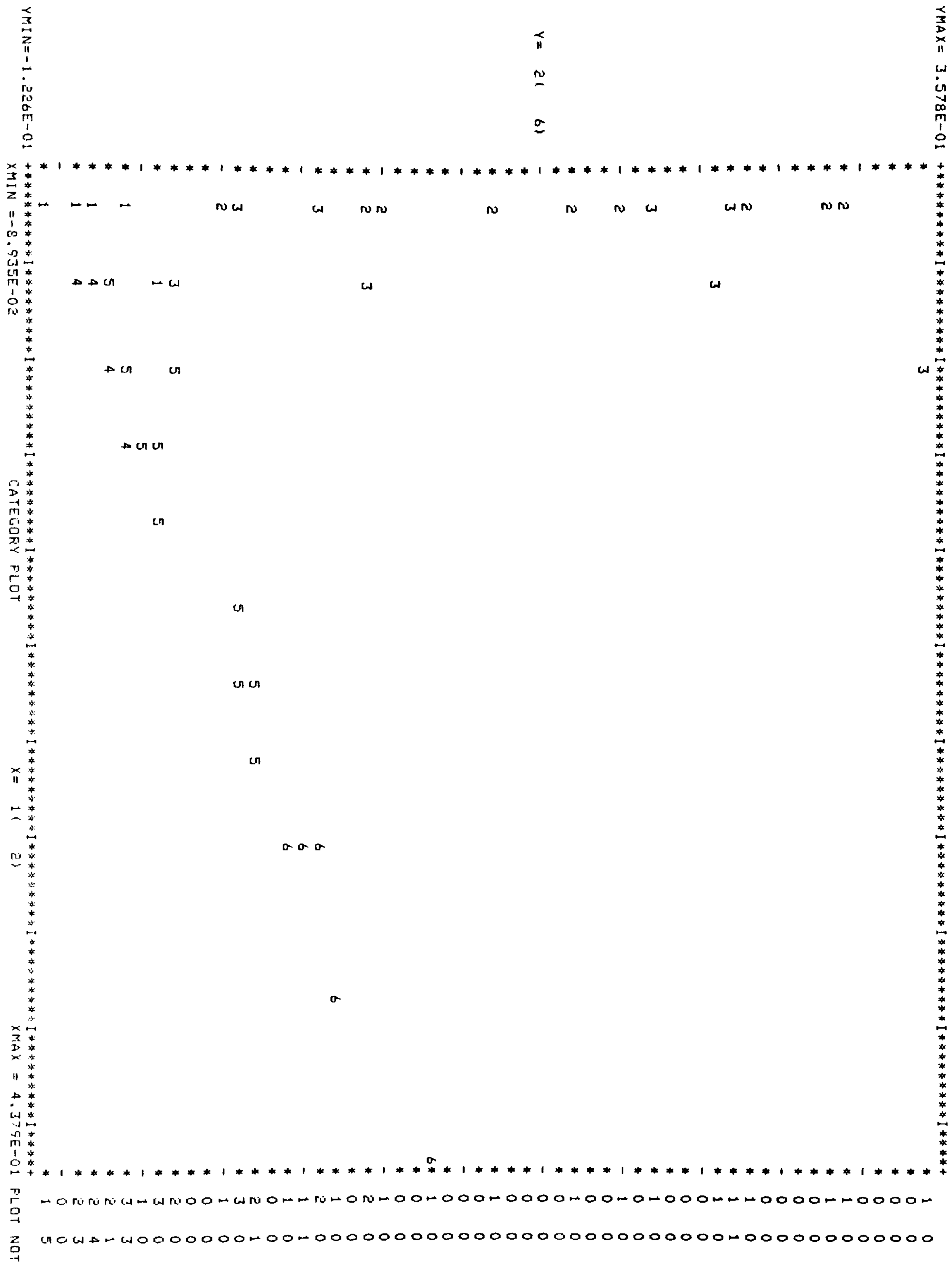

YMIN=-1.226E-01
YMAX= 3.578E-01
Y= 2(6)
XMIN =-8.935E-02
CATEGORY PLOT
X= 1(2)
XMAX = 4.379E-01

Fig 73

Dendrogram using Centroid Method

```
                         Rescaled Distance Cluster Combine

  C A S E      0         5        10        15        20        25
 Label   Seq   +---------+---------+---------+---------+---------+

           3    -+
          60    -+
          30    -+
          43    -+
          56    -+
          57    -+
          51    -+
          47    -+
          49    -+
          50    -+
          52    -+
          31    -+
          35    -+
          53    -+
          36    -+
          40    -+
          34    -+
          32    -+
          33    -+
          38    -+
          55    -+
          58    -+
          26    -+
          39    -+
          41    -+
          46    -+
          45    -+
          42    -+-----+
          54    -+     |
           4    -+     |
          24    -+     |
          18    -+     +-----------------------+
          17    -+     |                       |
          20    -+---+ |                       |
          15    -+   | |                       |
          14    -+   +-+                       |
          59    -+-+ |                         |
           1    -+ | |                         |
          28    -+ +-+                         |
          29    -+ |                           |
          16    -+ |                           |
           2    -+-+                           |
           5    -+                             |
          44    -+                             +-----------------+
          21    -+                             |                 |
          37    -+                             |                 |
          22    -+                             |                 |
          27    -+---+                         |                 |
           7    -+   |                         |                 |
           8    -+   |                         |                 |
           9    -+   +-+                       |                 |
          13    -+   | |                       |                 |
          23    -+   | |                       |                 |
          12    -+-+ | +---------+             |                 |
          25    -+ +-+ |         |             |                 |
          10    ---+   |         +-------------+                 |
          11    -------+         |                               |
           6    -----------------+                               |
          19    -------------------+-----------------------------+
          48    -------------------+
```

31-JUL-87 SPSS-X RELEASE 2.2+ FOR VAX/VMS
10:45:36 THE POLYTECHNIC OF WALES DEC VAX-8600 VMS V4.5

* H I E R A R C H I C A L C L U S T E R A N A L Y S I S *

Fig 74

Dendrogram using Median Method

```
                        Rescaled Distance Cluster Combine

 C A S E  0         5        10        15        20        25
Label Seq +---------+---------+---------+---------+---------+

        3  -+
       60  -+
       30  -+
       43  -+
       47  -+
       49  -+
       50  -+
       52  -+
       56  -+
       57  -+
       51  -+
       31  -+
       35  -+
       53  -+
       55  -+
       58  -+
       36  -+
       40  -+
       34  -+
       32  -+
       33  -+
       39  -+
       38  -+
       26  -+
       41  -+
       46  -+
       45  -+---+
       42  -+   |
       54  -+   |
        4  -+   |
       24  -+   +-----------------------------+
       18  -+   |                             |
       14  -+   |                             |
       59  -+   |                             |
        1  -+   |                             |
       28  -+---+                             |
       29  -+                                 |
       16  -+                                 |
        2  -+                                 |
        5  -+                                 |
       44  -+                                 |
       37  -+                                 |
       21  -+                                 +-------------+
       17  -+                                 |             |
       20  -+-+                               |             |
       15  -+ +-----+                         |             |
       11  ---+     |                         |             |
       22  -+       |                         |             |
       27  -+-+     +---+                     |             |
        7  -+ |     |   |                     |             |
        8  -+ |     |   |                     |             |
        9  -+ +-----+   |                     |             |
       13  -+ |         +---------+           |             |
       23  -+ |         |         |           |             |
       12  -+-+         |         |           |             |
       25  -+ |         |         +-----------+             |
       10  ---+         |         |                         |
       48  -------------+         |                         |
       19  -----------------------+                         |
        6  -------------------------------------------------+
```

31-JUL-87 SPSS-X RELEASE 2.2+ FOR VAX/VMS
10:45:36 THE POLYTECHNIC OF WALES DEC VAX-8600 VMS V4.5

* * * * * * * * * * * * * * * * * * * H I E R A R C H I C A L C L U S T E R A N A L Y S I S *

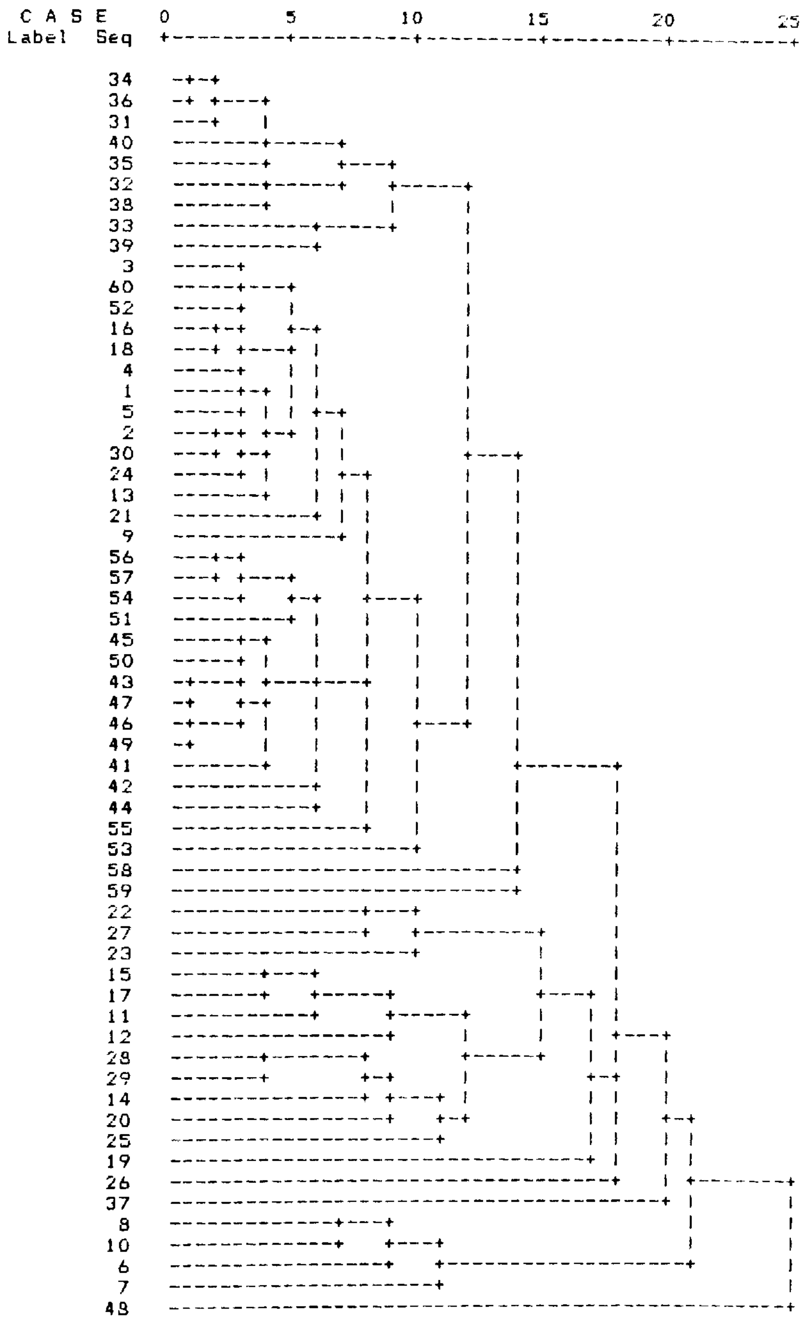
Fig 75

```
Dendrogram using Complete Linkage

                           Rescaled Distance Cluster Combine

  C A S E    0         5        10        15        20        25
 Label  Seq  +---------+---------+---------+---------+---------+

         34   -+-+
         36   -+ +-+
         31   ---+ +---+
         40   -----+   +---+
         32   -----+---+   +-----+
         38   -----+       |     |
         33   -------+-----+     +-----------+
         39   -------+           |           |
         37   -------------------+           |
         44   ---------+---------------+     +-----------------+
         59   ---------+               |     |                 |
         55   ---------+---------+     |     |                 |
         58   ---------+         |     +-----+                 |
          3   ---+-+             |     |                       |
         60   ---+ +-----+       |     |                       |
         35   -----+     +---+   +-----+                       |
         53   -----------+   |   |                             |
         43   -+---+         |   |                             |
         47   -+   +-+       |   |                             |
         52   -----+ |       +---+                             |
         56   -+-+   +-----+ |                                 |
         57   -+ +---+     | |                                 |
         54   ---+   |     | |                                 |
         51   -------+     +-+                                 |
         45   ---+-+       |                                   |
         50   ---+ +---+   |                                   |
         46   -+---+   |   |                                   |
         49   -+   |   +---+                                   |
         41   -----+   |                                       |
         42   ---------+                                       |
         15   -----+---+                                       |
         17   -----+   +---+                                   |
         11   ---------+   +-------+                           |
         12   -------------+       +-----------+               |
         19   ---------------------+           |               |
         28   ---+-----+                       |               |
         29   ---+     +---+                   |               |
         14   ---------+   +-+                 |               |
         20   -------------+ +---------+       |               |
         25   ---------------+         |       |               |
          1   ---+-+                   |       +---------+     |
          5   ---+ +-+                 |       |         |     |
         13   -----+ +---+             |       |         |     |
          9   -------+   |             +-+     |         |     |
          2   -+-+       |             | |     |         |     |
         30   -+ +-+     +---------+   | |     |         |     |
         24   ---+ +-+   |         |   | |     |         |     |
         16   -+-+ | |   |         |   | |     |         |     |
         18   -+ +-+ +---+         +---+ +-----+         |     |
          4   ---+   |             |     |               +-----+
         21   -------+             |     |               |
         22   ---------+---+       |     |               |
         27   ---------+   +-------+     |               |
         23   -------------+             |               |
         26   ---------------------------+               |
          8   ---------+-+                               |
         10   ---------+ +---+                           |
          6   -----------+   +---------------------+     |
          7   ---------------+                     +-----+
         48   -------------------------------------+
```


Fig 76

Dendrogram using Average Linkage (Between Groups)

Rescaled Distance Cluster Combine




```
31-JUL-87   SPSS-X RELEASE 2.2+ FOR VAX/VMS
10:33:55    THE POLYTECHNIC OF WALES            DEC VAX-8600    VMS V4.5

* * * * * * * * * * * * * * * * * * * * H I E R A R C H I C A L   C L U S T E R   A N A L Y S I S * * * *
```

Fig 77

Dendrogram using Ward Method

```
                         Rescaled Distance Cluster Combine

  C A S E     0         5        10        15        20        25
  Label  Seq  +---------+---------+---------+---------+---------+

           3   -+
          60   -+
          30   -+
          43   -+
          47   -+
          53   -+
          36   -+
          40   -+
          34   -+
          26   -+
          56   -+
          57   -+
          51   -+
          55   -+
          58   -+
          49   -+
          50   -+
          52   -+
          31   -+
          35   -+
          38   -+
          32   -+---+
          33   -+   |
          39   -+   |
           4   -+   |
          24   -+   |
          18   -+   |
          41   -+   |
          46   -+   +-------------------------------------------+
          45   -+   |                                           |
          42   -+   |                                           |
          54   -+   |                                           |
           2   -+   |                                           |
           5   -+   |                                           |
          44   -+   |                                           |
          21   -+---+                                           |
          37   -+                                               |
          22   -+                                               |
          27   -+-----+                                         |
           7   -+     |                                         |
           8   -+     |                                         |
           9   -+     |                                         |
          13   -+     +-----------+                             |
          23   -+     |           |                             |
          12   -+     |           |                             |
          25   -+-+   |           |                             |
          10   -+ +---+           |                             |
           6   ---+               |                             |
          14   -+                 +-----------------------------+
          59   -+-+               |
           1   -+ |               |
          28   -+ +---------+     |
          29   -+ |         |     |
          16   -+-+         |     |
          17   -+           +-----+
          20   -+           |
          15   -+           |
          11   ---+-+       |
          48   ---+ +-------+
          19   -----+
```

31-JUL-87   SPSS-X RELEASE 2.2+ FOR VAX/VMS
10:45:37   THE POLYTECHNIC OF WALES   DEC VAX-8600   VMS V4.5

Fig 78

```
I-M PRIN... YOU WANT COMPONENTS, WELL I-M THEIR PRINCIPAL.

NIN       31  CREATED IN WEIG     NPAT   60     NTEST    0     NVAR  17    NCAT  6    IFER 0    N -999    XLF 0.000  XHF 0.000

NOUTV     32  OUTPUT UNIT FOR PRINCIPAL COMPONENTS.

NPNT       1
NPCH       0

NVEC      17  MAXIMUM NUMBER OF EIGENVALUES/VECTORS EXTRACTED.

   EIGENVALUE   VAR. PRESERVED ********************************************FACTORS********************************************
                  EACH   TOTAL

 1  2.976E+06    82.1    82.1 -2.712E-01 -1.570E-02 -1.243E-02 -2.137E-02 -1.179E-01 -1.053E-03 -9.473E-01 -3.225E-02 -1.105E-01
                              -8.567E-03 -5.033E-04 -1.837E-04 -1.170E-03 -8.044E-04 -3.092E-02 -1.462E-04 -2.113E-03

 2  4.116E+05    11.4    93.4 -6.982E-01 -1.025E-01 -7.456E-02 -1.498E-01 -3.349E-01 -1.388E-02  3.118E-01 -1.038E-01 -4.968E-01
                              -2.574E-02 -2.106E-03 -3.257E-03 -1.749E-02 -9.371E-03 -7.379E-02 -1.833E-03 -1.861E-02

 3  1.076E+05     3.0    96.4  6.575E-01 -1.164E-01 -9.806E-02 -1.626E-01 -3.834E-01 -3.722E-02 -6.085E-02 -1.457E-01 -5.847E-01
                              -2.601E-02 -3.650E-03 -7.188E-03 -1.813E-02 -2.687E-02  2.460E-02 -3.479E-03 -2.515E-02

 4  7.518E+04     2.1    98.5 -3.000E-02  2.418E-01  1.592E-01  2.720E-01  5.838E-01 -5.332E-02 -2.188E-02  2.214E-01 -6.097E-01
                               7.488E-02 -7.182E-03 -1.232E-02  5.341E-02 -1.860E-02  2.594E-01 -7.219E-03  5.168E-03

 5  3.102E+04     0.9    99.3  6.076E-02 -2.145E-01 -1.120E-01 -1.081E-01  3.346E-01 -2.850E-02 -1.468E-02  2.333E-01 -1.383E-01
                              -1.147E-01 -3.817E-03 -6.369E-03 -1.249E-01 -5.626E-02 -8.412E-01 -4.000E-03  6.555E-03

 6  1.496E+04     0.4    99.7 -3.399E-02 -3.552E-01 -3.329E-01 -6.803E-01  3.768E-01  8.497E-04 -3.033E-02  8.316E-02  2.871E-02
                               2.214E-02 -6.680E-04 -5.821E-04  2.525E-02  9.662E-03  3.807E-01  8.637E-04 -4.797E-02

 7  6.407E+03     0.2    99.9 -8.845E-03  1.341E-02  1.724E-02 -6.059E-03  3.508E-01 -1.432E-02 -4.118E-03 -9.156E-01 -2.703E-02
                               1.336E-01  1.021E-03 -3.782E-03 -7.830E-03 -6.106E-03 -1.313E-01 -3.183E-03  4.255E-02

 8  1.079E+03     0.0   100.0  2.130E-02 -3.664E-02  1.244E-01 -7.275E-02  1.438E-02  7.770E-01 -4.931E-04  2.669E-02 -7.914E-02
                               6.450E-02  5.912E-02  1.172E-01  3.223E-02  4.391E-01 -3.784E-02  4.636E-02  3.843E-01

 9  6.363E+02     0.0   100.0 -1.310E-02 -7.924E-02 -3.828E-01  3.012E-01  7.929E-02  6.013E-02  1.517E-03 -1.169E-01 -1.222E-02
                              -8.332E-01  2.747E-02  1.879E-02  3.348E-02  7.119E-02  1.350E-01  9.397E-03  1.130E-01

10  2.731E+02     0.0   100.0  1.834E-03  3.235E-01 -8.987E-03 -2.425E-01 -2.932E-02 -4.951E-01  9.629E-04  3.041E-02  1.272E-02
                              -4.826E-02  3.377E-02 -4.332E-02 -1.438E-01  2.744E-01 -2.363E-02  5.381E-02  6.962E-01

11  2.147E+02     0.0   100.0  3.165E-03 -2.881E-01  1.366E-01  1.294E-01  1.891E-02 -2.992E-01 -1.508E-03 -1.099E-02 -8.603E-03
                               1.022E-02 -9.123E-02  7.182E-03 -4.959E-02  8.096E-01  4.412E-03 -9.660E-03 -3.535E-01

12  1.947E+02     0.0   100.0  1.392E-02  6.163E-01  2.104E-01 -4.574E-01  1.735E-02  1.212E-01  1.003E-04 -3.862E-02 -1.790E-03
                              -3.687E-01 -1.378E-01  4.597E-03  7.202E-02  1.171E-01 -1.037E-01 -1.723E-02 -4.064E-01

13  1.541E+02     0.0   100.0  2.816E-03  3.871E-01 -7.694E-01  1.359E-01 -2.879E-02  5.450E-02  2.678E-03  3.406E-02 -4.123E-03
                               3.502E-01 -9.515E-02  9.709E-02  1.231E-01  2.009E-01 -9.806E-02  1.001E-01 -1.362E-01

14  7.996E+01     0.0   100.0 -8.261E-04  8.072E-03 -5.224E-02  2.458E-02 -2.552E-03  1.290E-01 -1.480E-04  9.523E-04  3.346E-03
                               1.995E-02 -1.059E-01 -9.586E-01 -6.622E-02  4.772E-02  6.642E-03  2.066E-01 -5.721E-03

15  5.986E+01     0.0   100.0 -8.654E-03  6.223E-02 -5.450E-02  4.138E-02  1.374E-02  1.224E-01 -2.968E-03 -9.973E-03  3.790E-04
                               8.850E-03 -2.448E-01  1.312E-01 -9.305E-01 -5.140E-02  1.234E-01  9.243E-02 -8.134E-02

16  5.026E+01     0.0   100.0  8.246E-04 -1.084E-01  1.139E-01 -3.629E-04  3.107E-03 -5.292E-02  5.414E-04 -4.467E-03 -2.159E-03
                              -3.916E-02 -4.778E-01  1.925E-01  2.100E-01 -8.355E-02 -8.184E-03  8.067E-01  6.055E-02

17  4.353E+01     0.0   100.0  6.132E-04  6.556E-02  8.915E-03 -2.633E-02  8.766E-03 -2.290E-02 -8.242E-04 -5.236E-03 -6.800E-03
                              -1.290E-02  8.116E-01  3.326E-02 -1.423E-01  2.962E-02  2.543E-03  5.314E-01 -1.753E-01

FEATURE   NAME     COMMUNALITY
```

Fig 79

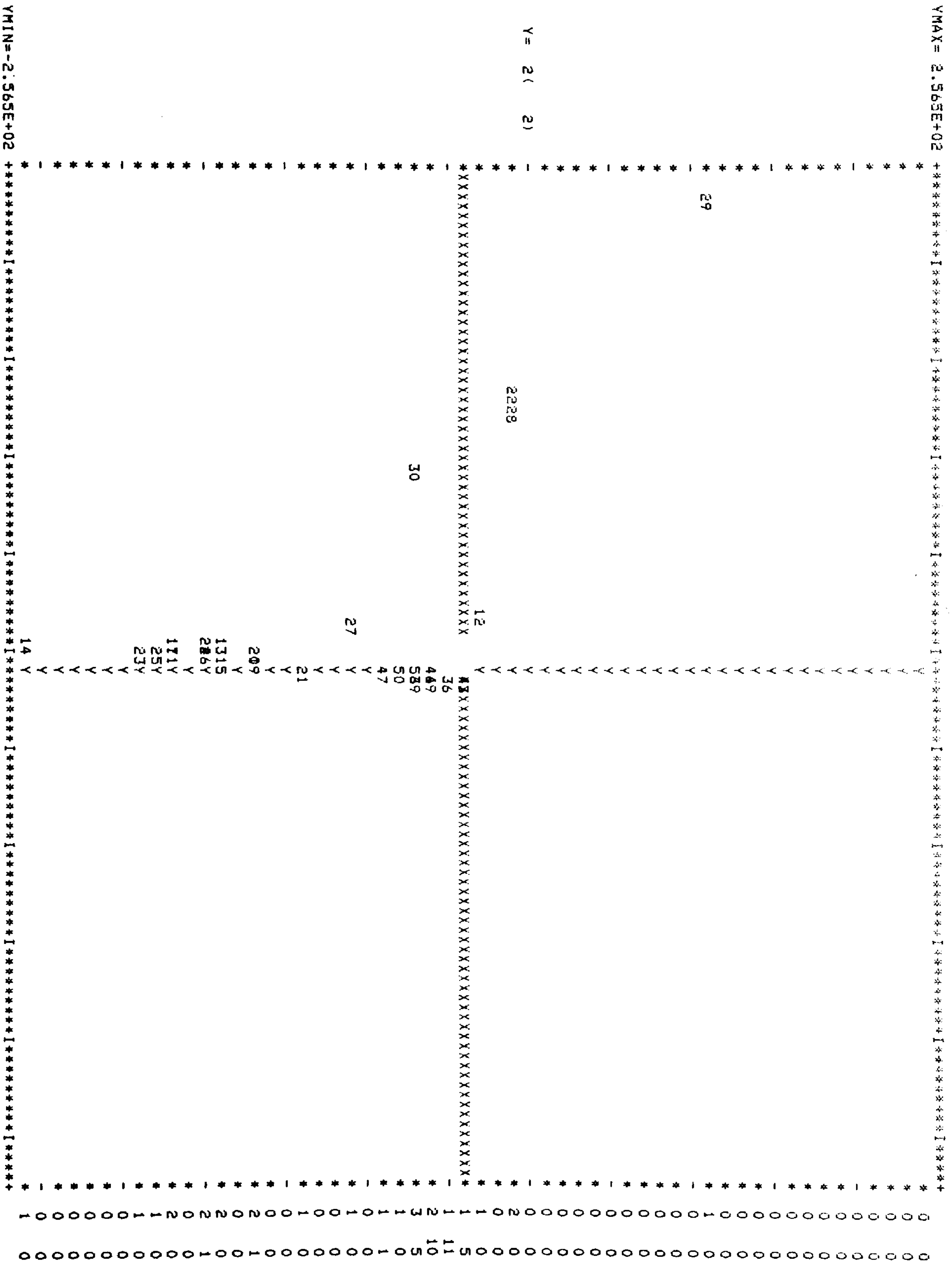

YMAX= 2.565E+02
YMIN=-2.565E+02
Y= 2(2)
XMIN =-1.232E+03
INDEX PLOT
X= 1(1)
XMAX = 1.232E+03 PLOT NOT

Fig 80

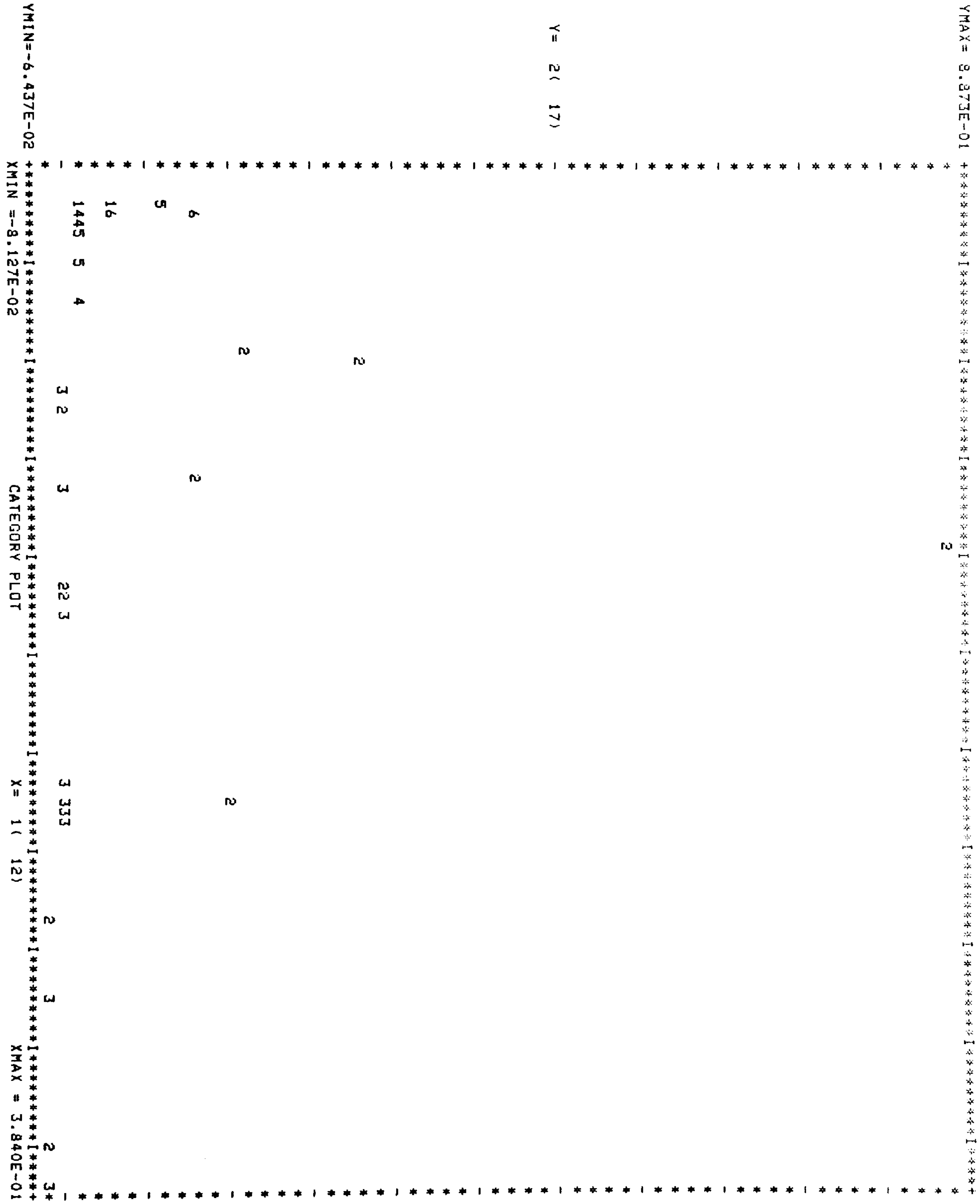
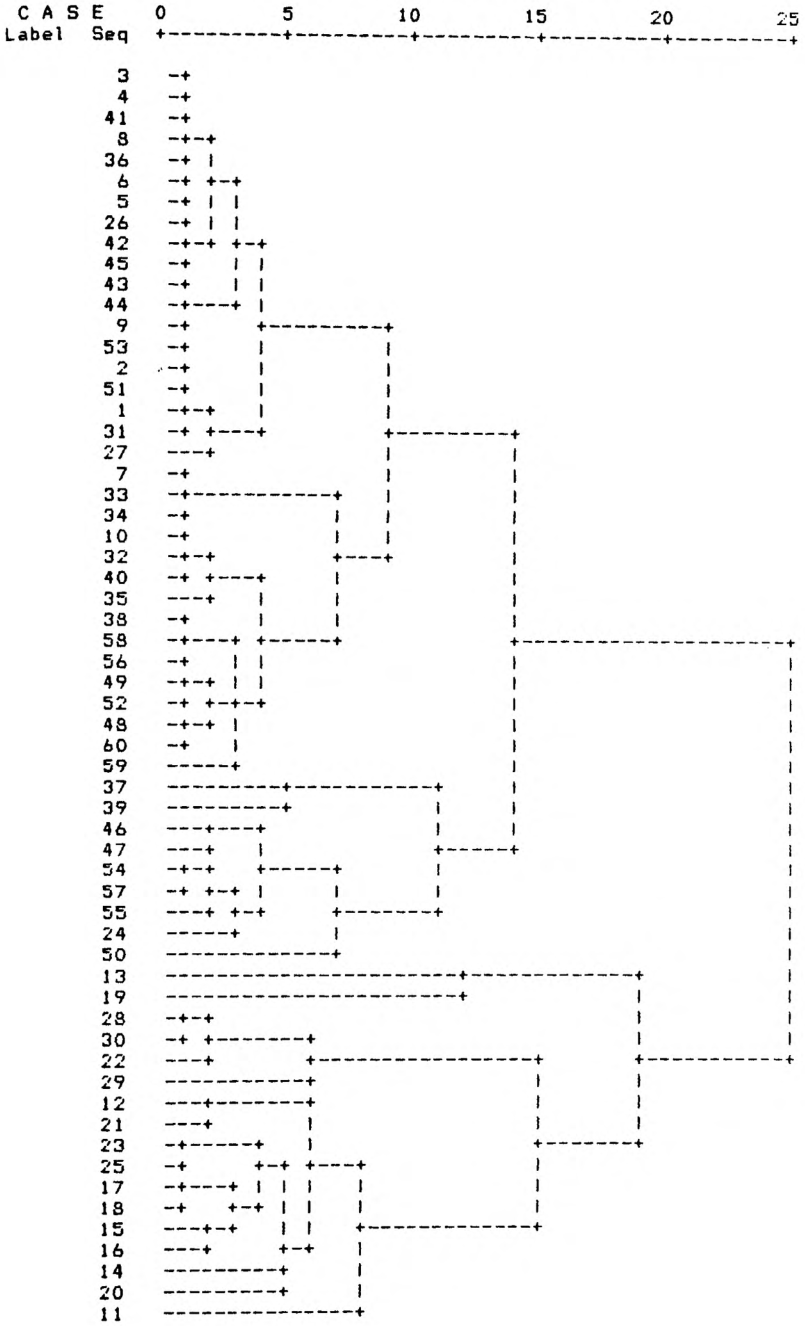

YMAX= 8.873E-01
YMIN=-6.437E-02
Y= 2(17)
XMIN =-8.127E-02
XMAX = 3.840E-01
CATEGORY PLOT
X= 1(12)
PLOT NOT

Fig 81

Dendrogram using Ward Method

Rescaled Distance Cluster Combine



29-JUL-87 SPSS-X RELEASE 2.2+ FOR VAX/VMS
11:11:38 THE POLYTECHNIC OF WALES DEC VAX-8600 VMS V4.5

PRECEDING TASK REQUIRED 1.05 SECONDS CPU TIME; 1.78 SECONDS ELAPSED.

Fig 82

```
Dendrogram using Single Linkage

                         Rescaled Distance Cluster Combine

    C A S E      0         5        10        15        20        25
  Label  Seq     +---------+---------+---------+---------+---------+

           2      -+
          51      -+
           8      -+
          36      -+
           5      -+
           1      -+
          38      -+
          42      -+
          45      -+
          44      -+
           3      -+
          41      -+
          31      -+
          32      -+-+
          10      -+ |
           4      -+ |
          53      ---+
           7      ---+
           9      ---+
          48      ---+
          35      ---+
          40      ---+
          34      ---+
          33      ---+
          43      ---+
          52      ---+
          26      ---+-+
           6      ---+ |
          49      ---+ |
          60      -----+
          59      -----+
          47      -----+
          23      -----+
          56      ---+-+
          58      ---+ |
          46      -----+
          57      -----+
          55      -----+-+
          54      -----+ |
          50      -----+ |
          37      -------+
          14      -----+-+
          16      -----+ +-+
          25      -------+ +-+
          24      -------+ | |
          39      ---------+ |
          27      -----------+---+
          22      ---+-----+ |   |
          28      ---+     +-+   |
          30      ---------+     |
          12      -----------+---+-+
          21      -----------+   | |
          17      -------+-------+ |
          18      -------+       | |
          20      ---------------+ +-------------------------+
          15      -----------------+                         +-+
          29      -----------------+                         | +-+
          13      -------------------------------------------+ | |
          11      ---------------------------------------------+ |
          19      -----------------------------------------------+


31-JUL-87    SPSS-X RELEASE 2.2+ FOR VAX/VMS
10:20:12     THE POLYTECHNIC OF WALES           DEC VAX-8600    VMS V4.5

* * * * * * * * * * * * * * * * * * * * H I E R A R C H I C A L   C L U S T E R   A N A L Y S
```

Fig 83

ARTHUR, VER 7-1-79 KAPR 26-A UG-8 1610 9:07 10.250

NOVEMBER DATA

I-M PRIN... YOU WANT COMPONENTS, WELL I-M THEIR PRINCIPAL.

NIN ' 31 CREATED IN WEIG NPAT 60 NTEST 0 NVAR 11 NCAT 6 IFER 0 N -999 XLF 0.000 XHF 0.000

NOUTV 32 OUTPUT UNIT FOR PRINCIPAL COMPONENTS.

NPNT 1
NPCH 0

NVEC 11 MAXIMUM NUMBER OF EIGENVALUES/VECTORS EXTRACTED.

	EIGENVALUE	VAR. PRESERVED EACH	VAR. PRESERVED TOTAL	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11
1	1.816E+05	88.4	88.4	9.615E-01	7.323E-02	1.728E-01	9.184E-02	1.469E-02	1.632E-01	1.828E-02	5.898E-02	2.818E-02	1.892E-02	4.505E-03
2	9.477E+03	4.6	93.0	2.045E-01	-4.184E-02	-4.462E-01	-1.026E-01	-2.906E-03	-3.511E-01	-1.976E-02	-7.828E-01	-7.703E-02	-4.318E-02	-5.013E-02
3	8.021E+03	3.9	96.9	1.622E-01	-1.125E-01	-3.125E-01	-7.887E-02	-1.226E-02	-7.303E-01	3.615E-04	5.679E-01	-1.834E-02	2.528E-03	-2.854E-02
4	3.761E+03	1.8	98.8	-7.459E-02	3.046E-01	6.080E-01	4.208E-01	6.771E-02	-5.370E-01	8.923E-02	-2.109E-01	9.183E-02	2.669E-02	1.913E-02
5	1.485E+03	0.7	99.5	2.610E-02	2.068E-01	4.049E-01	-8.503E-01	-7.438E-02	-1.325E-01	-1.408E-01	-4.101E-02	-7.869E-02	-9.026E-02	-1.033E-01
6	4.963E+02	0.2	99.7	-2.036E-02	6.526E-01	-2.047E-01	1.071E-01	1.843E-02	6.451E-02	-4.709E-02	9.873E-02	-7.059E-01	7.121E-02	2.255E-02
7	3.159E+02	0.2	99.9	1.652E-02	-6.231E-01	2.989E-01	4.896E-02	5.808E-02	-4.748E-02	1.661E-01	-4.604E-02	-6.806E-01	1.867E-04	-1.454E-01
8	8.810E+01	0.0	99.9	1.930E-02	-9.782E-02	5.316E-02	7.392E-04	-9.713E-02	-4.530E-02	-1.812E-01	-1.442E-02	-1.190E-01	-4.328E-01	8.609E-01
9	6.159E+01	0.0	100.0	2.478E-03	-4.152E-02	9.161E-03	-1.970E-01	2.014E-01	-2.940E-02	2.281E-01	-4.473E-02	6.080E-03	8.031E-01	4.679E-01
10	4.806E+01	0.0	100.0	5.370E-03	-1.388E-01	7.320E-02	1.440E-01	-1.675E-01	-3.587E-02	-8.912E-01	-2.389E-02	-4.553E-02	3.537E-01	-5.779E-02
11	3.622E+01	0.0	100.0	3.003E-03	8.436E-03	1.756E-02	3.707E-02	-9.528E-01	-1.178E-02	2.502E-01	-2.047E-02	-2.015E-02	1.624E-01	2.287E-02

FEATURE	NAME	COMMUNALITY
1	10	1.000E+00
2	1	1.000E+00
3	2	1.000E+00
4	6	1.000E+00
5	4	1.000E+00
6	7	1.000E+00
7	3	1.000E+00
8	8	1.000E+00
9	11	1.000E+00
10	5	1.000E+00
11	9	1.000E+00

Fig 84

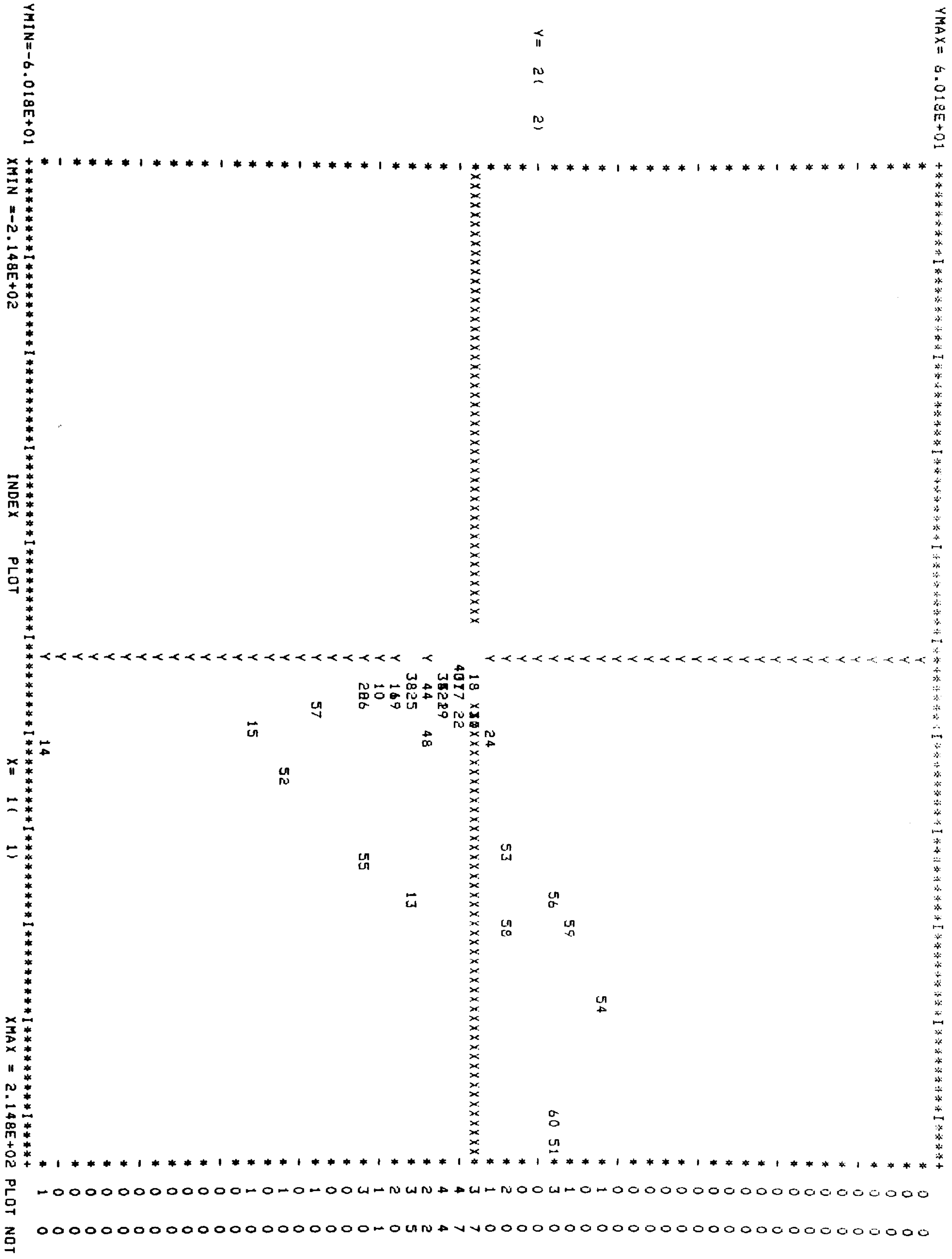

YMAX= 6.018E+01
Y= 2(2)
YMIN=-6.018E+01
XMIN =-2.148E+02
INDEX PLOT
X= 1(1)
XMAX = 2.148E+02
PLOT NOT

Fig 85

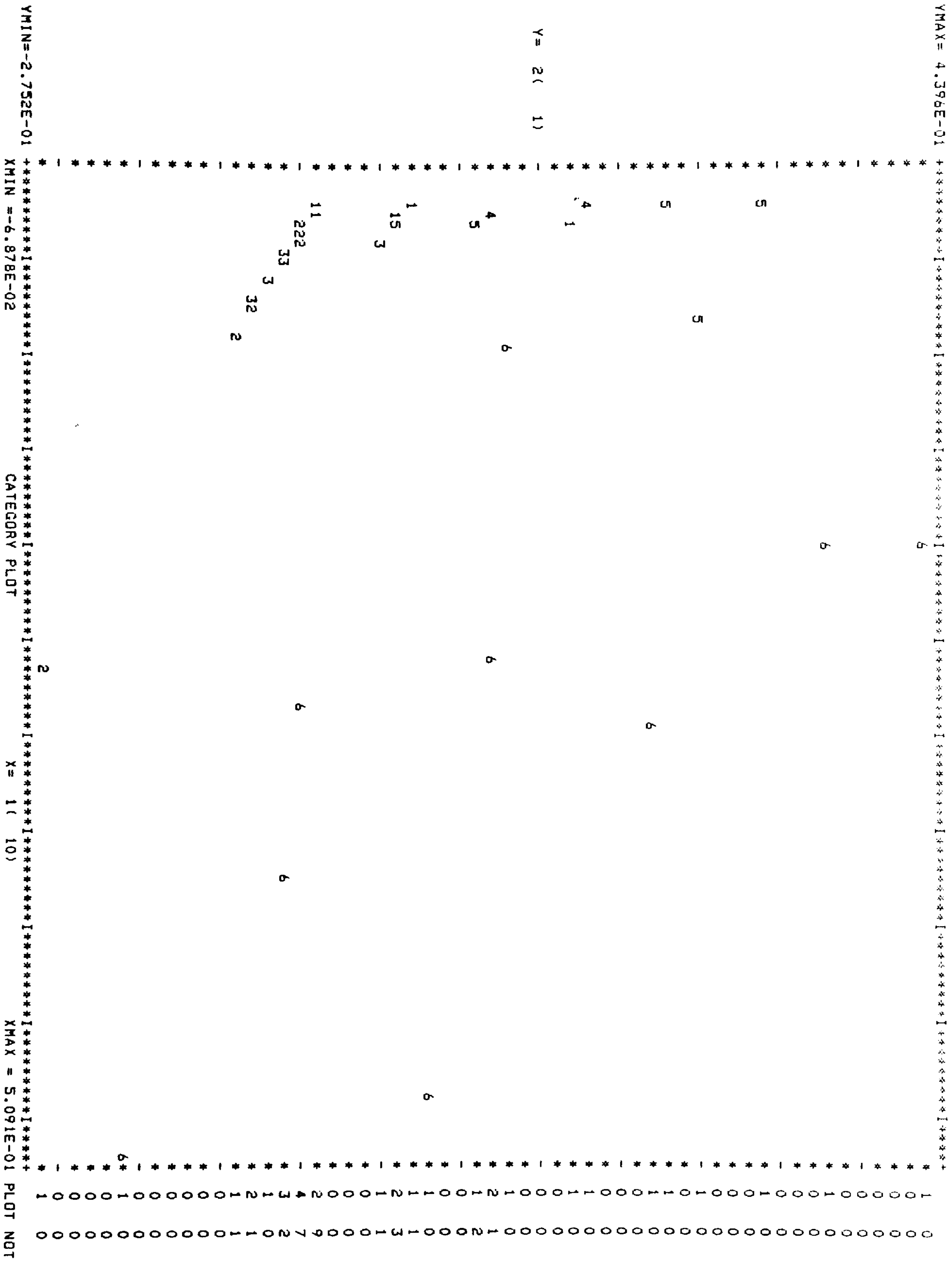
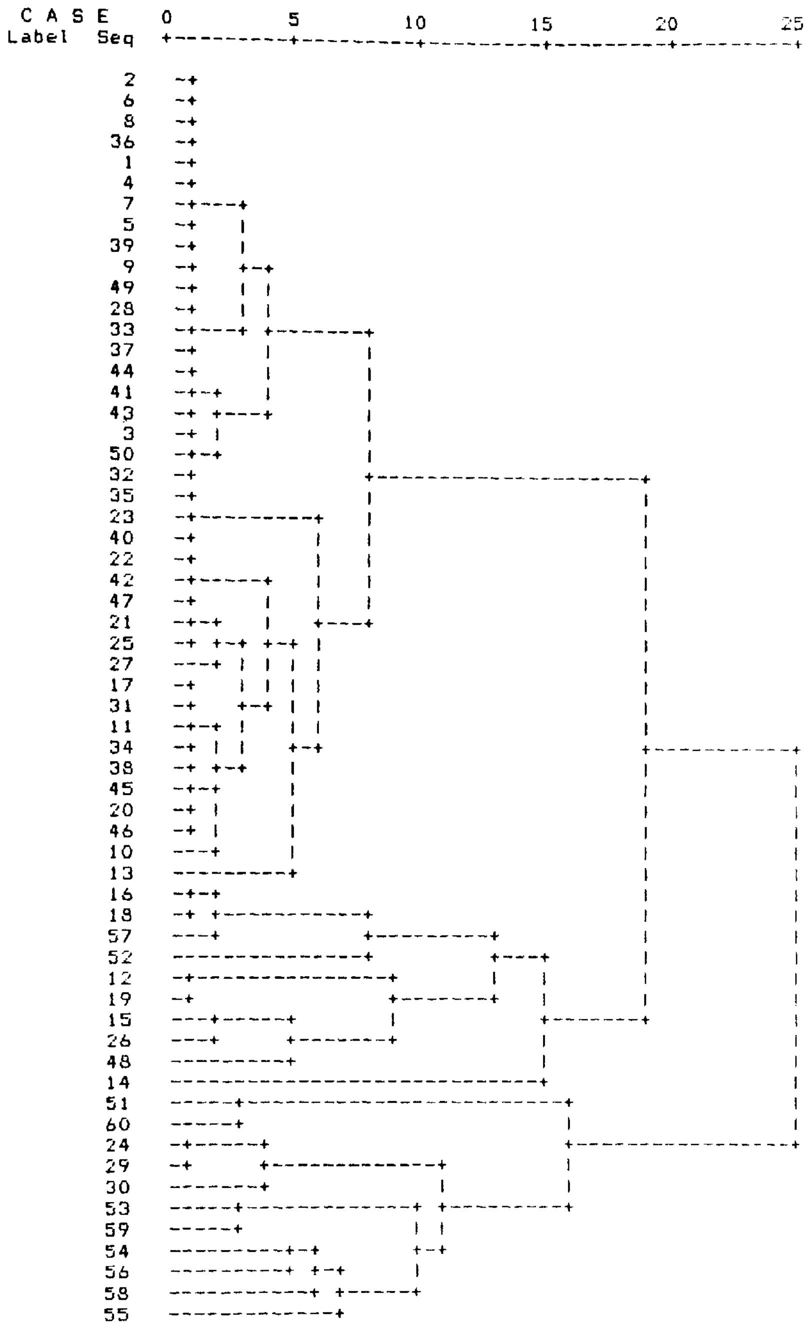

YMAX= 4.396E-01
YMIN=-2.752E-01
Y= 2(1)
XMIN =-6.878E-02
CATEGORY PLOT
X= 1(10)
XMAX = 5.091E-01
PLOT NOT

Fig 86

Dendrogram using Ward Method

Rescaled Distance Cluster Combine



29-JUL-87 SPSS-X RELEASE 2.2+ FOR VAX/VMS
10:54:54 THE POLYTECHNIC OF WALES

Fig 87

Appendix 8.

Scoring systems used for the various indices: Tables 70 - 73.

Table 70: Trent biotic index.

Table 71: Chandler score.

Table 72: BMWP score.

Table 73: WWA score.

Trent biotic index.

	number of groups present									
	0 - 1	2 - 5	6 - 10	11 - 15	16 - 20		26 - 30	31 - 35	36 - 40	41- 45
	Biotic index									
Clean										
Plecoptera >1 species	-	7	8	9	10	11	12	13	14	15
nymph present 1 species only	-	6	7	8	9	10	11	12	13	14
Ephemeroptera>1 species	-	6	7	8	9	10	11	12	13	14
nymph present 1 species only	-	5	6	7	8	9	10	11	12	13
Trichoptera>1 species	-	5	6	7	8	9	10	11	12	13
larva present 1 species only	4	4	5	6	7	8	9	10	11	12
Gammarus All above absent	3	4	5	6	7	8	9	10	11	12
Asellus present All above absent	2	3	4	5	6	7	8	9	10	11
Tubificid worms and/or red present All above absent	1	2	3	4	5	6	7	8	9	10
Polluted										
All above absent Some species such as Eristalsis may be present	0	1	2	-	-	-	-	-	-	-

Baetis rhodani excluded

Baetis rhodani included here for classification purposes.

Table 70

Chandler score.

Abundance in standard sample

Groups present in sample	present 1 - 2	few 3 - 10	common 11 - 50	abundant 51 - 100	very abundant 100+
	Points scored				
Planaria alpina Each species of Taenopteriygidae Perlidae, Perlodidae Chloroperlidae	90	94	98	99	100
Each species of Leuctridae, Capnidae Nemouridae(except Amphinemoura)	84	89	94	97	98
Each species of Ephemeroptera (except Baetis)	79	84	90	94	97
Each species of cased caddis Megaloptera	75	80	86	91	94
Each species of Ancylus	70	75	82	87	91
Each species of Rhyacophila	65	70	77	83	88
Genera Dicranota, Limnophora	60	65	72	78	84
Genus Simulium	56	61	67	73	75
Genera of Coleoptera, Nematoda	51	55	61	66	72
Amphinemoura	47	50	54	58	63
Baetis	44	46	48	50	52
Gammarus	40	40	40	40	40
Each species of uncased caddis (except Rhyacophila)	38	36	35	33	31
Each species of Tricladia (except P.alpina)	35	33	31	29	25
Genera of Hydracarina	32	30	28	25	21
Each species of Glossiphonia	26	23	20	16	13
Each species of Asellus	25	22	18	14	10

Table 71

	present 1 - 2	few 3 - 10	common 11 - 50	abundant 51 - 100	very abundant 100+
			points scored		
Each species of leech(except Glossiphonia, Haemopsis)	24	20	16	12	8
Haemopsis	23	19	15	10	7
Tubifex	22	18	13	12	9
Chironomus riparius	21	17	12	7	4
Nais	20	16	10	6	2
Each species of air breathing spcs	19	15	9	5	1
No animal life			0		

Table 71(cont)

BWMP amended score system.

Families	Score
Siphonuridae, Heptagenidae, Leptophlebidae, Ephemerellidae, Ephemeridae Taenopterygidae, Leuctridae, Capniidae, Perlodidae, Perlidae Aphelocheridae Beraeidae, Odontoceridae Leptoceridae,Goeridae,Lepidostomatidae, Brachycentridae, Sericostomidae	10
Agriidae, Cordugasteridae Psychomyiidae, Philopotamidae	8
Caenidae Nemouridae Rhyacohilidae, Polycentropidae, Limnephilidae	7
Ancylidae Hydroptilidae Gammaridae Coenagriidae	6
Mesovelidae, Hydrometridae, Notonectidae,Corixidae Halipidae, Hygrobiidae, Dytiscidae, Gyrinidae Hydrophilidae, Clambidae, Helodidae, Dryopidae, Elminthidae Chrysomelidae, Curcolinidae Hydropsychidae Tipulidae, Simulidae Planariidae, Dendroceolidae	5
Baetidae Sialidae Piscicolidae	4

Table 72

Families	Score
Valvatidae, Hydrobiidae, Lymnaeidae, Physidae, Planorbidae Sphaeridae Glossiphonidae, Hirudidae, Erpobdellidae Asellidae	3
Chironomidae	2
Oligochaeta(whole class)	1

Table 72(cont)

WWA score

Groups present	1 - 2	3 - 10	11 - 40	>40
	number of specimens			
Each sp of Taenoptrygidae, Perlidae, Perlodidae, Chloroperlidae Species Planaria alpina	85	90	95	100
Each sp of Leuctridae, Capniidae, Nemouridae(exc. Amphinemoura sulcicollis)	50	75	85	95
Each sp of Ephemeroptera(exc. Baetis rhodani and Ephemerella ignita)	46	70	80	90
Each sp of cased Trichoptera(exc. Hydroptila and Sericostoma personatum) Each sp of Rhyacophila(exc. R.dorsalis)	43	65	75	85
Family Simulidae	40	60	70	80
Each sp of Elminthidae Each family of Coleoptera larvae Genera Dicranota, Limnophora, Pedicia, Atherix, Tipula	37	55	65	75
Each sp of uncased Trichoptera(exc. H.silitalai (inc. R.dorsalis) Genus Hydroptila. Sp Ancylus Fluviatile, E.ignita, S.personatum	33	50	60	70
Sp A.sulcicollis Genus Sialis	30	45	55	65
Sp Gammarus pulex, Hydropsyche silitalai	30	40	45	50

Table 73

Groups present	Number of specimens 1 - 2	3 - 10	11 - 40	>40
Family Lumbriculidae Sp Eiseniella tetrahedra Group Hydrachnellae	30	40	40	40
Each sp of Tricladida(exc. P.alpina)	30	40	35	30
Each sp of Mollusca(exc. A.fluviatile) Sp B.rhodani	26	35	30	25
Sub-families Tanypodinae Orthocladiinae tribe - Tanytarsini	26	30	25	20
Each sp of Hirudinea Species Asellus meridianus	25	25	20	15
Sp Asellus aquaticus	20	20	15	10
Family Enchytraeidae	18	18	12	8
Family Tubificidae	15	15	10	5
Family Chironomini	13	13	9	4
Family Naididae	10	10	6	2

Table 73(cont)

Appendix 9.

Method for the determination of dissolved oxygen

Method for the determination of dissolved oxygen.

The following method was used during the 24 hour survey to determine the dissolved oxygen present at each site:

Apparatus.

6 x 250ml stoppered water sample bottles.
3 x 5ml pipettes.
teat pipette.
measuring cylinder.
50ml burette.
100ml flask.
stand.
manganous sulphate solution.
alkaline potassium iodide with azide modification solution.
N/80 sodium thiosulphate ampoules.
Starch solution.
50% sulphuric acid.

Method.

To a full 250ml stoppered bottle of the water sample add 1ml of manganous sulphate followed by 1ml of alkaline azide(These reagents should be added immediately the sample is taken).

Replace the stopper carefully so as to avoid the inclusion of air bubbles. Thouroughly mix the contents by repeated inversion and rotation. The sample at this stage with oxygen fixed may be stored for several hours before titrating.

A flocculent precipitate develops which readily settles. After settlement a second mixing is usually necessary to clarify the liquor. A white precipitate(manganous hydroxide) indicates the absence of oxygen: with rising oxygen concentrations of the sample the precipitate becomes increasingly brown(manganic hydroxide).

After the precipitate has settled add 3ml of 50% sulphuric acid. Replace the stopper quickly to avoiding loss of precipitate or introduction of air.Shake well - the precipitate dissolves lberating free iodine. Alow upto 2 minutes for even distribution throughout the bottle.

Transfer 100ml into a flask and titrate against N/80 thiosulphate until only a faint yellow colour remains. At this stage add 2ml of starch indicator and continue titration to disappearance of blue colour. Since iodine is volatile the titration should be carried out as expedentiously as possible.

Calculation.

$$\text{Dissolved oxygen(ppm)} = \frac{\text{ml N/80 thiosulphate} \times 100}{\text{ml of sample titrated}}$$

ie if 100ml of sample is titrated the titration reading in ml = DO ppm