'Some factors influencing the distribution of macro-invertebrates in the riffles of organically polluted streams'

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Summary

The literature relating to various aspects of fresh-water ecology has been reviewed. Special attention was paid to that dealing with limiting factors in fresh-water, methods of sampling bottom fauna, water pollution ecology and experimental work on fresh-water invertebrates.

The effects of sewage effluent discharges on water quality and the riffle benthic community of a number of Midlands streams were studied. The riffle community was sampled quantitatively and it was found that it was possible to relate different benthic communities to varying degrees of organic enrichment. The importance of seasonal changes in influencing distribution was observed and commented upon. Special attention was paid to the distribution of the Chironomidae in polluted waters, this group was found to be particularly abundant and different species varied in their tolerance of polluted conditions.

In the laboratory, apparatus was constructed to study the effects of some of the factors associated with organic pollution on a number of invertebrates associated with varying degrees of organic enrichment. The factors investigated were low dissolved oxygen concentrations, undissociated ammonia, dissolved carbon dioxide and potassium orthophosphate. It was found that invertebrates associated with polluted conditions were usually more tolerant of these factors than those found in good quality waters. Wherever possible the combined effect of these factors was studied and it was usually found to be more toxic.

An attempt was made to explain the distribution of the invertebrates observed from field work on the basis of the experimental results. In many cases it was found that the experimental results could explain the presence or absence of a species from a particular locality.

Notes are included on the biology of some common benthic invertebrates in relation to their use as indicators of organic pollution.

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Contents

1. Introduction

Water pollution, although a great problem of recent years, is not a feature solely of modern society. The polluting of natural waters almost certainly commenced several thousand years ago when man began living in large communities. The organic waste from many of these old cities was discharged into the neighbouring stream or river on whose banks they were built.

It was not until the 18th and 19th centuries, with the advent of the Industrial Revolution in Europe which resulted in increasing urbanisation, that the problem became really serious. The problem was realised in the 19th century and various acts were passed to try to improve the standards of the effluent. During this century increasing attention and money is being paid to the problem, but this, in most cases, is being matched by an expanding population resulting in increasing waste to be disposed of.

The earliest scientific work on pollution was almost soley chemical, mainly because chemistry was already an established science and not much was known about fresh-water biology. Interest in biological aspects of pollution probably began in Germany and the results of this early work were synthesized and published by Kolkwitz and Marsson (1908, 1909). They produced their "Saprobiensystem" for the assessment of organic pollution. They postulated that when a river receives a heavy load of organic matter the normal process of self purification would result in a series of zones, of decreasingly severe conditions, succeeding one another downstream, and each zone contains characteristic animals and plants.

Liebmann (1951) revised this system and, like Kolkwitz and Marsson, produced a list of indicator species for each of the zones.

Generally these were more carefully selected and therefore constituted a considerable advance. He also considered micro-organisms to be far more important as indicators of pollution, and as a result did not adequately consider the macro-invertebrates. Other continental workers have developed the system further and sub-divide some of the zones e.g. Sramek-Husek (1958).

In the United States workers such as Campbell (1939) and Brinley (1942) independently produced a similar system to that of the European fresh-water biologists. Other workers however had noted that pollution also influenced the distribution of macroscopic invertebrates. In Britain, Pentelow and Butcher (1938) were among the earlier workers, while later Hawkes (1956) and Hynes (1959) made similar observations. Richardson (1921, 1929) and later Gaufin and Tarzwell (1952, 1956) were also paying particular attention to macro-invertebrates with regard to pollution in the United States.

As a result of the great increase in information about pollution, it has become obvious that the same general type of succession occurs everywhere.

Water pollution has, for the sake of convenience, been divided into six kinds, depending on the type of effluent. One of the most important is organic pollution. This type of pollution is very complex and can result from a wide variety of effluents, the most widespread being sewage. An organic effluent can change the chemical composition of the river water and subsequently the biology of the stream bed, because of its complex nature it is not sure how the changes are brought about. The effluent usually brings about de-oxygenation of the water but also adds poisons such as ammonia and increases the carbon dioxide content, which can increase the effect of the de-oxygenation. It also causes silting of the stream bed.

The purpose of the present study was twofold. Firstly to investigate quantitatively the effect of various domestic organic discharges on the distribution of invertebrates with particular reference to the distribution of the Chironomidae. Secondly to try to establish the relative importance of the various chemical changes, associated with this type of pollution, in bringing about changes in the distribution of the macro-invertebrates.

The research was conducted along these two broad lines. The investigation of the effect of the organic discharges commenced with a detailed study of the River Cole. This tributary of the River Tame was studied for a period of 13 months, six stations were selected for study, one above the entry of a sewage works' effluent and five below. The species collected were identified as far as possible. The Chironomidae, which have been largely ignored in this country because of the difficulty of identification, were studied in great detail to try to establish if their distribution corresponds with the degree of pollution. Chemical samples were also taken every month to try to establish what chemical factors were likely to be important in this particular river.

Further quantitative field work was undertaken in the following two years. Where possible the rivers chosen were those in which the effluent produced very different chemical changes in the water to those in the River Cole e.g. Merry Hill Brook, Wolverhampton received an oxidised effluent and as a result very low concentrations of ammonia and very high concentrations of oxidised nitrogen, in the form of nitrates, and orthophosphates were present. The intention was to see if sewage effluents had a standard effect on the fauna.

The second line involved a laboratory study on the effects of such factors as low oxygen, high carbon dioxide and ammonia concentrations on a variety of invertebrates, ranging from species associated with gross pollution to species associated with very clean water conditions. To investigate those factors apparatus was constructed in which the water was continuously circulated and where such factors as the oxygen and carbon dioxide concentration could be automatically controlled. Wherever possible the combined effects of these factors were also studied.

2. Review of the Literature

2.1 Fresh-Water Ecology

Aquatic organisms have attracted the attention of biologists for a long time. The early work was seriously handicapped by the inability to identify the majority of the organisms living in fresh-water. It is only in the last 50 years or so, with the introduction of identification keys for most of the common groups, that a really scientific study has been possible.

Factors influencing the distribution of fauna in fresh-water

The nature of the stream-bed community is largely determined by the following interrelated factors:-

1. The speed of the current over the stream bed.
2. The physical nature of the stream bed.
3. The presence of macro-vegetation.
4. The chemical nature of the water.
5. The physical nature of the water.

The effect of each of these factors will now be considered in more detail.

1. The speed of the current

The importance of the current in determining the distribution of animals in streams has been demonstrated by many workers.

Ambuhl (1959) studied the distribution of organisms in relation to the speed of the current. He showed that animals appear to select certain current speeds in which to live. *Simulium* reaches maximum abundance at a speed of 80cm./sec., *Hydropsyche angustipennis* at 60cms./sec., whereas *Gammarus pulex* reaches its peak at 15cms./sec.

Edington (1965 and 1968) studied the distribution of net-spinning caddis larvae in relation to the water velocity. He found that some species e.g. Hydropsyche instabilis occur predominantly in rapids, while others e.g. Polycentropus flavomaculatus occur predominantly in pools. He found that larvae of Hydropsyche could detect changes in flow and redistribute themselves so as to remain in fast flow conditions.

Dorier and Vaillant (1954) tested experimentally the ability of various animals to withstand various current speeds. They found that generally the most tolerant animals in this respect were those which preferred rapids in nature, and the least tolerant were those which preferred stagnant water in nature.

Thus current is obviously an important factor in determining the distribution of animals. Animals vary in their tolerance to current; some are strong swimmers while others have special clinging structures enabling them to colonise fast reaches. On the other hand some are weak swimmers and are easily dislodged and washed away.

2. The Physical Nature of the Stream Bed

This is usually closely related to the rate of flow. Where the flow is rapid the stream bed is composed of rock or gravel, however where the flow is sluggish it allows silt to be deposited producing a bed of silt or mud. There are, of course, all types of intermediates between these extremes.

Many animals select clean stone surfaces e.g. Ecdyonurus and Rhyacophila, and are thus found where the current is fast. Others e.g. Tubificids and Chironomids are burrowers and mud dwellers so are found where the stream bed is muddy.

The distribution of fauna in relation to the nature of the stream bed has been investigated by many workers.

Percival and Whitehead (1929 and 1930) and Jones (1949 a and b) recognised various habitats based on the composition of the stream bed and then showed that each of the various biotopes had a characteristic community.

Maitland (1964) compared the invertebrate fauna of sandy and stony substrates and found striking differences in the fauna of the two habitats. Characteristic of the sandy substrates were worms, there were very few stoneflies, mayflies, leeches or Gammarus. In the stony substrates the reverse was found.

Thorup (1966) says that many European workers use Thienemann's classification, whereby he divides the stream into various biotopes based on the nature of the substratum.

The importance of the physical nature of the stream bed in influencing the distribution of animals is then widely acknowledged.

3. The Presence of Macro-Vegetation

The presence of vegetation in both the stony and silty reaches will change the nature of the habitat and the community of animals.

Percival and Whitehead (1929) on studying the various types of stream bed recognised four habitats with varying amounts and types of vegetation. They found that Gammarus abounded where the stones were covered with moss. Baetis had a similar distribution but was also found where there were dense outgrowths of Potomageton. Ecdyonurus and Agapetus however preferred stony substrates and were virtually absent where the stones were moss covered.

Harod (1964) studied the animals on four types of plant surfaces, namely, Ranunculus fluitans, Carex, Callitriche and Verronica beccabunga. It was found that several animals were present on all plants but others showed preferences for a particular plant e.g. Gammarus pulex and Hydropsyche spp. showed a distinct preference for Callitriche, Simulium ornatum dominated the populations of both Carex and Ranunculus but were hardly present elsewhere.

4. The Chemical Nature of the Water

The chemical composition of natural waters can vary greatly, 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 fresh water.

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 could possibly control the arrangement of the fauna over large areas. New Forest streams were generally acid (pH 6.0-6.5) and very hard, the Avon tributaries were more alkaline (pH 7.5-8.0). In the former the average number of animals per square foot was 68 with ten different species while in the latter it was 380 with 15 different species.

Mann (1955) studied the distribution of leeches in waters of varying hardness. He found that in soft water the most numerous leech was always *Erpobdella octoculata* while in hard waters *Helobdella stagnalis* was always the dominant type. Generally he found that leeches were more abundant in hard water.

Tucker (1958) compared sixteen ponds of varying chemical composition and concluded that the calcium concentration and the quantity of dissolved organic matter in the water are important factors in influencing the numbers of animals present. This was borne out by Reynoldson (1961) who found that there was a relationship between the distribution of *Asellus* in the Lake District and the total dissolved matter in the water.

5. The Physical Nature of the Water

The effect of temperature as an environmental factor is often difficult to assess because in stream environments it is often linked with the speed of the current and the type of bed, cooler waters usually being associated with the shallow rapids which are more common in the upper reaches of rivers.

The possible effects of temperature on the distribution of Heptagenia lateralis in Lake District streams has been studied by Macan (1963). He found that this species was abundant only in streams where the highest temperature was about 18°C or less. It was scarce or absent from all others except one.

Other known examples of animals being restricted by temperature are the flatworms, Crenobia alpina and Polycelis felina. Both are restricted to cold water, the former to below 13°C and the latter to below 17°C.

2.2 Methods of Sampling the Bottom Fauna in Stony Streams

The methods of sampling the bottom fauna have been reviewed by Macan (1958). He recognised five main methods and also outlined their disadvantages. These were:-

1. Lifting by hand of individual stones.

The main criticism of this method is that it is limited to substrata of large stones and that it is not really a quantitative technique. It is however used extensively and if the sizes of the stones are calculated it can yield comparable figures.

2. Provision of a known area of removable substratum for colonisation.

This method was used by Moon (1935) in his Windermere survey. However his technique of placing an artificial substratum, which was allowed to be colonised and then removed and the animals counted, on top of the real substratum, would seem more suited to a lake and there would be problems of bedding-down in streams. Other workers have used tiles and concrete blocks but these would be colonised only by the animals which occur on the bigger stones.

3. Boxes and cylinders. A given area is enclosed and the animals within it removed.

There are a number of different methods for enclosing a known area. Neill (1938) used a cylinder while Jonasson (1948) used a box. Generally a detachable net is attached to the back of the sampler so that organisms distributed within the cylinder are swept into it. The main problem encounted when using this type of sampler are that a fair current is needed and that the substratum should not be too stony.

4. Fixed nets. A known area upstream is disturbed and the animals dislodged from it are washed into the net.

This type of sampler is very popular in America and was extensively used by Surber (1937). His sampler consisted of two square frames at right angles. In operation one lies flat on the bottom, and this marks the area to be sampled while the other stands vertically and supports a net. Organisms that are dislodged from the sampling area are then swept into the net.

5. Nets that are pushed forward through the substratum

This type of sampler has been developed by a number of people including Percival and Whitehead (1926), and Macan (1958). In essence it is a type of shovel or scoop that is pushed through the substratum for a desired distance. The substratum removed is collected in a net behind the cutting edge. Although this type of sampler seems to give good results it does seem to be difficult to use and also the area sampled tends to be rather small.

The size of the mesh has been shown by Jonasson (1955) to be of supreme importance when dealing with samples of bottom fauna especially where accurate quantitative work is required. He found that the 0.6mm. which is commonly used is inefficient as chironomid larvae up to 10mms. can pass through. When small meshes gauges were employed the total number of individuals captured increased by 100-600%.

Maitland (1964) confirmed Jonasson's findings and found that many invertebrates are able to pass through coarse meshes of 8-16 threads/cm. and even meshes of 16-24 threads/cm. may allow a considerable proportion to pass through. It must be realised however that coarse meshes will certainly allow more samples to be taken and analysed in a given time, and that each mesh size has its uses.

To obtain a clear picture of the animals present in a particular area of stream bed Chutter and Noble (1966) calculated that 3 square feet should be sampled. They also pointed out that the variability of species counts will be reduced if the sampling areas are restricted to areas of similar physical nature.

2.3 History of Pollution Ecology

The fact that organic pollution could bring about a change in the communities living in a stream has been known for a long time. This fact was utilised by Kolkwitz and Marsson (1902, 1908, 1909) when they drew up their Saprobity system. They were among the first to study scientifically the effects of pollution on aquatic organisms, and as a result of their studies they were able to draw up their system whereby the degree of pollution of streams could be evaluated by the organisms living there. The organisms they used in their system however were mainly micro-organisms although a number of macro-organisms were included.

They recognised that rivers that have become polluted with organic matter undergo self-purification and they distinguished three main zones which they termed:-

1. Polysaprobic zone.
2. Alpha - and Beta - Mesosaprobic zone.
3. Oligosaprobic zone.

1. The Polysaprobic zone is characterised chemically by high

concentrations of complex decomposable organic matter. Oxygen is frequently absent and hydrogen sulphide is produced. The biological community is characteristic in that only a few groups are present. However those that are present are there in great numbers and of the macro-invertebrates they listed Tubifex tubifex and Eristalis tenax.

2. The Mesosaprobic zone which they sub-divided into

a) Alpha-mesosaprobic zone, this contains a high content of amino acids. Oxygen is usually present in this zone, and this can vary owing to the development of green plants especially algae. There is still a restriction of species, and the common forms were Chironomus plumosus, Sialis lutaria, Sphaerium corneum, Tubifex tubifex and Tanypus monilis.

b) Beta-mesosaprobic zone. In this zone the oxygen content is fairly high usually being more than 50% of saturation, and there is a great diversity of plants and animals. Gammarus fluviatilis, Asellus aquaticus, Hydropsyche angustipennis and Limnaea species are usually found in this zone.

In the mesosaprobic zone ammonia is usually present.

3. Oligosaprobic zone. In this zone oxidation is completed, the water is clear and rich in oxygen. This zone is characterised by having a wide range of species of both plants and animals.

Irrespective of the value of the indicator organisms they chose, Kolkwitz and Marsson nevertheless brought to light a number of important facts concerning pollution by decomposable organic matter. Firstly they showed that one finds a succession of different communities in organically polluted streams. Secondly communities nearest the pollution are few in numbers of species but rich in numbers of individuals. As one moves downstream the numbers of species in the communities increase. Thirdly they tried to define the chemical conditions persisting in their zones. They pointed out that an oxygen sag occurs as a result of pollution, and also that there is an increase in the concentrations of such substances as ammonia.

Although German biologists seem to have been the first to take an active scientific interest in water pollution, the increasing problems of pollution in the Western hemisphere prompted biologists in other countries to carry out survey work on polluted streams and rivers.

In the United States of America Richardson (1929) studied the Illinois River over a period of 12 years. Between 1913 and 1920 the river was becoming increasingly polluted, between 1920 and 1925 however, owing to better treatment the river could be said to have improved. He showed that during the first period the numbers of clean water species collected fell from 91 to 15. With the slight improvement in the second period the number of clean water species rose slightly to 28 in 1925. Another important fact to emerge from his work was that as a result of the increasing pollution the numbers of animals such as chironomids and tubificids greatly increased.

Following Richardson's early work, Gaufin and Tarzwell (1955 and 1956) made a useful contribution to our knowledge of the ecology of water pollution. Their work on Lytle Creek, Ohio entailed regular studies of the bottom organisms throughout the year, coupled with regular monthly water samples. As a result of their studies they showed that it was during the summer months when flows are low that variations in dissolved oxygen and pH were at a maximum. During winter, with increased flow rate and a slower rate of bacterial activity, higher concentrations of organic matter are carried into the lower sections of the stream. As a result of this greater organic content the "sewage fungus" zone extends further downstream in winter. This extension of the "pollutional carpet" can bring about a significant reduction in the variety of macro-invertebrates.

The results of their work in the benthos produced similar results to those of the other workers already discussed.

Their more important results can be summarised:-

1 - The septic zone (immediately below the effluent) had less than one fifth as many species as clean water areas, but the number of individuals of each species and the total numbers of animals per unit area were many times greater. Some of the animals typical of this zone are Tubifex, Eristalis and Culex pipiens. These organisms are adapted to live under low dissolved oxygen conditions either by being independent of oxygen dissolved in the water or by being specially adapted to utilise these low concentrations of dissolved oxygen.

2 - In the Recovery zone the community is characterised by lesser numbers of the species found in the septic zone together with variable numbers of the more tolerant animals found in clean water.

3 - The clean waters were characterised by a great variety of invertebrates, the communities consisting of herbivores, carnivores and omnivores. In general the population contains abundant gill breathing forms such as mayflies, stoneflies and caddis flies.

Studies on the effect of pollution on organisms in the United Kingdom really began with the work done by Butcher et al (1937). They showed what disastrous results can be produced when large quantities of organic matter are discharged into a stream. The original invertebrate fauna was completely wiped out for a considerable distance downstream to be replaced by a community consisting of worms. It took almost a full twelve months for the normal fauna to recolonise the upper reaches.

The survey on the River Tees (Butcher et al 1937) showed, as in other countries, that successive communities will be produced when a river is organically polluted. The River Skerne, one of the tributaries of the Tees was polluted near its source. In the polluted upper reaches only a few chironomid larvae and Tubificids were found. Downstream however chironomid larvae, Simulium ornatum and Hydropsyche sp. were common. Further downstream Baetis and Limnaea appeared, to be followed by Gammarus pulex and Hydroptila sp.

The Skerne, after flowing through Darlington, received numerous effluents which brought about two quite different results with regard to the composition of the fauna. Some species were progressively reduced in numbers and then completely eliminated. Animals affected in this way were Gammarus pulex, Hydropsyche sp. and Baetis.

The Skerne, on entering the Tees, produced marked changes in the flora and fauna. Below the entry of the Skerne, Tubificids were the dominant organism, these soon decreased in numbers giving way to large numbers of Asellus aquaticus, Erpobdella octoculata and Limnaea pereger. These also decreased in numbers downstream.

The River Trent (Butcher 1946) was organically polluted at Stoke and Butcher studied the biological recovery of the river over a distance of 35 miles. The river was very badly polluted, this being reflected by the oxygen and ammonia concentration. The oxygen concentration which above Stoke was 107% saturation dropped to nil below Stoke rising again to 77% after 35 miles. Ammoniacal nitrogen rose from 0.2p.p.m. to 14p.p.m. below Stoke and then dropped off to 1p.p.m. after 35 miles. The fauna was strikingly affected by the pollution at Stoke. The first animals to appear were Tubificids approximately 4 miles below the effluent to be followed by the red Chironomids when the dissolved oxygen was 34% of saturation and the ammonia concentration 11.5p.p.m. Asellus was the next animal to appear, by now the oxygen concentration was 40% of saturation and the ammonia concentration was still 11.5p.p.m. Asellus was followed by leeches, Gammarus and caddis respectively as the ammonia and oxygen concentrations gradually improved.

Butcher's work on the River Tame, which is a tributary of the Trent provided similar faunal sequences to his work on the Trent.

Hawkes (1956) also studied the effect of organic pollution on Midland streams. His work on Langley brook showed extremely well how various species of invertebrates attained their greatest numbers at various distances below the sewage outfall. Chironomus plumosus and Tubificids were most numerous within 100 yds of the source of pollution, Asellus aquaticus and Helobdella stagnalis were most numerous within 500 yds, Erpobdella sp. within 600 yds, Hydropsyche within 1,500 yds and Gammarus from 2,000 yds onwards.

Within the last twenty years increasing pollution of streams and rivers has led to more and more river surveys. The importance of the biota in helping to detect pollution has now been realised in most countries of the world.

In South Africa Harrison (1958 & 60) and Oliff (1960, 1963, 1964) have carried out thorough surveys of both polluted and non-polluted rivers.

Harrison investigated the Great Berg and Dwars Rivers, both of which were mildly polluted and also Krom stream which was more seriously polluted. In all cases mild pollution had two broad effects:-

1. It suppressed or eliminated forms normally found in mountain streams. Groups effected in this way were the may-flies Ephemerellidae, Leptophlebidae, stone-fly Nemouridae and most

families of the Trichoptera.

2. It favoured moderately tolerant forms. Baetis harrisoni, members of the Hydropsychidae, Orthocladiinae, Chironominae and Limnaeidae all increased in numbers.

In cases of more serious pollution as in Krom stream, the normal fauna was completely eliminated to be replaced by one rich in tubificid worms of the genus Tubifex and Limnodrilus and red Chironomids of the plumosus group.

Bushman's River was studied by Oliff (1960) and his results also showed how organic pollution can reduce the numbers of species but greatly increase the numbers of individuals. At one non-polluted station there were over 6,000 individuals belonging to 45 different species, while at a polluted station there were only 19 species yet over 27,000 individuals.

Balani and Sarkar (1961) studied the effect of organic pollution on the River Jumna in Delhi. The river was so badly polluted that the only organisms occurring in the stream bed, other than micro-organisms, were tubificid worms, Chironomus, Eristalis and Antocha larvae. At certain times of the year very high concentrations of carbon dioxide were noted, the highest recorded figure was 121p.p.m.

It does seem that organic pollution produces the same general pattern throughout the world. This becomes readily apparent from the results of the numerous surveys already carried out of which those described are just examples.

The effect of organic pollution on stream organisms in the United Kingdom has been summarised by Hawkes and Hynes. Hawkes (1962) whose work was mainly on the riffle sections of streams and rivers recognised three main trends.

1. The reduction and possible elimination of the non-tolerant

species e.g. Rhithrogena and Gammarus.

2. An increase in numbers of the moderately tolerant forms providing the pollution is not too severe e.g. Baetis rhodani, Hydropsyche and Erpobdella sp.

3. An invasion of the habitat by non-riffle species e.g. Asellus, Chironomus riparius and Tubifex.

The replacement community tends to be poor in numbers of species although rich in numbers of individuals.

Hynes (1966) outlines the effects in the following ways:-

1. Animals. If the river is badly polluted the clean-water animals are replaced by a very abundant pollution fauna consisting largely of Tubificidae, Chironomus thummi and Asellus aquaticus. These three types of animals succeed one another in importance proceeding downstream from the outfall. Also present in the Asellus zone are leeches e.g. Erpobdella testacea and Helobdella stagnalis, Molluscs e.g. Limnaea pereger and Sphaerium corneum.

2. Micro-organisms. Bacteria are at first abundant and then decline as organic matter is used up. Sewage fungus appears, increases and then declines in a similar way.

3. Plants. At first there is a decrease in the numbers of algae but then, as nutrient salts are released from the organic matter, they increase greatly in numbers.

The changes in the community are caused by a number of different ecological factors. Harrison (1960) summarises the factors responsible for these changes.

1) The addition of organic nutrients results in abnormal growths of bacteria, Protozoa etc. utilizing these nutrients. Larger organisms can abound feeding on these micro-organisms e.g. Tubificidae and Chironomidae.

2) The addition of soluble organic compounds of nitrogen and

phosphorus result in algal growth and associations of fauna which feed on them.

3) By causing oxygen depletion, this occurs when biochemical oxygen demand overtakes the re-oxygenation rate. As a result only forms resistant to low oxygen concentrations will survive.

4) By reducing the clarity of the water. Many animals cannot tolerate suspended matter.

5) The fouling of the substratum. Some animals are very sensitive to changes in the substratum and may disappear, other species are more tolerant and may even benefit from these changes.

In addition to these factors two other criteria which frequently characterise organic pollution must be considered.

a) The increase in the concentration of ammonia. Ammonia, especially in its undissociated state, is definitely toxic to most animals.

b) The increase in carbon dioxide concentration. Carbon dioxide is usually produced in large amounts by the breakdown of organic matter. Balani and Sarkar (1961) recorded concentrations of 121p.p.m. in the River Jumna. Concentrations of this order would make it an important toxin in its own right, but even at far lower concentrations it is known that carbon dioxide can double the minimum oxygen concentrations necessary for the survival of fishes.

It is obvious that the effect of a sewage effluent on an aquatic community is very complex. It is difficult to isolate any one factor as being of paramount importance and it does seem that changes produced in aquatic communities result from an interaction between these factors.

2.4 The Chemical and Physical Effects of Organic Effluents on a River

The discharge of an organic effluent into a river can bring about many changes in the chemical composition of the water. The more important changes are as follows.

1) De-oxygenation

This is a very common feature of organic pollution and has been observed by many workers. Because of the effect of the current the depletion in the oxygen concentration, which is usually known as the 'oxygen sag', takes place some distance downstream of the effluent outfall. Proceeding further downstream there is a gradual recovery in the oxygen content and eventually it will reach its former level.

There are a number of reasons for this oxygen depletion and these have been summarised by Downing (1967). He recognises four important factors as being responsible for the depletion:

a) The Biochemical oxygen demand of the water. This varies and depends on the carbonaceous content of the water and the numbers of micro-organisms.
b) Nitrification. The nitrogenous material present in the effluent is oxidised as it passes downstream, taking oxygen out of the water.
c) Respiration of muds and slimes.
d) Respiration of plants.

The recovery in oxygen concentration is brought about by:

a) Reaeration from the air, the amount of reaeration will vary with depth and current.
b) The photosynthetic activity of algae and rooted plants.

Owens and Edwards have made a special study of oxygen depletion and recovery in streams, and drew special attention to the role of bottom muds. They state (1963) that the mud can be responsible for more than 50% of the total oxygen consumption in a river less than 2.5ft. deep. This source of deoxygenation can be very important where there are large numbers of benthic organisms. In the River Lark these were as many as 140,000 per square metre.

Gaufin and Tarzwell (1955) observed that the degree and extent of the oxygen sag is affected by temperature and it is in summer that oxygen depletion is most intense when the rate of oxidation of the organic matter is affected by temperature. The higher summer temperatures increase microbial activity and therefore oxygen demand and the oxygen depletion is more intense. Consequently self-purification is more rapid and as a result the oxygen sag is deeper although it is not usually as extensive as in winter.

The degree of oxygen depletion varies greatly but it is not unusual, in badly polluted rivers to have anaerobic conditions. Butcher (1946) found that in the Trent, polluted at Stoke, the oxygen concentration dropped from 107% saturation above the effluent to 0% below the effluent, the oxygen concentration in the river then recovered gradually.

De-oxygenation is then a typical, and very important result of organic pollution, the degree is variable because of the many factors involved. Aquatic organisms vary in their oxygen requirements and low oxygen concentrations can be of great importance in determining the distribution of invertebrates in rivers.

2) Increase in Nitrogenous Material

An organic effluent usually increases the amount of nitrogenous material in the river. The ammonia concentration is usually increased, but the amount present usually depends on the type of treatment the sewage has undergone. If the effluent is an oxidised effluent very little ammonia is present, the nitrogenous material being mainly in the form of nitrates and nitrites. The ammonia concentration of a river usually declines downstream as it undergoes oxidation, and there is thus a corresponding increase in oxidised nitrogen in the form of nitrites and nitrates.

In the River Trent (Butcher 1946) the ammonia concentration reached a maximum of 11.5p.p.m. This is by no means an unusually high figure and Woodiwiss (1964) has recorded over 30p.p.m. within the Trent Drainage Area, and Owens and Edwards (1964) nearly 20p.p.m.

Ammonia is known to be an important toxicant especially in its unionised state and the increase in concentration could also be important in determining the distribution of aquatic organisms.

3) Increase in Carbon Dioxide Concentration

Carbon dioxide is produced in large amounts by the breakdown of organic matter. Balani and Sarkar (1961) recorded a concentration of 121p.p.m. while working on the River Jumna, this is an exceptionally high figure but concentrations of 50p.p.m. are referred to by Alabaster et al (1957).

Carbon Dioxide in these concentrations would radically effect the minimum concentrations of oxygen necessary for the survival of fish.

4) Change in the Nature of the Stream-Bed

Sewage effluents usually contain variable amounts of colloidal and suspended matter, this fine matter is then deposited on the stream bed, the rate of settling tailing off downstream. Hawkes (1962) says that this fine matter from one sewage works may exceed 10 tons dry weight per year.

The deposition of the solids on the stream bed can affect organisms in two ways:

a) By smothering the vegetation and thus eliminating any food chains based on it.

b) By changing what may have been previously an eroding substrate into a depositing one. This would cause stone loving forms such as stoneflies, and many mayflies to be replaced by burrowing forms such as tubificid worms and chironomid larvae.

5) Increase in various Salts

A sewage effluent can often contain high concentrations of orthophosphates. It is also probable that salts of potassium and sodium are also present, as they are important constituents of urine.

Unfortunately very little information is available on their presence in polluted waters as the determination of their presence is not usually included in river board analyses.

2.5 Experimental Work on Fresh-Water Animals

1. Effect of Low Oxygen in Aquatic Organisms

Experiments to investigate the effect of low oxygen can be broadly divided into two kinds:

a) Those designed to show survival levels.
b) Those concerned with oxygen consumption at various oxygen levels.

a) Tolerance Experiments

Generally the results of these experiments show a close correlation with evidence from field observations.

Fox and Taylor (1955) investigated the oxygen tolerance of Chironomus riparius and Ch. dorsalis and Tubifex sp. They found that all three animals survived longer in water containing 4% oxygen than water containing 21% oxygen. All three species are normally associated with organically polluted waters where the oxygen concentration would be low and this could help to explain their distribution.

Walshe (1948) also examined the oxygen tolerance of chironomid larvae, and selected larvae from flowing and still waters.

She found that the tolerance reflected the habitat, the most sensitive to anaerobic conditions being *Prodiamesa* where half the population died in 10hrs. In the case of *Chironomus longistylus* it was 68hrs before half the population had died. *Prodiamesa olivacea* is a stream form and associated with moderately polluted conditions whereas *Chironomus longistylus* can occur in grossly polluted conditions.

Very little work has actually been performed on the tolerance of British invertebrates to low oxygen concentrations, however a guide can be obtained from the work of Sprague (1963). He investigated the oxygen and temperature tolerance of four North American fresh-water crustaceans. These were *Asellus intermedius*, *Hyalella azteca*, *Gammarus fasciatus* and *Gammarus pseudolimnaeus*. *Asellus intermedius*, just like *Asellus aquaticus* in this country is associated with polluted rivers and deoxygenated conditions. The two species of *Gammarus* are never associated with de-oxygenated conditions and seem to be similar in this feature to *Gammarus pulex*.

The results obtained supported the field observations, *Asellus intermedius* was the most tolerant and at 20°C required an oxygen concentration of 0.03p.p.m. to kill 50% of the test animals in 24hrs. For *Gammarus fasciatus* and *pseudolimnaeus* the figures were 2.2 and 4.3p.p.m. respectively.

Jaag and Ambuhl (1962) investigated the effect of various oxygen concentrations on a variety of invertebrates. They were more interested however, in how the changes in current could influence the minimum oxygen concentrations necessary for survival. They found that even such species as *Rhyacophila nubila* and *Ecdyonurus venosus*, both of which are associated with good quality water, can survive at very low oxygen concentrations providing the current is fast. At 6cms/sec. *Ecdyonurus venosus* and *Rhyacophila* dorsalis both survived at 0.4p.p.m. At slower currents the low lethal level rose to 1.2p.p.m. and 1.5p.p.m. respectively.

Philipson (1954) investigated the effect of oxygen on six species of caddis fly larvae. His results were similar to those of Ambuhl, the species from swift waters, namely Hydropsyche instabilis and Rhyacophila dorsalis being greatly influenced in their tolerance of low oxygen concentrations by the speed of the current. In stirred waters Hydropsyche instabilis and Rhyacophila dorsalis could survive in water with oxygen concentrations of 0.9p.p.m. and 0.7p.p.m. respectively.

b) Experiments on the Oxygen Consumption of Aquatic Invertebrates

A number of experiments have been performed on invertebrates with the idea of showing how the rate of oxygen consumption is influenced by the oxygen concentration in the water.

Such experiments are particularly important as they help to show how animals are adapted for life in waters of differing oxygen concentrations. It would be expected that animals, usually associated with anaerobic or near anaerobic conditions, would be more independent of oxygen changes in the surrounding water than animals from well aerated water. The majority of such experiments do indeed show this, and it is usually possible to recognise those animals in which the oxygen consumption was independent and those in which oxygen consumption was dependent on the oxygen concentration of the surrounding water.

Mann (1961) investigated the oxygen requirements of five species of leech associated with a variety of habitats. His results show clearly these dependent and independent forms and they can also be correlated with different habitats. The independent forms were Erpobdella testacea and Helobdella stagnalis, the oxygen consumption of the former being independent between 6 and 3p.p.m.

while that of the latter was independent between 4 and 2p.p.m. dissolved oxygen. The dependent forms were Erpobdella octoculata, Piscicola geometra and Glossiphonia complanata.

These results are in accordance with the accepted habitat preferences of the five species. Erpobdella testacea and Helobdella stagnalis are usually abundant in lakes and ponds with a lot of decaying vegetation and also in organically polluted rivers; all of these are characterised by having low oxygen concentrations. Piscicola geometra, Erpobdella octoculata and Glossiphonia complanata are usually associated with running water, although the last two can be found in ponds and lakes. In general however they are likely to frequent habitats with a plentiful supply of oxygen.

Mann investigated four habitats, in two of which Erpobdella octoculata was the dominant leech and in the other two Erpobdella testacea was the dominant. He found that the mean oxygen concentration where Erpobdella octoculata was dominant was 6.1 and 4.3p.p.m. and where Erpobdella testacea was dominant it was 2.9 and 1.8p.p.m.

Edwards and Learner (1960) investigated the effect of a range of oxygen concentrations as well as temperature on the oxygen consumption of Asellus aquaticus. They found that the oxygen consumption of Asellus was of the independent type between 8.3p.p.m. and 1.5p.p.m. oxygen. Temperature however did influence the respiratory activity, the test animals respired 1.5 times as fast at 20°C as at 10°C. This experiment could also help to explain the distribution of Asellus which is usually associated either with decaying vegetation in ponds and the slower portions of rivers or with organically polluted rivers. In these environments low oxygen concentrations would be a feature of the environment with Asellus being well adapted for this criterion.

Species of Chironomidae have been experimented upon by several workers. Walshe (1948) found that larvae of species normally associated with streams have a dependent type of reaction while those from stagnant ditches have an independent reaction to changes in the oxygen content of the medium. The stream forms used were Prodiamesa olivacea and Anatopynia nebulosa and the ditch forms Chironomus longistylus and Anatopynia varia. These results show quite clearly how animals that normally experience deoxygenation in their environment have become adapted to these conditions.

Chironomus riparius, dorsalis and longistylus are red in colour and usually called "bloodworms", the red colouration being due to the presence of haemoglobin. It has been shown how the presence of this haemoglobin together with stores of glycogen in the tissues enable these animals to live in anaerobic conditions.

Ewer (1942) and Walshe (1950) both showed how important haemoglobin is to the bloodworm. Ewer demonstrated how the haemoglobin assisted oxygen transport at low oxygen concentrations, while Walshe also points out how it enables the animals to carry on with their normal feeding activities. Larvae in which the haemoglobin had been converted to oxyhaemoglobin were not able to filter feed at oxygen concentrations below 26% whereas the limiting concentration for normal larvae is 10%.

The importance of the haemoglobin is without question as it allows these animals to live in anaerobic conditions, and it has been shown by Czeczuga (1960) that the haemoglobin content of Chironomus plumosus varies with the oxygen present. He investigated the haemoglobin content of individuals from various levels of bed sediment and found that in the individuals near the surface the haemoglobin content averaged 8.2% of the dry mass whereas in the deeper layers the haemoblogin averaged 26.7% of dry mass.

Another important feature of Chironomus larvae which enables them to live in waters low in oxygen has been demonstrated by Augenfeld (1967). He showed that Chironomus thummi (riparius) and plumosus have glycogen comprising 13-14% of their body weight, for Tanytarsus however it is 2%. The first two species are very tolerant of low oxygen while Tanytarsus is intolerant. The reason for this high glycogen content in the Chironomus species is that they are able to break down glycogen anaerobically. This type of respiration however, yields only 10% of the energy resulting from complete oxidation, and so to meet their needs a plentiful supply of glycogen would be required. Another feature of their metabolism is that the lactic acid formed as a result of anaerobic respiration and usually accumulated in the tissues, is somehow removed.

As a result of these experiments it would seem that animals that colonise polluted waters, such as Chironomus spp., Tubificidae and Asellus, are able to do so by having specially modified respiratory metabolism which makes them relatively independent of the oxygen in the surrounding water. It has also been demonstrated in species of Chironomus how the haemoglobin and stores of glycogen can assist their survival in waters of very low oxygen content. It may be that similar mechanisms are at work in other tolerant invertebrates such as the tubificids and leeches.

2. The Effect of Ammonia on Aquatic Organisms

Most of the experiments using ammonia as a toxicant have been performed on fish. They do nevertheless provide a useful guide as to how invertebrates would react to this toxicant.

It has been shown that the toxicity of ammonia is influenced by a number of factors including pH, temperature and dissolved oxygen concentration of the water.

Downing and Merkens (1955) using Rainbow trout have demonstrated that ammonia is more toxic in its un-ionised form NH_3 than as the ion NH_4^+. Since the degree of dissociation is less at higher pH values, ammonia is more toxic in alkaline waters than acid ones. It has been suggested by Warren (1962) that the reason that un-ionised ammonia is much more toxic than ionised ammonia is that cell membranes are relatively impermeable to the latter but allow the former through.

Although very little experimental work has actively been carried out on invertebrates it is probable that they will be affected in a similar way.

Ball (1967) showed that in terms of the asymptotic LC 50 values there is little difference between the species of fish experimented on. If the concentration is increased however the survival times of the fish fall and differences become more marked.

The influence of dissolved oxygen on the toxicity of ammonia has clearly been shown by Downing and Merkens (1955). With an undissociated ammonia concentration of 1.38p.p.m. the time it took for half the experimental fish to die varied from 80 minutes at 3p.p.m. dissolved oxygen to 500 minutes at 7p.p.m. dissolved oxygen.

It is known that an increase in temperature decreases the survival time of fish to ammonia. The reason for this is that temperature affects the ionization of ammonia, there being a relatively greater proportion of the more toxic un-ionized molecule present at higher temperatures.

Carbon dioxide can also influence the toxicity of ammonia but inversely, the greater the concentration of carbon dioxide the less toxic the ammonia solution. This fact has been demonstrated by Lloyd and Herbert (1960) and results from the fact that an increase in carbon dioxide would make the water more acid which would then be reflected by more ammonia being present in its less toxic ionized form.

3. The Effect of Carbon Dioxide on Aquatic Organisms

Carbon dioxide can be produced in organically polluted water by the oxidation of the organic matter. The carbon dioxide produced will influence the survival of organisms in the stream.

Dissolved carbon dioxide, in high concentrations, is known to be toxic to fish but even at lower concentrations it is very important as it can influence the survival of fish at low oxygen concentrations. This fact was clearly demonstrated by Alabaster et al (1957). They showed that concentrations of carbon dioxide which can occur in polluted streams can more than double the minimum concentration of dissolved oxygen necessary for the survival of 50% of Rainbow trout for 24 hrs. At 12.5°C the lethal oxygen level for 50% survival for 24 hrs. was 1p.p.m., when there was 60p.p.m. of carbon dioxide present the lethal oxygen level rose to 3.8p.p.m. An increase in temperature between 12.5°C and 19.5°C was found to shorten the period of survival.

Fox and Johnson (1934) found that the effect of carbon dioxide is variable in its effect on invertebrates. When Asellus aquaticus was the test animal they found that in fully aerated water there was no movement of the pleopods, when the oxygen concentration was lowered to 0.84 ccs/litre it induced a rapid and regularr rhythm of the pleopods. The introduction of carbon dioxide into the water had no effect on this pleopod movement. This was not the case with Gammarus pulex, both a drop in oxygen and an increase in carbon dioxide concentration quickened respiratory movement.

It would appear that dissolved carbon dioxide could affect certain invertebrates in a similar way to fish.

4. The Effect of pH on Aquatic Organisms

The pH of the water is frequently altered by organic pollution. The presence of carbon dioxide lowers the pH and so generally organic pollution makes the water more acid. It would seem that in organically polluted streams it is the indirect effects of pH in affecting the toxicity of poisons which are the most important. It is hardly likely that organic pollution would lower the pH to such an extent that the acid nature of the water itself would affect the organisms living there.

Bell and Nebeker (1969) studied the tolerance of aquatic insects to low pH. They found that the test animals varied markedly in their tolerance of acid conditions but even the least tolerant could survive for 4 days in acid conditions. The pH at which 50% of the test species died after 96 hours is known as the TLM^{96}. For the caddisfly, Brachycentrus americanus the TLM^{96} was pH 1.5, for the stonefly, Taenopteryx maura it was 3.25 and for Stenonema, a mayfly it was 3.32. The least tolerant was another mayfly, Ephemerella subvaria where the TLM^{96} was 4.65.

Lowndes (1952) states that most species of Entomostraca can tolerate considerable variation in pH. Cyclops languidus can occur in water with a pH of 3.0 and yet it breeds in waters with a pH of 8.6, other species have even wider ranges of tolerances.

It would be supposed that other invertebrates would tolerate considerable variation in pH and that the changes produced in this respect by organic pollution would not, in themselves, be of great importance.

5. The Effect of Non-Poisonous Salts on Aquatic Organisms

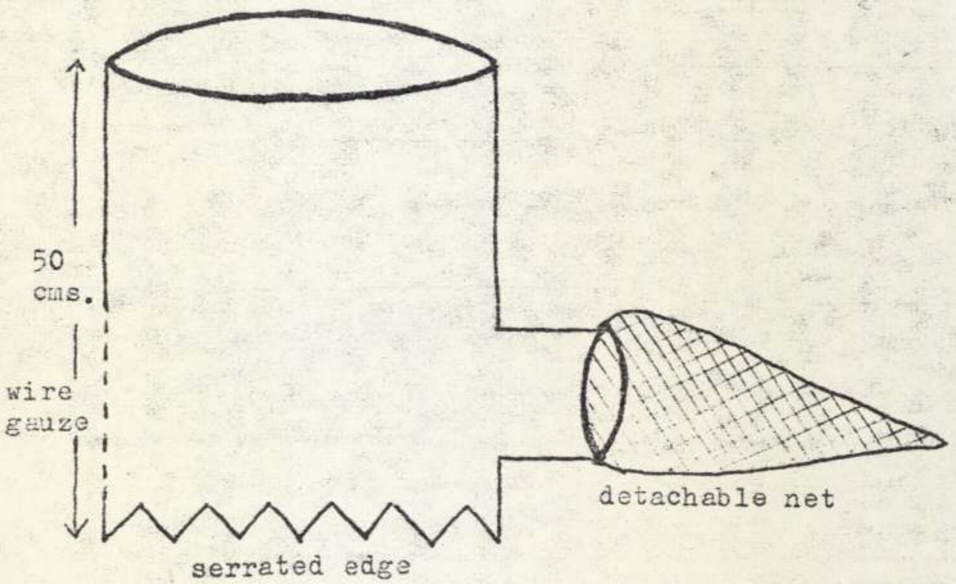
Very little experimental work has been carried out on the effect of the non-toxic elements of sewage on organisms.

Anderson (1944) did study the effect of certain salts on Daphnia magna, he found that comparatively high concentrations were required to immobilise the test animals, for potassium chloride it was 373p.p.m., ammonium chloride 134p.p.m. and sodium chloride 6,143p.p.m.

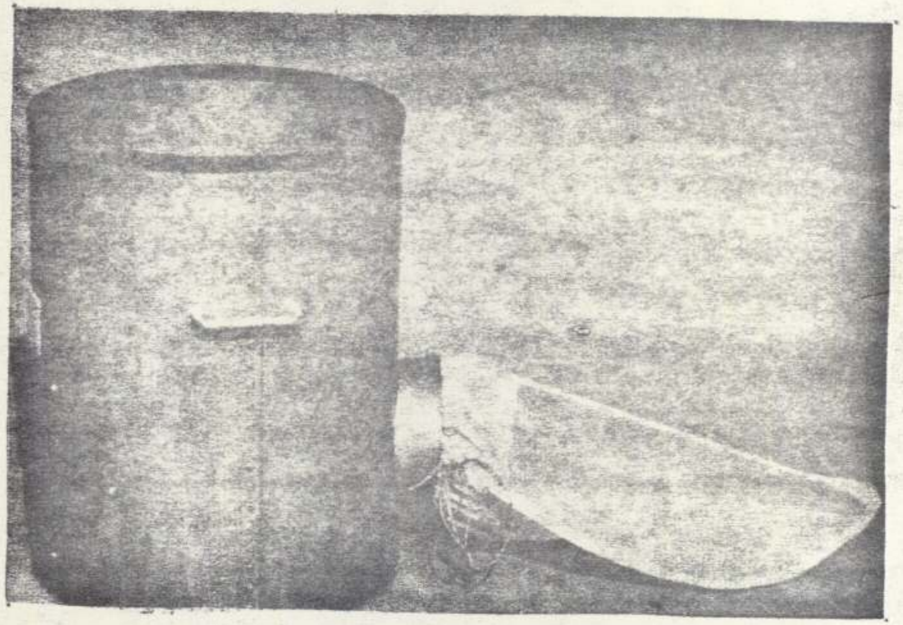
Jones (1937) using Polycelis nigra and Gammarus pulex investigated the toxicity of several metallic salts. He concluded that salts of the alkalis and alkaline earth metals were comparatively harmless below isotonicity. Anions are generally more toxic than the cations and this was demonstrated by Jones (1941). Using Polycelis nigra as a test animal he assessed the degree of toxicity of 27 anions. He found that chlorine was least toxic and the hydroxide ion the most toxic. Between these extremes he found that the following were toxic, increasingly so in the following order, carbonates, nitrates, phosphates, citrates and iodates.

Although it is apparent that these non toxic elements of sewage could prove toxic in very high concentrations, it is doubtful whether the amounts normally present would exert much of an influence on aquatic organisms.

Fig. 1. Diagram of quantitative sampler.



Photograph 1.



3. Field Work

3.1 Sampling Methods and Materials

It was decided to investigate quantitatively the effect of organic enrichment on the distribution of fresh-water invertebrates in the riffle sections of streams.

The quantitative samples of the freshwater benthos were taken using a saw cylinder sampler (fig. 1). This sampler was made in the Biology Department of the University of Aston in Birmingham and was based on that developed by Neill and described in Macan (1958). Macan made a number of criticisms of this type of sampler, but after being used in preliminary work it was found to be easy to use and provided good quantitative results. As a result it was decided to use it for the quantitative bottom samples required in this project.

Two cylinders were construgted of stainless steel, one enclosing an area of 0.05M^2 the other an area of 0.1M^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 passed out through a detachable sampling net made of nylon attached to an opening on the downstream portion of the sampler. The mesh size of this net was 60 threads per inch, which according to Maitland (1946) should prevent all but the very small individuals passing through. Although it would have been desirable to have collected these immature stages as well, it was obvious that the finer the mesh size the more sorting would be required and as a result less samples could be taken and analysed. Because it was intended that a larger number of routine samples be taken every month it was decided to chose a fine mesh size rather than a very fine one.

The area enclosed by the sampler was sampled by first of all disturbing and removing the larger stones and detaching any attached organisms. After the larger stones had been removed the fine sediment was stirred and sifted. The flow then carried the catch disturbed in this way into the net. The net was then detached and the catch together with the fine sediment swept into the net was transferred to a container and preserved in formalin for subsequent examination in the laboratory. The animals present were first of all sorted from the sediment. Afterwards they were then identified to species, an exception to this were the Oligochaeta which were identified as far as families. The identification of the Ephemeroptera, Plecoptera, Simulidae, Malacostraca, Oligochaeta, Gastropoda and Hirudinea were carried out using the keys produced by the Freshwater Biological Association. The Trichoptera were identified using the keys in 'Caddis Larvae' (Hickin 1967). The chironomid larvae were identified as far as possible using a variety of keys of which Johanssen (1937), Roback (1957), Bryce (1960) and Chernovskii (1961) were the most useful. To verify these identifications,larvae were reared to the adult stage and the adults identified using 'Coe, Freeman and Mattingley' (1950). Other books that proved useful for general identification were Mellanby (1963) and Macan (1959).

After the animal material had been idenfitied the total numbers of each species present were counted. In the River Cole survey three samples were taken at each station every month, from the numbers of each species present in the three samples the mean was calculated together with the 95% 'Confidence Limits' using the method described in Bishop (1966). These figures were then used to help show trends in the distribution of animals in relation to organic enrichment.

At the same time as the bottom sample was taken a water sample was taken for analysis. In the laboratory the following determinations were carried out - dissolved oxygen, temperature, biochemical oxygen demand, ammonia, oxidised nitrogen, orthophosphates, calcium, magnesium, pH and alkalinity. The methods employed for these determinations were those described in 'Methods of Chemical Analysis' (1956) for ammonia, oxidised nitrogen, oxygen, and biochemical oxygen demand. The dissolved oxygen was determined with the azide modification of the Winkler test. Distillation into boric acid was the method used for determining ammonia and oxidised nitrogen. Calcium, magnesium, alkalinity and carbon dioxide concentrations were determined using methods described by MacKereth (1963). The orthophosphate concentration was measured by using an Eel Absorptiometer and a method supplied with the instrument, while the pH was measured using an E.I.L Vibret pH meter. The termperature was always measured in the field with a centigrade thermometer (-50 to 50°C scale).

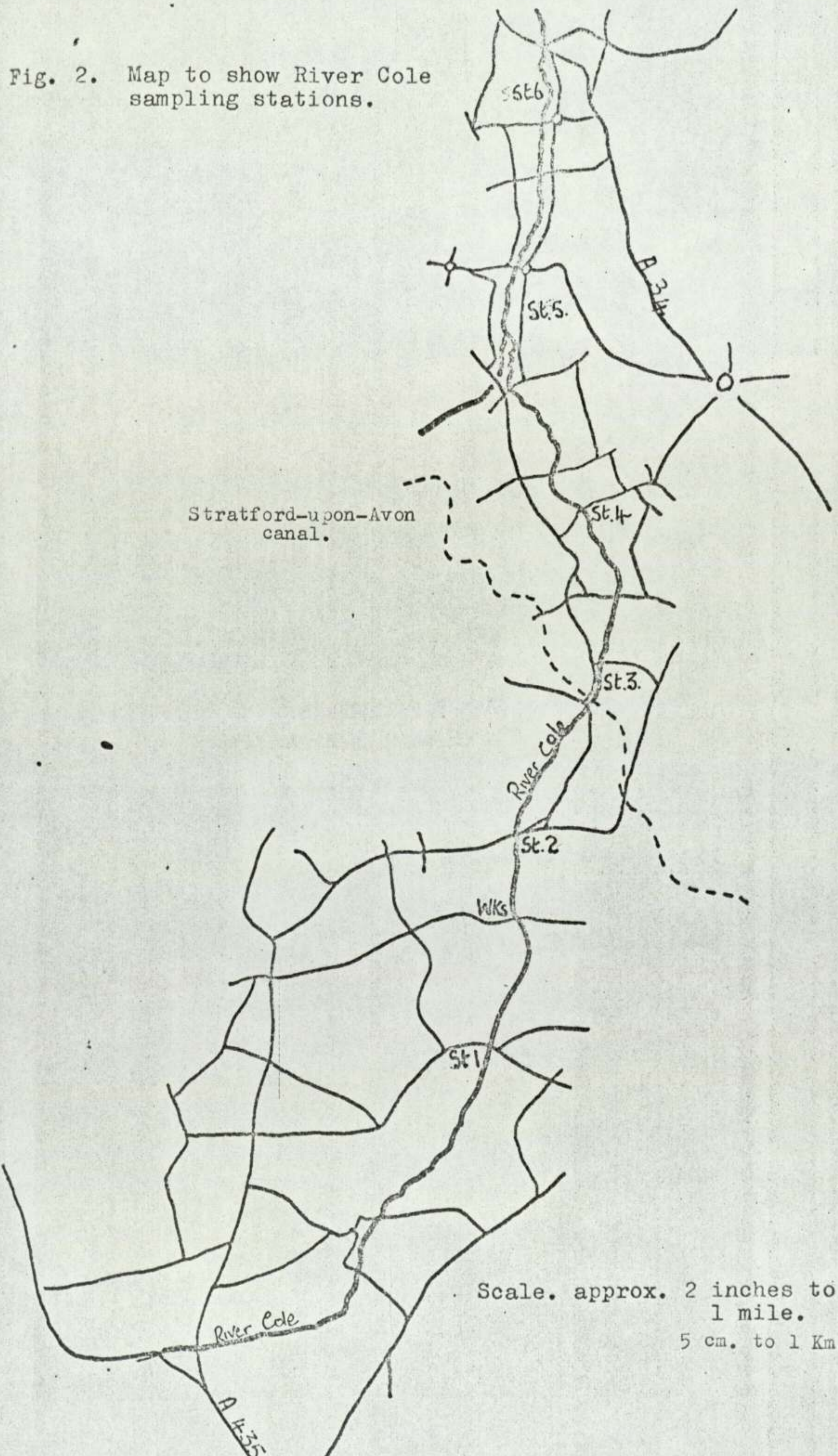
Description of Streams

The initial investigations were carried out on the upper stretch of the River Cole. This river arises to the south-west of Birmingham and then flows northwards to eventually join the River Blythe.

The River Cole (fig. 2) after reaching the southern outskirts of the city flows through a rural then residential area before entering a highly industrialised zone of the city. This study was carried out on the upper stretch of the river which was organically polluted by an effluent from a sewage works.

Six sampling stations (I-VI) were selected in the riffle zones, one above the effluent outfall from the sewage works and the other five, approximately equidistant, over the Six Kilometre stretch below. It was hoped that these stations would represent different

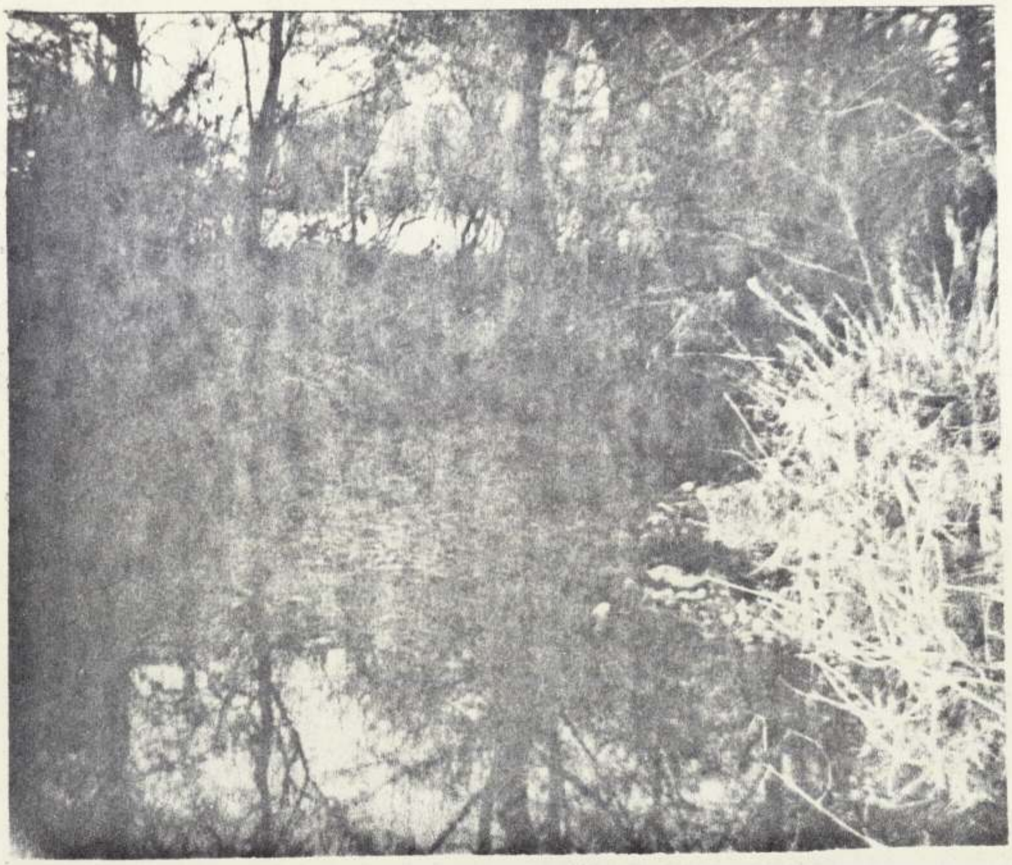
Fig. 2. Map to show River Cole sampling stations.



Scale. approx. 2 inches to 1 mile.
5 cm. to 1 Km.

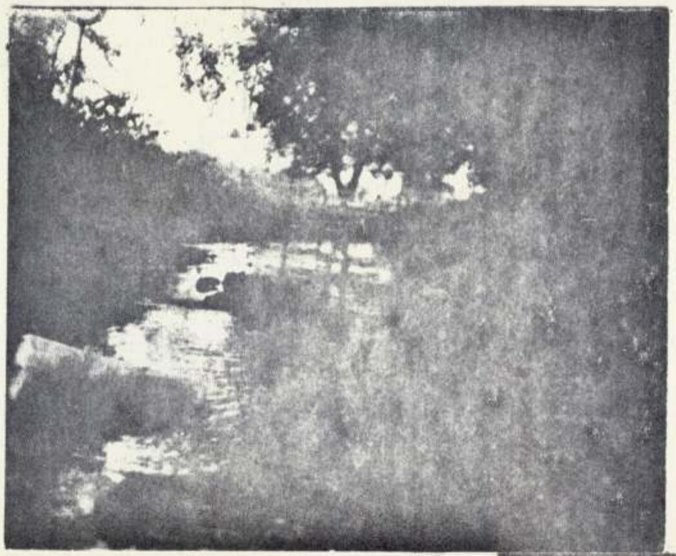
Photograph 2

River Cole, Station 1.

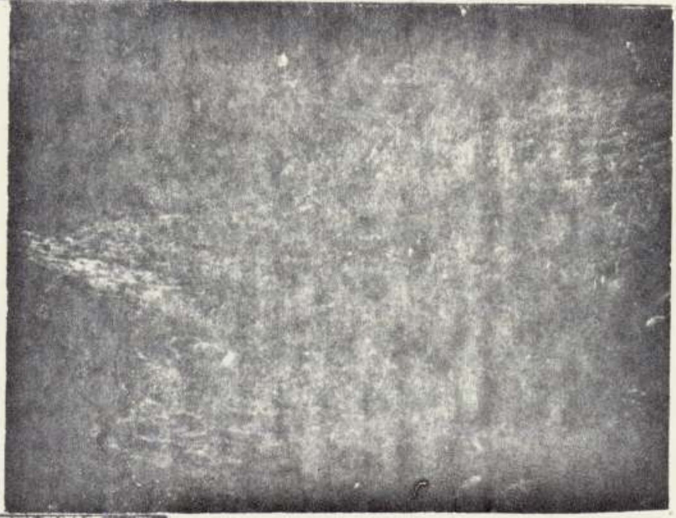


Photograph 3

River Cole, Station 2.



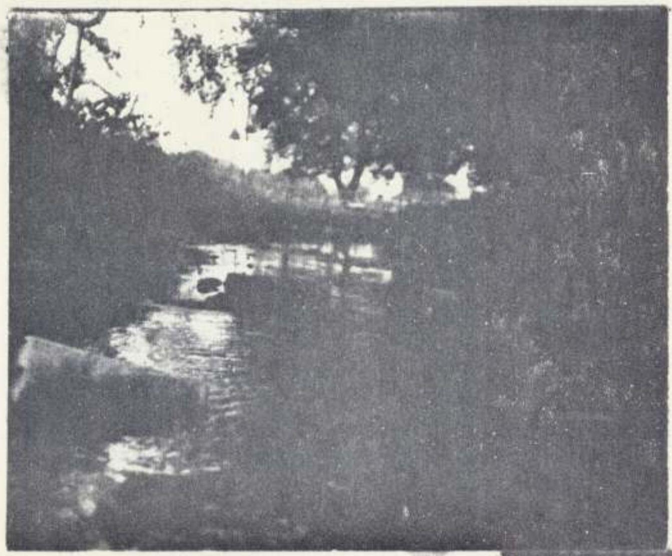
Photograph 4.
River Cole, Station 3.



Photograph 5.
River Cole, Station 4.

Photograph 6.
River Cole, Station 5.

Photograph 7.
River Cole, Station 6.

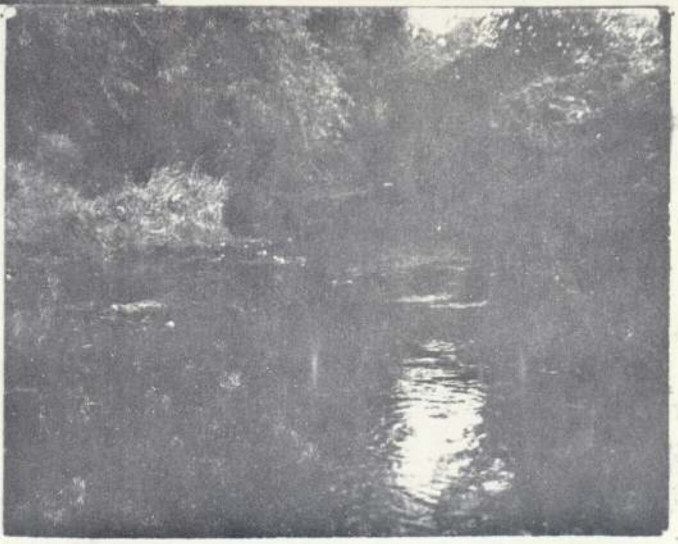


Photograph 4.
River Cole, Station 3.

Photograph 5.
River Cole, Station 4.

Photograph 6.
River Cole, Station 5.

Photograph 7.
River Cole, Station 6.



stages in polluted conditions. The river upstream of the effluent had received minor organic enrichment which had mostly been mineralised before the major discharge entered. As a basis for comparison a station was selected in a riffle zone of Dowles Brook. Dowles Brook is a stream of exceptionally good quality receiving no obvious organic enrichment. It flows through the Wyre Forest to enter the River Severn just upstream of Bewdley. The station was selected at Far Forest on the western edge of the forest. These seven stations were selected so as to provide as similar physical conditions in terms of stream bed and flow as possible.

River Cole Stations

Station I (photograph 2) GR SP 095756

At this point the River Cole was a very small stream shaded by elm trees. It varied in width between two and three metres. The stream bed in this region was composed of water worn stones of 6-8 cms in diameter.

Station II (photograph 3) GR SP 098773

The river had not increased in size at this point. The most important physical difference between the stations was that the river was not shaded. The bed was composed of similar sized pebbles to that at Station I. The stones at this station were covered in 'sewage fungus' while between the stones there was black mud produced from the settlement and decomposition of organic matter.

Station III (photograph 4) GR SP 103783

The river had increased in size due to the entry of a small tributary stream and was now approximately 3-4 metres wide. It was shaded at this station by elm and willow trees. The bed had a similar composition to that of the two previous stations, and as in Station II the stones were covered by 'sewage fungus'.

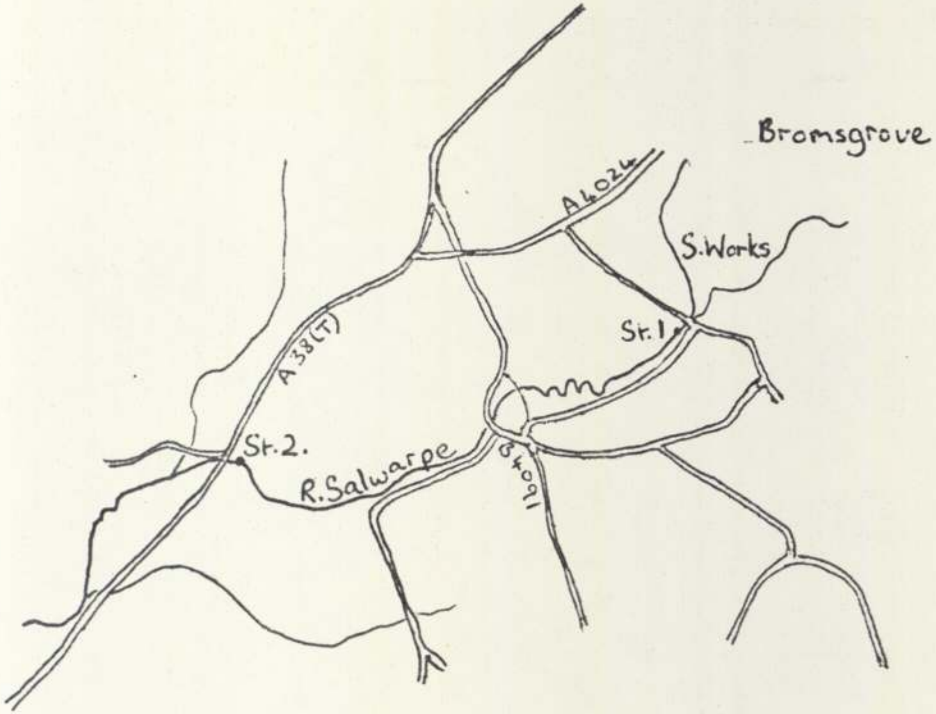
Fig. 3. Map to show location of Dowles Brook sampling station.

Scale: 2·5cm.to 1500 metres.

Photograph 8.

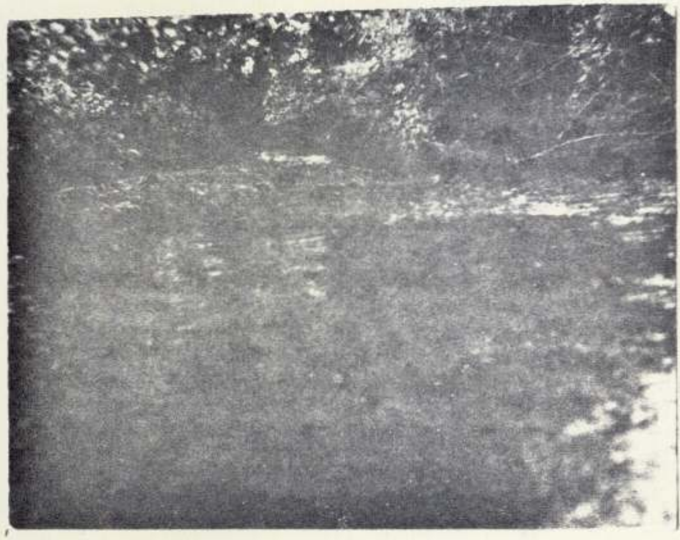
Scale: 2·5cm.to 1500 metres.

Fig. 4. Map to show location of River Salwarpe sampling stations.



Scale: 2·5 cm. to 1000 metres.

Photograph 9.



Photograph 10.

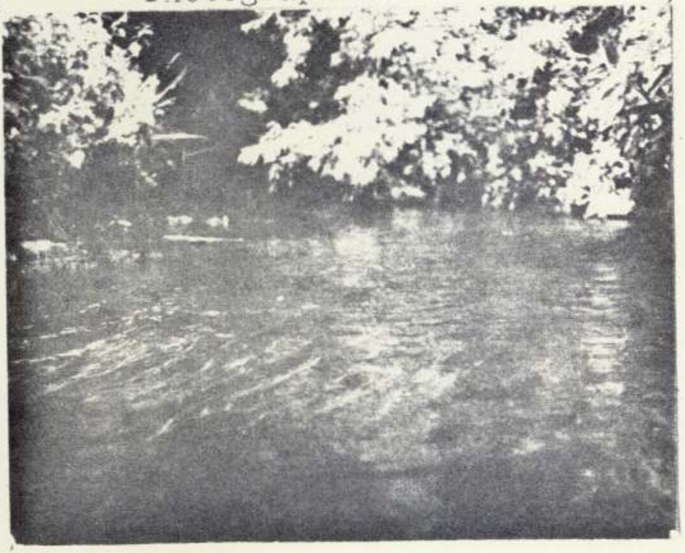
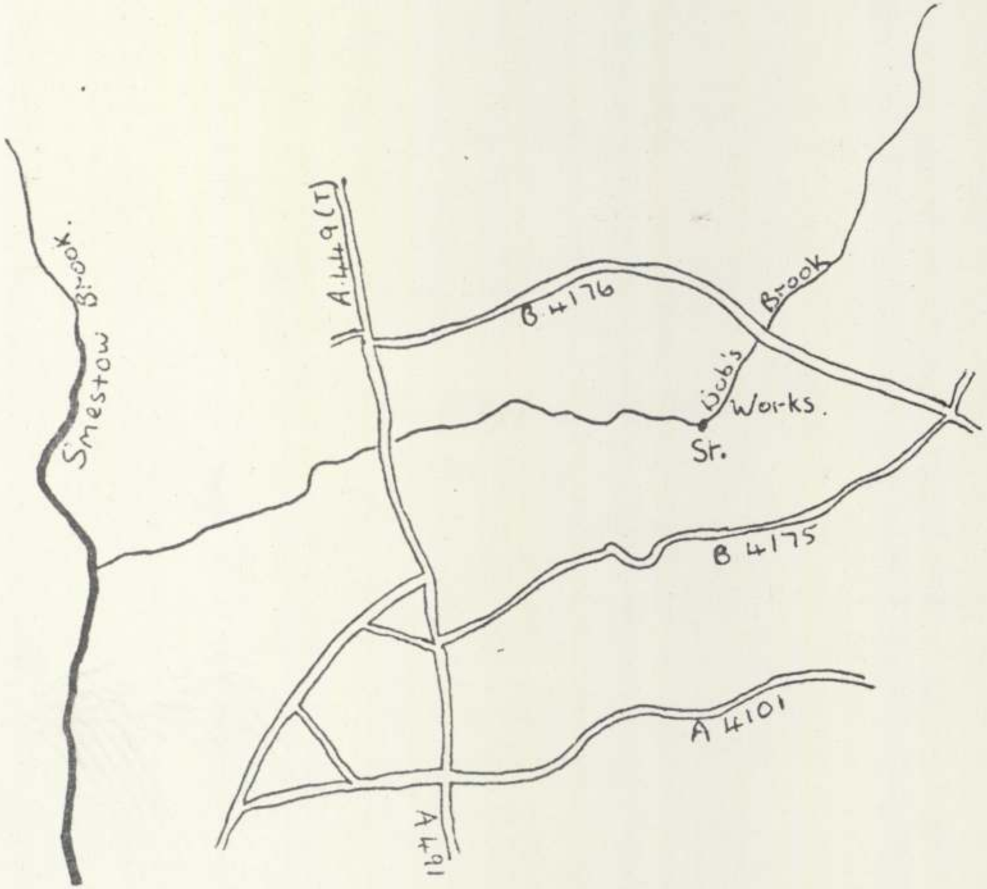


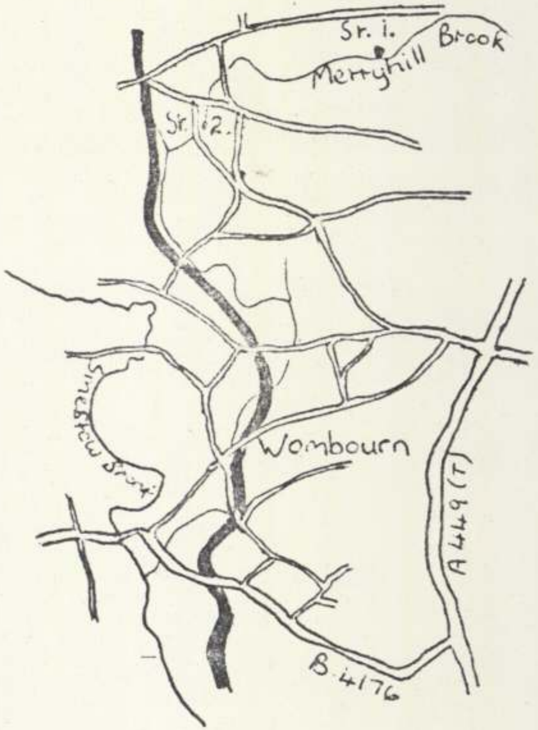
Fig. 5. Map to show sampling station on Bob's Brook.



Scale: 2.5 cm.to 1000 metres.

Photograph 11.

Fig. 6. Map to show location of Merryhill Brook sampling stations.



Scale: 2·5cm. to 1500 metres.

Photograph 12.

Photograph 13.

Station IV (photograph 5) GR SP 103793

The river was of similar dimensions at this station to the previous station. The river was not shaded at this point. The bottom was again composed of water worn pebbles and was partially covered by growths of Stigeoclonium.

Station V (photograph 6) GR SP 096805

The river was again of similar dimensions at this point with a bed of water worn pebbles. Ranunculus fluvitans sometimes formed thick growths at this station.

Station VI (photograph 7) GR SP 100825

The river had increased in size at this station and was 4-5 metre wide due to the entry of a tributary stream. The river was shaded with willows being the most common trees along the banks. The stream bed was again similar to that of the previous stations, but the stones at this station were frequently covered by growths of Cladophora.

Dowles Brook (fig. 3) SO 725762

At the sampling station the stream was of similar dimensions to the River Cole and was approximately 4 metres wide. The bottom in addition to having water worn pebbles also had large slabs of limestone and as a result the stream bed was slightly different to that of the River Cole Stations. The riffle zones were partly shaded by hazel, oak and elm trees.

The intensive study of Dowles Brook lasted from November 1966 to December 1967 and of the River Cole from December 1966 to December 1967. From Dowles Brook one sample was taken each month from $0.1M^2$ of the stream bed. From the River Cole in December 1966 one sample was taken from $0.1M^2$, but in all other months three samples were taken, each from $0.05M^2$ of the stream bed. In addition to these samples from the River Cole one sample was taken each month for the following year from $0.05M^2$ from Station 6. The results of this study proved to be very interesting, some species apparently favoured organic enrichment while others seemed to be restricted by it. The larvae of the Chironomidae were very numerous at all the stations below the effluent, and it appeared that different specie varied in their tolerance. This was particularly interesting for as a group the larvae have been virtually ignored in this country owing to the difficulty in identification.

After the completion of the study on the River Cole and Dowles Brook, further survey work was started on the River Salwarpe, Bobs Brook and Merry Hill Book. It was hoped to show that the positive results especially with regards the distribution of the Chironomidae were general the same in other 'Midland streams'. It was found during the River Cole survey that although three samples were taken at each station every month the individual samples were very similar for any one station with regards the species present and their abundance (Table 5). As a result it was decided to take onły one sample per month from each station as this should provide a good indication of the composition of the community and at the same time allow more stations to be investigated.

<u>River Salwarpe</u> (fig. 4)

The study of this river commenced in March 1968 and lasted until March 1969. This river arises as the result of the confluence of two streams to the south of Bromsgrove. The river then flows in a south westerly direction and eventually enters the Stratford Avon. The river receives the effluent from the Fringe Green Sewage Works of Bromsgrove Urban District Council. The effluent discharges into the more westerly tributary just before the union of the two tributaries. The effluent is wholly domestic. Two stations were chosen on the River Salwarpe, they were both in riffle zones and similar in other respects.

<u>Station 1</u> SO 957681

This station was approximately 300 metres below the confluence of the two tributaries. At this point the river was approximately 4 metres wide and 5-8 cms deep during normal flow. The bottom was composed of water worn pebbles with fine sediment in between. For the first three months or so the stones were covered by 'sewage fungus', this gradually disappeared during the course of the study. The river at this point was largely shaded by elm trees.

Station 2 SO 933674

The second station was approximately 3 kms downstream of Station 1. The river was of similar dimensions as at Station 1. The bottom was also similar, the main difference being that the 'sewage fungus' growths had been replaced by Cladophora. The river was again partly shaded by elm and willow trees.

Bobs Brook (fig. 5) SO 898907

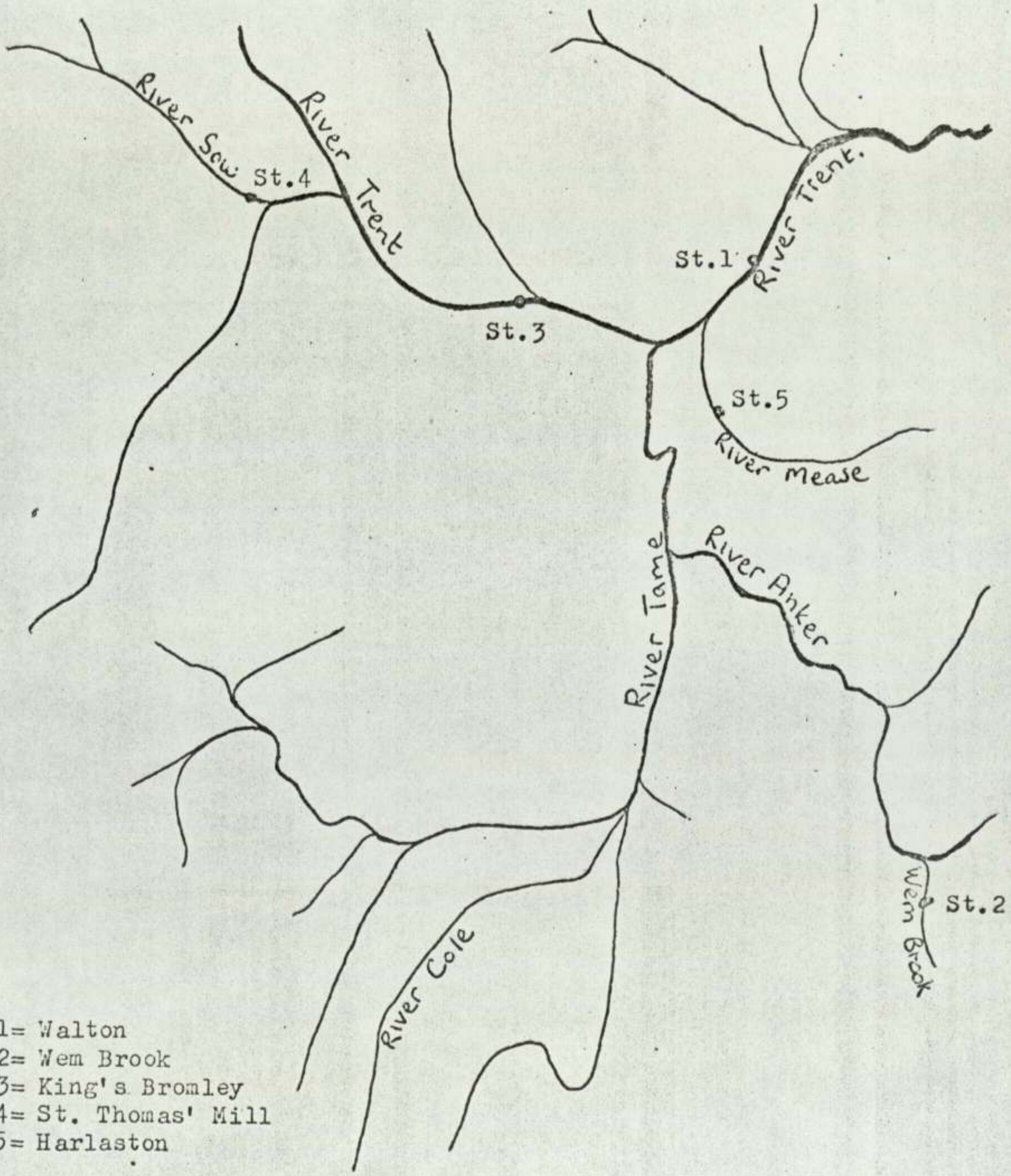
The study of Bobs Brook also commenced in March 1967 and was completed in March 1968. This is a small stream to the west of Dudley and is a tributary of Holbeache Brook which in turn unites with Smestow Brook which enters the River Stour (a tributary of the Severn).

Bobs Brook received an effluent from a sewage works, the effluent was largely domestic and was well oxidised. The sampling station chosen was approximately 100 metres downstream of the effluent outfall. At the station the stream was approximately 2 metres wide. At this point flow was exceedingly rapid while the bottom although composed mainly of stones and pebbles also contained broken house bricks etc. The stream in this region was shaded, mainly by willow and elm trees.

Merry Hill Brook (fig. 6)

Merry Hill Brook arises in south west Wolverhampton and is almost wholly composed of sewage effluent. The stream flows in a south-westerly direction and then enters Smeston Brook which is a tributary of the River Stour. This study commenced in June 1967 and was completed in June 1968.

Fig. 7. Map to show the position of Trent sampling stations

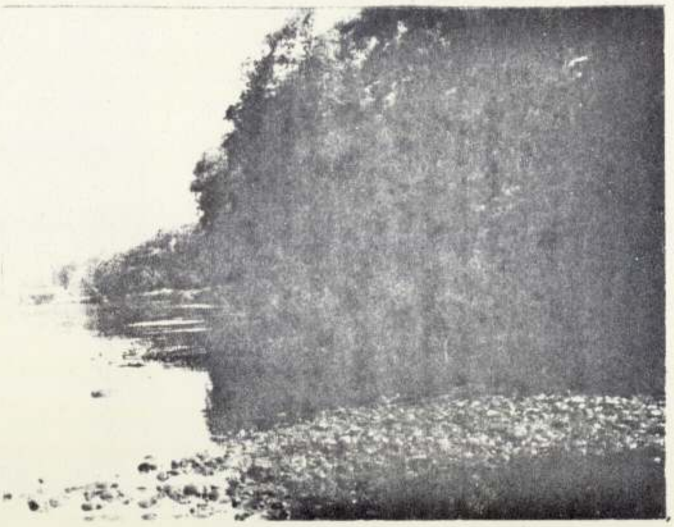


Key
St.1= Walton
St.2= Wem Brook
St.3= King's Bromley
St.4= St. Thomas' Mill
St.5= Harlaston

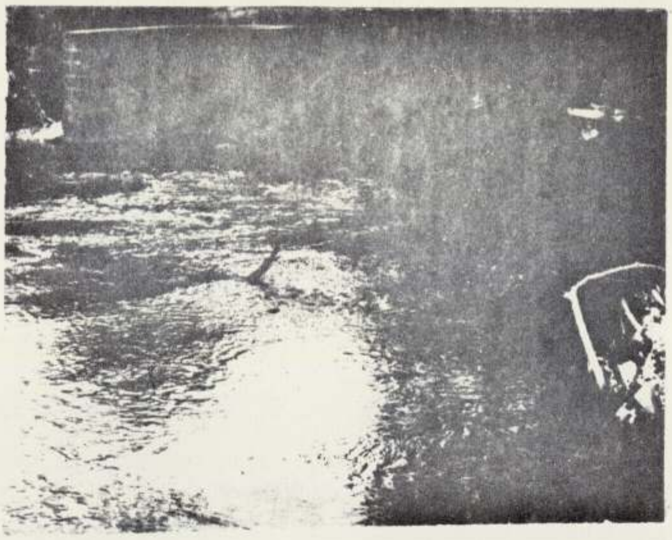
Scale- Approx. 1 inch to 5 miles
1 cm. to 2 Km.

River Trent sampling stations.

Photograph 14. Walton.



Photograph 15. Wem Brook.



Photograph 16. King's Bromley.

River Trent sampling stations (cont.)

Photograph 17. River Sow at St. Thomas' Mill

Photograph 18. Harlaston.

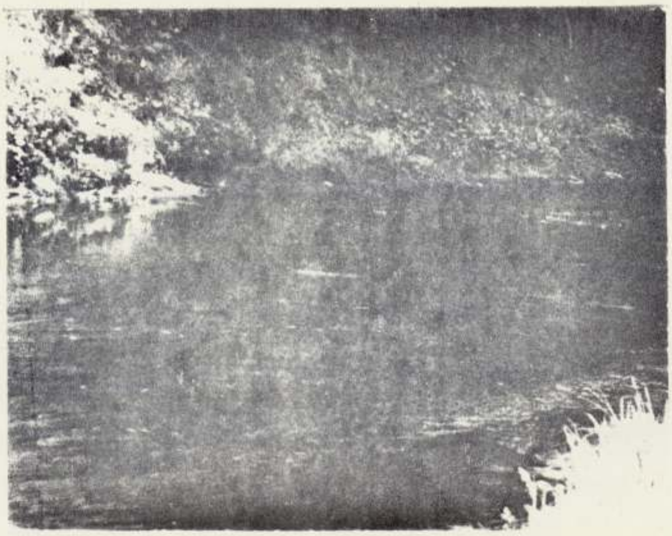
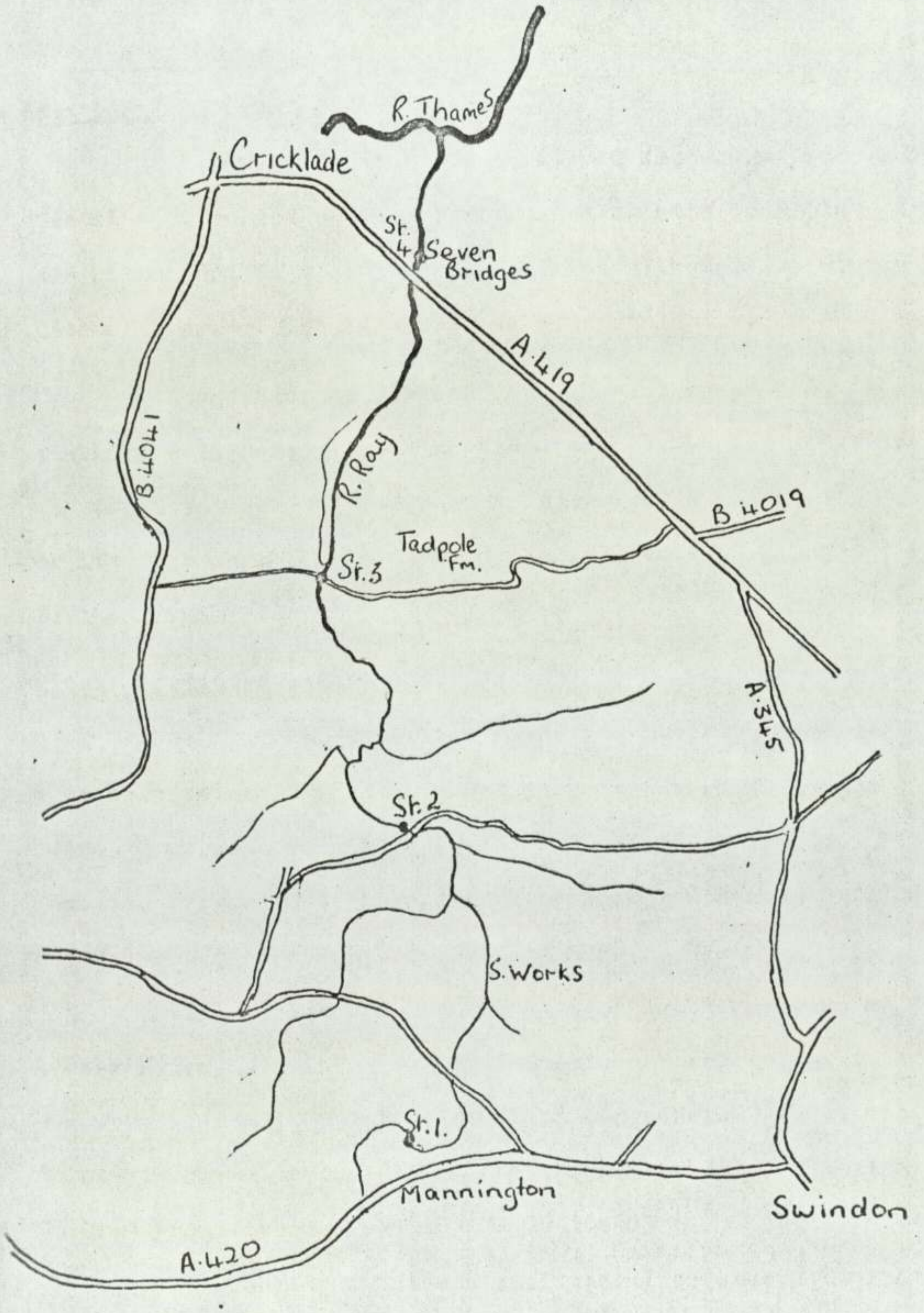


Fig. 8. Map to show location of River Ray sampling stations.



Scale: 1 inch to 1 mile.
5 cm. to 2 Km.

Station 1 SO 878965

The stream at this point was 2 metres wide and in the riffle sections 5-8 cms deep. The bottom was composed of water worn stones, and these usually had a covering of either 'sewage fungus' or Stigeoclonium. At this point the station was not shaded.

Station 2 SO 862958

This station was approximately 2 Kms downstream of Station 1. The stream had not obviously increased in size from Station 1 and the bottom was of a similar composition although the stones were no longer covered by sewage fungus or Stigeoclonium.

In addition to the stations already described, five other stations were sampled regularly and another stream occasionally. The five stations sampled regularly were situated on the River Trent or its tributaries, the other stream was the River Ray a tributary of the River Thames.

Trent Sampling Stations (fig. 7)

The stations were sampled at two-monthly intervals and were specially selected from information provided by the Trent River Board to provide varying degrees of organic enrichment. This sampling programme commenced in June 1968 and lasted until June 1969.

(1) Walton (photograph 14) GR SK 211178

This station was approximately 4 Kms downstream of the entry of the River Tame into the River Trent. The Trent at this point was approximately 40 metres wide and very deep. Quantitative samples were taken near the banks where the bottom was stony.

(2) Wem Brook (photograph 15) GR SP 369903

Wem Brook is a tributary of the River Anker and the sampling station was situated in the Pingle Fields area of Nuneaton. The stream was 3-4 metres wide and in the riffle sections about 12 cms deep. The bottom was stony with thick growth of Cladophora.

(3) Kings Bromley (photograph 16) GR SK 123173

This sampling station was situated on the southern fork of the River Trent. The river at this point was approximately 15 metres wide and in the riffle sections 25 cms deep. The bottom was composed mainly of rounded pebbles with fine sand in between.

(4) St. Thomas' Mill (photograph 17) GR SJ 949229

This station was situated on the River Sow approximately 500 metres downstream of the entry of the River Penk. The river at this point was approximately 18-20 metres wide. Quantitative samples were only taken near the banks. The bottom of the river in the sampling places was of water worn pebbles, which were occasionally covered in growths of Cladophora.

(5) Harlaston (photograph 18) GR SK 214113

This station was situated on the River Mease. At this sampling station the river was approximately 20 metres wide. Quantitative samples were again taken near the banks.

River Ray Sampling Stations (fig. 8)

The River Ray which is a tributary of the River Thames was sampled at four places on two occasions. The first set of samples were taken in March 1968 and the second in July 1969. The samples taken were not quantitative.

Station 1. GR SU 125845

This station was upstream of Rodbourne Works effluent and the river at this station was approximately 4 metres wide.

Station 2. GR SU 122873

The second station was approximately 2.5 Kms downstream of the effluent outfall. The river was now considerably larger and was approximately 12 metres wide. The bottom was stony with thick growths of Cladophora.

Station 3. GR SU 111897

This station was approximately 6 Kms downstream of the effluent. As in the previous station the bottom was stony with profuse growths of *Cladophora*.

Station 4. GR SU 119927

This sampling station was approximately 9.5 Km. downstream of the effluent, approximately 1 Km upstream of where the Ray enters the Thames.

3.2 River Cole and Dowles Brook

3.2.1 Results

3.2.1.1 Chemical Results

Dowles Brook and the River Cole were sampled for 13 months from December 1966 to December 1967.

The results from the seven stations sampled showed clearly the effect of an organic discharge on the chemical composition of the water. Dowles Brook has no source of organic pollution and this is reflected in the results. River Cole, Station I, was generally in a worse condition than Dowles Brook owing to the poultry farm upstream. The entry of the sewage effluent however has a marked effect and Station 2 can be described as being badly polluted. There was usually a gradual recovery downstream, but unfortunately Station 6 did not show complete recovery before the river received further pollution of an industrial origin. The relevant chemical and physical factors will now be considered. These are shown on Table 1. (Appendix)

Dissolved Oxygen (fig. 9)

The dissolved oxygen figures for the 13 months clearly reflected the polluted state of the River Cole. The effect of the organic effluent however was far more noticeable during the summer

Fig.9. Monthly oxygen and temperature recordings for Dowles Brook and the River Cole from December 1966 to December 1967.

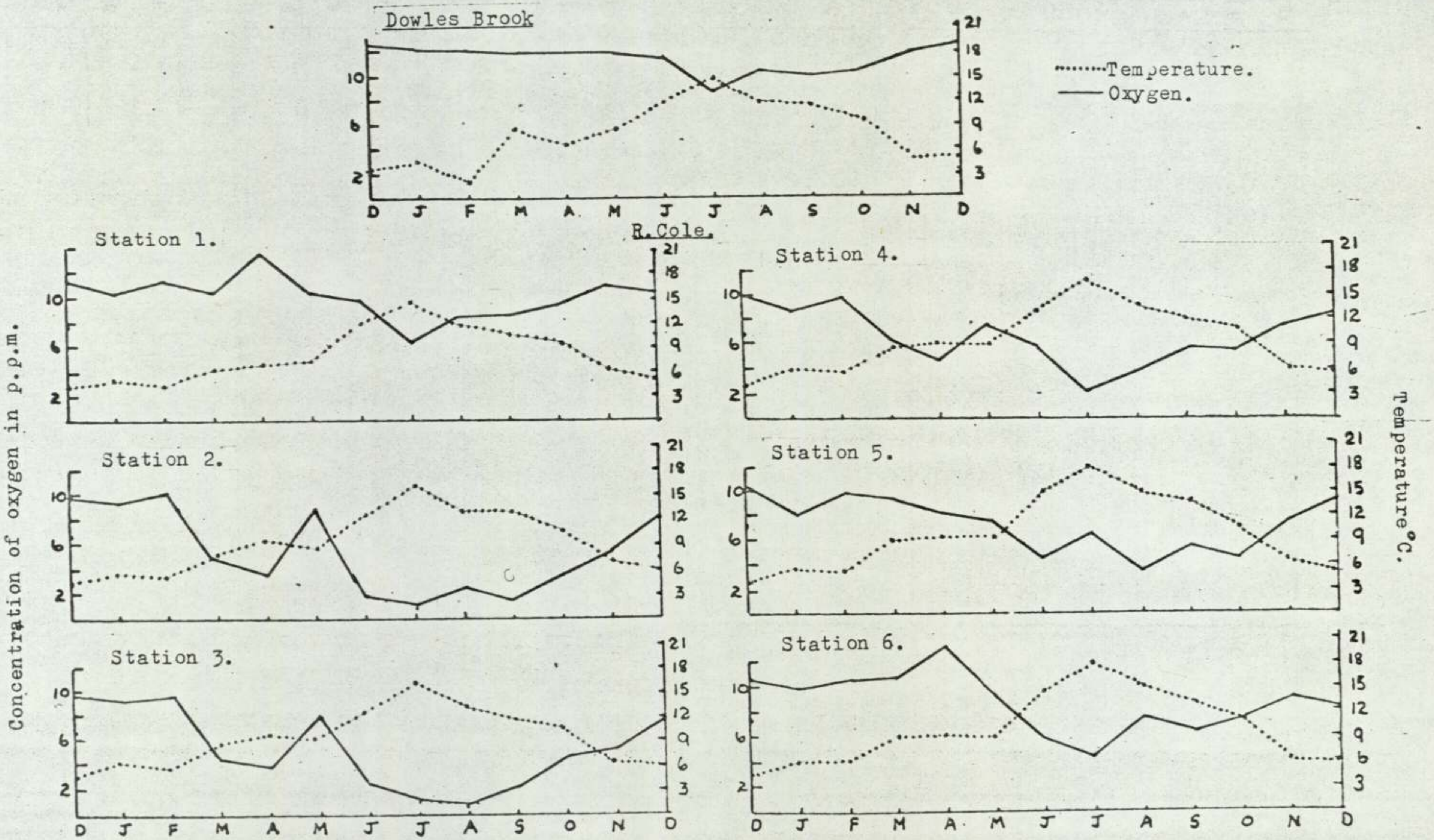
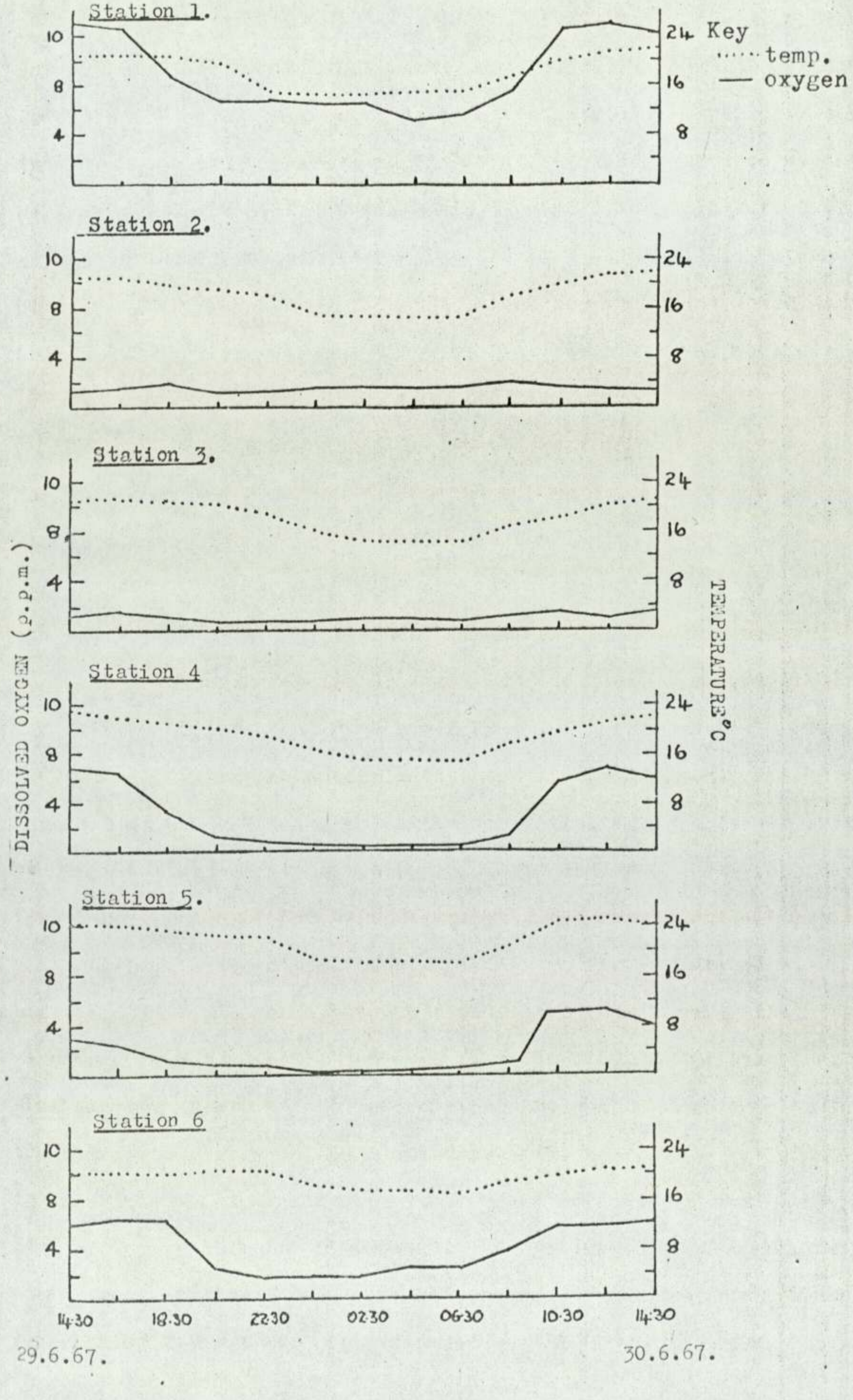


Fig. 10 Temperature and oxygen recordings made during a 24hr. survey on the River Cole.



months.

In Dowles Brook and the River Cole Station 1 the water was usually well oxygenated, but with the discharge of organic effluent downstream of Station 1 the oxygen concentration was greatly reduced, in some cases to just above zero. The lowest figures were recorded at Stations 2 and 3, and there was then usually a gradual recovery as can be seen from the records for Stations 4, 5 and 6. At Station 6, the lowest point sampled, recovery was by no means complete and the oxygen figures would suggest that the river was moderately polluted at this point.

In Dowles Brook and Cole 1 the lowest figures recorded were for July and they were 8.9 p.p.m. and 6.5 p.p.m. respectively. With the exception of the July figures the daytime oxygen concentration did not vary a great deal at these two places. At the polluted sampling stations on the River Cole the oxygen concentration began falling in April and the lowest recordings were for July or August. At Stations 2 and 3, for four months during the summer, the oxygen concentration was around 2 p.p.m. De-oxygenation was not quite so marked at Station 4, to a lesser extent at Station 5 and least at Station 6. The lowest figures recorded for these three stations were 2.1 p.p.m., 3.8 p.p.m. and 4.2 p.p.m. respectively. The dissolved oxygen figures for May are particularly high for all stations on the River Cole, the reason being that the samples were taken when there were high flows following heavy rain.

Diel Fluctuations Over a period of 24 hrs. samples were taken at two hourly intervals on the River Cole. These results are given in figure 10. At Stations 1, 4, 5 and 6 there were marked diel fluctuations, while at Stations 2 and 3 the oxygen concentrations varied very little. In the four stations showing diel variations the highest figures were recorded between 12 noon and 4 p.m., there was then a gradual fall in the oxygen concentration until midnight. For the next six hours the oxygen concentration remained approximately the same. At day-break, which was approximately 6.0 a.m. the oxygen concentration began to rise and increased steadily until noon. Station 1 showed the diel fluctuation very well and the highest oxygen concentration recorded was 11 p.p.m. at 2.30 p.m. while the lowest was 5.2 p.p.m. at 4.30 a.m. At Stations 4 and 5, during the period of darkness, the oxygen concentration was exceptionally low and well below 1 p.p.m. for eight hours. The lowest recorded figures for Stations 4 and 5 were 0.35 p.p.m. and 0.3 p.p.m., the highest during daylight being 6.8 and 5.2 p.p.m. Low oxygen figures were also recorded for Station 6 and for a period of four hours, the oxygen concentration was below 2 p.p.m. During the day the oxygen concentration was nearly 7 p.p.m.

The oxygen concentration at Stations 2 and 3, as previously mentioned, varied very little during the 24 hrs. and was uniformly very low. The highest recorded figure for Station 2 was 2.1 p.p.m. and the lowest 1.2 p.p.m., for Station 3 it was 1.4 p.p.m. and 0.6 p.p.m. respectively.

Temperature

The temperature recordings were generally very similar at all seven stations (fig. 9) and showed the obvious increase during the summer months. The discharge of the effluent into the River Cole always seemed to increase the temperature of the water. Station 2 was always warmer than Station 1, this increase was usually small, the biggest variation being 2.5°C.

During the summer months there was a tendency for the River Cole to become warmer as it flowed downstream. The highest water temperature recorded from the monthly samples was from Stations 5 and 6 when it was 18°C.

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During the summer months there was a tendency for the River Cole to become warmer as it flowed downstream. The highest water temperature recorded from the monthly samples was from Stations 5 and 6 when it was 18°C.

The 24 hr. survey on the River Cole which was undertaken during a period of dry hot weather provided very high temperature recordings (fig. 10). The highest figures were recorded at 2.30 and 4.30 p.m., the lowest figures at 2.30 a.m. The diel variation in all stations was approximately 6°C. At all stations the temperature exceeded 20°C at 2.30 p.m. and at Station 5 it was over 24°C.

Calcium and Magnesium

In terms of hardness the water at all seven stations was fairly similar and could be described as hard water. The calcium content at any one station tended to remain fairly constant throughout the year, although if sampled after heavy rain the concentration was usually significantly lower.

Dowles Brook had an average calcium content for 12 months of 48.5 p.p.m., for the River Cole 1 it was 40 p.p.m. The calcium concentration usually increased downstream and the average for Stations 2, 3, 4, 5 and 6 was 43, 47.7, 49.7, 49.7 and 52.9 p.p.m. respectively.

Magnesium tended to vary more than calcium. The water in Dowles Brook usually contained less calcium than the stations on the River Cole. The magnesium concentration of the water varied more from month to month than the calcium although in the six stations on the Cole, all were fairly similar each month. The water in Dowles Brook usually contained less magnesium than the River Cole, the average for 12 months being 5.9 while the lowest average figure in the Cole was the 9.1 of Station 2.

As with calcium the magnesium content, with the exception of Station 2, tended to increase downstream, the averages for the six stations (1-6) being 12.3, 9.1, 11.2, 12.0, 12.4 and 13.9 p.p.m.

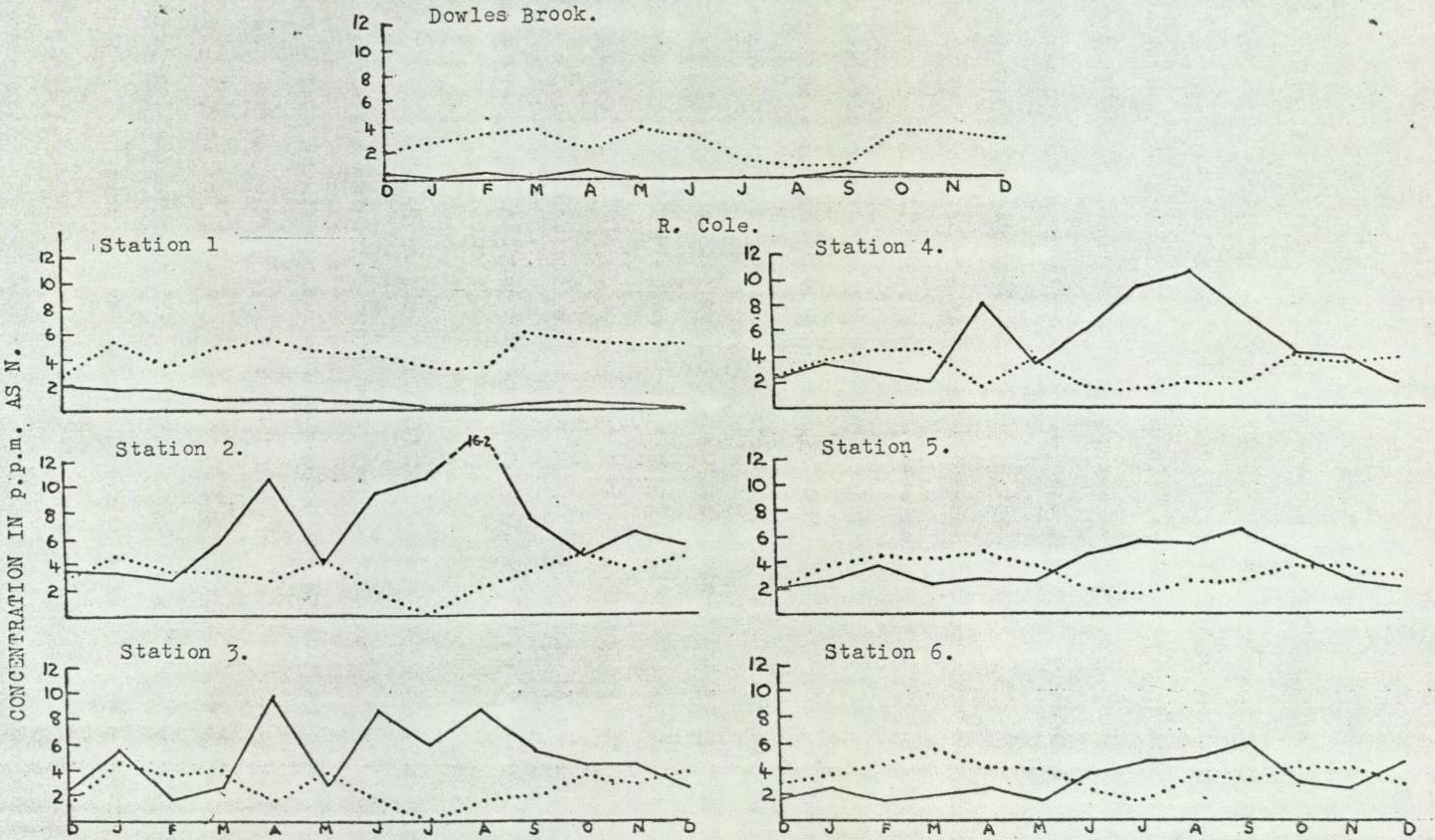


Fig.11 Monthly concentrations of ammonia (—) and oxidised nitrogen (····) for Dowles Brook and the River Cole from December 1966 to December 1967.

Ammonia (fig. 11)

The concentrations of ammonia recorded for the seven stations varied with the polluted state of the river.

The water in Dowles Brook usually contained no ammonia at all, the average for 12 months being 0.1 p.p.m. Station 1 on the River Cole usually had slightly more, the average here being 0.69 p.p.m. but again the concentrations were low, the highest recorded was 2.0 p.p.m. Below the effluent however the ammonia concentration was greatly increased and the highest concentrations were usually recorded at Station 2, the ammonia concentration usually falling progressively downstream as oxidation occurred.

The water at Station 2 usually contained high concentrations of ammonia especially during the summer months and during July a figure of 36.5 p.p.m. was recorded, giving a clear indication of how badly polluted the river was at this point. At Stations 3, 4, 5 and 6 the water, although containing less ammonia than at Station 2, still had high concentrations of ammonia present, the highest figures recorded for these stations being 9.4, 10.6, 6.4 and 6.0 p.p.m. respectively.

It was found that in the polluted stretch of the River Cole the ammonia concentration could vary over a period of 8 hours, but always within the limits recorded from routine monthly samples at any one station. Five stations on the River Cole were sampled at 10 a.m., 2 p.m. and 6 p.m. (Table 2). The ammonia concentration at Station 1 was similar for all three samples. The concentration at Station 2 however was approximately 50% higher at 2 p.m. than for the other two samples taken. Station 3 differed in that the highest concentration recorded was at 6 p.m. when 8.2 p.p.m. was present. At both Stations 4 and 5 there was little fluctuation on the three occasions it was sampled.

The results were, on the whole, as would be expected, the lowest average concentration was at Station 1 (0.43 p.p.m.), the highest at Station 2 (9.2 p.p.m.) from where the concentrations gradually decreased downstream.

Nitrates (fig. 11)

Oxidised nitrogen was never present in large concentrations at any station and did not reflect the polluted condition; the station with the highest monthly average was in fact Station 1 (4.6 p.p.m.). The low concentrations of oxidised nitrogen, together with the high concentrations of ammoniacal nitrogen recorded in the polluted regions of the Cole pointed to the fact that it was a poorly oxidised effluent.

Orthophosphates

As with ammonia and dissolved oxygen the orthophosphates present indicated the polluted state of the river, the concentrations being highest in the summer months. Quite high concentrations were recorded at Station 2 especially during the summer months. Downstream of Station 2 there was a gradual fall in the amount present although during July concentrations of over 2 p.p.m. were recorded at both Stations 5 and 6. The concentrations recorded for the two non-polluted stations were always negligible.

pH

Dowles Brook was generally more alkaline than the Cole, the pH usually being about 8 compared to the average 7.4 of Station 1 of the Cole. The entry of the effluent into the Cole had the effect of lowering the pH, the average for Station 2 being 7.2. Downstream the water became progressively more alkaline and the average for 12 months for Station 6 was 7.66.

B.O.D.

The variation in this factor in the seven stations again clearly reflected the degree of pollution. Dowles Brook generally had very low values the highest recorded figure being 3.8 p.p.m. The results clearly demonstrate the extremely good quality of the stream. River Cole 1 also had low values, although usually higher than Dowles Brook. The B.O.D. at this station would suggest that the water is slightly polluted. As was expected the B.O.D. of the water was greatly increased below the effluent. The highest figures were usually obtained at Station 2, the values then decreasing downstream.

The B.O.D. clearly shows that during the summer months, in periods of low flow, the whole river below the effluent was badly polluted, even at Station 6 in July the B.O.D. of the water was 27.4 p.p.m. In some months the B.O.D. of the river water was so high that the sample was not sufficiently diluted and all the oxygen in the sample was used up. This occurred in the sample from Station 3 during April and the samples from Stations 2, 3 and 4 in July.

3.2.1.2 Biological Results

The results of the intensive survey are summarised in Tables 3-9.

Dowles Brook (Table 3)

The faunal samples from Dowles Brook revealed that the fauna was one dominated numerically by Ephemeropteran nymphs and Gammarus pulex. Other groups such as the Plecoptera and Trichoptera were also represented.

One of the most striking features of the fauna was the great variety of Plecoptera, Trichoptera and Ephemeroptera present. The nymphs of fourteen different species of Plecoptera were recorded although they did not appear to be present in large numbers. Capnia *bifrons* appeared to be the most abundant form in the winter months, while in early summer it was *Amphinemoura sulcicollis* and in late summer *Leuctra moselyi*. Other nymphs frequently found in the samples were those of *Leuctra hippopus*, and *Isoperla grammatica*.

The Trichoptera was also well represented and the larvae of nine species were recorded. *Hydropsyche fulvipes* appeared to be the most numerous species, while the larvae of *Rhyacophila dorsalis* were also present in comparatively large numbers considering that it is a carnivore.

This diversity of species was also encountered in the Ephemeroptera where the nymphs of five species were recorded. The nymphs of this group often formed a large proportion of the numbers of individuals caught. *Rhithrogena semicolorata* and *Baetis rhodani* were usually the most numerous species in the samples. In the summer *Ephemerella ignita* was also numerous as was *Ecdyonurus dispar* in the late summer and autumn.

Gammarus pulex was well represented in all the monthly samples and appeared to be an important member in terms of numbers of the benthic community. Larvae of species belonging to the Coleoptera and Diptera were also usually present in the samples but with the exception of *Dicranata* they were never present in large numbers.

The Oligochaeta were never present in large numbers in the samples and were mainly represented by the Lumbriculidae, although the Tubificidae were also present in relatively small numbers.

Two groups which can sometimes form large populations in fresh-water streams are the Hirudinea and Chironomidae. Both these groups seemed to be poorly represented in Dowles Brook. Only two leeches were recorded and these belonged to different species. A number of different species of Chironomid larvae were usually present in the samples but they were never present in large numbers. Measurements of the body length of five species found commonly in the samples revealed some interesting features concerning growth rates.

Baetis rhodani (fig. 12) was present throughout the year. It was represented in the December sample by seven half-grown nymphs, from January to April the numbers slightly increased and a number of fully grown nymphs were present in the samples. From May to July there was a marked increase in the numbers of nymphs taken but these were immature forms. Very few were taken in August while large numbers were once again present in the September sample, although these were mainly small nymphs. In the last three samples the numbers taken dropped again and the individuals present varied in size.

Ephemerella ignita (fig. 13). The nymphs of Ephemerella ignita were only taken during the summer. The first individuals were recorded in May and the last in September. The species was most numerous in the July samples, the numbers falling in the succeeding months. The measurements revealed how the individuals making up the population increased in size. In May only very small nymphs were taken, the first fully grown nymphs were present in the July sample.

Rhithrogena semicolorata (fig. 14). Nymphs of Rhithrogena were present in the samples throughout the year. This species was well represented in the monthly samples from December to May, for the next three months were was a considerable drop in the numbers taken to be followed by a sharp increase in numbers in the September sample. The size measurements revealed a steady increase in the size of the nymphs from December to May. The first fully grown nymphs being recorded in April. In June and July only a few individuals of

Fig. 12 . The size distribution of the total numbers of Baetis rhodani collected each month from $0{\cdot}1m^2$ of the stream bed of Dowles Brook. (Numbers at the top of each block are the total for that month. Horizontally 0·1 of an inch represents 5 animals.)

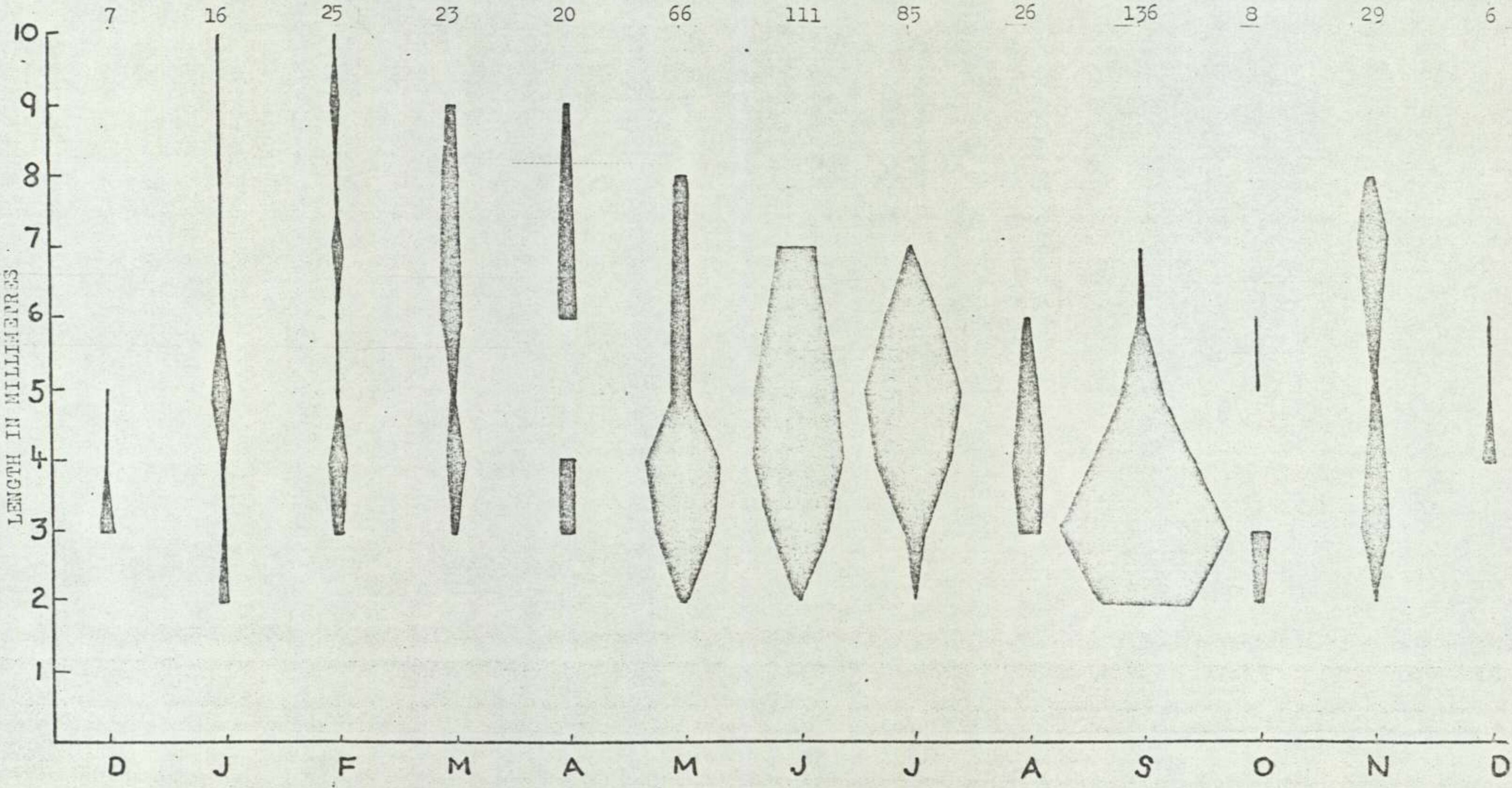


Fig.13.The size distribution of the total numbers of *Ephemerella ignita* collected each month from 0·1m² of the stream bed of Dowles Brook.(Numbers at the top of each block are the total for that month. Horizontally 0·1 of an inch represents 5 animals.)

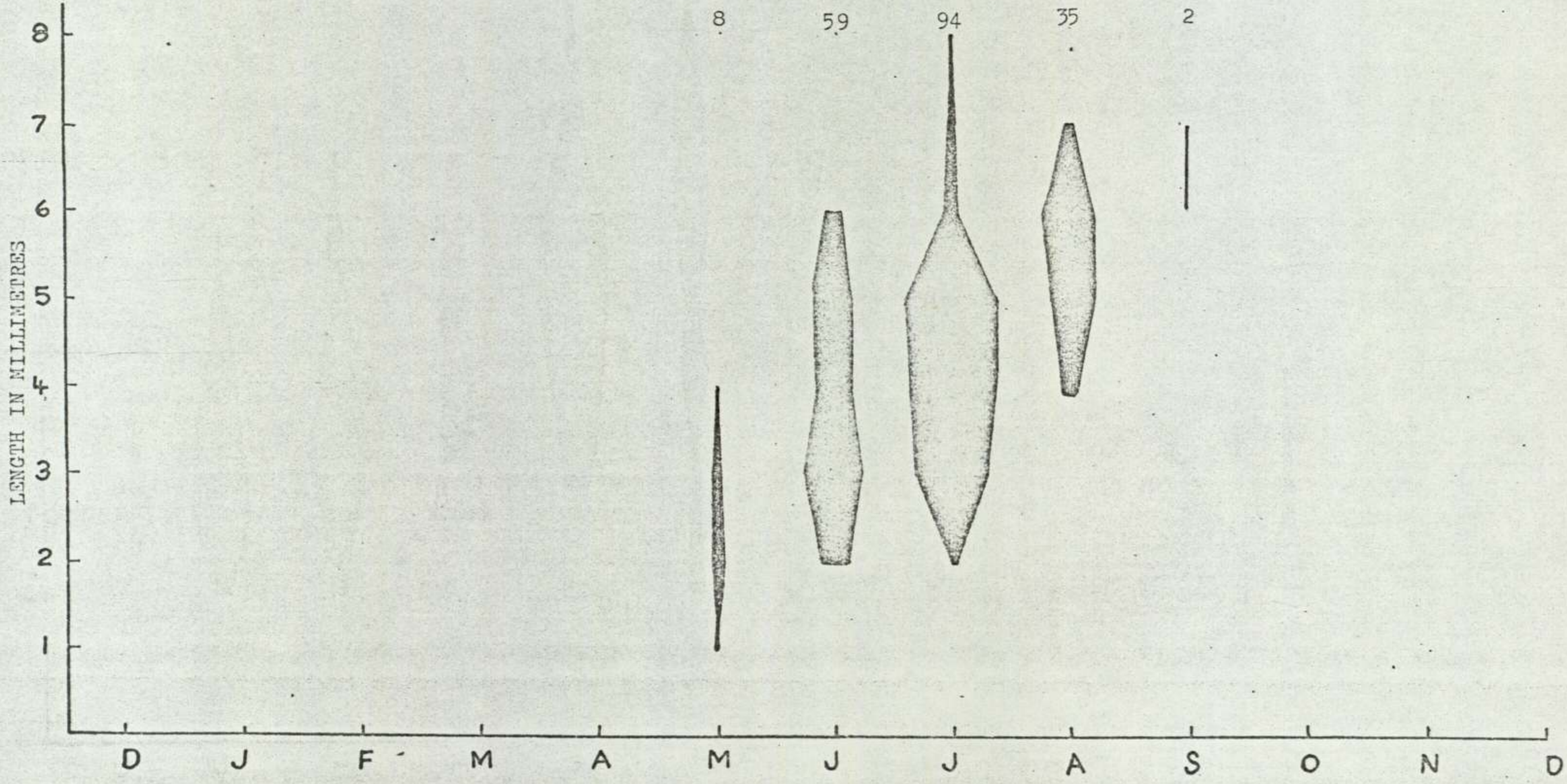


Fig.14. The size distribution of the total numbers of Rhithrogena semicolorata collected each month from 0·1m² of the stream bed of Dowles Brook. (Numbers at the top of each block are the total for that month, horizontally 0·1 of an inch represents 5 animals.)

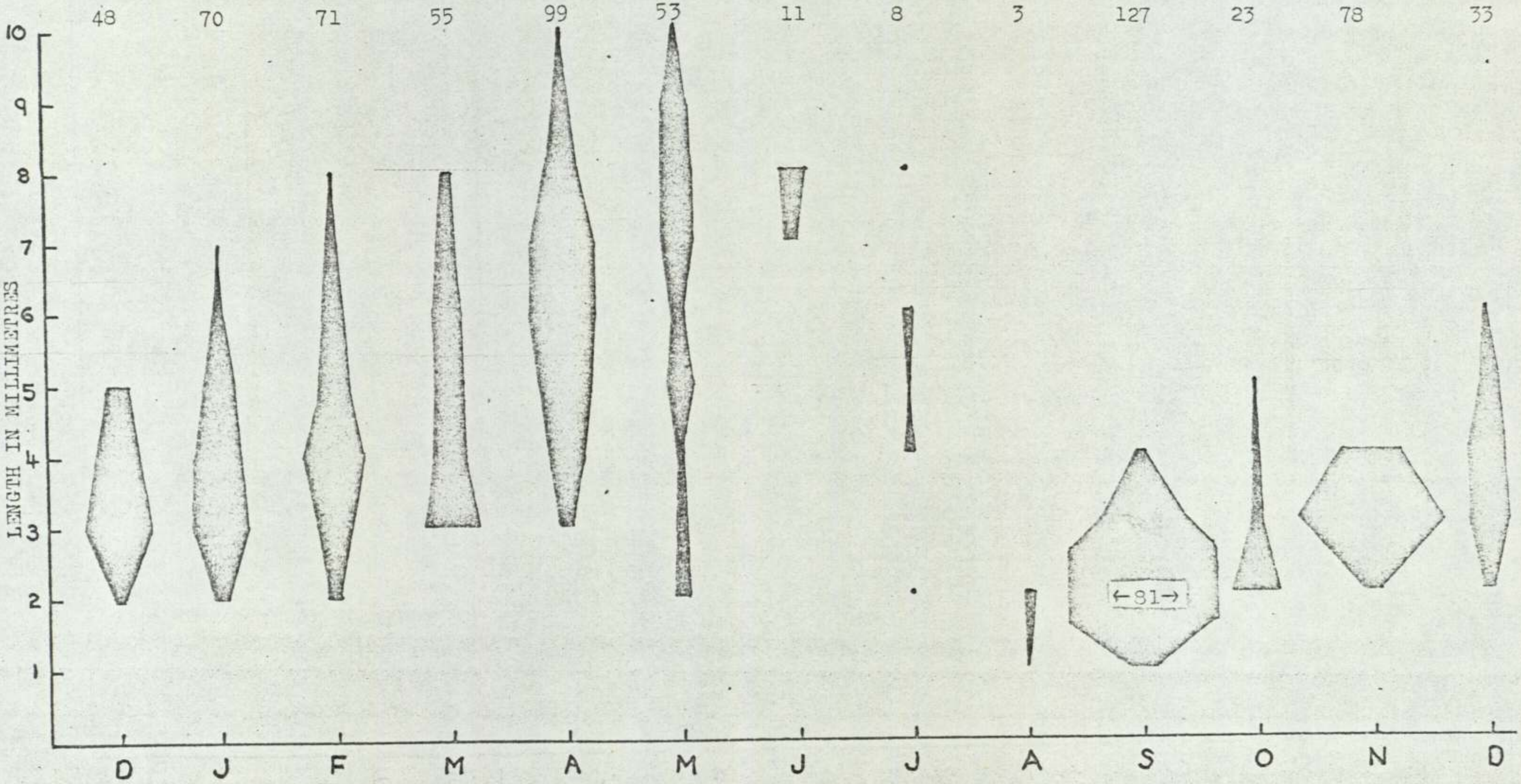


Fig.15. The size distribution of the total numbers of *Hydropsyche fulvipes* collected each month from 0·1m² of the stream bed of Dowles Brook. (Numbers at the top of each block are the total for that month. Horizontally 0·1 of an inch represents 5 animals.)

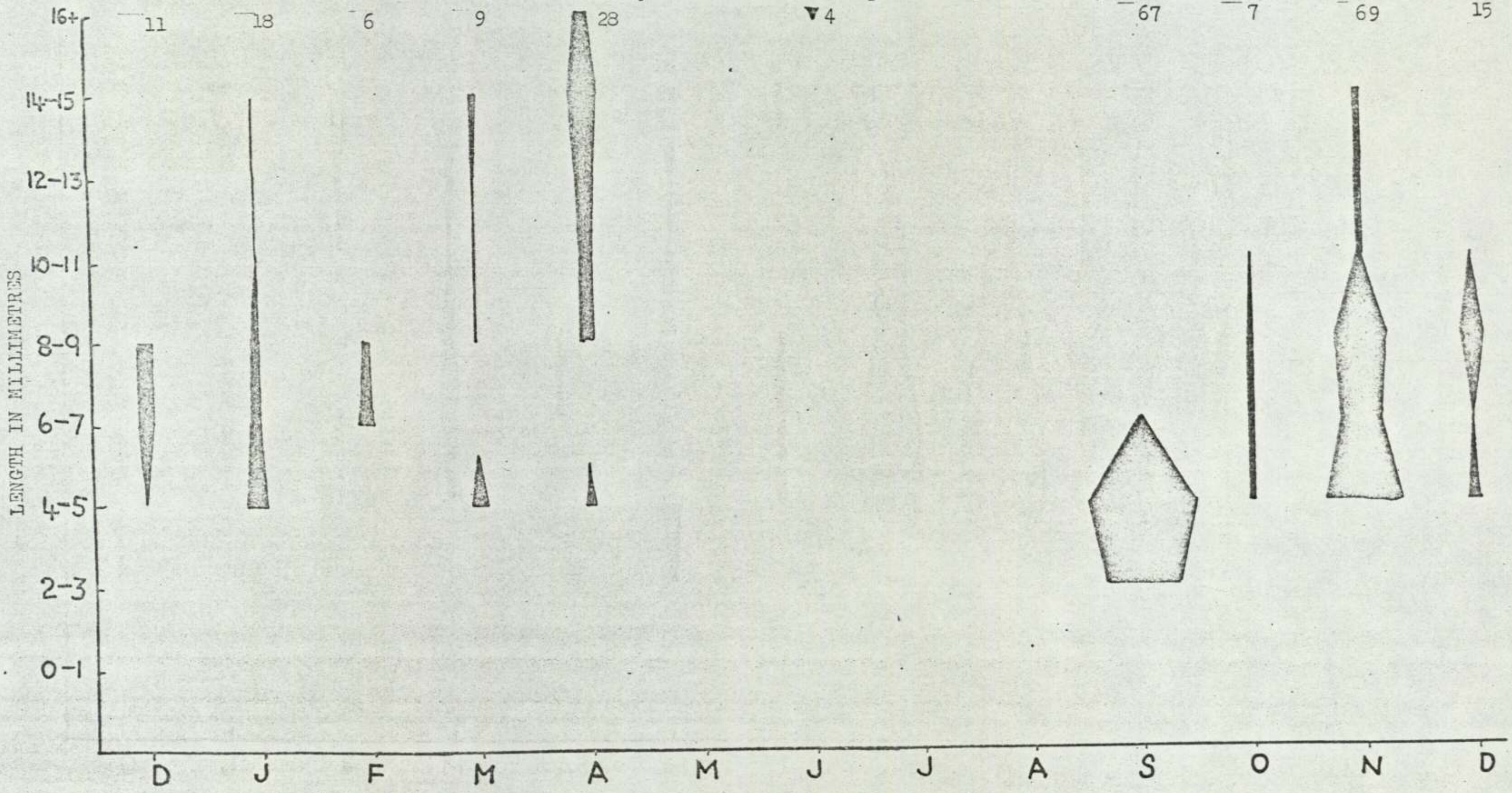
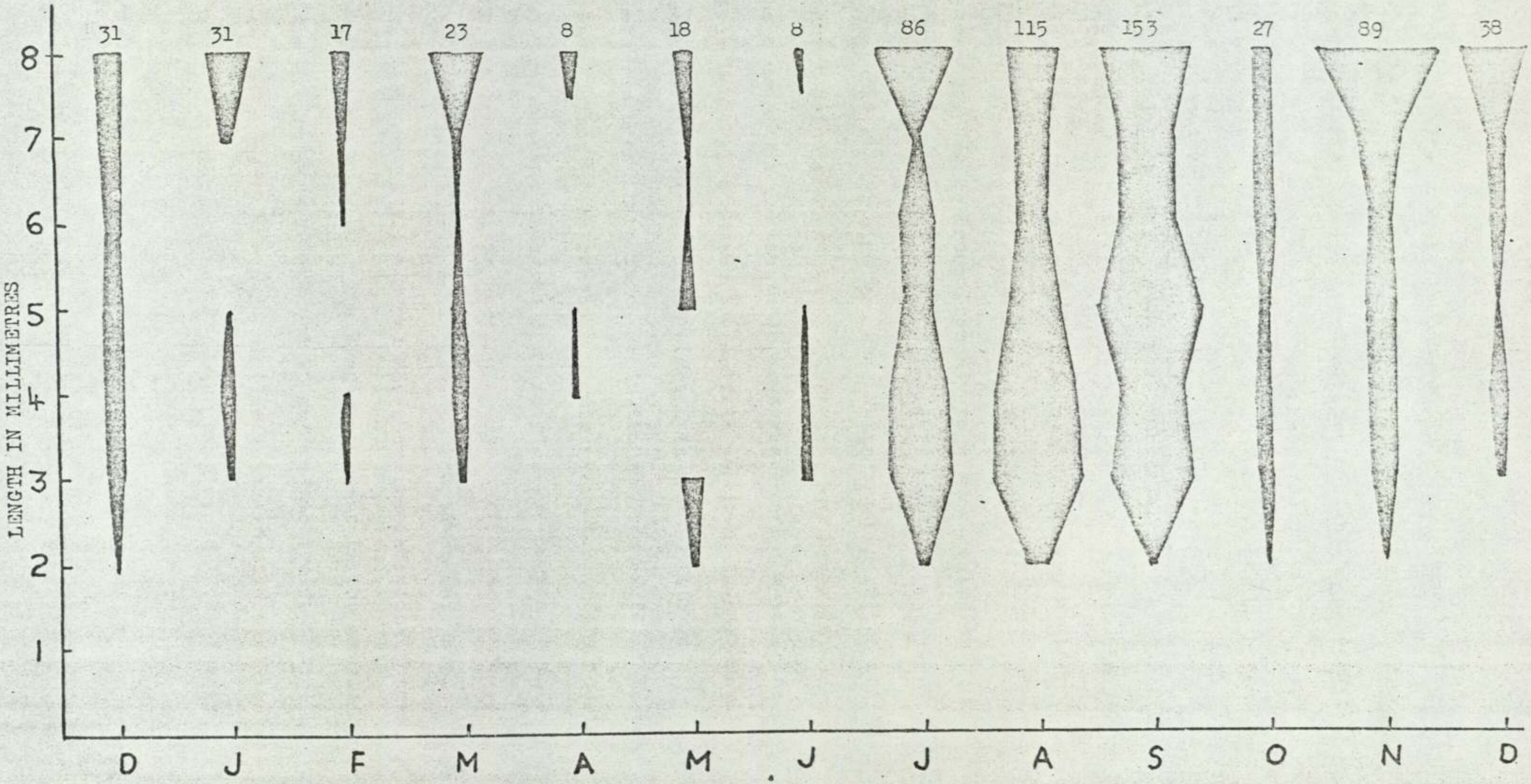


Fig.16. The size distribution of the total numbers of *Gammarus pulex* collected each month from $0{\cdot}1m^2$ of the stream bed of Dowles Brook. (Numbers at the top of each block are the total for that month, horizontally 0·1 of an inch represents 5 animals.)



different lengths were present in the samples. In August only three individuals were taken and these were all small. In the September sample there was a tremendous increase in the numbers of these small nymphs. For the remaining three months of the year the samples suggested that the species was abundant in the stream and largely represented by half-grown nymphs.

Hydropsyche fulvipes (fig. 15). The numbers of the larvae of this species present in the first four monthly samples was similar. In April the numbers taken increased, to be followed by a sharp decrease in the May sample. The larvae of this species was apparently rare in Dowles Brook from May to August, only four individuals being taken during this period. For the last four months of the year the species was once again present in the samples, largest numbers being present in the September and November samples.

The size of the larvae taken appeared to show a definite trend. From December to March the animals measured in any month showed a considerable variation in size. In the April sample however there was a definite increase in the numbers of fully grown larvae. For the next four months with the exception of the four fully grown larvae present in the June sample, the larvae of this species was not present in the samples. The larvae reappeared in the September sample but only small larvae were taken (six mms. being the largest). In October and November the individuals taken became progressively larger. The largest present in the samples for these two months were 11 mms and 15 mms respectively. The larvae in the December sample were similar in their size distribution to those present in the previous December sample, that is, mainly half grown larvae.

Gammarus pulex (fig. 16). G. pulex was present in all the samples, greatest numbers being taken in late summer. The numbers present in the first four monthly samples were approximately the same, and this was followed by a decrease in the numbers present in the samples for the succeeding three months (April, May and June). This was followed in July by a marked increase in the numbers present and large numbers were also present in the August and September samples. The numbers taken then fluctuated there being a decrease in October followed by an increase in November. For the first seven months the size distribution was similar, in any one month the individuals varied in size from very small to full grown. The July, August and September samples were characterised by a great increase in numbers, the animals taken differing in size with no particular size being more common than any other. In both the November and December samples there was a definite increase in the proportion of fully grown individuals to other sizes.

River Cole

Station 1 (Table 4)

The fauna of this station appeared to be quite different to that of Dowles Brook. Although there was a variety of species present the fauna was here dominated by relatively few species. A number of species were common to both e.g. Gammarus pulex and Baetis rhodani but there was a marked change in the relative abundance of other groups. The leeches now formed an important group numerically while the stoneflies appeared to be far less numerous. The Oligochaeta were now present in far larger numbers in the samples, the Tubificidae apparently being the most numerous group at this station, followed by the Lumbriculidae. The Enchytraeidae on the other hand appeared to be rare. The Hirudinea was represented by at least five species. Erpobdella octoculata was common especially in August and September. The other two species usually present in the samples were Glossiphonia complanata and Helobdella stagnalis.

Two species of Crustacea were taken at this station. Gammarus pulex was very common especially in the summer and autumn while Asellus aquaticus was also usually present but in smaller numbers.

The Ephemeroptera appeared to be represented by only one species, namely Baetis rhodani, but this species was always numerous in the samples and at certain times of the year abundant. This apparent restriction in the numbers of species was also found in the Trichoptera and Plecoptera. At least four species of trichopteran larvae were present but only one of these, namely Hydropsyche angustipennis appeared to be common. In August and September this larvae was abundant in the river at this station.

Of the Plecoptera only species belonging to the Nemouridae were recorded. Nemoura cinerea nymphs most frequently occurred in the samples. The Diptera was quite well represented by the Simulidae and Chironomidae. Simulium ornatum larvae were common in the samples taken during the winter and spring. The larvae of three species of Chironomidae were also frequently taken, these being Trichocladius rufiventris, Cricotopus bicinctus and Eukiefferiella hospitus. Trichocladius rufiventris and Cricotopus bicinctus appeared to be most numerous in the summer months while Eukiefferiella hospitus was apparently abundant in the winter months.

The body lengths of four common species at Station 1 were measured in order to obtain some information about growth rates and the composition of the populations during the year.

Erpobdella octoculata (fig. 17) was present in quite large numbers in the samples throughout the year. From December to June the specimens taken varied in size. In June and even more so in August and September the numbers increased and this was largely due to large numbers of very small individuals. In the last three months

Fig.17. The size distribution of the total numbers of Erpobdella octoculata collected each month from 0·1m² of the stream bed of Station 1 of the River Cole. (Numbers at the top of each block are the total for that month, horizontally 0·1 of an inch represents 8 animals.)

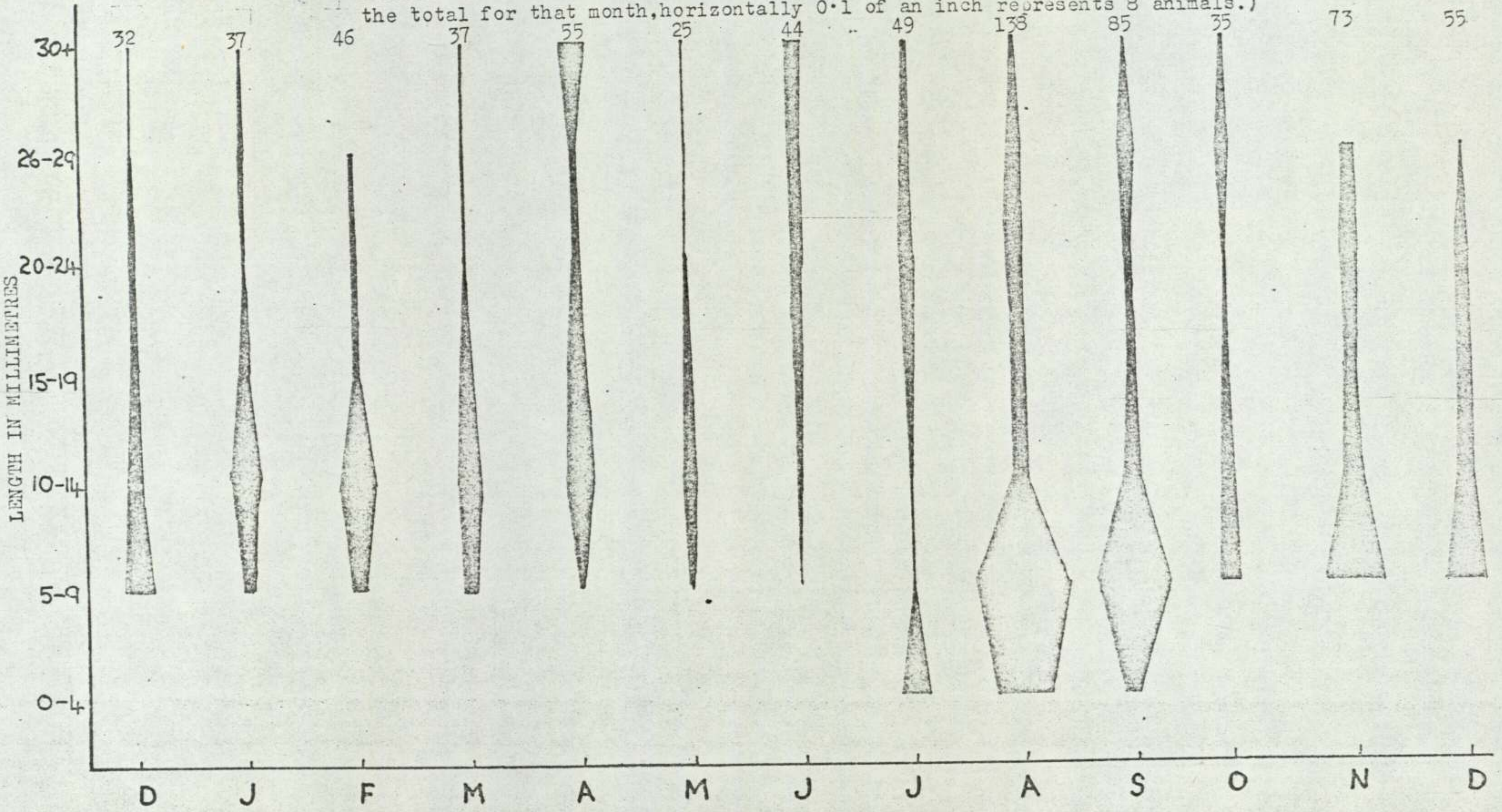


Fig.18. The size distribution of the total numbers of *Gammarus pulex* collected each month from $0{\cdot}1m^2$ of the stream bed of Station 1 of the River Cole. (Numbers at the top of each block are the total for that month, horizontally 0·1 of an inch represents 10 animals.)

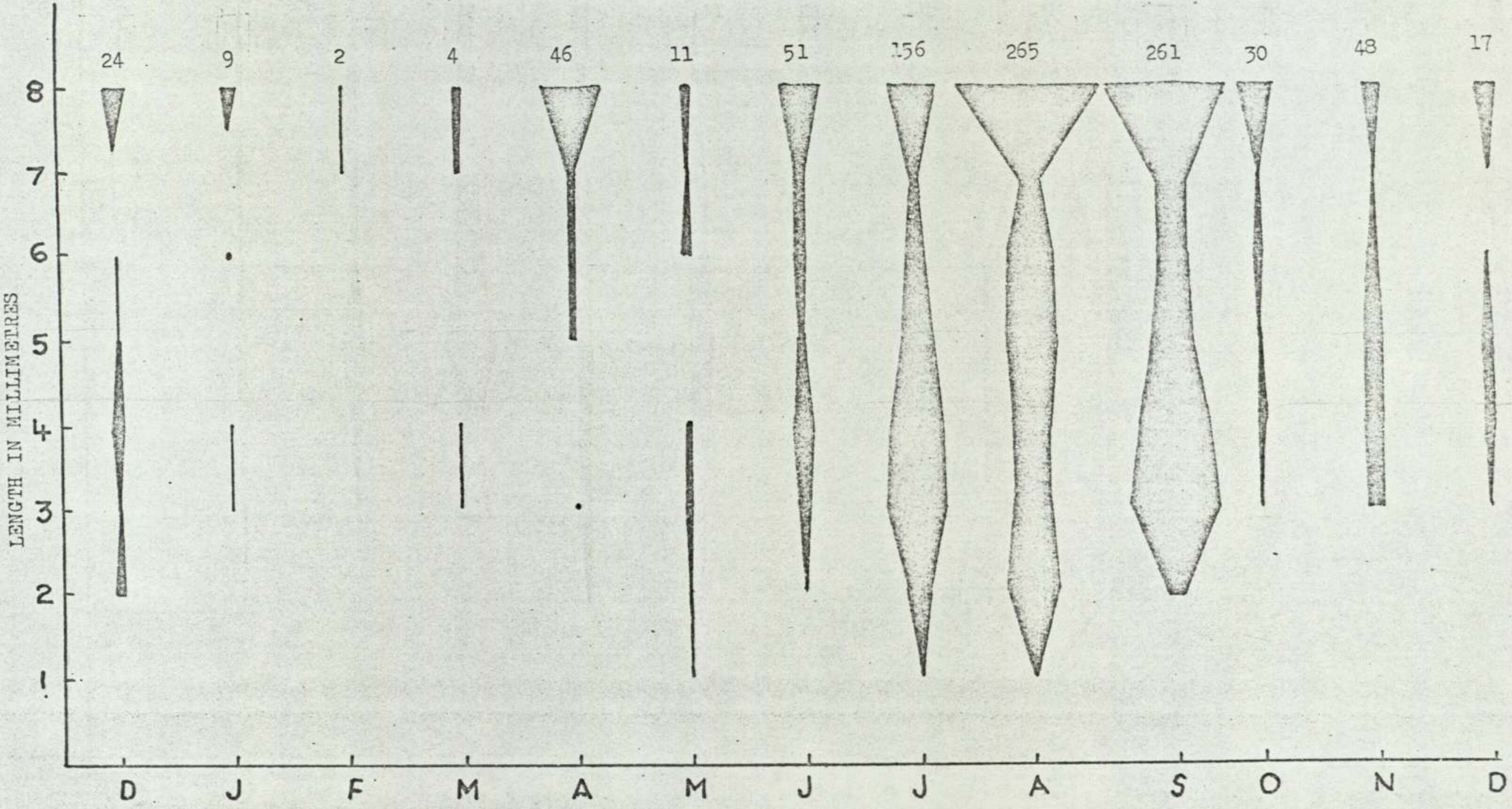


Fig. 19. The size distribution of the total numbers of *Hydropsyche angustipennis* collected each month from $0{\cdot}1m^2$ of the stream bed of Station 1 of the River Cole. (Numbers at the top of each block are the total number for that month. Horizontally 0·1 of an inch represents 10 animals.)

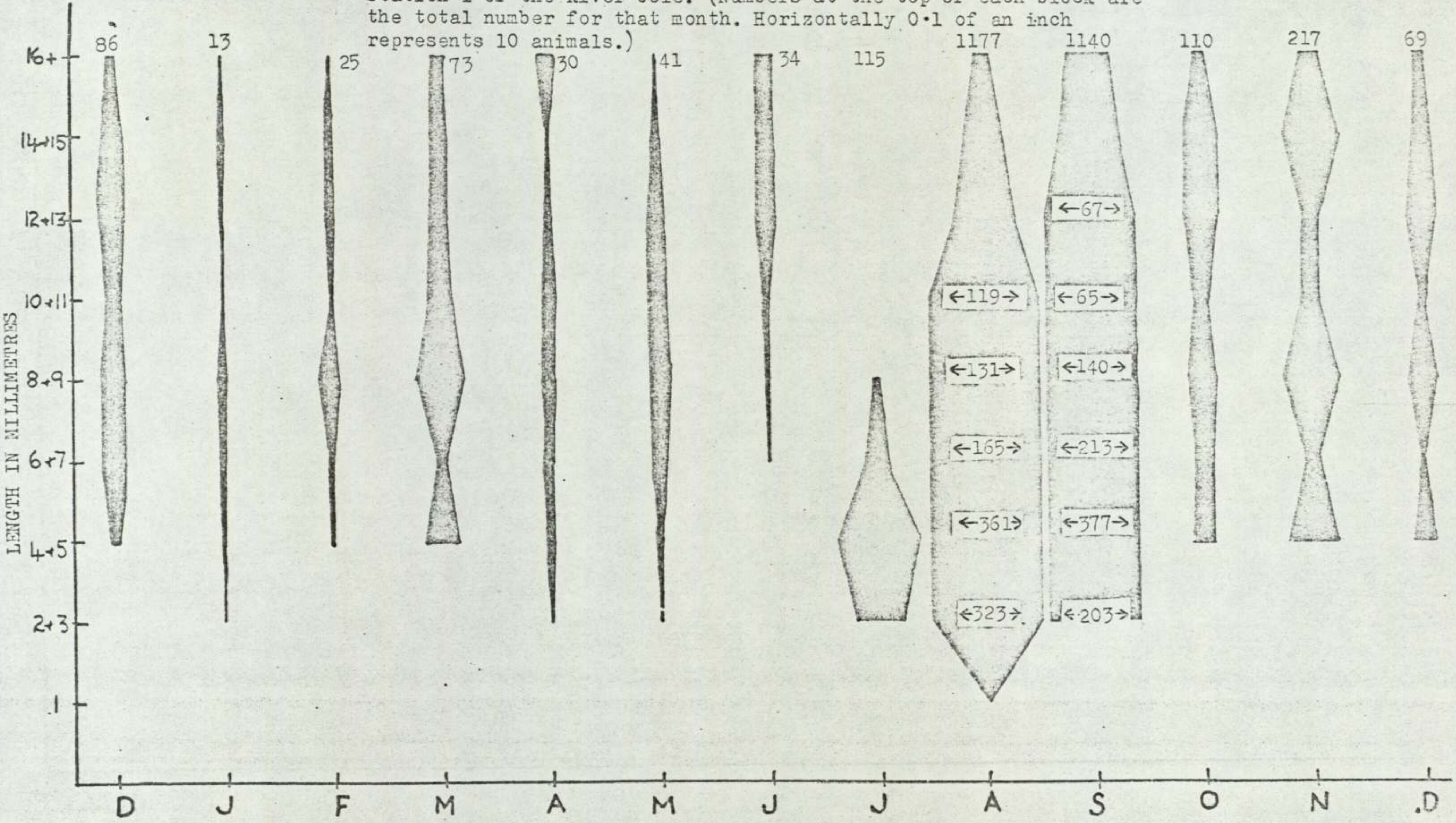
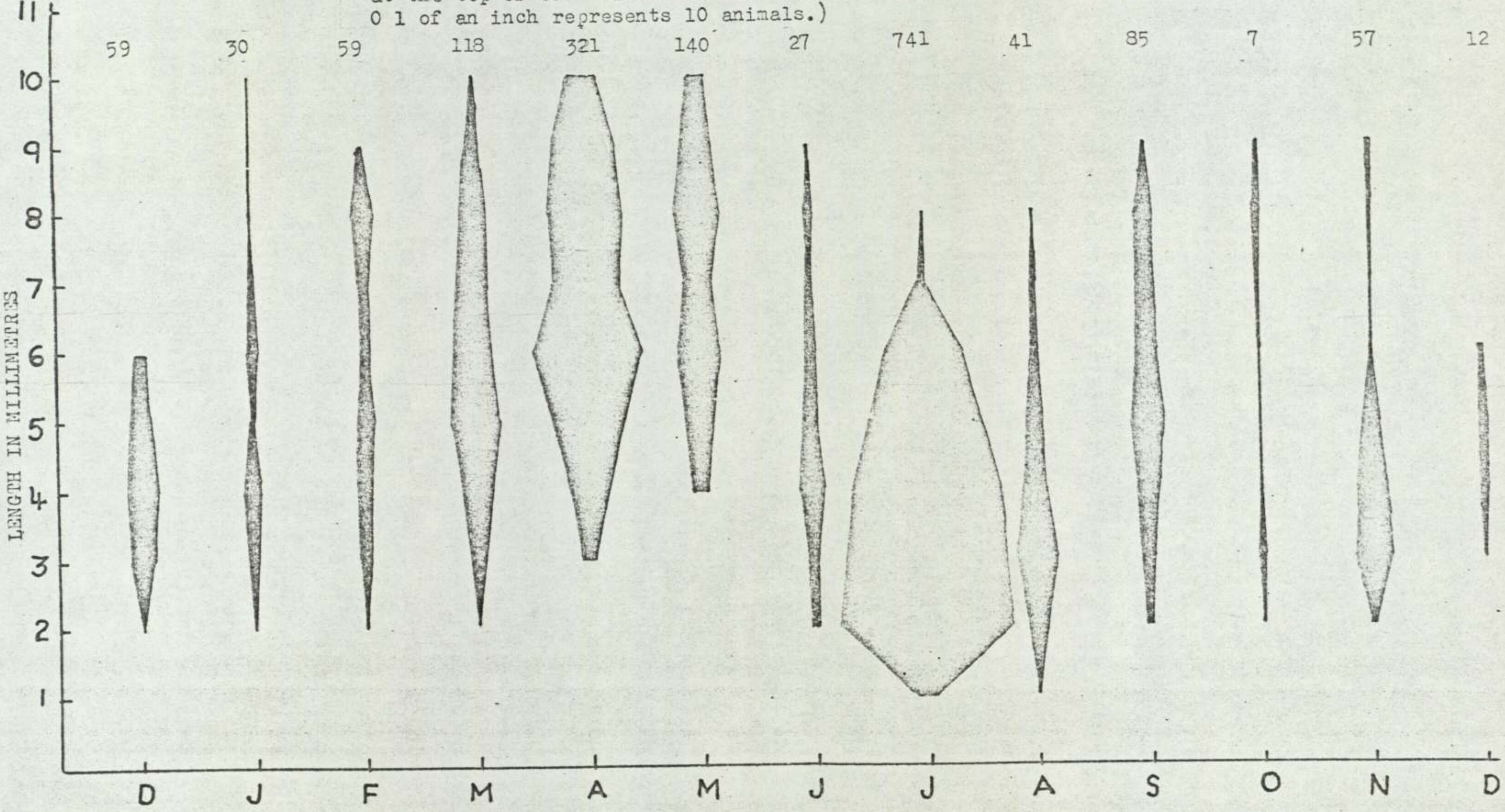


Fig.20.The size distribution of Baetis rhodani collected each month from 0 1m² of the stream bed of Station 1 of the River Cole. (Numbers at the top of each block are the total for that month, horizontally 0 1 of an inch represents 10 animals.)



these very small individuals were no longer present in the samples, although slightly larger individuals (5-9 mms) were the most abundant size range.

Gammarus pulex (fig. 18). The numbers of G. pulex in the monthly samples varied. This species was not very numerous from December to May. The numbers taken rose sharply in June and large numbers were present in the samples from June to October. It would appear that G. pulex was abundant at this station in August and September. The measurements of the individuals revealed that in December all sizes were present in the samples, from January to April the larger and full grown individuals were the most abundant. In May very small individuals appeared in the samples, these were not present in the June samples but reappeared in the July and August samples, only to disappear from the samples for the remainder of the year. Gammarus was abundant in the samples for these four months and the population appeared to be composed of individuals of a variety of sizes which were present in roughly equal numbers. The samples taken in October, November and December were similar, they all showed a drop in the numbers taken when compared with the June - September period and the individuals taken were half or full grown.

Hydropsyche angustipennis (fig. 19). The larvae of this species was present in all the monthly samples. It apparently became extremely abundant at this station from June to November. From December to June the samples showed that the population was made up of larvae of various sizes, those taken varied from 4 mms to 16 mms. In July however the population was apparently composed of only small and medium sized individuals. In August and September there was a sharp increase in the numbers taken and these varied in size from very small to full grown. The September sample differed from the August, in that the very small individuals were not present. The smallest taken in September were now 2 mms and there was a greater proportion of fully grown larvae present. In October, November and December there was a tremendous decrease in the numbers of larvae present in the samples. The smallest individuals taken were 4 mms in length, and the population was composed of larvae of varying sizes.

Baetis rhodani (fig. 20). The numbers of the nymphs of this species present in the samples fluctuated during the year, greatest numbers were taken in April and July. This species always seemed to form an important member of the community. The growth patterns which emerged from the measurements revealed that in December the species seemed to be represented by half grown nymphs. From January to June fully grown nymphs were taken in the samples and these were most numerous in April and May. In the July sample there was a tremendous increase in the numbers taken of this species and this was due to large numbers of small and half-grown nymphs. The size distribution of the nymphs in the August sample was fairly similar to that of the July sample, the important difference between the two samples being that the nymphs were now present in fewer numbers. In September, October and November the nymphs once again varied in size from small to full grown. The November sample differed to the other two in that it was largely composed to small nymphs. The December sample was similar to that of the previous December in that only half-grown nymphs were present.

Station 2 (Table 5)

The fauna of this station appeared to be very restricted and strikingly different to that of Station 1.

The most abundant animals in the samples were oligochaete worms of the families Tubificidae and Enchytraeidae and Chironomus larvae of the species Chironomus riparius (thummi). The dominant species of Station 1, namely Erpobdella octoculata, Gammarus pulex, Hydropsyche angustipennis and Baetis rhodani were now rare. The Tubificidae were most abundant in the spring samples, being present in far fewer numbers in the summer and autumn. The enchytraeid worms seemed to have a similar seasonal distribution and were most abundant in the February sample. The Lumbriculidae were not as apparent as at Station 1 and only appeared in the samples sporadically.

Chironomus riparius, which had not appeared in samples from Dowles Brook or Station 1, was now the dominant insect larva.. This species was not present in all the monthly samples, being absent in the May sample and rare in the other summer samples. Large numbers were taken in the spring and autumn. A number of other species of chironomid larvae were taken of which Trichocladius rufiventris was the most numerous. All these species were most abundant in the spring samples being, for the greater part, absent in the summer and autumn samples.

The only non-chironomid insect larvae taken in large numbers were those of Simulium ornatum which were also restricted to the winter and spring samples. Only a few scattered individuals of other species were recorded of which Baetis rhodani was the most numerous. Baetis also was absent from the summer samples.

Station 3 (Table 6)

The fauna of Station 3 appeared to be similar qualitatively to that of Station 2, the main difference between the two stations being quantitative. The Tubificidae were still apparently the most numerous worms, with the Enchytraeidae also being present in large numbers. Both groups were again most abundant in the spring samples, the Tubificidae were also present in the summer samples but in much reduced numbers. As at Station 2 the Lumbriculidae never appeared to be abundant.

The larvae of *Chironomus riparius* were again the most numerous Chironomid in the samples. The seasonal incidence of this species (fig. 21) seemed to be different to that at Station 2 for although this species was present in the spring samples it was present in far greater numbers in the samples from July onwards. An important feature of the samples from this station was that the larvae of other chironomid species now became abundant, being present in far greater numbers than in samples from Station 2. The most important of these species were *Trichocladius rufiventris*, *Brillia longifurca*, *Polypedilum arundineti*, *Prodiamesa olivacea* and *Eukiefferiella hospitus*. These five species were most numerous in the spring and autumn samples (figs. 23-26) being absent from the summer samples.

As at Station 2, *Simulium ornatum* larvae were abundant in the spring samples and virtually absent from samples for the rest of the year. A similar seasonal distribution was recorded for *Baetis rhodani* which was only present in the spring samples. Also similar to Station 2, the leeches, *Gammarus pulex*, *Asellus aquaticus* and *Hydropsyche angustipennis* were only present in the samples sporadically and then never in large numbers.

Station 4 (Table 7)

The samples taken at this station showed a continuation of the trend observed in the fauna at Station 3. Many of the species which had established themselves at the previous station e.g. *Brillia longifurca* and *Prodiamesa olivacea* were apparently far more abundant. The Tubificidae again appeared to be the dominant worms followed by the Enchytraeidae. The Lumbriculidae although not as abundant in the samples as the other two groups did seem to show a definite increase in numbers when compared to Station 3. An interesting fact that emerged was that the Tubificidae were now taken in large

Fig.21. Seasonal incidence of *Chironomus riparius* in 5 stations on the River Cole. Points on graphs represent the mean of 3 samples. Superimposed on the graphs for Stations 2 and 4 are the 95% confidence limits.

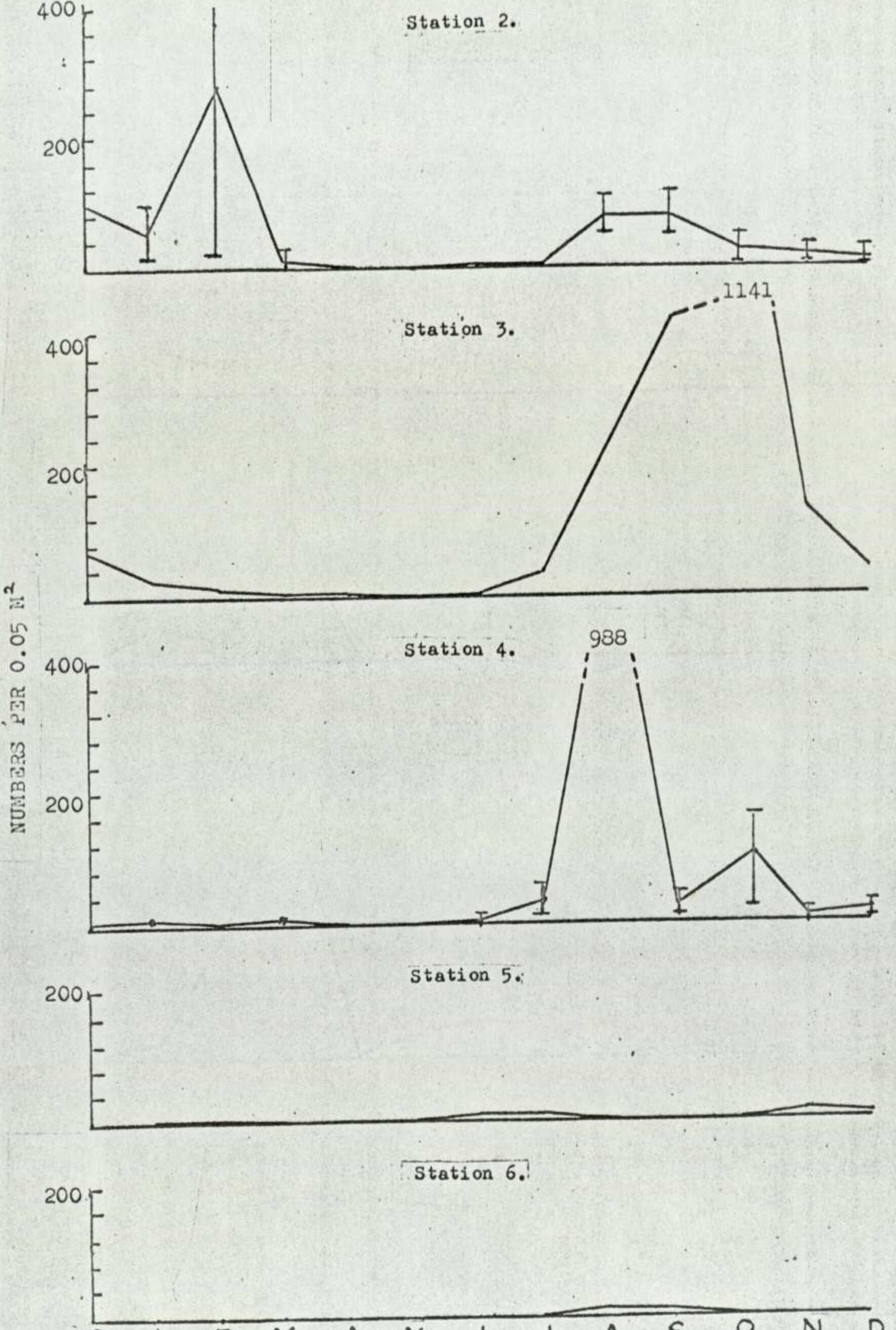


Fig. 22. Seasonal incidence of *Trichocladius rufiventris* in 6 stations on the River Cole. Points on graphs represent the mean of 3 samples. Superimposed on the graphs for Stations 3 and 4 are the 95% confidence limits.

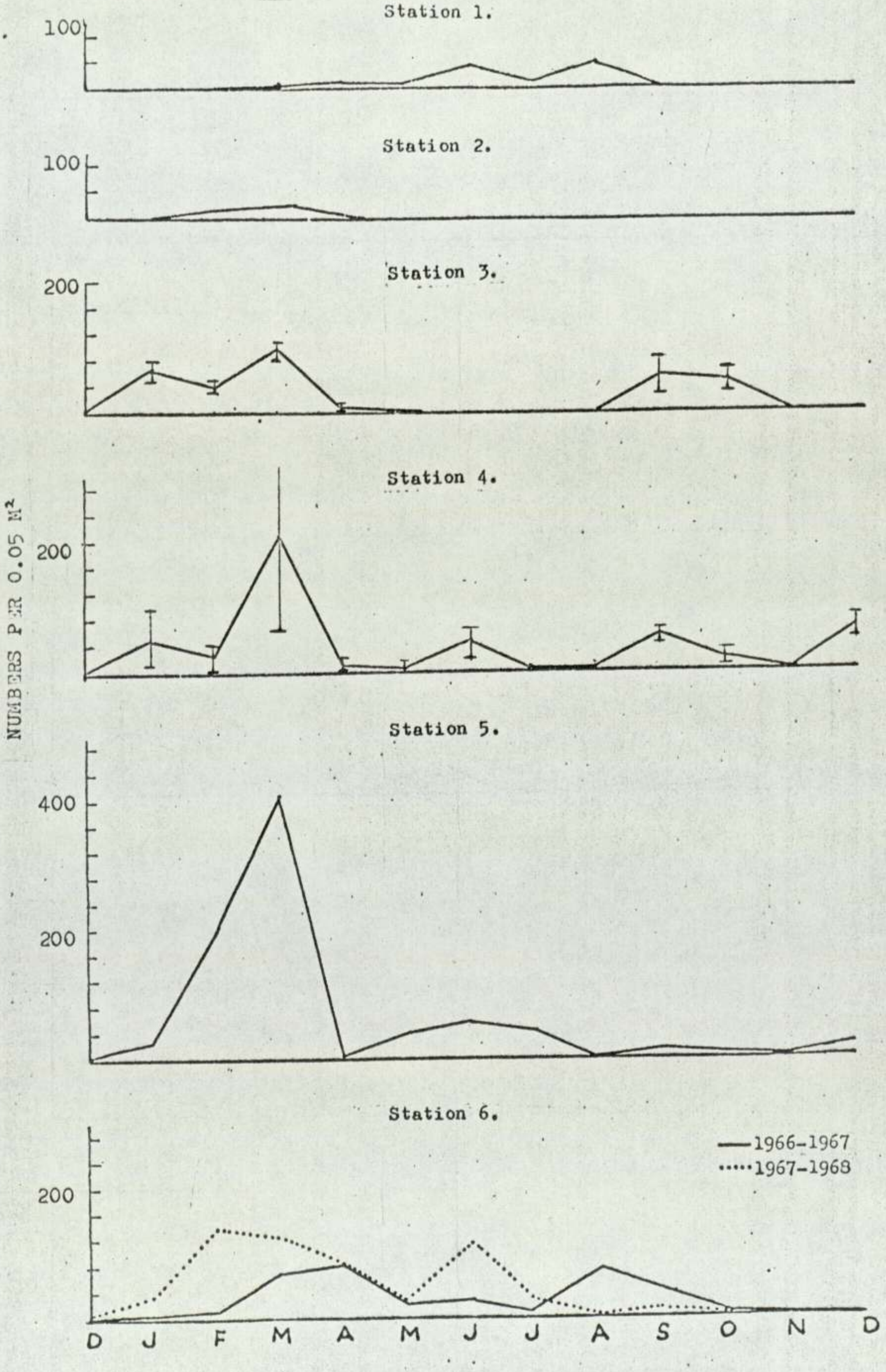


Fig.23. Seasonal incidence of *Brillia longifurca* in 6 stations on the River Cole. Points on graphs represent the mean of 3 samples. Superimposed on the graphs for Stations 3 and 4 are the 95% confidence limits.

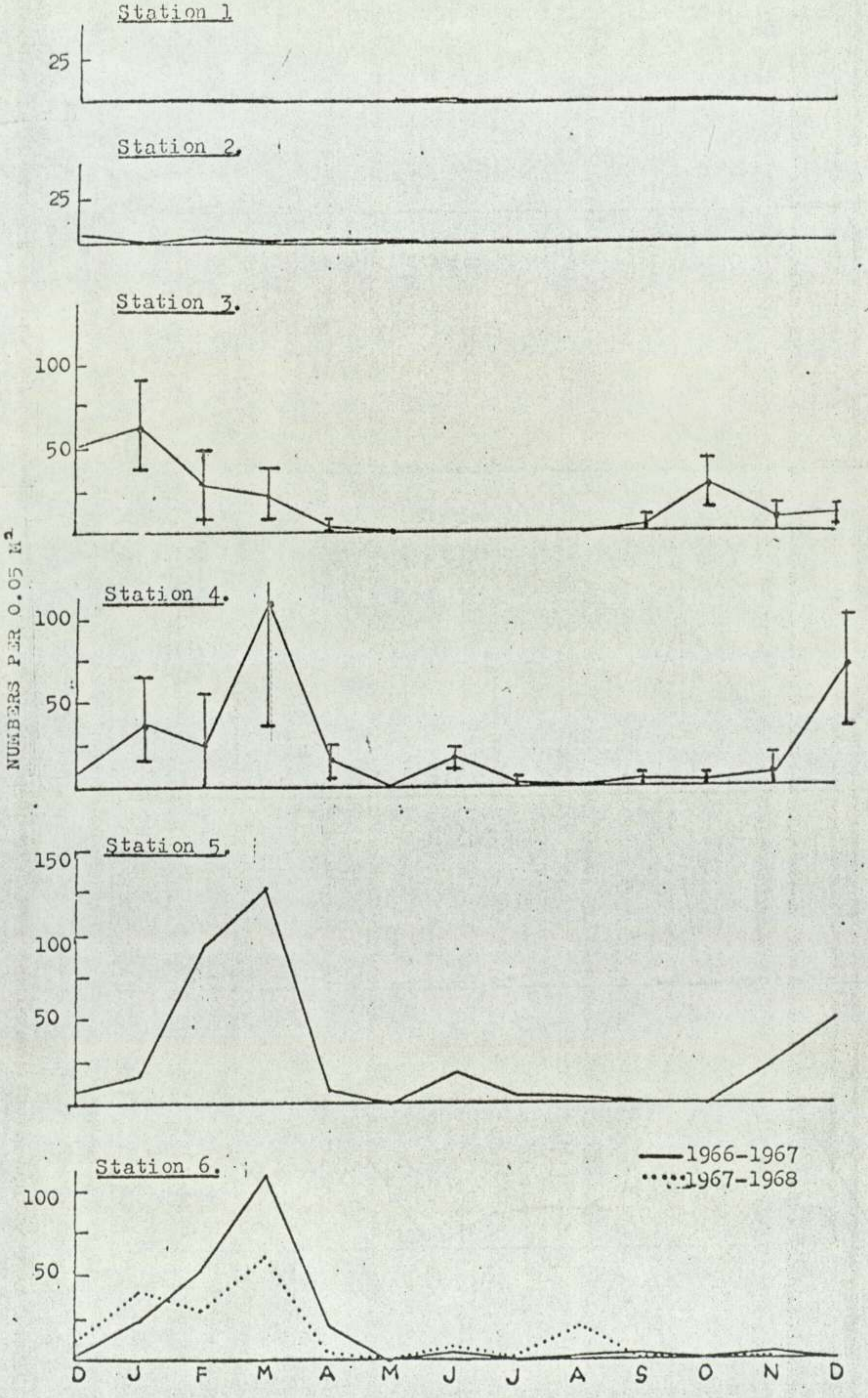


Fig. 24. Seasonal incidence of Prodiamesa olivacea in 5 stations on the River Cole. Points on graphs represent the mean of 3 samples. Superimposed on the graphs for Stations 3 and 4 are the 95% confidence limits.

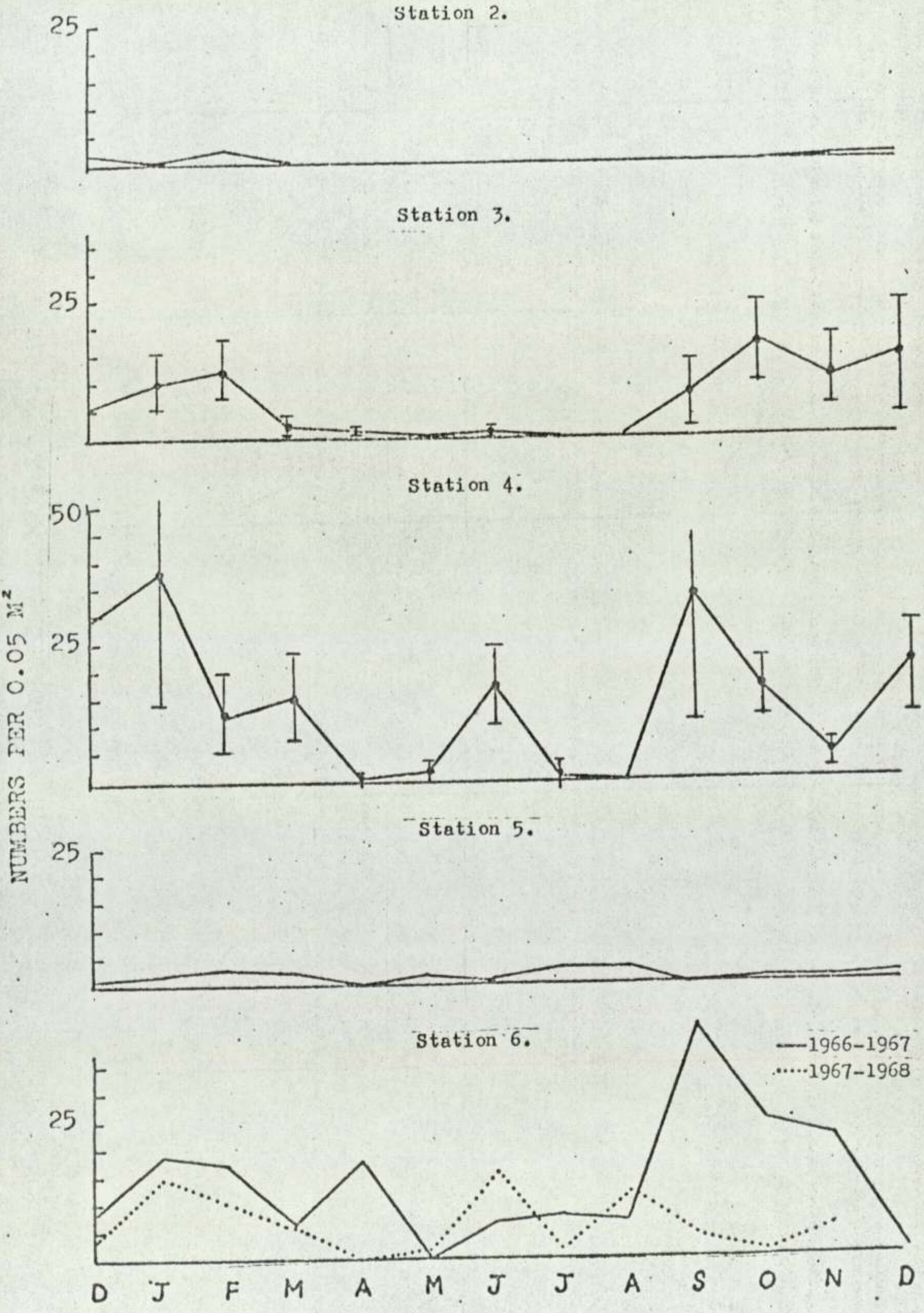


Fig.25. Seasonal incidence of *Eukiefferiella hospitus* in 6 stations on the River Cole. Points on graphs represent the mean of 3 samples. Superimposed on the graphs for Stations 3 and 4 are the 95% confidence limits.

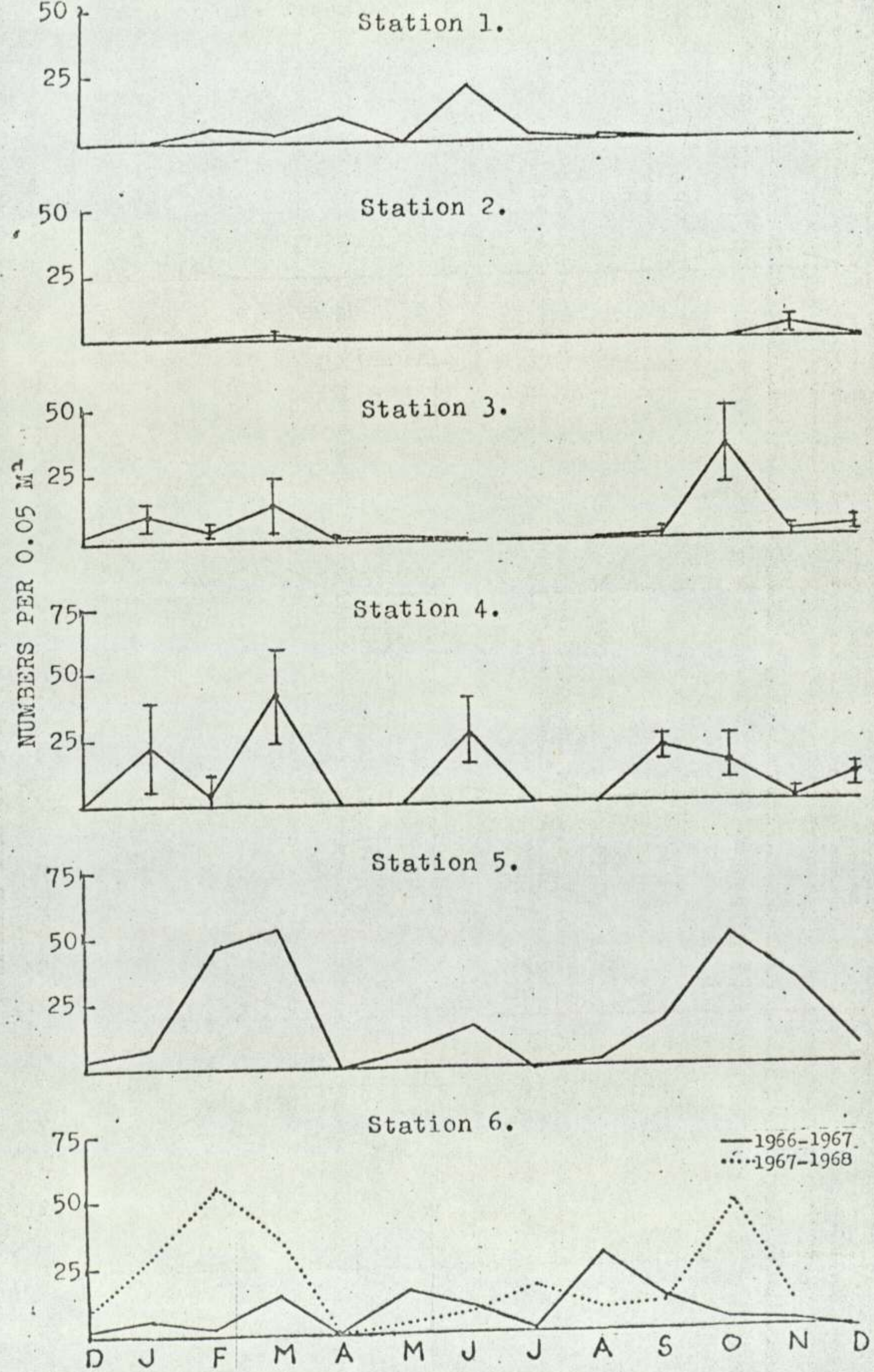


Fig.26. Seasonal incidence of Polypedilum arundineti (……) and Micropsectra atrofasciatus (——) in five stations on the River Cole.

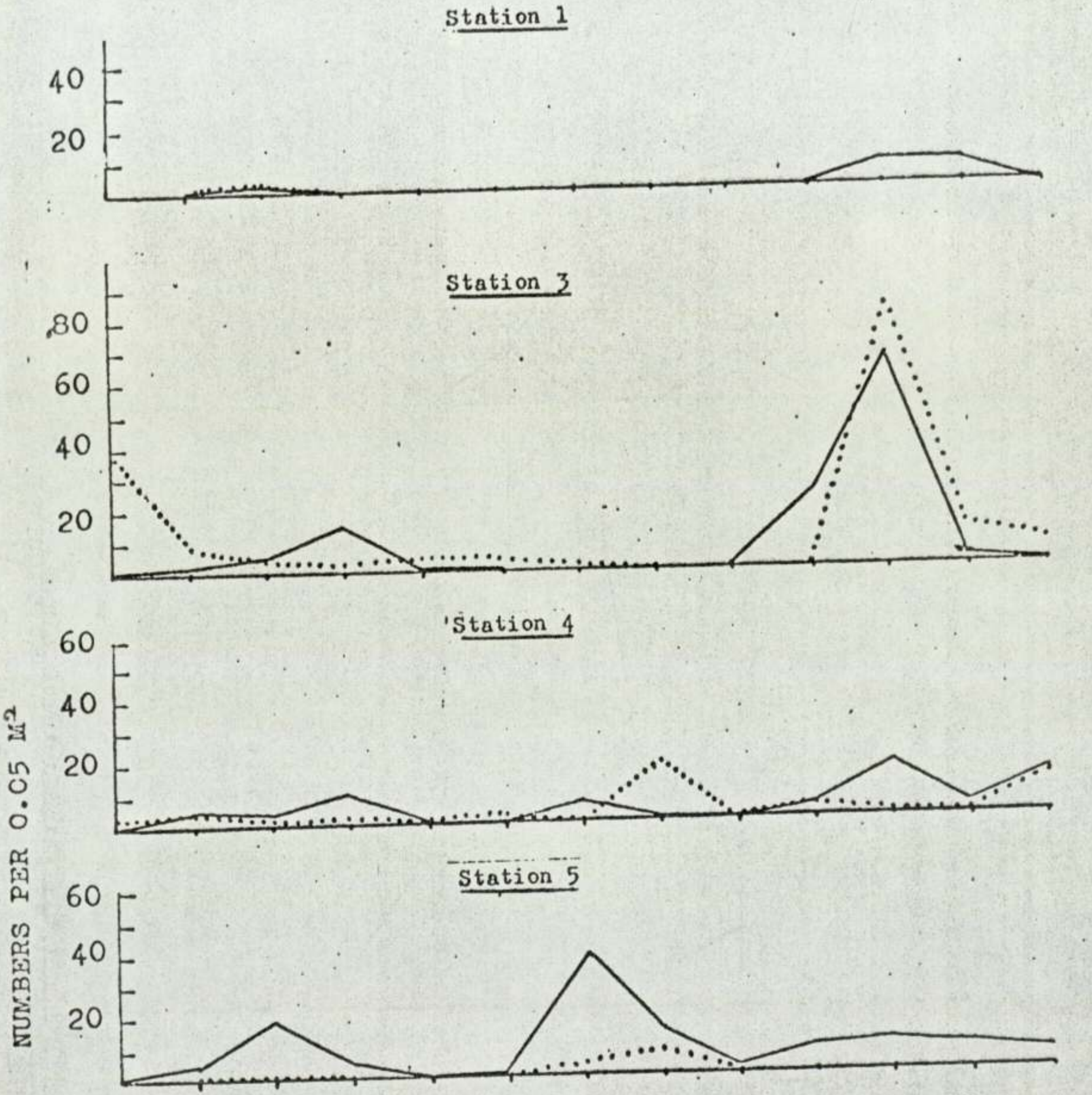


Fig. 27. Seasonal incidence of Cricotopus bicinctus in 5 stations on the River Cole. Points on graphs represent the mean of 3 samples. Superimposed on the graphs for Stations 4 and 5 are the 95% confidence limits.

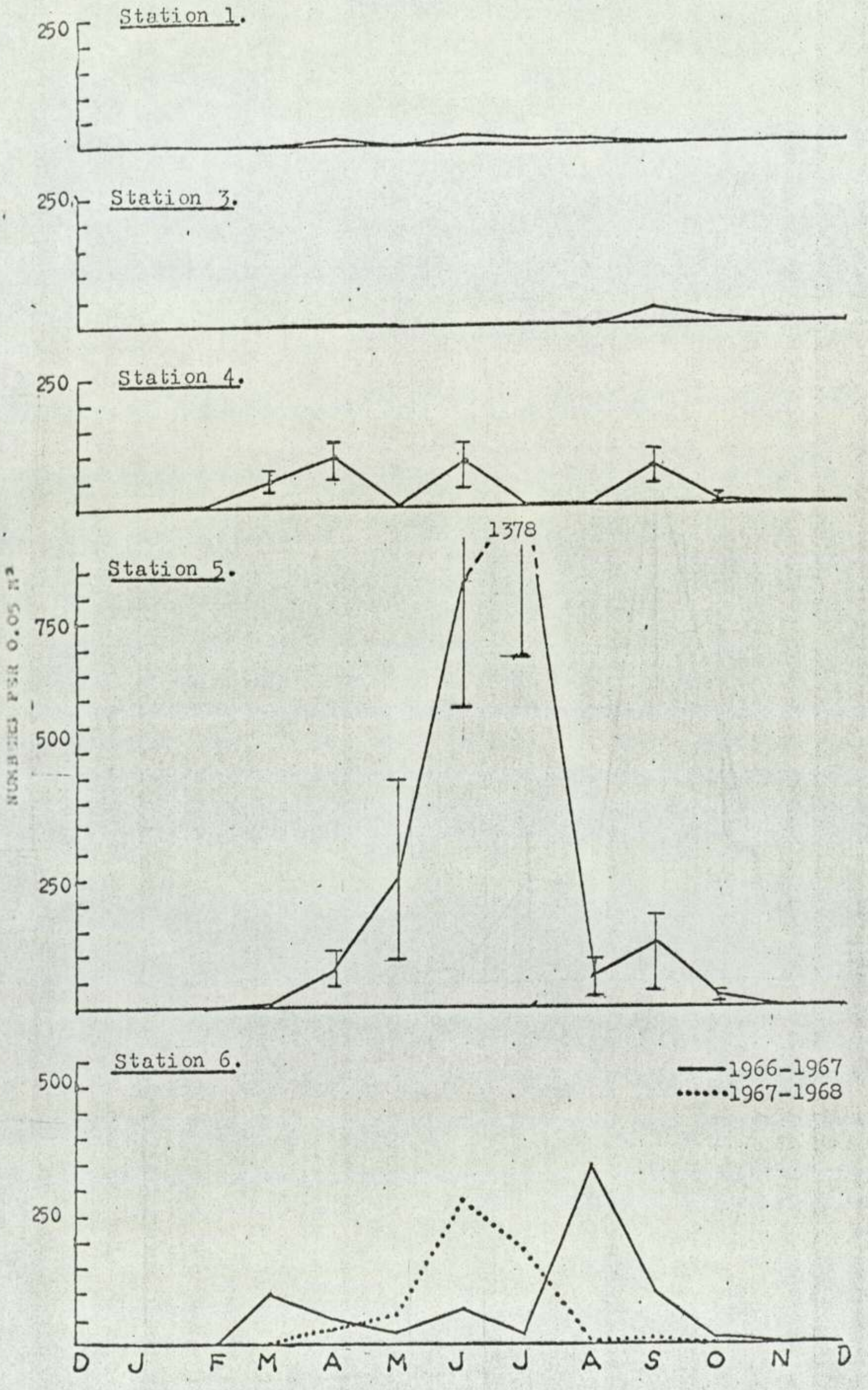
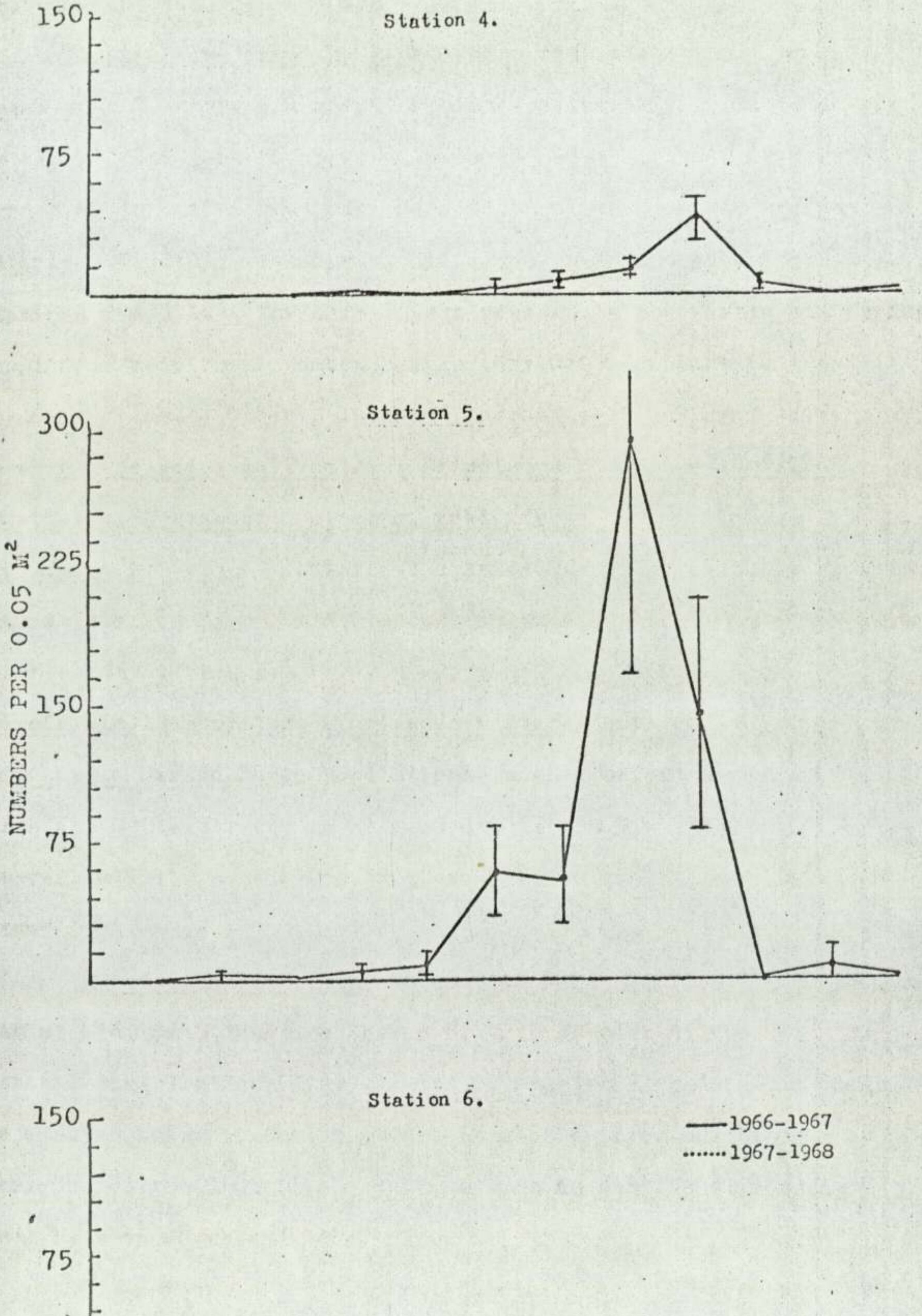


Fig. 28. Seasonal incidence of *Cricotopus sylvestris* in 3 stations on the River Cole. Points on graphs represent the mean of 3 samples. Superimposed on the graphs for Stations 4 and 5 are the 95% confidence limits.



numbers throughout the year and in fact the greatest numbers were recorded in July.

Chironomus riparius larvae were once again, in terms of total annual numbers, the most common species of chironomid larvae in the samples, but as previously mentioned other species were common at this station. The seasonal incidence of *Chironomus riparius* (fig. 21) seemed very different to that observed at Stations 2 and 3. The larvae were present in the winter and spring samples in only small numbers while they were abundant in the August samples. Other chironomid larvae taken in large numbers were *Trichocladius rufiventris*, *Cricotopus bicinctus*, *Brillia longifunca*, *Pentaneura melanops*, *Eukiefferiella hospitus* and *Prodiamesa olivacea*. All these species were taken in larger numbers than at Station 3. Their seasonal incidence also differed to that observed at Station 3, (figs. 22-25), *Brillia longifurca*, *Eukiefferiella hospitus*, *Prodiamesa olivacea* and *Trichocladius rufiventris* formed large populations in the periods January to March and September to December as at Station 3. At Station 4, however, a third population of these species was present in mid-summer (Table 7).

Cricotopus bicinctus was now far more numerous in the samples than at Station 3, and the larvae of this species differed in its seasonal distribution (fig. 27) to the species already mentioned, the species being virtually absent in samples from November to February and the individuals being common in samples at certain times between March and October.

The numbers of animals taken, other than chironomid larvae, had also increased at this station. The leeches, although present in small numbers in the samples, were definitely more abundant than those taken at Station 3, four species were recorded with no one species being really dominant.

Asellus aquaticus and *Baetis rhodani* had both increased in numbers in the samples. *Asellus* was taken in small numbers throughout the year whereas *B. rhodani* appeared to have a similar seasonal distribution to that at Stations 2 and 3, that is, fairly common from December to April and rare during the summer months.

Station 5 (Table 8)

The fauna taken at Station 5 was very different to that of the previous stations and indicated how the river had recovered. Although samples from this station were again rich in tubificid worms, chironomid larvae, leeches and *Asellus aquaticus* had also become important constituents of the samples. Four species of leech were recorded but only two species seemed to be common, and these were *Erpobdella octoculata* and *Helobdella stagnalis*. Both species were common throughout the year. *Asellus aquaticus* was also abundant at this station and like the leeches present in all monthly samples.

The Chironomidae present showed distinct changes when compared with the upstream stations. *Chironomus riparius* larvae no longer seemed to be abundant, and although present in most of the monthly samples were never common. The dominant chironomids were *Cricotopus bicinctus*, *Trichocladius rufiventris*, *Cricotopus sylvestris*, *Brillia longifurca* and *Eukiefferiella hospitus*. As at Station 4, *Cricotopus bicinctus* larvae were abundant in the summer samples (fig. 27) and only sporadically present in samples taken at other times. In July a population of nearly 30,000 per square metre was recorded. The numbers of *Cricotopus sylvestris* also increased remarkably from Station 4 and this species had a similar seasonal distribution to *Cricotopus bicinctus* with populations being largest during the summer months (fig. 28). The numbers of Brillia longifurca, Trichocladius rufiventris and Eukiefferiella hospitus taken had also increased. The seasonal distribution of these three species (figs. 22, 23 and 25) was the same as was observed at Station 4, with three populations being present during the year.

Other macro-invertebrates were never abundant although there was a definite increase in the numbers of Ancylus fluviatile taken.

Station 6 (Table 9)

The samples taken at this station showed distinct changes in the benthic community, with those observed at Station 5, and this could be associated with the improvement in water quality. Species such as Gammarus pulex which are characteristic of non-polluted conditions increased in numbers in the samples while the numbers of Tubificidae taken decreased in numbers. The Tubificidae were still the dominant worms although the populations were nowhere near as large as in the preceeding stations.

The leeches also declined in numbers at this station. Erpobdella octoculata was the most common leech found in the samples followed by Erpobdella testacea. Two species of Crustacea were recorded at this station, but whereas the numbers of Asellus aquaticus present in the samples dropped when compared to Station 5, there was an increase in the numbers of Gammarus pulex taken. Although G. pulex did not appear to be present in large numbers, breeding populations were present throughout the year.

The Chironomidae were once again abundant, and as in the previous station Cricotopus bicinctus, Trichocladius rufiventris and Brillia longifurca were particularly numerous. The total numbers of these three species taken at this station were however considerably lower than at Station 5. In the case of Prodiamesa *olivacea* the larvae of this species was more abundant at Station 6.

The results of the samples taken in the following year were similar to those already described (Table 10). The total numbers of *Asellus aquaticus* and *Gammarus pulex* taken for the two years were remarkably similar. For *A. aquaticus* it was 593 and 708 and for *G. pulex* 82 and 142.

The relative abundance of the various species of Chironomid larvae was also similar and in both years *Cricotopus bicinctus* and *Trichocladius rufiventris* provided the highest annual totals taken. The monthly incidence of the species did however appear to differ in the two years with the apparent peaks in the populations not quite coinciding. If this is the case it can almost certainly be attributed to differing climatic conditions during the two years. The incidence of *Cricotopus bicinctus* for the two years (fig. 27) reveals that although the larvae seemed to reach greatest abundance at different months, the results were similar in that the larvae of this species is most abundant in the summer and autumn. The detailed incidence of *Trichocladius rufiventris* also differed in the two years (fig. 22), but again there was a general similarity and in both years it would appear that there were three major populations present during the year, these being present in early spring, mid summer and autumn. *Cricotopus sylvestris* (fig. 28) on the other hand had a remarkably similar monthly incidence in the samples in the two years and like *Cricotopus bicinctus* was most abundant in those taken during the summer.

Certain species however were present in greatest numbers in the spring samples and such a species was *Brillia longifurca*. The monthly incidence of the larvae of this species was similar in the two years, with large numbers being present in the March samples. *Eukiefferiella hospitus* was more abundant at this station in

1967-68 (fig. 25). Although the monthly incidence varied quite a lot in the two years it seemed that for both years there were three major populations present during the year.

3.2.2 Discussion

The results from the Dowles Brook and River Cole investigation show quite clearly how organic enrichment can produce changes in water quality with corresponding changes in the benthic community. It was found that certain taxa seem to be adversely affected while others are favoured by organic enrichment.

If Dowles Brook is taken to represent a normal fast flowing stream receiving little or no organic enrichment and the stations on the River Cole to represent different degrees of organic enrichment the effect of organic enrichment on the various invertebrates can be considered as a whole.

The different families of the Oligochaeta (fig. 29) differed in their distribution. The Tubificidae and Enchytraeidae were more abundant in the organically polluted waters, and obviously favoured organic enrichment. The Enchytraeidae however seemed to be abundant over a narrower range than the Tubificidae. With both groups however they were most abundant not at Station 2 but further downstream. It would seem that severe organic pollution can restrict the distribution of even these two tolerant groups. This would possibly explain their apparent rareness during the summer months at Station 2 when conditions became particularly severe. The distribution of the Lumbriculidae appeared to be less related to the organic content and they were most abundant in the samples from Station 1.

The leeches also differed in their distribution. Apart from the rare occurrence of <u>Piscicola geometra</u> and <u>Erpobdella</u>

Fig. 29. Comparison of the distribution of certain annelids in Dowles Brook(D) and the R.Cole(1-6), showing the effect of the organic discharge. Blocks represent total numbers of animals collected in twelve months from $0{\cdot}1m^2$ of stream bed.

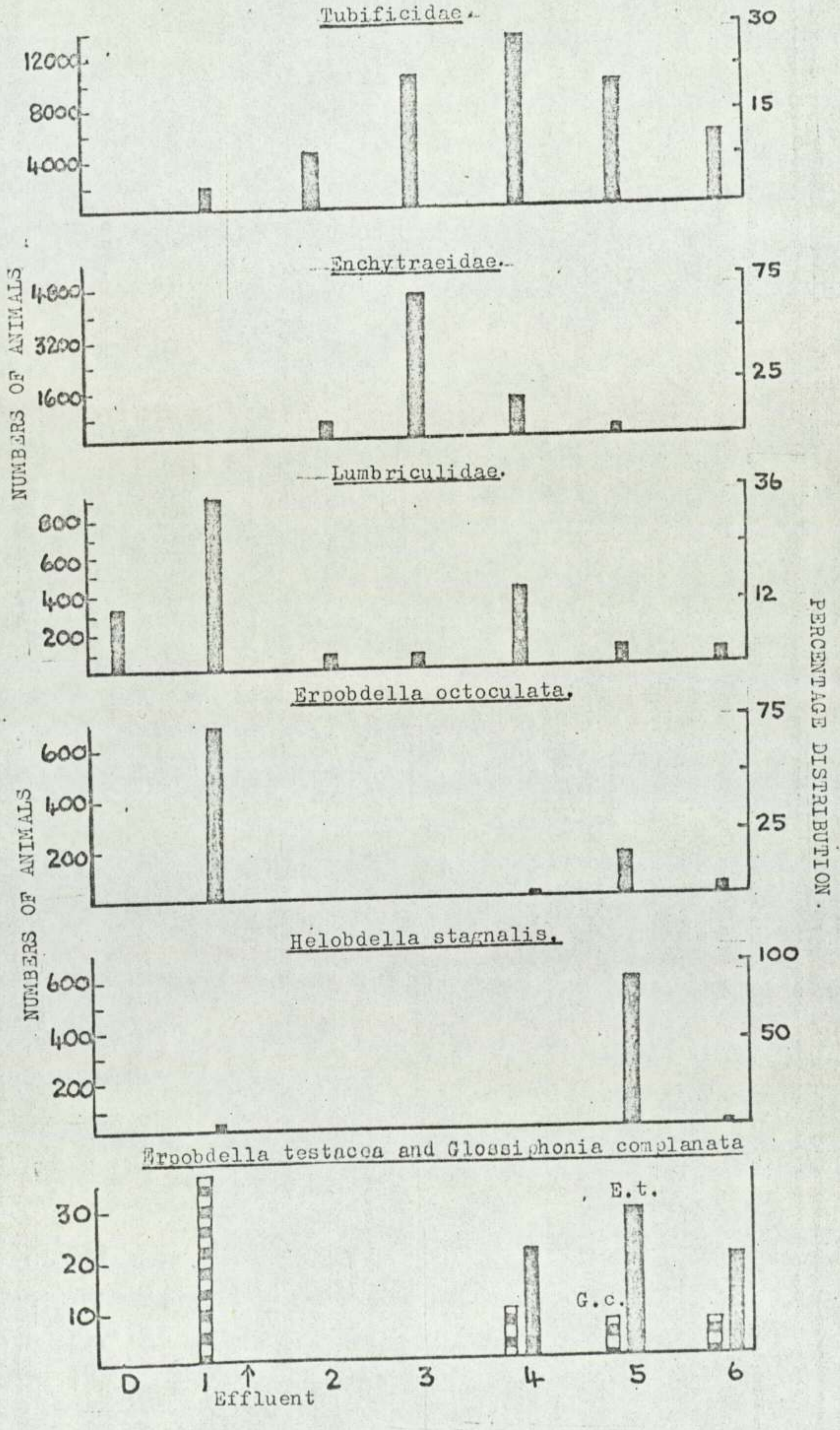


Fig.30. Distribution of two invertebrate species in six stations on the River Cole(1-6), on two sampling occasions. Points represent the mean of three samples. Superimposed are the 95% confidence limits.

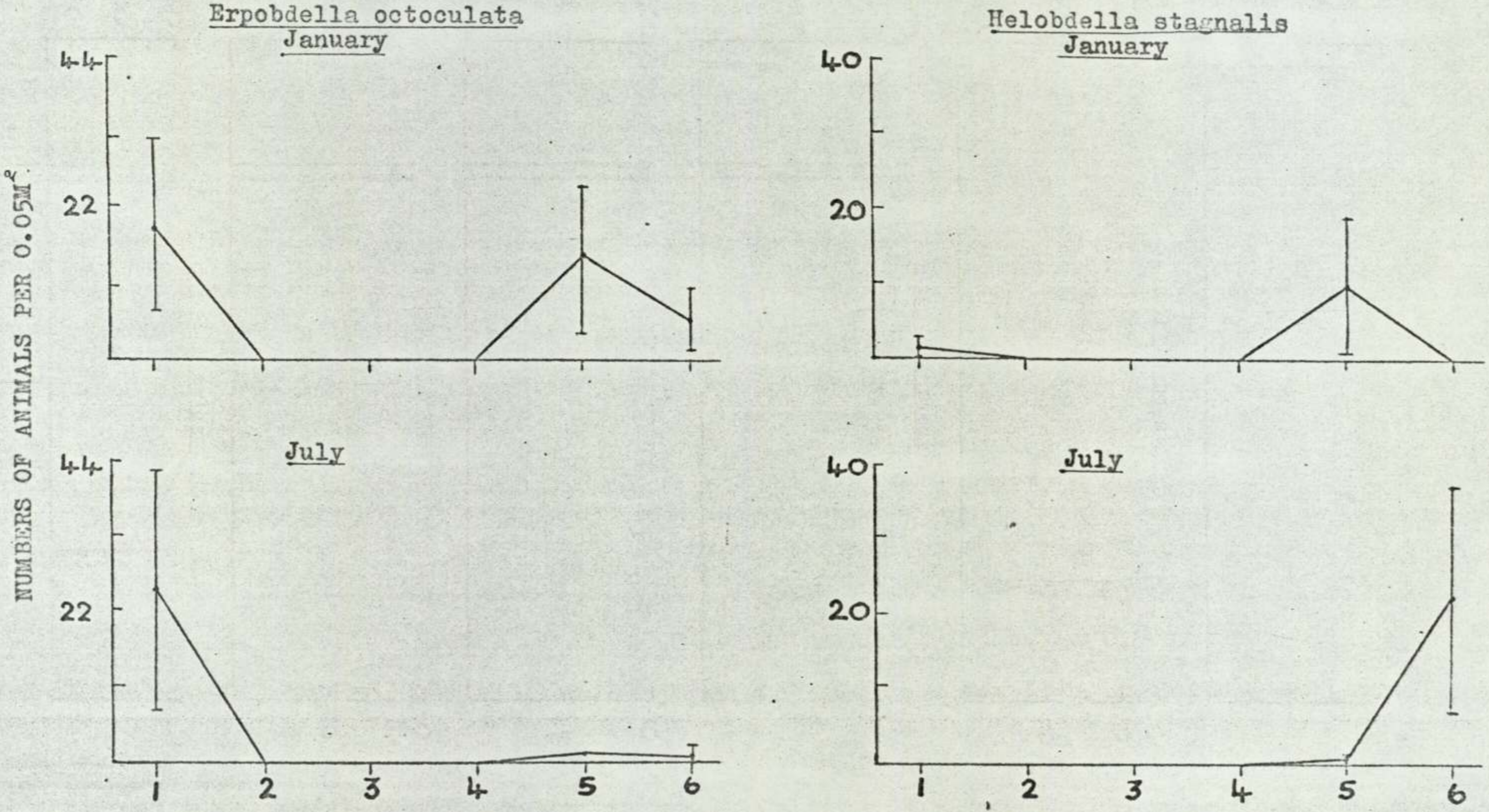


Fig.31.Comparison of the distribution of some macro-invertebrates in Dowles Brook (D) and the R.Cole (1-6), showing the effect of the organic discharge. Blocks represent total numbers of animals collected in twelve months from $0{\cdot}1m^2$ of stream bed.

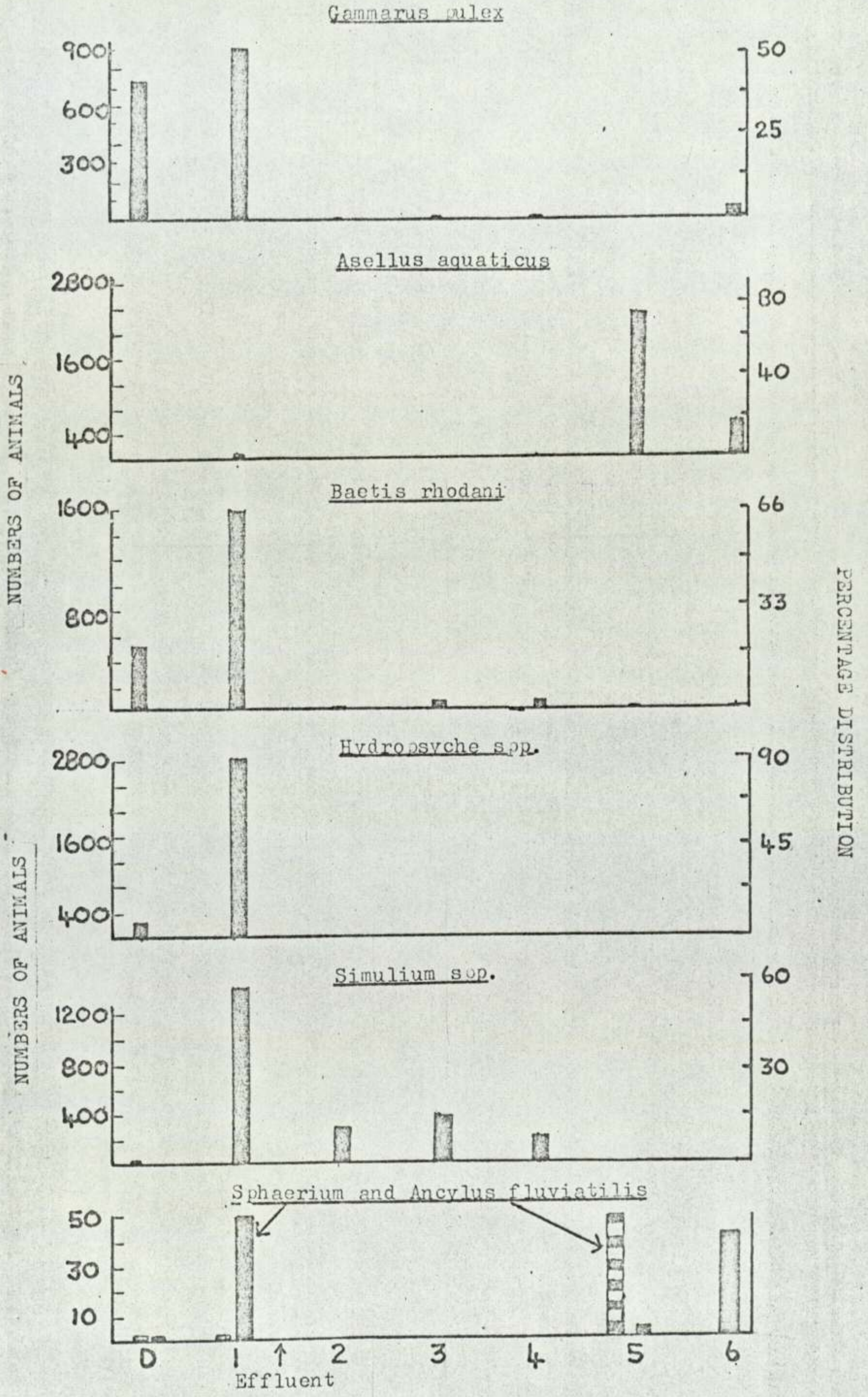


Fig.32. Distribution of two invertebrate species in six stations on the River Cole(1-6),on two sampling occasions. Points represent the mean of three samples. Superimposed are the 95% confidence limits.

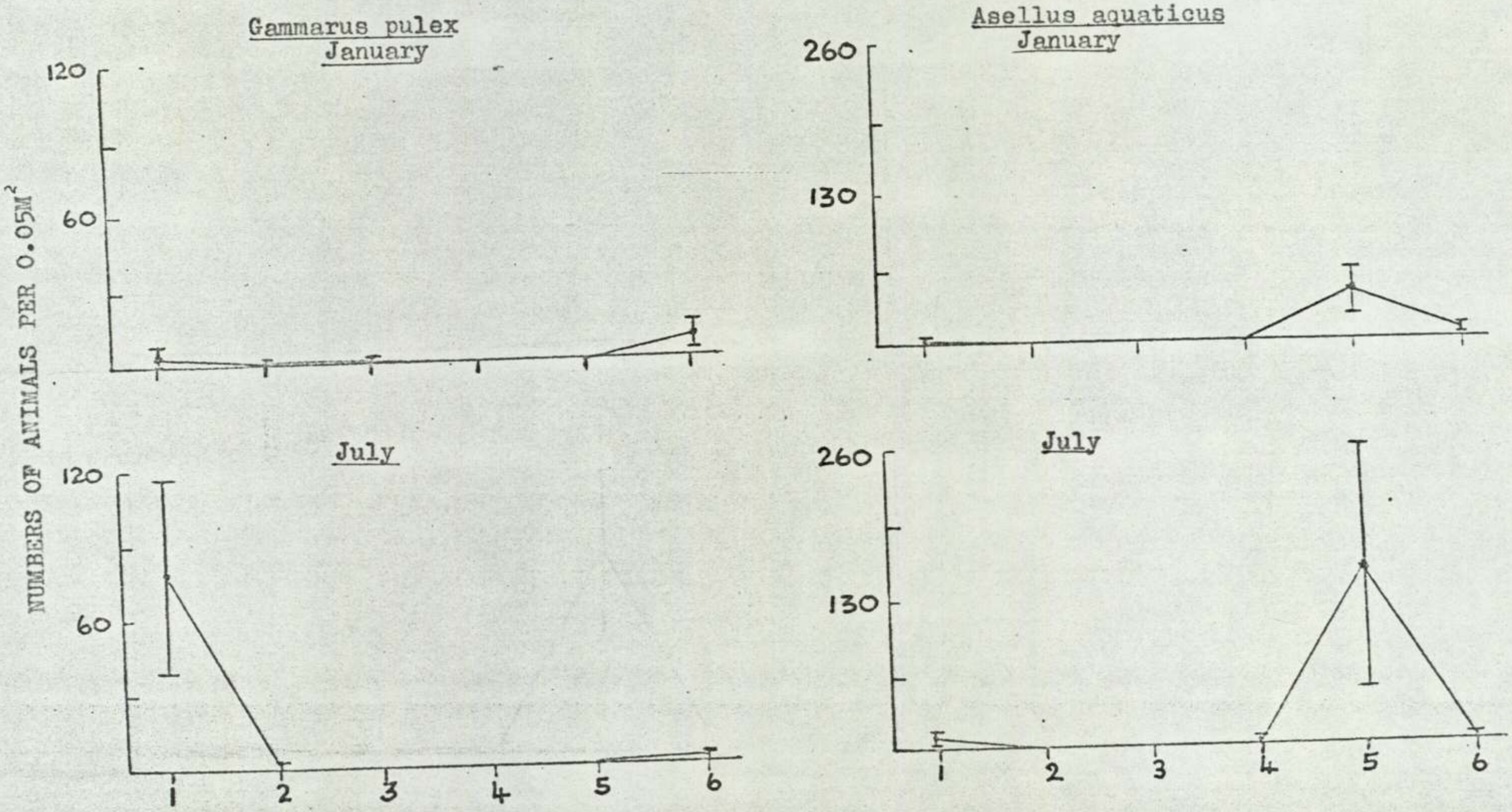
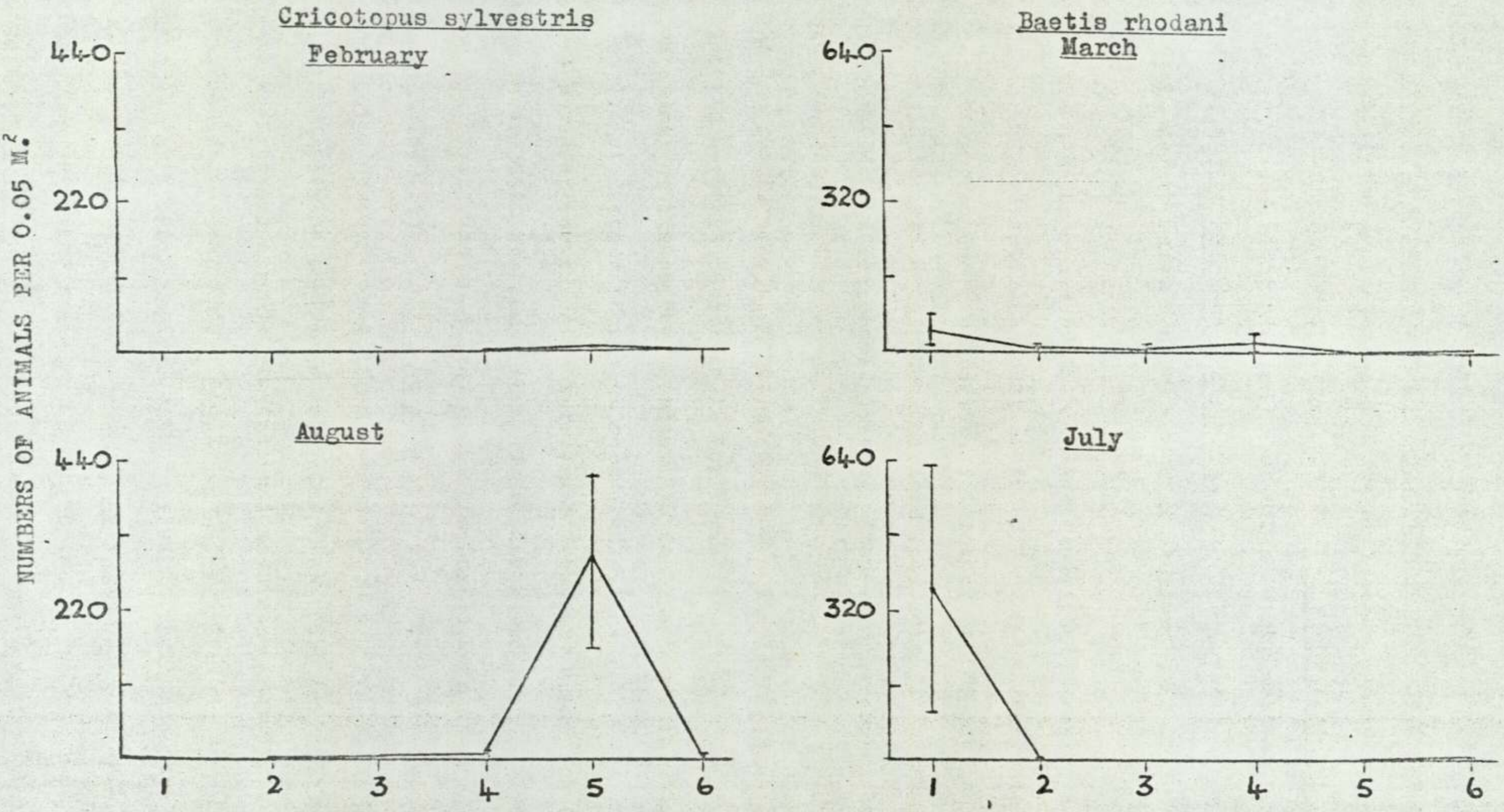


Fig.33. Distribution of two invertebrate species in six stations on the River Cole (1-6), ontwo sampling occasions. Points represent the mean of three samples. Superimposed are the 95% confidence limits.



octoculata leeches seemed to be absent from Dowles Brook. In the River Cole, *Piscicola geometra* and *Batracobdella paludosa* were only found above the effluent at Station 1. Other leeches seemed to be favoured by organic enrichment (fig. 29). *Erpobdella octoculata* was particularly abundant at Station 1 but was also abundant at Station 5 (fig. 30). *Helobdella stagnalis* although present above the effluent seemed to reach a marked peak at Station 5, in the recovery zone (fig. 30). *Erpobdella testacea* although never abundant in the samples appeared to have its distribution restricted to the polluted stretches, being most numerous in the recovery stages. It would seem then that certain species of leech do prefer organic enrichment, probably because of the increased food supply in the form of Oligochaetes and chironomid larvae; they must nevertheless be very tolerant forms.

The two common species of malacostracan crustacean (figs. 31 and 32) also had marked differences in their distribution. *Gammarus pulex* was abundant at Dowles Brook and at Station 1 and was largely absent below the effluent although it recovered slightly at Station 6. This species would appear to be an intolerant form, the reason that it was more numerous at Station 1 than Dowles Brook was probably due to the fact that there was more food available in the form of decaying vegetable matter. *Asellus aquaticus* had a very different distribution, it was not recorded from Dowles Brook and was only taken in small numbers in the River Cole above the effluent. Below the effluent the numbers appeared to fall and then rise sharply at Station 5 where it was abundant. *Asellus aquaticus* is then a moderately tolerant species, and able to survive in environmental conditions that would prove lethal to *Gammarus pulex*. This would explain its presence in the recovery stages of the River Cole and the absence of *Gammarus pulex*, the reason why *Asellus aquaticus* is apparently absent from Dowles Brook is more difficult to explain and it could be due to the presence of predators or competition with Gammarus pulex.

The Plecoptera, Trichoptera and Ephemeroptera also reacted sharply to organic enrichment, and all three groups seemed to be adversely affected by it. In Dowles Brook fourteen species of Plecoptera were recorded, while in the River Cole they were only taken above the effluent and even then only three species were recorded. The Trichoptera were similarly restricted in their distribution. At least nine species were present in Dowles Brook, while in Station 1 only four species were recorded, downstream of the effluent outfall the group was exceedingly rare. Two species of Hydropsyche were recorded in the investigation, and these appeared to have a very restricted distribution (fig. 31). Hydropsyche. fulvipes was only recorded at Dowles Brook while Hydropsyche angustipennis was recorded at Station 1, where it formed large populations. Of the five species of Ephemeroptera taken from Dowles Brook only one, namely Baetis rhodani was recorded in the River Cole. This species (figs. 31 & 33) formed large populations above the effluent, but although it was found in all stations below it was found in greatly reduced numbers. The species belonging to the Trichoptera, Ephemeroptera and Plecoptera would seem on the whole to be sensitive to organic enrichment. No species from these groups would appear to be even moderately tolerant although slight organic enrichment seems to favour certain species. From this investigation such species are Baetis rhodani and Hydropsyche angustipennis both of which formed very large populations at Station 1 which was known to have some organic enrichment.

The distribution of the chironomid larvae was in striking contrast to that of the other insects. Certain species were found to be very tolerant and as a group they seemed to thrive in organically enriched waters. They were poorly represented at Dowles Brook and Cole 1 and rich in numbers and species in the moderately polluted regions. It was possible to recognise various degrees of tolerance within the group. Chironomus riparius was certainly the most tolerant and was the only species to form large populations at Station 2. It was most abundant, however, in the samples from Stations 3 and 4, the numbers then appeared to fall sharply at Stations 5 and 6 and the larvae were not recorded from Cole 1 or Dowles Brook (figs. 34 & 35). This species was apparently restricted to polluted conditions and was certainly the most tolerant species of this group for no other species were numerous at Station 2. A number of species became quite common at Station 3, the four most commonly occurring species were Trichocladius rufiventris, Brillia longifurca, Eukiefferiella hospitus and Micropsectra atrofasciatus.

Trichocladius rufiventris and Eukiefferiella hospitus (fig. 34) were not recorded from Dowles Brook, both species were however recorded at Station 1. Immediately below the effluent the numbers seemed to be reduced, they then became more abundant in the samples downstream. The larvae of both species were usually most abundant at Station 5 (fig. 36). The larvae of Cricotopus bicinctus had a similar distribution (fig. 34) but differed in that this species was only abundant in the samples taken during the summer months (fig. 35). Cricotopus sylvestris and Brillia longifurca were not recorded from Dowles Brook or Station 1 but were present in small numbers at Station 2; from Stations 3 to 5 they became increasingly abundant in the samples, apparently reaching a peak at Station 5, the numbers then falling again at Station 6 (fig. 34). Cricotopus sylvestris like Cricotopus bicinctus was most abundant in the samples taken

Fig.34. Comparison of the distribution of seven species of the Chironomidae in Dowles Brook(D) and the R.Cole(1-6), showing the effect of the organic discharge. Blocks represent total numbers of animals collected in twelve months from $0{\cdot}1m^2$ of stream bed.

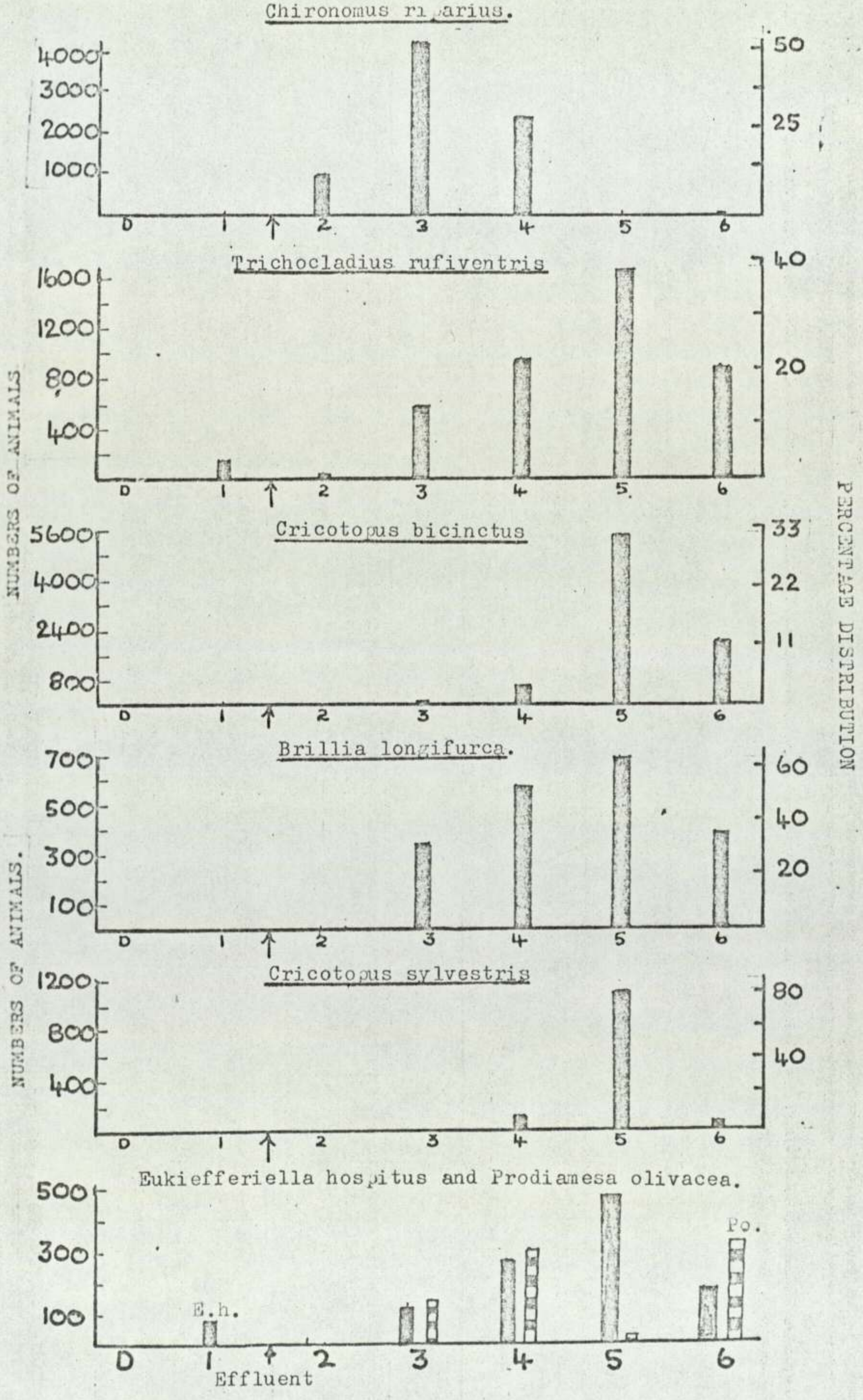
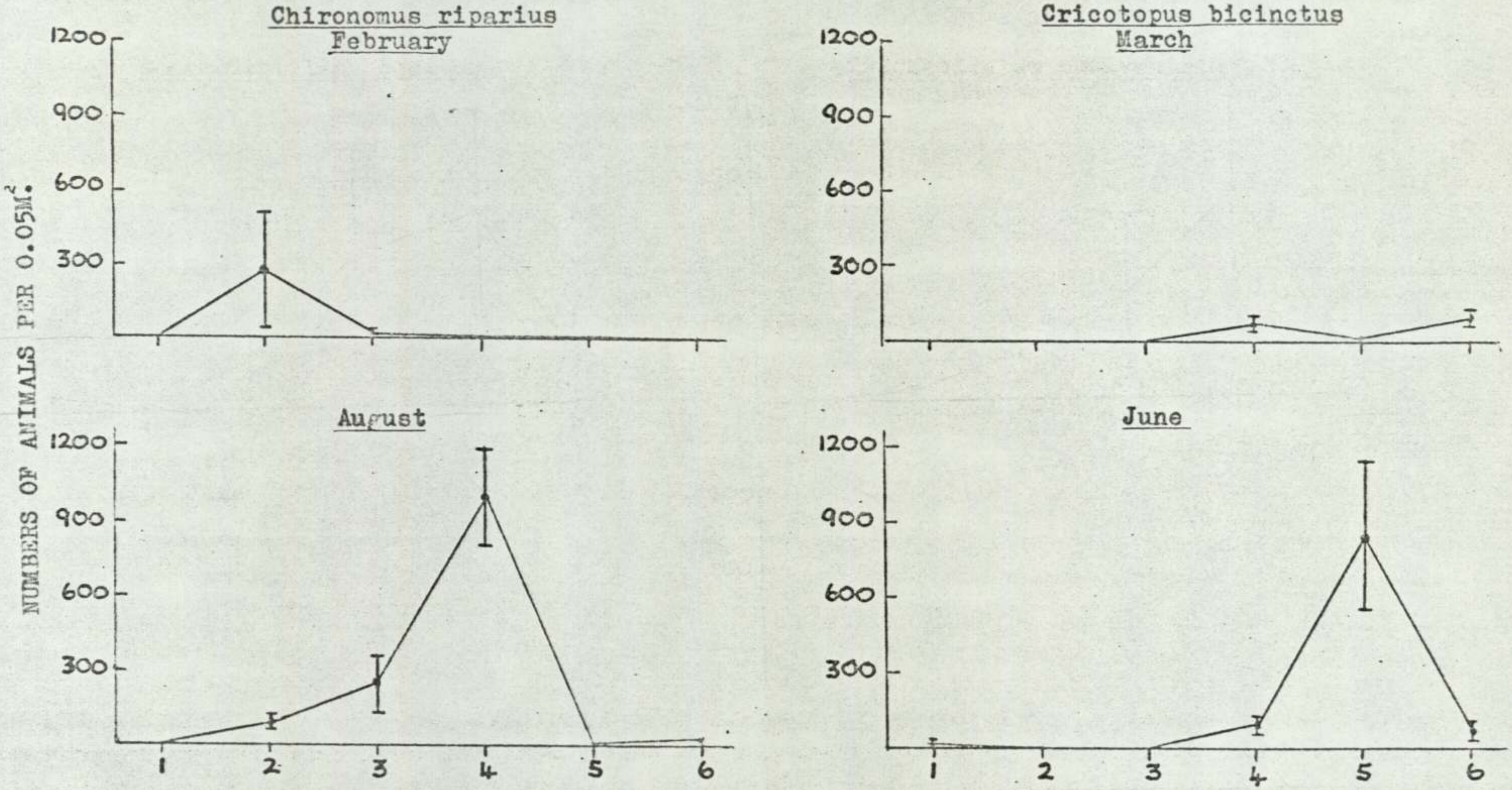


Fig.35. Distribution of two invertebrate species in six stations on the River Cole (1-6), on two sampling occasions. Points represent the mean of three samples. Superimposed are the 95% confidence limits.



Chironomus riparius

February

August

Cricotopus bicinctus

March

June

Fig.36. Distribution of two invertebrate species in six stations on the River Cole(1-6), on two sampling occasions. Points represent the mean of three samples. Superimposed are the 95% confidence limits.

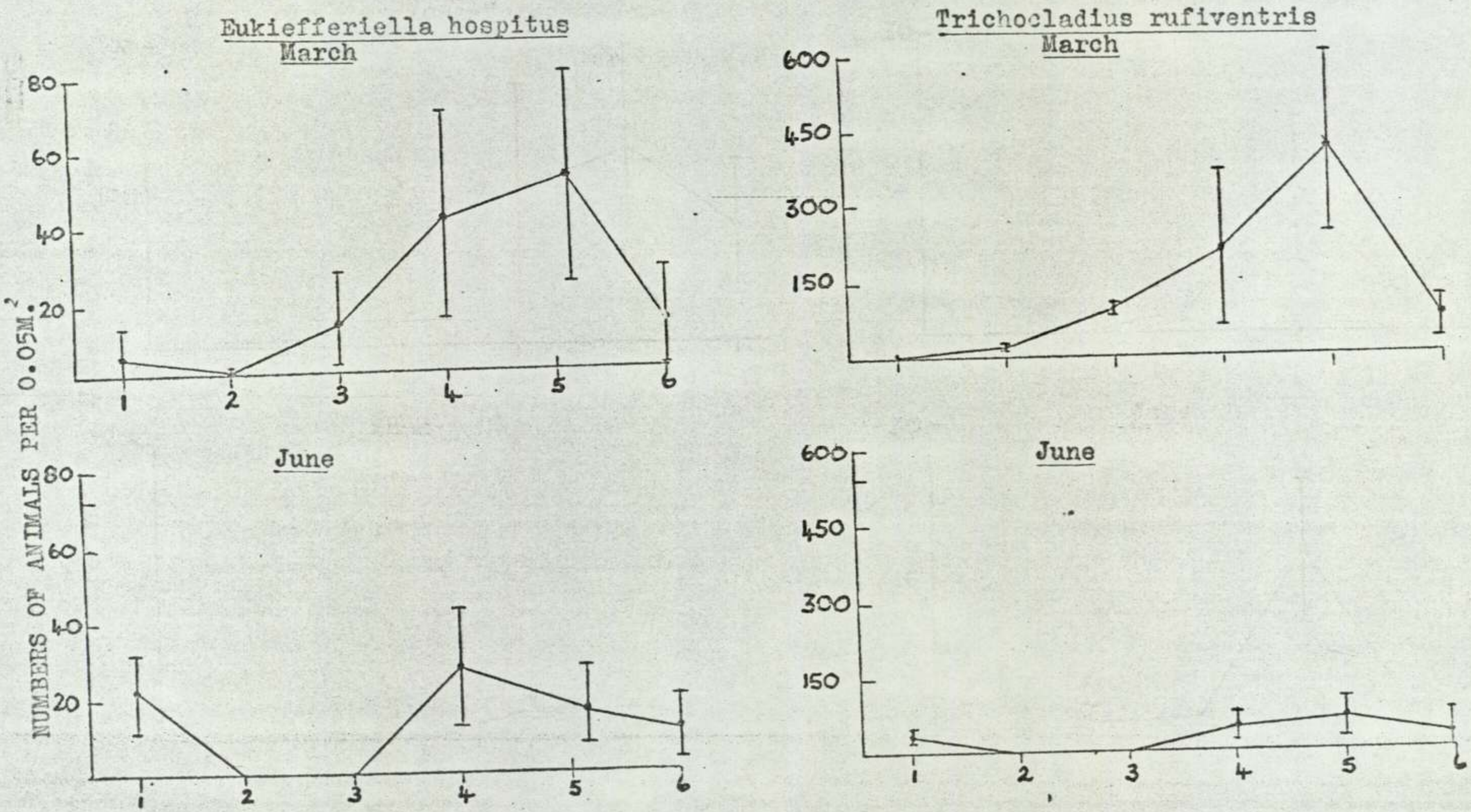


Fig.37. Distribution of two invertebrate species in six stations on the River Cole(1-6),on two sampling occasions. Points represent the mean of three samples. Superimposed are the 95% confidence limits.

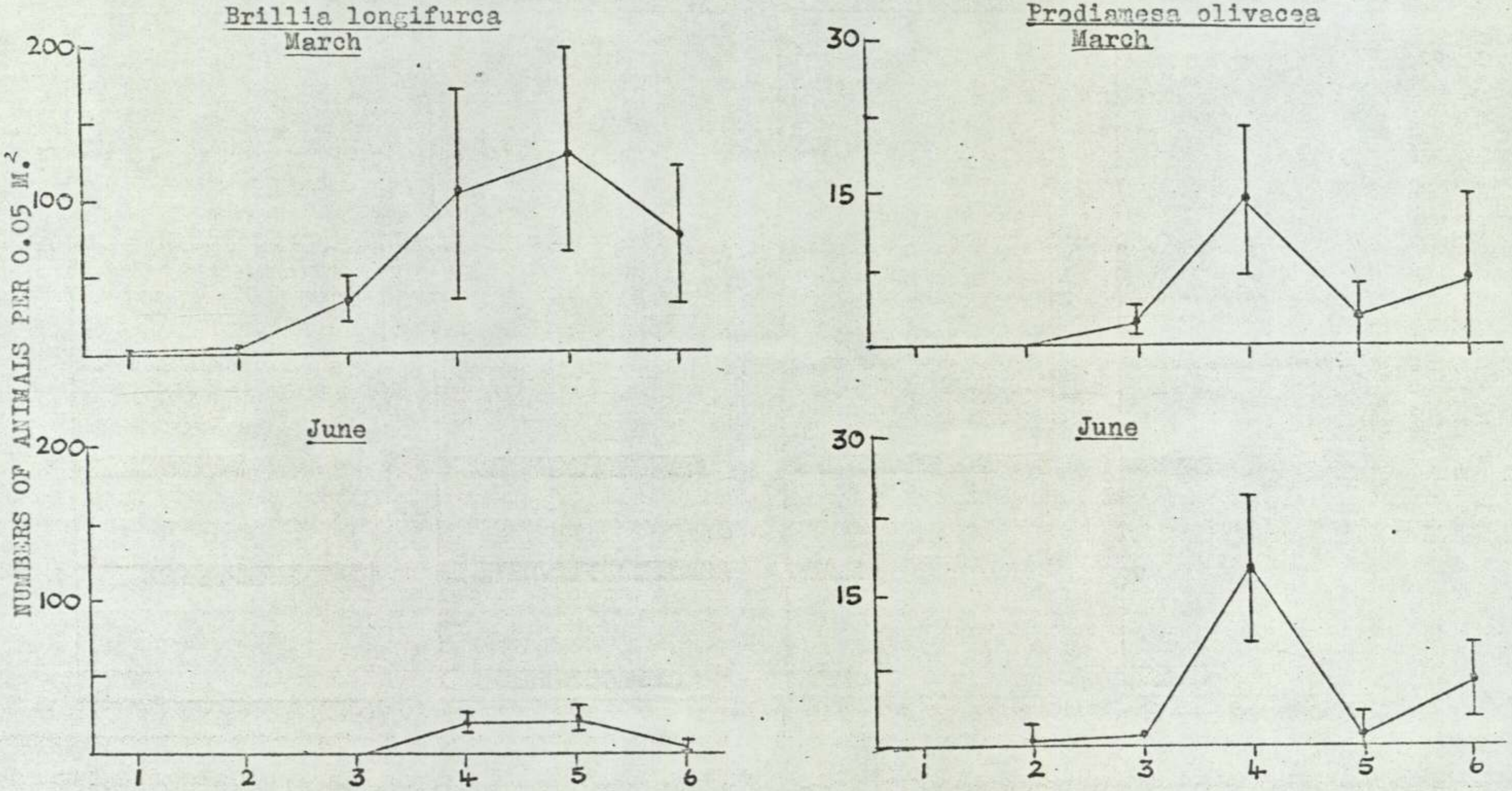


Fig.38 Comparison of the distribution of four species of Chironomidae in Dowles Brook (D) and the R.Cole (1-6), showing the effect of the organic discharge. Blocks represent total numbers of animals collected in twelve months from $0{\cdot}1m^2$ of stream bed.

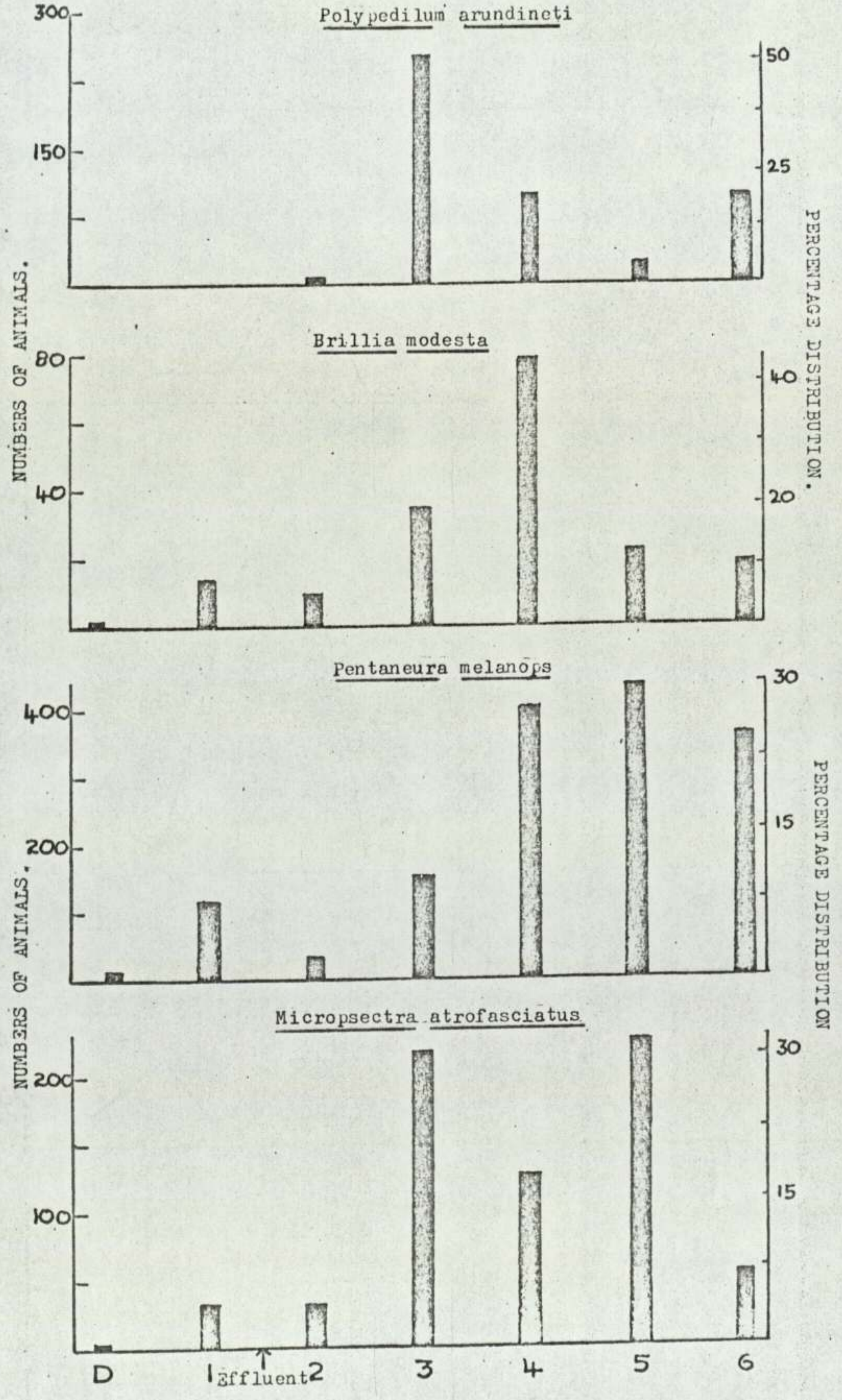
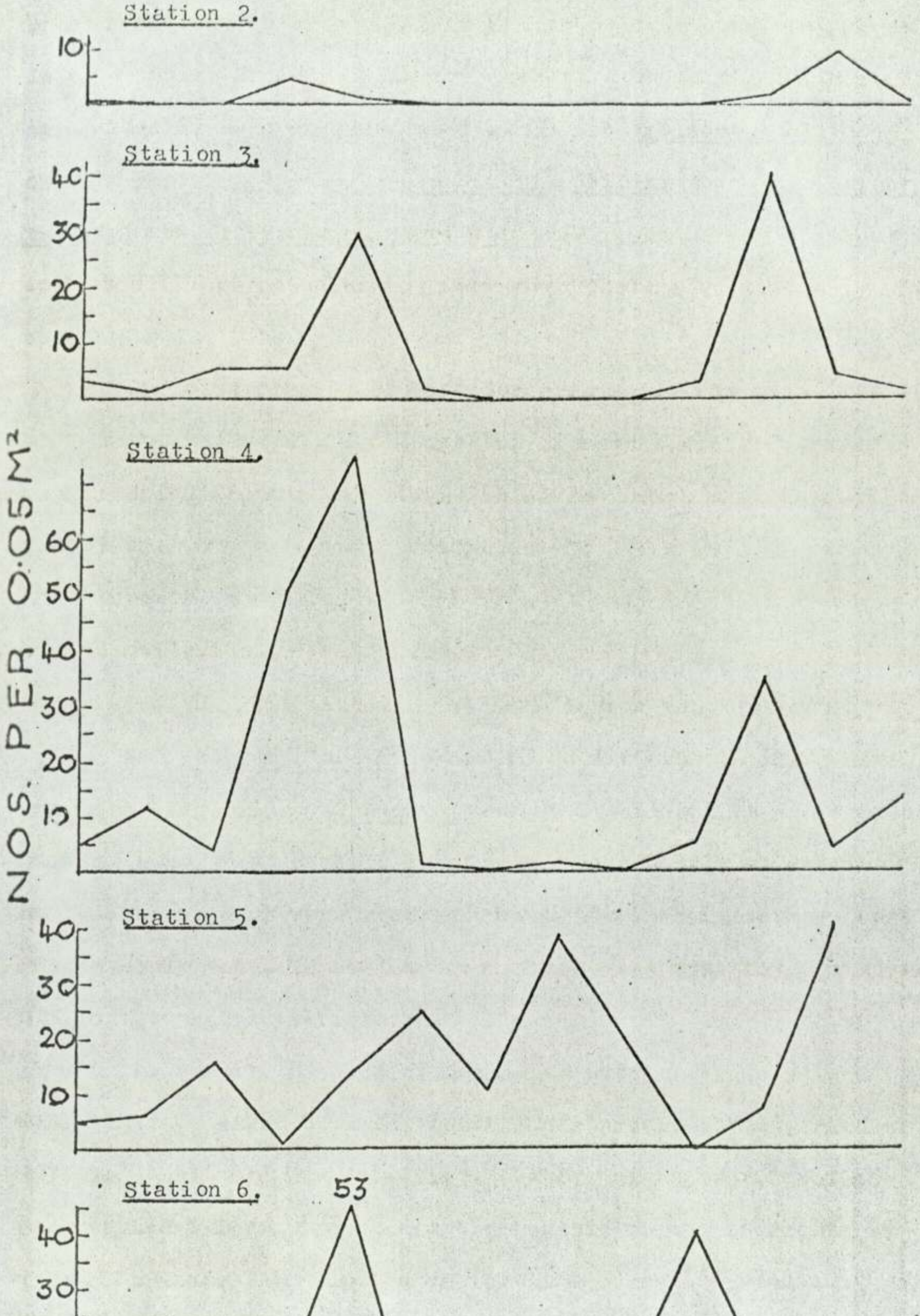


Fig.39. Seasonal incidence of Pentaneura melanops in five stations on the River Cole.



during the summer (fig. 33), whereas Brillia longifurca was most abundant in the winter and spring samples (fig. 37). Other species of chironomid larvae had similar distributions being most abundant in the samples from the recovery stages. The distributions of these species is summarised in fig. 34 for Prodiamesa olivacea and in fig. 38 for Polypedilum arundineti, Brillia modesta, Pentaneura melanops and Micropsectra atrofasciatus. The larvae of these five species although not abundant were nevertheless consistently present at certain stations.

The distribution of Simulium ornatum larvae (fig. 31) also seems to be related to the degree of organic enrichment, only scattered individuals were found in Dowles Brook while quite large populations were sometimes present in the River Cole. It would seem, however, that this species is adversely affected by severe organic pollution.

The two most abundant molluscs in the samples were Sphaerium corneum and Ancylus fluviatile and these differed in their distribution (fig. 31). Sphaerium was most abundant in the samples from Stations 1 and 6 while Ancylus was common only at Station 5. The Coleoptera were very restricted and like the Plecoptera were only commonly found in Dowles Brook which suggests they are adversely affected by organic enrichment.

The results confirm trends which have previously been established by other workers, notably Richardson (1929), Butcher (1937 and 1946) and Hawkes (1956). They do, however, provide quantitative information on how the benthic community reacts to organic enrichment and indicate that the community reacts by changes in the percentage species composition and not merely by the presence or absence of species. The results also revealed the importance of seasons in bringing about changes in the benthic community and that it was possible to have a different benthos at any one station during the winter to that of the summer. These changes in the community are associated with a worsening of conditions during the summer. Another point that emerged was that the Chironomidae which have long been ignored in this country are very important constituents of the benthic community especially in the recovery stages.

Gaufin and Tarzwell (1956) drew attention to the fact that the septic zone contains relatively few species but the numbers of individuals of each species and the total numbers of organisms per unit area was very great. The recovery zone on the other hand was characterised by lesser numbers of the species found in the septic zone plus the more tolerant forms found in clean water. The main characteristic of the clean water fauna being a great variety of invertebrates consisting of nymphs belonging to the Ephemeroptera and Plecoptera and larvae of the Trichoptera. Very similar conclusions can be drawn from this investigation. Stations 2, 3 and 4 can be thought to represent the septic zone and it was found that at these stations the benthic community was almost entirely composed of tubificid and enchytraeid worms, Chironomus riparius and a few other Chironomid species, thus relatively few species. Stations 5 and 6 would represent the recovery stages, the numbers of Tubificidae Enchytraeidae and Chironomus riparius being far less while the numbers of other Chironomids, Asellus aquaticus, Erpobdella octoculata and Helobdella stagnalis had increased. The two species of leech can certainly be regarded as tolerant clean water forms. The clean waters of Gaufin and Tarzwell would be represented by Station 1 and Dowles Brook which are both characterised by a variety of invertebrates containing few individuals.

Organic pollution causes these changes in faunal associations in a number of ways. Harrison (1960) suggests that the following factors are important:-

a) Changes in the nature of the stream bed due to fungal and bacterial growths and deposition of organic matter.

b) By causing oxygen depletion due to the oxidation of the organic matter and the increased respiratory activity.

c) By producing pH changes.

d) By stimulating algal growths.

e) By reducing water clarity.

f) By affecting current speed.

The present investigation would in general support Harrison's views but would also include the effect of carbon dioxide and ammonia. It would appear that probably the most important factor influencing the distribution of animals in the River Cole was deoxygenation. In the summer months the River Cole became seriously deoxygenated. The degree of deoxygenation varied with the distance downstream from the effluent and whether or not vegetation was present. Stations 2 and 3 suffered severe deoxygenation and during the summer months the dissolved oxygen concentration was typically below 2 p.p.m. There was very little diel variation at both these stations (fig. 10) the oxygen varying from 1.2-2.1 p.p.m. at Station 2, and from 0.6-1.4 p.p.m. at Station 3. This absence of a marked diel variation was almost certainly due to the fact that green plants were virtually absent from these stations. In Stations 4, 5 and 6 there were growths of Stigeoclonium and diatoms and diel variations occurred (fig. 10). During the day the river would not appear to experience severe deoxygenation at these stations and at Stations 4 and 5 dissolved oxygen concentrations of 6.8 p.p.m. and 5.2 p.p.m. respectively were recorded at 12.30 p.m. During the night however the dissolved oxygen concentration for a period of 10 hrs. (from

8.30 p.m. to 6.30 a.m.) was well below 1 p.p.m. At Station 6 a similar pattern was found although the water nearly always contained more oxygen, but even as far downstream as this, for a period of nearly ten hours the oxygen concentration was below 2.5 p.p.m. These uniformly low oxygen concentrations at Stations 2 and 3 coupled with the high temperatures would almost certainly prove fatal to most macro-invertebrates, and would eliminate the species common at Station 1. It can be seen from Tables 6 and 7 that even the numbers of Tubificidae and Chironomus riparius appeared to be very much reduced during the summer months.

The quite high dissolved oxygen concentrations that occurred during the day at Stations 4 and 5 certainly allowed moderately tolerant invertebrates such as Asellus aquaticus, Erpobdella octoculata, Helobdella stagnalis and various Chironomids to establish themselves. It would appear that these species can survive low dissolved oxygens for a number of hours every day but not a prolonged period as they would experience at Stations 2 and 3. Most of the macro invertebrates were far more abundant at Station 5 than at Station 4 although during the 24 hour period the oxygen was usually lower at Station 5, this could probably be explained by the influence of other factors such as ammonia, orthophosphates and carbon dioxide which were usually present in higher concentrations at Station 4.

The improvement in the overall oxygen concentration in the river at Station 6 allowed Gammarus pulex and Baetis rhodani to become established once again. Both species were not abundant however and this was probably due to the effect of the low oxygen concentrations prevailing during the night.

Other possible factors which, from this study, appear to be important in causing these faunal changes were the increases in ammonia, carbon dioxide and orthophosphate concentrations. In

Dowles Brook and the River Cole Station 1 very low concentrations of these substances were recorded, in the stations below the effluent outfall however high concentrations were present especially during the summer months. The concentrations of all three usually showed a gradual fall downstream. Ammonia, which is usually accepted as being a toxic substance, was sometimes present in exceptionally high concentrations at Station 2 and a figure of 36.5 p.p.m. (undissociated concentration 0.26 p.p.m.) has been recorded by the Trent River Board during July 1967. Concentrations of this order in nature would almost certainly have a limiting effect on many animals. Carbon dioxide, which is not usually thought to be a toxicant in its own right, is known to influence the toxic effect of low oxygen concentrations. The chemical results show that carbon dioxide was again present in high concentrations during the summer and at Station 2 a concentration of 25 p.p.m. was recorded during September 1967. It is probable that these high concentrations, together with high temperatures, would almost certainly accentuate the effect of the low oxygen concentrations in restricting the distribution of invertebrates. Orthophosphates were also present in comparatively large concentrations and although little is known about the toxic effect, it is conceivable that concentrations of 5 p.p.m. that were recorded from Station 2 could also influence the distribution of certain animals. As mentioned, the concentrations of all three factors usually gradually decreased downstream and this, together with improvement in the oxygen present, allowed the establishment of a succession of populations downstream.

The chemical results from the River Cole were generally similar to those established by many other workers. Butcher (1946) also found variations in dissolved oxygen and ammonia in the Trent. The deoxygenation was even more marked in the Trent and in fact no oxygen at all was present just below the effluent outfall while at the same time the ammonia concentration increased from 0.2 p.p.m. above the effluent to 14 p.p.m. some distance below. As previously mentioned similar faunal sequences were found in the Trent.

It became obvious as a result of this investigation that conditions are far more severe in the summer months, this fact had previously aroused the attention of Gaufin and Tarzwell (1955). The chemical results of the River Cole (Table 1) clearly show the effect of high flows and low temperatures on the condition of the water, even at Station 2 for four months the dissolved oxygen concentration in the monthly samples was over 8 p.p.m., there being a corresponding decrease in the concentrations of ammonia and orthophosphates. These improved conditions during the winter months in even the most polluted stretches appeared to allow moderately tolerant species to establish themselves. Baetis rhodani nymphs and chironomid larvae such as Trichocladius rufiventris, Eukiefferiella hospitus and Brillia longifurca were all taken during the winter months at Stations 2 and 3. They did not appear to be present however at these stations during the summer months although the chironomid larvae were all present at Stations 5 and 6, and Baetis rhodani at Station 1 and Dowles Brook.

The seasonal incidence of a number of the chironomid larvae found in the River Cole seemed to vary at the different stations and this could possibly be correlated with the more severe conditions prevailing during the summer. The seasonal incidence of Eukiefferiella hospitus at six stations is illustrated in figure 25. It was most abundant in the samples from the lower recovery zone where there was apparently three major populations present during the year. Further upstream, nearer the effluent (Station 3) this summer population was apparently absent (fig. 36) although those of spring and autumn were present. This possible repression of the summer generation could also be seen in the incidence of Prodiamesa olivacea (figs. 24 & 37), Trichocladium rufiventris (figs. 22 & 36), Pentaneura melanops (fig. 39) and Chironomus riparius (fig. 21). The seasonal distribution of Chironomus riparius was also interesting in that the range is extended downstream in the summer (fig. 35). This species was virtually absent from the samples taken at Station 4 from November to June, but during the period July to October large populations were present at this station. Thus the incidence seems to be strikingly different to that at Station 2. It would appear that at Station 4 during the winter, conditions were not suitable for Chironomus riparius to become established, during the summer however the station became badly polluted allowing the species to extend its range downstream. The seasonal incidence of other species of chironomid larvae such as Brillia longifurca, which are normally abundant as larvae in the winter-spring period, were naturally less affected by the summer conditions. Aerial dispersal of the adults is probably responsible for the re-establishment of the species after the elimination in the summer, whereas other invertebrates such as Gammarus pulex would have to rely on downstream drift to colonise the stations in winter and as a result hardly showed a winter recovery.

3.3 River Salwarpe

3.3.1 Results

3.3.1.1 Chemical Results (Table 11)

The River Salwarpe provided an interesting example of the recovery, over a period of time, of a river from severe organic pollution. For the first two months that the river was sampled the effluent was treated by the overloaded old sewage works, the new works coming into operation in May; the chemical data reflects the changeover. The effluent from the old works was badly polluting the water. With the changeover, there was at first, no marked improvement, probably because of a settling down period. From July onwards however, except for a couple of "bad" results, there was a steady improvement in the polluted state of the water. Previously, at Station 1, there were thick growths of sewage fungus but these gradually disappeared.

Hardness

The water at both stations was exceptionally hard, the calcium concentration was very high and magnesium was also present in high concentrations. The water at Station 2 was usually harder than at Station 1, there was not however, any marked seasonal variation in the concentrations present.

pH

The water at both stations was usually alkaline, Station 2 being more alkaline than Station 1. The pH fluctuated from month to month but with the opening of the new works there was not such a great variation in the monthly figures.

Temperature (fig. 40)

Normal seasonal temperature fluctuations occurred. Station 1 was usually warmer than Station 2.

Dissolved Oxygen (fig. 40)

The dissolved oxygen concentration definitely reflects the improvement in the condition of the water. From March until September the dissolved oxygen concentration of the water fluctuated. The improvement in the condition of the effluent is shown by the July and August figures, in September however the river became badly polluted again, the oxygen concentration fell to 2.8 p.p.m. at Station 1 and 3.7 p.p.m. at Station 2. From October onwards the

Fig.40 Monthly oxygen and temperature recordings for five stations.

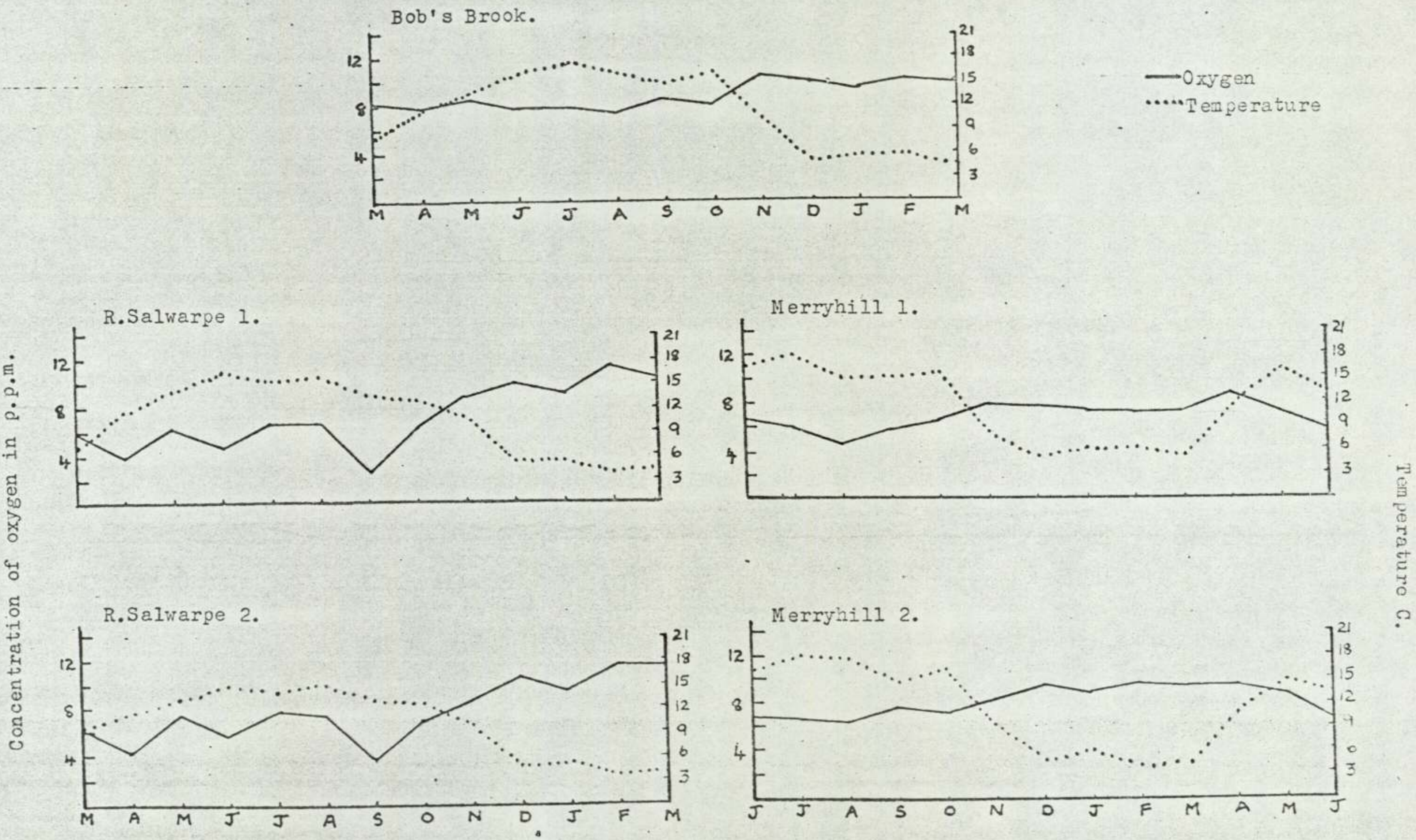
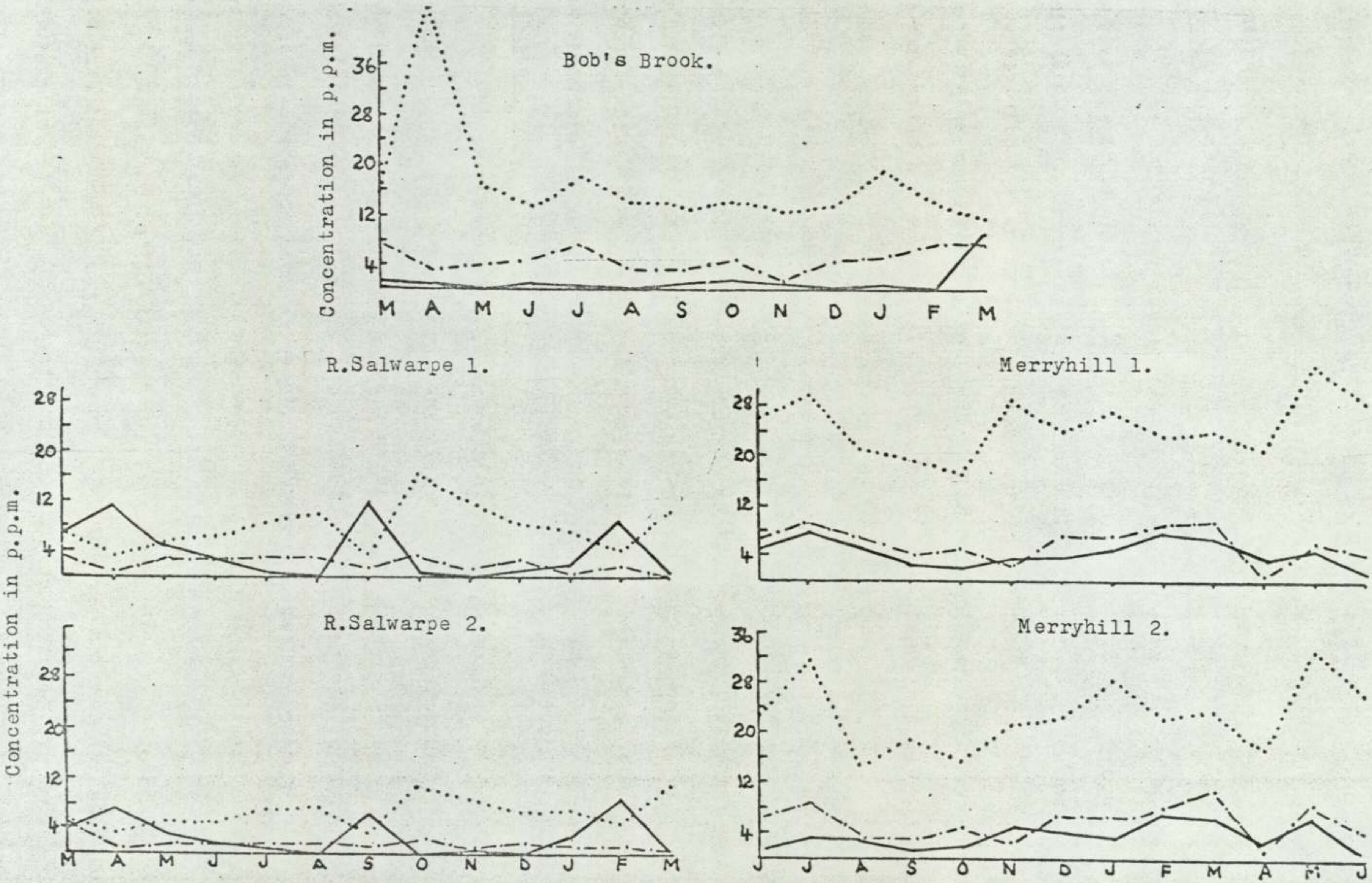


Fig.41. Monthly concentrations of ammonia(—), oxidised nitrogen(···) and orthophosphate(-·-) for five stations.



water was always well oxygenated, even at Station 1. There was usually more oxygen present in the water at Station 2 than at Station 1.

Ammonia (fig. 41)

The ammonia content of the water also reflects the subsequent improvement in the condition of the river. Ammonia was present in quite high concentrations for the first three months, from June onwards, with the exception of September and February, the concentration in the water was markedly reduced, and in some of the monthly samples it was hardly present at all. The concentration present decreased downstream so there was usually less at Station 2.

Nitrates (fig. 41)

The oxidised nitrogen content of the water varied irregularly from month to month. The improvement in the condition of the water is not reflected in these results. Generally the concentrations were not high, although for certain months e.g. October this was not the case.

Orthophosphates (fig. 41)

The concentrations of orthophosphates present, as with oxidised nitrogen, were never very high. The concentrations present did not vary much throughout the year and the improvement in the condition of the effluent is not reflected by a decrease in the amount of orthophosphates present. The concentrations present nearly always decreased downstream.

Carbon Dioxide (Table 11)

Dissolved carbon dioxide was usually present in significant concentrations throughout the year. As with the other chemical factors measured the concentrations usually decreased downstream.

B.O.D. (Table 11)

The improvement in the standard of the effluent is paralleled by an improvement of the B.O.D. of the water of the River Salwarpe. For the first five months the B.O.D. was usually very high, afterwards however there was a marked improvement at both stations.

The chemical figures show that while the old works was in operation the river, especially at Station 1, was grossly polluted. With the opening of the new works there was generally a steady improvement in the condition of the water. The new works did however experience "teething troubles" and the polluted state in September was almost certainly due to this. Towards the end of the sampling programme the improvement was obvious by the appearance of the water. It was now clear whereas previously it was generally turbid, and all traces of sewage fungus at Station 1 had disappeared. This improvement, as already stated, is reflected in the steady increase in the dissolved oxygen present, and the steady decrease in the concentration of ammonia present and in the B.O.D. of the water.

3.3.1.2 Biological Results

The results of the study on the river are summarised on Tables 12 and 13.

It was found that the improvement in water conditions during the period was parallelled by changes in the stream community. Previous samples from the river, prior to the detailed study described, had shown Station 1 to be grossly polluted, with the fauna composed of tubificid worms and Chironomus riparius larvae, while at Station 2, although C. riparius was still abundant, large populations of Asellus aquaticus were present.

Station 1 (Table 12)

The community at this station underwent a remarkable change over the twelve month period. The first quantitative sample, taken in March, contained tubificid worms and *Chironomus riparius* larvae. The worms were abundant while *C. riparius* larvae were only present in small numbers in the sample. For the next two months only tubificid worms and a few *C. riparius* larvae were present. The first change was observed in June when the larvae of the seven other chironomid species were present in the samples. From July onwards these other species became more numerous and in certain cases abundant while the numbers of *C. riparius* larvae decreased.

Other invertebrates, such as *Gammarus pulex* and nymphs of *Baetis rhodani* also appeared in the samples. These were never abundant but were nevertheless usually present. The chironomid species which appeared in the river following the improvement in the conditions were species that had been recorded in other polluted rivers. The seven most abundant species recorded were *Cricotopus bicinctus*, *Brillia longifurca*, *Trichocladius rufiventris*, *Polypedilum arundineti*, *Cricotopus sylvestris*, *Eukiefferiella hospitus* and *Brillia modesta*.

Station 2 (Table 13)

As in Station 1 it is possible to divide the monthly samples into three broad groups based on the organisms present. The first group is represented by the March sample. In this sample animals such as *Asellus aquaticus*, *Ancylus fluviatile*, *Chironomus riparius* and *Cricotopus sylvestris* were common.

The second group of monthly samples were those from April to June. In this period most of the species previously mentioned decreased in numbers. Then from July to the following March there wasan increase in their numbers together with the appearance of species not previously recorded at this station e.g. *Erpobdella testacea* and *Brillia longifurca*. *Chironomus riparius* is a noticeable exception to this trend, although the numbers did increase in June, it became rare in the following two months and was totally absent from the rest of the samples.

As at Station 1 Cricotopus bicinctus, Trichocladius rufiventris, Eukiefferiella hospitus, Brillia longifurca and Cricotopus sylvestris were common at this station. An apparent difference between the two stations was observed with regard to the relative abundance of Polypedilum arundineti and Pentaneura melanops. At Station 1 Polypedilum was abundant but it was rare at Station 2, the converse distribution was observed for Pentaneura melanops. In addition to the species of chironomid larvae, species of other groups now became established at this station, notably Erpobdella testacea, Baetis rhodani, Limnaea pereger and Ancylus fluviatile.

The results of the quantitative samples are interesting in two ways. Firstly they confirm the trends that have been observed in an organically polluted river and secondly they show how the various invertebrate taxa respond to an improvement in the water quality during the twelve month period. This will be considered later. As mentioned, the chironomid larvae recorded from the two stations on the Salwarpe had all been recorded in other rivers and it was found that the seasonal incidence also appeared to be similar. The seasonal incidence of Cricotopus bicinctus and Cricotopus sylvestris is shown in figures 42 and 43. It was found once again that both species seemed to be most abundant in the summer months, and rare during the winter and spring. Brillia longifurca had a very different seasonal incidence (fig. 42). This species, as had been noticed at other stations, is most abundant in the winter and spring samples.

The distribution of Trichocladius rufiventris and Eukiefferiella hospitus (fig. 43) was once again found to have a number of generations a year, being most abundant in the spring,

Fig. 42. Seasonal incidence of three species of the Chironomidae from two stations on the River Salwarpe.

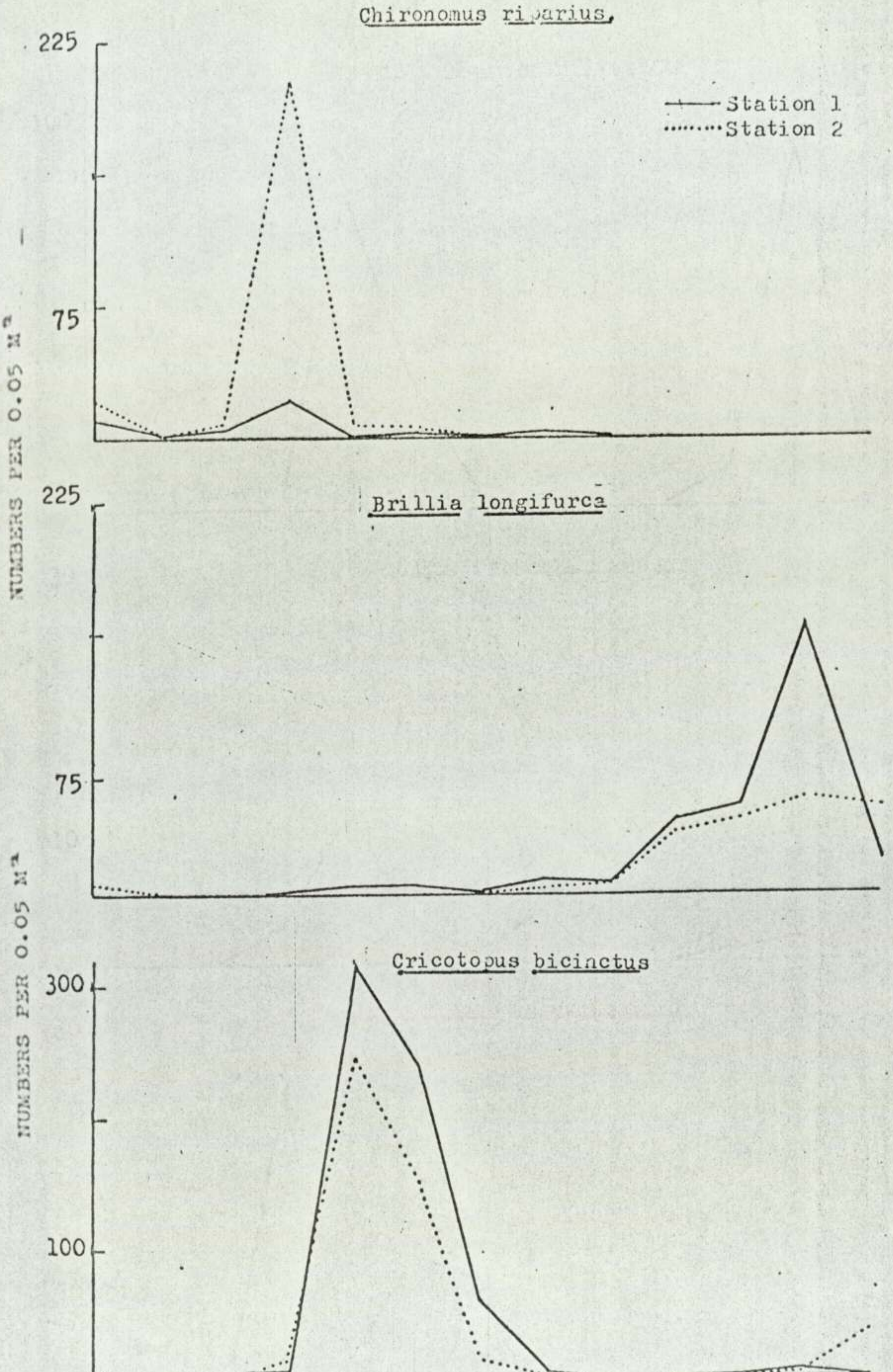


Fig. 43. Seasonal incidence of three species of the Chironomidae in two stations on the River Salwarpe.

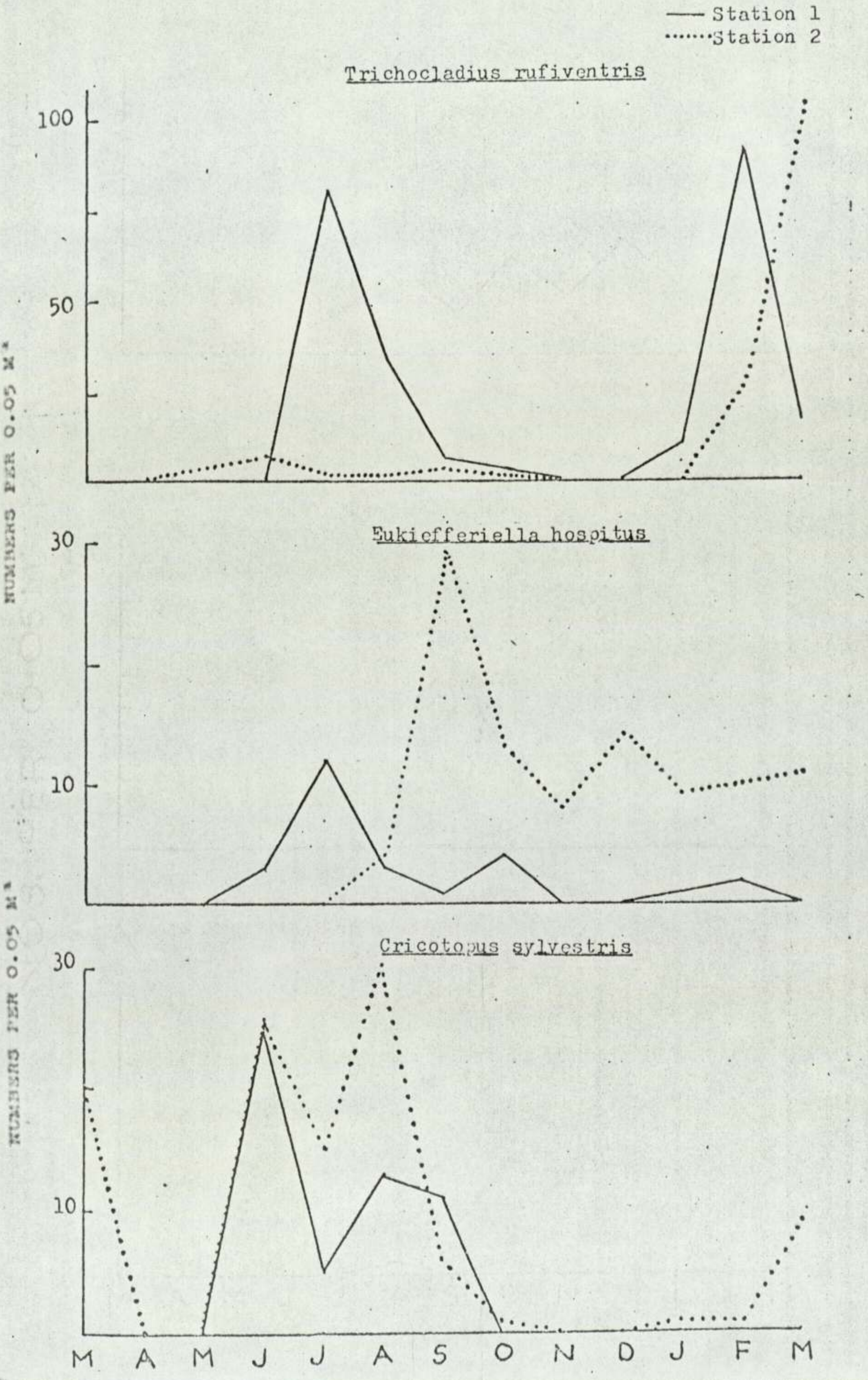
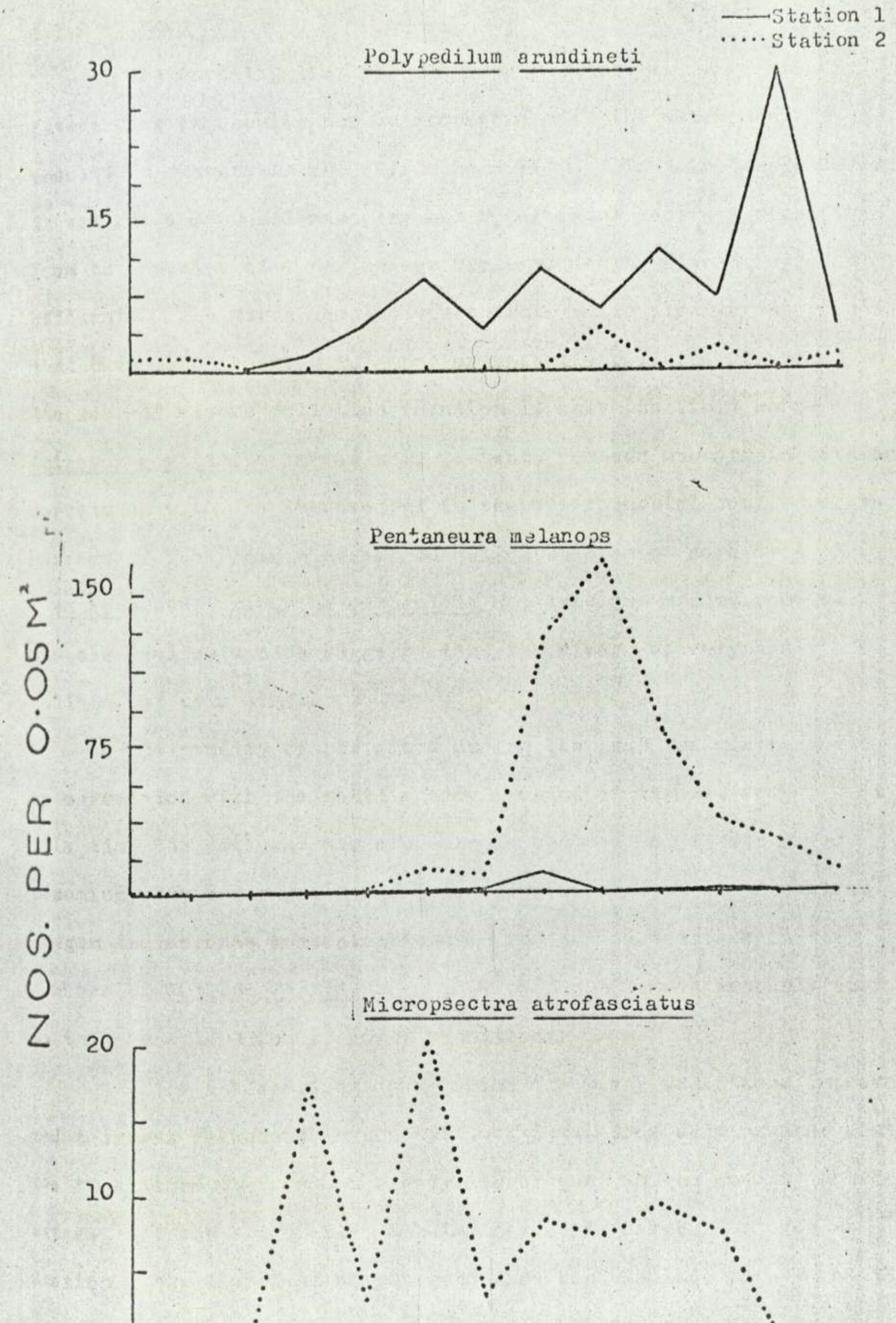


Fig. 44. Seasonal incidence of three species of the Chironomidae in two stations on the River Salwarpe.



mid-summer and autumn samples.

3.3.2 Discussion

The investigation of the River Salwarpe was particularly interesting in showing how an improvement in the water quality results in changes in the riffle community. In this case however it was not a seasonal recovery but a permanent recovery resulting from the opening of a new sewage works producing a much improved effluent. The March samples demonstrate quite clearly the trends that have been observed in other organically polluted rivers. In the zone of severe pollution (Station 1) only tubificid worms and Chironomus riparius larvae were present, further downstream (Station 2) correlated with the improvement in the environmental conditions the numbers of Tubificidae decreased while other species such as Asellus aquaticus and Erpobdella octoculata appeared and became common. The chemical data also suggests that the river was very badly polluted at this time.

The paucity of the fauna during the next two months could be correlated with the settling down period of the new works. At this time the effluent was exceedingly bad and led to the river becoming very badly polluted, this was reflected in the dissolved oxygen and ammonia concentrations. The marked decrease in the numbers of Asellus aquaticus in the April sample was probably due to this deterioration in river conditions.

After the settling down period the river conditions improved and this was reflected in the chemical data, from July onwards with two exceptions there was a steady improvement in the quality of the water. At the end of the sampling period in March 1968 even at Station 1 the dissolved oxygen concentration was 11.3 p.p.m. and the ammonia concentration 0.3 p.p.m., twelve months previous the corresponding figures were 6.0 p.p.m. and 6.8 p.p.m. respectively.

This improvement allowed the establishment at both stations of organisms which had not previously been recorded there. At the same time there appeared to be a decrease in the numbers of tolerant species. At Station 1, Gammarus pulex and Baetis rhodani nymphs appeared in the samples, these were never abundant but nevertheless were present, chironomid larvae which appeared in the river following the improvement in the conditions were Cricotopus bicinctus, Brillia longifurca, Trichocladius rufiventris, Polypedilum arundineti, Cricotopus sylvestris, Eukiefferiella hospitus and Brillia modesta (figs. 42, 43 & 44). These were all species that had been recorded from moderately polluted conditions in other rivers but not in severely polluted conditions. With the steady increase in the numbers of these species there was an apparent decrease in the numbers of Chironomus riparius larvae (fig. 42) which is known to favour and is restricted to badly polluted stretches of rivers. It would appear that Chironomus larvae were adversely affected by these improvements in water quality which accounted for their decline.

At Station 2 similar seasonal trends were observed there being a steady decrease in the numbers of Chironomus riparius present in the samples, while at the same time there was an increase in the numbers of moderately tolerant species such as Cricotopus bicinctus, Cricotopus silvestris, Pentaneura melanops, Eukiefferiella hospitus and Brillia longifurca. Other invertebrates which now appeared in the samples were Baetis rhodani, various molluscs and occasionally Gammarus pulex.

It was surprising how quickly the groups established themselves at both stations following the improvement in water conditions. It is noticeable however that this colonisation was mainly by insect larvae and nymphs, particularly the larvae of the Chironomidae. This can almost certainly be attributed to the aerial dispersal of

3.4 Merry Hill Brook (Wolverhampton)

3.4.1 Results

3.4.1.1 Chemical Results (Table 14)

The monthly chemical tests carried out on Merry Hill Brook indicated that the stream was very badly polluted. Very high concentrations of orthophosphates and oxidised nitrogen were usually found. They also showed that there was a slight recovery between Stations 1 and 2.

Dissolved Oxygen (fig. 40)

Very low values were never recorded, the lowest concentration for Station 1 was 4.8 p.p.m., while for Station 2 it was 6.5 p.p.m. The dissolved oxygen content of the water was always higher at Station 2 although the difference was not very great. The greatest recorded difference between the two stations for any one month was 2.3 p.p.m. Seasonal variation was not marked and this was almost certainly due to the fact that the stream commenced as a works effluent and so the flow throughout the year was fairly constant. The highest dissolved oxygen concentration recorded for Station 1 was in April (8.6 p.p.m.) and the lowest in August (4.8 p.p.m.).

The results of samples taken at intervals over a period of 24 hrs. are shown in Table 15. A diel fluctuation did occur but this was not very great. The dissolved oxygen concentration was highest for both stations at 8.30 p.m. and lowest at 6.00 a.m.

Temperature (fig. 40)

The temperature showed the expected seasonal variation, the highest temperatures in the routine samples for Stations 1 and 2 were 18.5°C and 18°C respectively in July. The water at Station 1, with one exception, was warmer than at Station 2 and this was almost certainly due to the fact that the effluent leaving the sewage works was warm. The temperatures recorded during the 24 hr. period

(Table 15) were high. Station 1 reached a maximum of 21.6°C at 2 p.m. and Station 2 a maximum of 22°C at 4 p.m. The lowest temperature figures were recorded for both stations at 4.00 a.m. when 16°C and 14.9°C were recorded for Stations 1 and 2 respectively.

Calcium

The water at both stations was generally hard although there were considerable variations in the monthly concentrations. There were no consistent differences in hardness between the two stations and there seemed to be no seasonal variations.

Magnesium

As with the calcium no consistent differences were seen between the two stations. The magnesium was usually present in quite high concentrations at both stations. The concentrations present varied considerably from month to month and there seemed to be no seasonal variation.

Ammonia (fig. 41)

Ammonia was usually present in the water, the concentration being greater at Station 1. There was not an obvious seasonal variation, the concentrations fluctuated from month to month. The ammonia never reached high concentrations at either station and the figures obtained would not suggest that the river was badly polluted.

Nitrates (fig. 41)

The concentrations of oxidised nitrogen in the form of nitrates and nitrites were exceedingly high at both stations. The concentrations in the water at Station 1 were nearly always higher than at Station 2. The maximum concentration found at Station 1 was 34.6 p.p.m. and at Station 2 33 p.p.m. As with ammonia there was no obvious seasonal variation.

The very high concentrations of oxidised nitrogen and the relatively low concentration of ammoniacal nitrogen suggests that the effluent was well oxidised which was very different to the effluent discharged into the River Cole.

Orthophosphates (fig. 41)

The water at both stations was characterised by having high concentrations of orthophosphates. The concentrations were usually higher at Station 1 than Station 2. Once more there was no obvious seasonal variation. The highest concentration recorded at Station 1 was 9.7 p.p.m. and at Station 2 it was 10.9 p.p.m.

The high concentration of orthophosphates would suggest that the river was badly polluted.

pH

The water at both stations was usually slightly alkaline, being more so at Station 2. Again there was no obvious seasonal variation, the pH fluctuated from month to month.

Carbon Dioxide

There were usually high concentrations of free carbon dioxide dissolved in the water, especially at Station 1. The concentration decreased from Station 1 to 2. Concentrations fluctuated from month to month and seasonal variation was not obvious.

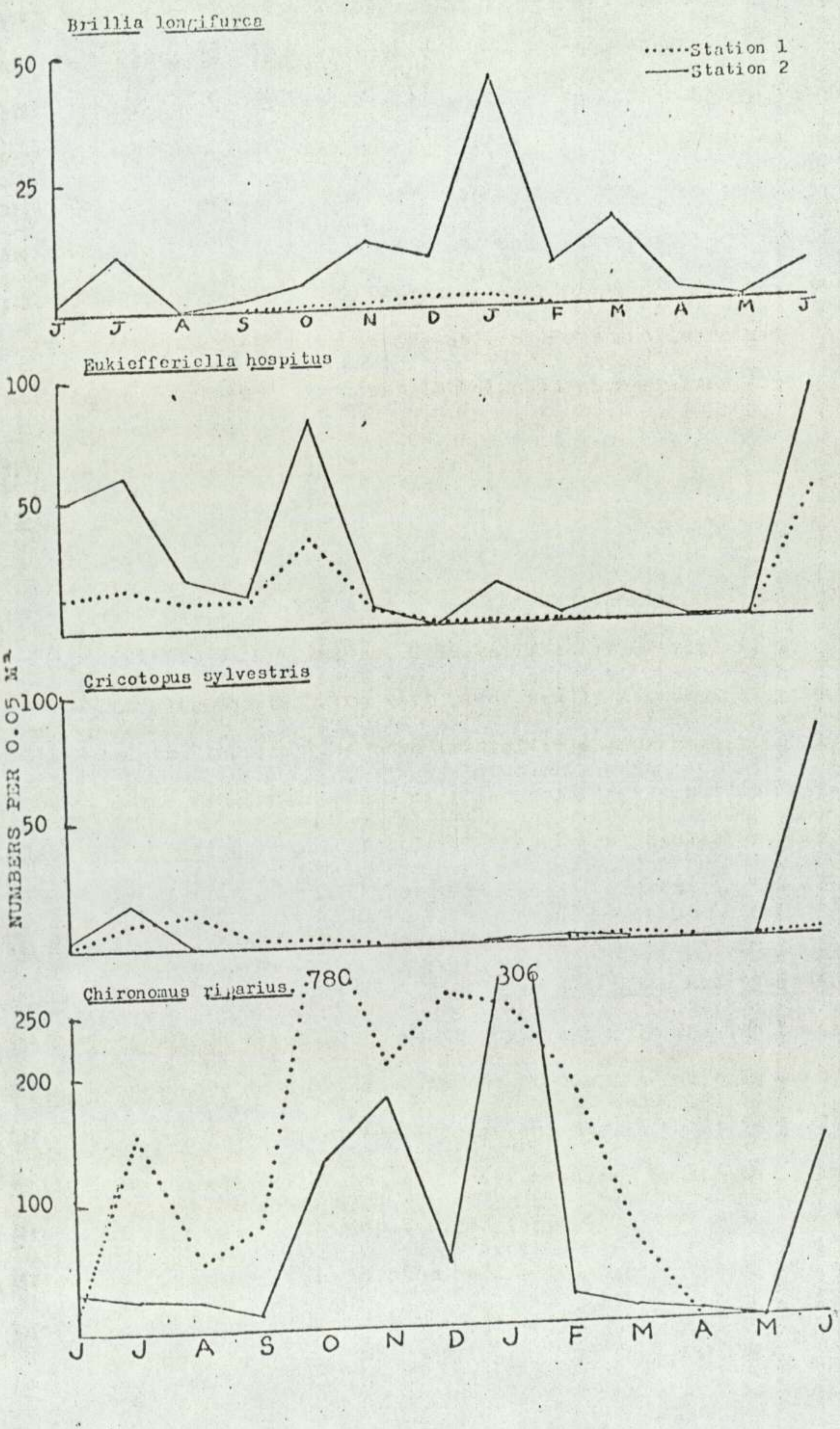
B.O.D.

The water at both stations usually had a high B.O.D., usually higher at Station 1. The highest B.O.D. recorded at Station 1 was 27.1 p.p.m. while for Station 2 it was 16.1 p.p.m.

The various monthly tests suggest, that at the two stations sampled, Merry Hill Brook was badly polluted.

The chemical information was interesting in that it revealed that Merry Hill Brook was polluted in quite a different way to the River Cole. In the Cole the pollution was seasonal and the two most important ways in which the effluent affected the composition of the water was by greatly reducing the oxygen content and by

Fig. 45. Seasonal incidence of four species of the Chironomidae from two stations on Merryhill Brook.



increasing the ammonia concentration. These two factors only became marked during the summer. In Merry Hill Brook the oxygen was never seriously depleted nor did the ammonia reach the concentration found in the badly polluted regions of the Cole. There were, however, exceedingly high concentrations of nitrates and orthophosphates present all through the year. The conditions in the stream could be considered as eutrophic rather than organically polluted. Merry Hill Brook in terms of chemical composition, was similar throughout the year. The only obvious and important difference between summer and winter being the temperature levels.

3.4.1.2. Biological Results

Station 1 (Table 16)

The fauna at this severely polluted station was very restricted. It consisted almost entirely of species belonging to the Tubificidae, Enchytraeidae, Chironomidae and Simulidae.

The oligochaete worms were never really abundant at this station and the two families were present in approximately equal numbers. The dominant species of chironomid larvae was definitely Chironomus riparius. This species formed large populations for most of the year (fig. 45) although it was not present in the April and May samples. Only three other species were apparently present in considerable numbers, namely Cricotopus bicinctus and sylvestris and Eukiefferiella hospitus. As in the River Cole the two species of Cricotopus were most numerous in the summer samples only scattered individuals being taken between October and May. Eukiefferiella hospitus on the other hand had a broader seasonal incidence, being present in most of the monthly samples (fig. 45). Simulium reptans larvae were common at this station during the winter months but were apparently rare during the summer months.

Station 2

The fauna at this station is summarised in Table 17. It reflected a recovery in the polluted state of the river, which is borne out by the chemical data. This recovery is shown by the fact that Asellus aquaticus was present in the samples and that species of chironomid larvae other than Chironomus riparius had increased in numbers. The Enchytraeidae now appeared to be the dominant worms, being far more numerous than at Station 1, while the numbers of Tubificidae had apparently decreased.

One of the most obvious differences between the fauna at the two stations was the fact that Asellus aquaticus was now present in the samples. Individuals were usually present although never in very great numbers. Chironomus riparius was abundant at this station but the monthly incidence (fig. 45) suggested that the numbers were lower than at Station 1. Cricotopus bicinctus also seemed to be present in fewer numbers at this station. Other species, notably Brillia longifurca, Eukiefferiella hospitus and to a lesser extent Cricotopus sylvestris were far more abundant in the samples from Station 2. The seasonal incidence of the two species of Cricotopus once again suggested that they formed large populations only during the summer months. The seasonal incidence of Brillia longifurca (fig. 45) revealed that, as in the River Cole, it was present in greatest numbers in the samples taken from November to March. It was also possible to recognise that as in the River Cole, Eukiefferiella hospitus (fig. 45) formed three populations during the year. As at Station 1 the larvae and pupa of Simulium reptans were important constituents of the fauna but were usually present in greater numbers in the samples from Station 2.

3.4.2. Discussion

It was possible in a limited way to observe the effect of varying degrees of organic enrichment on the fauna in Merry Hill Brook. The chemical data (Table 14) clearly show that Station 1 is more organically polluted than Station 2, and this improvement in the condition of the water influences the distribution of aquatic organisms. Certain animals such as the Tubificidae, Chironomus riparius and Cricotopus bicinctus which are known to be tolerant of organic pollution usually decreased in numbers downstream. While the numbers of not so tolerant species such as Asellus aquaticus, Brillia longifurca and Eukiefferiella hospitus apparently increased in numbers downstream.

The result of the investigation on Merry Hill Brook was particularly interesting in that it showed that low dissolved oxygen and high ammonia concentrations are not the only important criteria influencing the distribution of invertebrates. Station 1 on Merry Hill Brook was characterised by a benthic community consisting mainly of tubificid worms and Chironomus riparius larvae which suggests that the stream at this point is severely polluted. The lowest dissolved oxygen concentration recorded at this station was 4.8 p.p.m. in August 1967 while the highest ammonia concentration was 8.0 p.p.m., neither would suggest that the river was very badly polluted and in fact similar figures had been recorded in the River Cole Station 6 which had a much more varied benthic community. If other factors such as nitrates, orthophosphates and carbon dioxide concentrations are considered however it is at once apparent how badly polluted Merry Hill Brook was. At Station 1 a nitrate concentration of 34.6 p.p.m., an orthophosphate concentration of 9.7 p.p.m. and a carbon dioxide concentration of 35 p.p.m. were recorded. It would seem that these are the possible limiting factors in this particular stream and not the more widely accepted criteria of deoxygenation and high ammonia concentrations. There was usually an improvement in these three chemical criteria at Station 2 and the fauna showed a corresponding improvement, the numbers of Chironomus riparius in the samples decreasing while those of Asellus aquaticus, Brillia longifurca, Cricotopus sylvestris and Eukiefferiella hospitus increased.

3.5 Bob's Brook

3.5.1 Results

3.5.1.1 Chemical Results (Table 18)

The chemical figures reveal that Bob's Brook was affected in a similar way to Merry Hill Brook. The water was always well oxygenated with hardly any ammonia present. However there were usually high concentrations of oxidised nitrogen and orthophosphates present.

Hardness

The water was always particularly hard. This was largely due to calcium which was always present in very high concentrations, the magnesium, on the other hand, varied from a maximum of 19.6 p.p.m. to a minimum of 1.46 p.p.m.

Temperature (fig. 40)

The temperature showed the normal seasonal variation. Because the stream was overhung by trees it was prevented from becoming very warm during the summer. The highest temperature recorded during a series of samples over a 24 hr. period was 18°C whereas at Merry Hill Brook, on the same day, the maximum temperature recorded at Stations 1 and 2 was 22°C and 21.6°C respectively.

pH

The water was always slightly alkaline. There was no seasonal variation in the pH of the water, the most alkaline figure recorded was 7.65 in March and the least alkaline 7.05 in May.

Dissolved Oxygen (fig. 40)

The samples revealed that Bob's Brook was always well oxygenated and this was probably due to the turbulent nature of the stream. There was a slight seasonal fluctuation, the lowest recorded concentration was 7.2 p.p.m. in August and the highest was 10.4 p.p.m. in November. The samples taken in July 1969 over a 24 hr. period showed no diel fluctuation, in fact the dissolved oxygen concentration was lowest at 4.00 p.m. and highest at 6.00 a.m.

Ammonia (fig. 41)

The concentrations of ammonia found in Bob's Brook were with one exception, very low.

Nitrates (fig. 41)

The oxidised nitrogen reflected the abnormal conditions of the river. High concentrations were usually present and in April 1968 a concentration of 46.2 p.p.m. was recorded. The lack of ammonia together with the high concentrations of nitrates suggest that the effluent was a well oxidised one.

Orthophosphates (fig. 41)

Orthophosphates were present in all samples in relatively high concentrations. No seasonal variation is apparent, the highest concentration recorded was 7.6 p.p.m. in April while the lowest was 1.7 p.p.m. in October.

Carbon Dioxide

During the summer months dissolved carbon dioxide was present in high concentrations and 29 p.p.m. was recorded in May.

B.O.D.

The B.O.D. of the water fluctuated from month to month in an irregular manner. From a study of the B.O.D. figures recorded it is difficult to assess the polluted state of the river. The highest figure recorded was 24.4 p.p.m. in April and this would suggest that the river was grossly polluted. On the other hand, the 6.4 p.p.m. recorded in October would, at the most, signify a moderately polluted stream.

The chemical analyses reveal that Bob's Brook is not what could be described as a typically polluted stream. It is unusual in that it is always well oxygenated and the ammonia present was negligible. Its polluted state was made obvious however by the large concentrations of orthophosphates, oxidised nitrogen and dissolved carbon dioxide usually present. As in the case of Merry Hill Brook the condition could be considered as eutrophic rather than organically polluted.

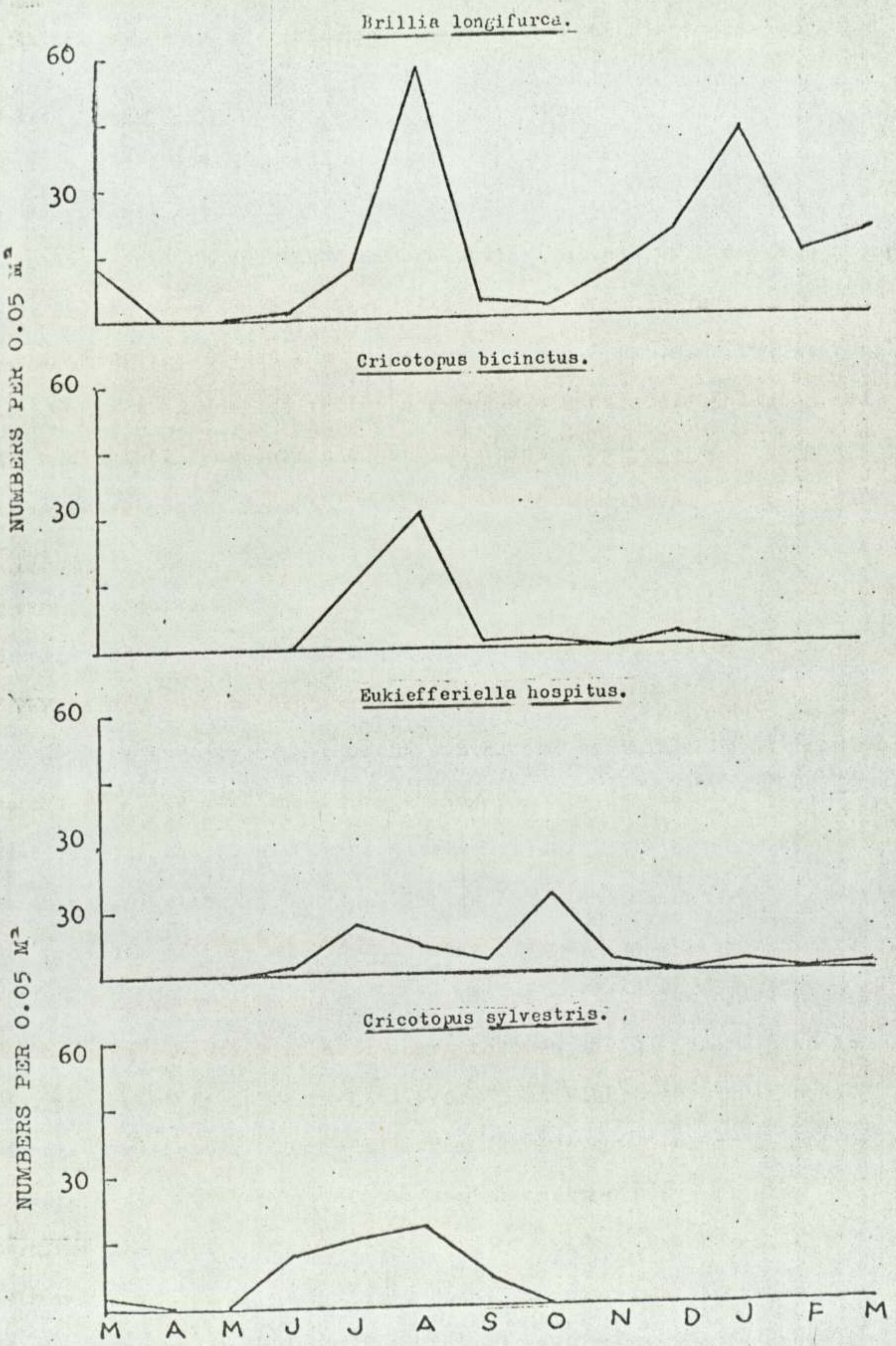
3.5.1.2 Biological Results

The results of the samples are summarised in Table 19. The fauna at this station was again very restricted. It was also poor in terms of numbers of individuals. The two most abundant groups were the Tubificidae and Chironomidae, but even these did not form large populations. Two species of leech were recorded of which the most numerous was Trocheta subviridis but this species was never abundant.

The Chironomidae were represented by the larvae of a number of species and it was found that the most abundant species in the samples were Brillia longifurca, Cricotopus bicinctus, Cricotopus sylvestris and Eukiefferiella hospitus. All four species had been found in the polluted regions of the River Cole.

The seasonal incidence of the larvae of these four species is illustrated in fig. 46. It can be seen that Cricotopus bicinctus and Sylvestris were most numerous in the summer samples. Brillia longifurca on the other hand, had a similar seasonal incidence to that observed in the River Cole, that is the larvae were most abundant in the samples taken in the spring and autumn and tended

Fig. 46. Seasonal incidence of four species of the Chironomidae from Bob's Brook (Dudley).



to be scarce in mid-summer. The three populations of Eukiefferiella hospitus which had been observed in other sampling stations, although not very obvious could nevertheless be distinguished.

3.5.2 Discussion

The chemical conditions were found to be similar to those in Merry Hill Brook. The water contained high concentrations of nitrates, orthophosphates and carbon dioxide and, with one exception, only traces of ammonia. The water however was always well oxygenated, the lowest figure recorded was 7.2 p.p.m. The chemical data would then suggest that the river was moderately polluted and the biological results would confirm this. Chironomus riparius larvae were absent from the samples, while the larvae of Brillia longifurca, Cricotopus sylvestris and Eukiefferiella hospitus were present. These three species had been found in many of the other sampling stations and were common in the recovery stages of the River Cole (Stations 4, 5 and 6).

The paucity of the fauna can almost certainly be attributed to the physical conditions prevailing at this station. The very fast current would, almost certainly, restrict the numbers of swimming and clinging forms while the lack of sediment would restrict the presence of burrowing forms such as worms and chironomid larvae.

The investigation of Bob's Brook, despite the sparseness of the benthic community nevertheless provided useful information in that it showed as in Merry Hill Brook that high concentrations of nitrates, orthophosphates and carbon dioxide could also be important in determining the nature of the benthic community. It also verified the fact that the larvae of the different species of Chironomid varied in their tolerance of organic pollution; the species present at this station had all been recorded elsewhere in moderately polluted conditions.

3.6 Trent Sampling Stations

3.6.1 Results

a) Walton

Chemical Results (Table 20)

This stretch of the River Trent, below the entry of the River Tame, as can be seen from the chemical analysis (Table 20) was very badly polluted. The dissolved oxygen concentration was depleted throughout the year although there was generally more oxygen present in the water during the winter. Ammonia was also present in appreciable concentrations throughout the year, the concentration fluctuated from month to month and no seasonal pattern is apparent. Oxidised nitrogen, in the form of nitrates and nitrites, were also usually present in concentrations associated with badly polluted conditions. The carbon dioxide concentration and B.O.D. of the water varied from month to month but these also signified organic pollution.

Biological Results (Table 21)

The fauna at this locality was found to be very restricted, consisting mainly of Asellus aquaticus, Erpobdella octoculata, chironomid larvae and Tubificidae. The chemical data showed this to be a very badly polluted stretch of the river and this is reflected in the fauna. Chironomid larvae were never present in very large numbers, but the species which were present had been found in other rivers which the chemical data suggest had a similar degree of pollution. The most abundant species were Cricotopus sylvestris, Cricotopus bicinctus and Chironomus riparius. The larvae of the two species of Cricotopus were once again most abundant in the late spring and summer.

b) Wem Brook

Chemical Results (Table 22)

Chemical analysis suggests that Wem Brook was quite badly polluted. The oxygen concentration was never seriously depleted during the day, although considerable diel fluctuations may have occurred owing to the profuse growths of Cladophora. Ammonia in particular and, to a lesser extent, oxidised nitrogen were usually present in considerable concentrations and suggest that the stream at this point was quite badly polluted. The B.O.D. of the water however was never particularly high, even during the summer months and this would suggest that the stream was only moderately polluted.

Biological Results (Table 23)

The fauna found in the seven samples taken from Wem Brook suggest that the stream was moderately polluted and this agrees with the polluted condition suggested by the chemical data. Tolerant forms such as Asellus aquaticus, leeches and certain chironomid larvae were well represented, while less tolerant forms such as trichopteran larvae, plecopteran nymphs and Gammarus pulex were either absent from the samples or poorly represented. Asellus aquaticus was abundant at this station and was present in large numbers in all the samples. The dominant leech was Erpobdella octoculata although it was significant that the two species usually associated with polluted conditions namely Erpobdella testacea and Helobdella stagnalis were also present.

The chironomid larvae were all species that had been found in other polluted rivers in the Midlands. Chironomus riparius was found at this station but only in the summer months and this could be explained by the fact that it is only in the summer months, when there is a low flow, that the stream is badly polluted enough to 'suit' the species. Cricotopus bicinctus and Cricotopus sylvestris were found at this station and here they were also common in the late spring and summer samples and absent from the winter samples. The most abundant species taken in the early spring was Trichocladius rufiventris as was found in the Rivers Cole and Salwarpe. Other species present at this station which had been recorded elsewhere were Eukiefferiella hospitus, Prodiamesa olivacea, Brillia longifurca, Brillia modesta and Pentaneura melanops.

c) Kings Bromley

Chemical Results (Table 24)

The chemical data would suggest that the Trent, at this locality, was not seriously polluted. The oxygen concentration did not seem to be seriously depleted even in summer, the lowest concentration recorded was 5.1 p.p.m. in June 1968. The ammonia and nitrate concentrations in the water were not particularly high and would suggest moderate pollution.

Biological Results (Table 25)

The seven samples taken from this sampling station were all similar and showed the station to have a restricted fauna. Leeches were present in all samples with Erpobdella octoculata being the most abundant. Asellus aquaticus was also common. The insects were poorly represented in the Trent at this locality and this is reflected in the numbers of chironomid larvae in the samples. The molluscs, on the other hand, were well represented with Sphaerium sp. and Limnaea pereger being the most common. The paucity of the insect fauna cannot really be correlated with the conditions induced by organic pollution. The dissolved oxygen concentrations were never seriously depleted, while the ammonia and orthophosphate concentrations were never high, it would seem that other factors, not measured in this study, could be responsible.

d) St. Thomas' Mill (River Sow)

Chemical Results (Table 26)

The chemical data for this station suggests that the river is only slightly polluted. At the times of sampling the river was always well oxygenated, while ammonia was present only in traces. The concentration of nitrates, and to a lesser extent the B.O.D. of the water, were higher than would normally be expected in a non polluted stream and suggest that the river is slightly polluted.

Biological Results (Table 27)

The animals recorded from the river at this point also suggest that the river was only slightly polluted. The most important difference to the previous three sampling stations was that *Gammarus* was now by far the most numerous crustacean. An interesting point was that the species of *Gammarus* was *Gammarus tigrinus* and not *Gammarus pulex*. *Asellus aquaticus* was present at this station but was never abundant. The larvae of two species of Trichoptera and Coleoptera were also taken at this station.

Other important constituents of the community were leeches and molluscs. The leeches in the samples were usually represented by two species namely *Erpobdella octoculata* and *Glossiphonia complanata*, the two species were present in similar numbers. The molluscs were well represented as a group with *Sphaerium* and *Hydrobia jenkinsi* being common. The presence of such clean water animals as *Gammarus*, Trichoptera and Coleoptera larvae together with the absence, or near absence, of animals associated with polluted conditions e.g. *Asellus aquaticus* and various chironomid larvae would imply that the river is not badly polluted at this point.

e) Harlaston

Chemical Results (Table 28)

The River Mease at Harlaston was very slightly organically polluted. The water was well oxygenated and the ammonia concentration very low in all the samples. As with the River Sow (St. Thomas' Mill) the nitrate concentration is higher than would normally be expected and reveals that the river has received slight organic enrichment.

Biological Results (Table 29)

The animals recorded in the seven samples taken at this sampling point would suggest, as did the chemical data, that the river has received only slight organic enrichment. The presence of Asellus aquaticus and Erpobdella octoculata would suggest that the river is not entirely without organic enrichment but the presence of Gammarus pulex, Caenis moesta, Baetis rhodani and various Trichoptera and Coleoptera larvae makes it obvious that the river is generally of good quality.

3.6.2 Discussion

The sampling stations on the River Trent confirmed that with varying degrees of pollution there would be different benthic communities. Thus the five stations can be thought of as being comparable to stations on a river that is undergoing recovery. From chemical evidence it would have appeared that the five stations were polluted to various degrees, the worst being the Trent at Walton, followed by Wem Brook, Trent at Kings Bromley, River Sow at St. Thomas' Mill and the River Mease at Harlaston which is only slightly polluted. This is exactly the same order as would be deduced from a study of the fauna.

The fauna of the Trent at Walton, during the summer, was composed of tubificid worms, Asellus aquaticus, Erpobdella octoculata, Chironomus riparius and Cricotopus sylvestris. This is a similar benthic community to that found in the River Cole, Stations 4 and 5. As in the River Cole stations the animals in this locality were subjected to very low oxygen and high ammonia concentrations and these factors were obviously important in determining the benthic community.

The fauna of Wem Brook was similar to that at Walton, the most important differences being that Asellus aquaticus was more abundant and the occasional Gammarus pulex was recorded. Thus the fauna would suggest that this station is not as badly polluted as the Trent at Walton. The chemical data would agree with this for although ammonia concentrations are as high, Wem Brook did not experience the same degree of severe deoxygenation and it could have been this fact that allowed the more resistant individuals of Gammarus pulex to survive.

The Trent at King's Bromley also had a fauna in which Asellus aquaticus and leeches were important constituents. At Wem Brook the most abundant leech was Erpobdella octoculata with Helobdella stagnalis also being important. Erpobdella octoculata was also the most abundant leech at King's Bromley but another species, Glossiphonia complanata, which is not thought to be as tolerant as Helobdella stagnalis was also common. Also present at King's Bromley were a variety of molluscs including Sphaerium sp. and Limnaea pereger, which also suggests that the river is not very badly polluted. The chemical data similarly suggest that the river is not badly polluted because it was usually well oxygenated while such factors as the ammonia concentration were never high. The unusual feature of the river at this point is the paucity of insects, even larvae of the Chironomidae which are known to thrive in polluted conditions far worse than the benthic community would experience in this locality. Thus it would seem that other factors, not usually associated with organic pollution, could be responsible for the paucity of this group.

The River Sow at St. Thomas' Mill and the River Mease at Harlaston were revealed, by the chemical data, to be only slightly polluted, being well oxygenated with low ammonia and carbon dioxide concentrations. The fauna of the former sampling point reflects these environmental conditions for although Erpobdella octoculata was common Gammarus was now the dominant crustacean and two species of Trichoptera were recorded there. Gammarus pulex was also an important constituent of the benthic community at Harlaston but in addition there were three species of Ephemeroptera and two species of Trichoptera in a number of the samples, all of which are usually diagnostic of good quality water. This points to the fact that the river can only be slightly polluted. The presence of Asellus aquaticus and Erpobdella octoculata in the riffle sections at both sampling stations points to the fact that the rivers are receiving some organic enrichment which is obvious from nitrate concentrations.

3.7 River Ray Survey

3.7.1 Results

3.7.1.1 Chemical Results

The results from the samples taken in March 1968 are summarised in Table 30. The water at the station above the effluent (Station 1), although well oxygenated seemed to be slightly polluted, the B.O.D., ammonia and nitrate concentrations being quite high. Downstream of the effluent outfall (Station 2) there was a decrease in the oxygen concentration and marked increases in the ammonia and nitrate concentrations. The river at Stations 3 and 4 showed no real improvement in these factors, in fact the highest ammonia concentration recorded was at Station 4.

The results from the second set of samples taken in August 1969 are summarised in Table 31. Below the effluent outfall the chemistry of the water was now quite different to that found the previous year.

Ammonia was no longer present in high concentrations at Stations 2, 3 and 4, the water at these stations did however contain very high carbon dioxide concentrations. The sample taken at Tadpole Bridge containing 50 p.p.m. of carbon dioxide.

3.7.1.2 Biological Results

The biological results from the samples taken in March 1968 are summarised in Table 32. At Station 1 the fauna was rather restricted and it appeared that the river was mildly organically polluted. Asellus aquaticus was common but the presence of Gammarus pulex and Baetis showed that the river was not severely polluted. Downstream of the effluent (Station 2) the benthic community was dominated by Asellus aquaticus, there being a marked increase in the numbers of this species, the numbers of Baetis present in the samples decreased. The benthic community at Stations 3 and 4 was similar to that found at Station 2, Asellus continued to be abundant.

The results from the samples taken in August 1969 are summarised in Table 32. The results are similar to those of the previous year. At Station 1, the benthic community was again restricted, but although Asellus aquaticus was abundant other invertebrates such as Gammarus pulex, Baetis and Glossiphonia complanata were present in the samples. At Station 2 there was an increase in the numbers of A. aquaticus in the samples and a decrease in the numbers of the clean water species such as G. pulex. No real recovery occurred at Stations 3 and 4 although there was a fall in the numbers of A. aquaticus.

3.7.2 Discussion

The investigation of the River Ray was interesting from a number of aspects. The river although organically polluted did not exhibit the recovery associated with this type of pollution, Station 4 although four miles downstream of Station 2 appeared to be just as badly polluted. Because the river did not exhibit this natural recovery the sequences of benthic communities typically found in organically polluted rivers were absent. The stretch of the river below the effluent outfall had a riffle community dominated by the moderately tolerant Asellus throughout its length.

Although the river below the effluent outfall was largely composed of sewage effluent, the oxygen concentration was not severely depleted and this would possibly explain the absence of Chironomus riparius from the benthic community. This species, although exceedingly tolerant of polluted conditions, has been shown by Fox and Taylor (1955) to be adversely affected by well oxygenated water.

The benthic community at each station was found to be similar in August 1969 to that found in March 1968. The chemistry of the water however was quite different on these two sampling occasions, in 1968 the water contained high concentrations of undissociated ammonia. A concentration of 0.26 p.p.m. was recorded at Station 4, concentrations of this order would make ammonia a very important limiting factor to most clean water species and explain why no recovery occurred at these stations. In 1969, however, the water at Stations 2, 3 and 4 contained high concentrations of carbon dioxide and very little ammonia, at Station 3 a figure of 50 p.p.m. was recorded. Such high concentrations would almost certainly limit the distribution of many clean water invertebrates and explain why these animals were not present in the river at these stations.

3.8 Discussion of Field Work Results

The present study of Midlands streams showed that it was possible to recognise the degree of organic pollution from the benthic community. In streams severely organically polluted one would expect to find a community of tubificid worms and Chironomus riparius larvae, this type of community was encountered in Stations 2 and 3 on the River Cole, Station 1 on the River Salwarpe (before the opening of the new works) and Station 1 on Merry Hill Brook. If conditions are not quite so bad, in addition to these species *Asellus aquaticus* and leeches such as *Erpobdella octoculata*, *testacea* and *Helobdella stagnalis* would be present together with chironomid larvae such as *Prodiamesa olivacea*, *Cricotopus sylvestris*, *Trichocladius rufiventris* and *Brillia longifurca*. Such communities were found at Station 4 on the River Cole, Station 2 on the River Salwarpe, Walton on the River Trent. With a further improvement in the quality of the water these latter species would become more abundant while the number of Tubificidae and *Chironomus riparius* would fall. Sampling stations exhibiting such a community were Station 5 on the River Cole, Station 2 on the River Salwarpe, Wem Brook and Station 2 on Merry Hill Brook. If the water quality is even better one would expect the reappearance of the more tolerant clean water fauna such as *Gammarus pulex* and molluscs such as *Sphaerium corneum* in addition to the previous community. Station 6 on the River Cole and King's Bromley on the Trent possessed such a community.

Slight organic enrichment seems to restrict the most sensitive species and allow species not usually associated with riffle communities to be present. River Cole Station 1 had large populations of *Gammarus pulex*, *Hydropsyche angustipennis*, *Baetis rhodani* and several species of Nemouridere, all of which can be regarded as clean water fauna, but in addition the moderately tolerant species *Asellus aquaticus*, *Helobdella stagnalis* and *Erpobdella octoculata* was present. Very similar communities were found at Harlaston and St. Thomas' Mill. If the stream or river receives no obvious organic enrichment, the moderately tolerant species previously mentioned would not be present and the riffle community would consist of Gammarus sp. and a variety of mayflies, stoneflies, caddis flies and beetles. This is the benthic community found at the non-polluted Dowles Brook.

Because pollution by organic matter is very complex it is not always possible to understand how it is exerting its influence on the riffle community. From the present study it would seem that no one factor produces these changes in the community because very different chemical conditions may be found in polluted rivers and yet the same sequences of riffle community may be found. In the River Cole the marked deoxygenation coupled with the high ammonia, orthophosphate and carbon dioxide concentrations that prevailed during the summer months were obvious possible limiting factors. In fact it is known that the low oxygen concentrations alone would account for the absence of nearly all the clean water fauna found upstream of the effluent. If the high concentrations of ammonia, which is known to be toxic, and carbon dioxide, which is known to influence the toxicity of low oxygen concentrations to fish, are taken into consideration it is not difficult to understand why a totally different and far more tolerant community is found below the effluent. The gradual improvement of these conditions downstream allowed progressively less tolerant communities to become established. Similar environmental conditions of low oxygen and high ammonia concentrations were found to exist in the River Salwarpe (from March to May 1967) and at Walton and as already described similar riffle communities existed at these places. Wem Brook differed in that although the ammonia concentration was high the organisms living in the stream were not subjected to the same degree of deoxygenation and this was reflected in the occasional presence of Gammarus and Baetis. Thus it would seem that ammonia is the most important limiting factor at this sampling station.

The four stations below the effluent on the River Ray at Swindon were similar in that the water was usually well oxygenated but had high concentrations of ammonia. As in Wem Brook the fauna was very restricted, the community being largely composed of Asellus aquaticus, so it would appear that once again, of the criteria measured it is ammonia that is probably the most important limiting factor.

That low dissolved oxygen and high ammonia concentrations are not the only important criteria influencing the distribution of invertebrates was immediately obvious from the results from Merry Hill and Bob's Brook. In both streams the water was characterised not by low oxygen and high ammonia concentrations but by high concentrations of nitrates and orthophosphates. In Merry Hill in particular the benthic community was that associated with severely polluted conditions.

It became apparent that benthic invertebrates are extremely sensitive to their environment and either a worsening or improvement in the environmental conditions brought about changes in the benthic community. The partial recovery in the fauna at Stations 2 and 3 on the River Cole and the permanent recovery noticed in the River Salwarpe demonstrated this. In both examples, the one due to dilution, the other to an improvement in the quality of the effluent, there was an improvement of such criteria as dissolved oxygen, ammonia, orthophosphates and carbon dioxide concentrations and it could be the improvement in these conditions that allowed the moderately tolerant species to establish themselves.

The results from the field work as a whole confirm the sensitivity of benthic invertebrates to nutrient enrichment which enables them to be used as indicators of pollution. The changes in water quality brought about by an effluent could vary greatly as in the River Cole and Merry Hill Brook, but nevertheless the changes in the fauna are basically similar. Thus it is indeed possible to recognise communities which can definitely be associated with pollution and these will be present irrespective of the type of effluent.

4. Experimental Work

Aim

The aim of the experimental work was to try to evaluate the relative importance of some of the chemical changes associated with organic pollution, in determining the distribution of some fresh-water invertebrates. The criteria investigated, on a variety of invertebrates, were those normally cited as resulting from organic pollution and which have been generally accepted as being possible limiting factors. The factors investigated were:-

1. The effect of low oxygen tensions
2. The effect of undissociated ammonia concentration
3. The effect of carbon dioxide concentration
4. The effect of potassium orthophosphate concentration

In some cases the combined effects were also examined.

4.1 Methods and Materials

4.1.1 Animals used in the Experiments

The animals used in the experiments were chosen with two objectives. Firstly, and most important, were animals that could be associated with varying degrees of organic pollution and had figured prominently in this and past river pollution surveys. Secondly, they were animals which could be collected in sufficient numbers for regular experimental work. The animals used in the experiments were:-

1. *Rhyacophila dorsalis* larvae
2. *Ecdyonurus dispar* nymphs
3. *Gammarus pulex*
4. *Hydropsyche angustipennis* larvae
5. *Asellus aquaticus*
6. *Erpobdella octoculata*

7. Erpobdella testacae

8. Helobdella stagnalis

From the results of this and past work, the first two species are usually thought to inhabit streams of good quality water. The next two species seem, from the results of field work, to be more tolerant of organic pollution and can be found where there is mild organic pollution. The last four species are animals which can tolerate severe organic pollution and will only be absent when river conditions are exceptionally bad.

In addition three species of chironomid larvae were used in certain experiments. All animals were collected a few days before the experiment began and kept in the laboratory to become acclimatised. Twenty individuals of each species were normally used in the experiments. In some cases, where there was difficulty in obtaining sufficient numbers, ten animals were used. It was impossible to include chironomid larvae in all the experiments as they were not present in the streams at certain times of the year.

4.1.2 Dissolved Oxygen Experiments

The experiments were carried out to try to establish a) at what concentration oxygen would become a limiting factor, b) whether the different tolerances of species reflect their distribution in the field and c) the effect of temperature on the survival times at the various oxygen concentrations.

To investigate the effect of low dissolved oxygen, apparatus was designed which could control the concentration of oxygen in the water. As can be seen from the diagram (fig.47) and photograph (19) it consisted of a closed system in which water was continuously circulated by means of a Multifix peristaltic pump.

The oxygen concentration was measured and controlled by the following apparatus:

a) Model A15A dissolved oxygen electrode produced by E.I.L.
b) Model 15A dissolved oxygen meter also produced by E.I.L.
c) Fielden Bikini Potentiometric Recorder (Model PTR BJ 6)

d) Alcon Solenoid Valve, type ACO_2 produced by Alexander Controls

e) Nitrogen cylinder

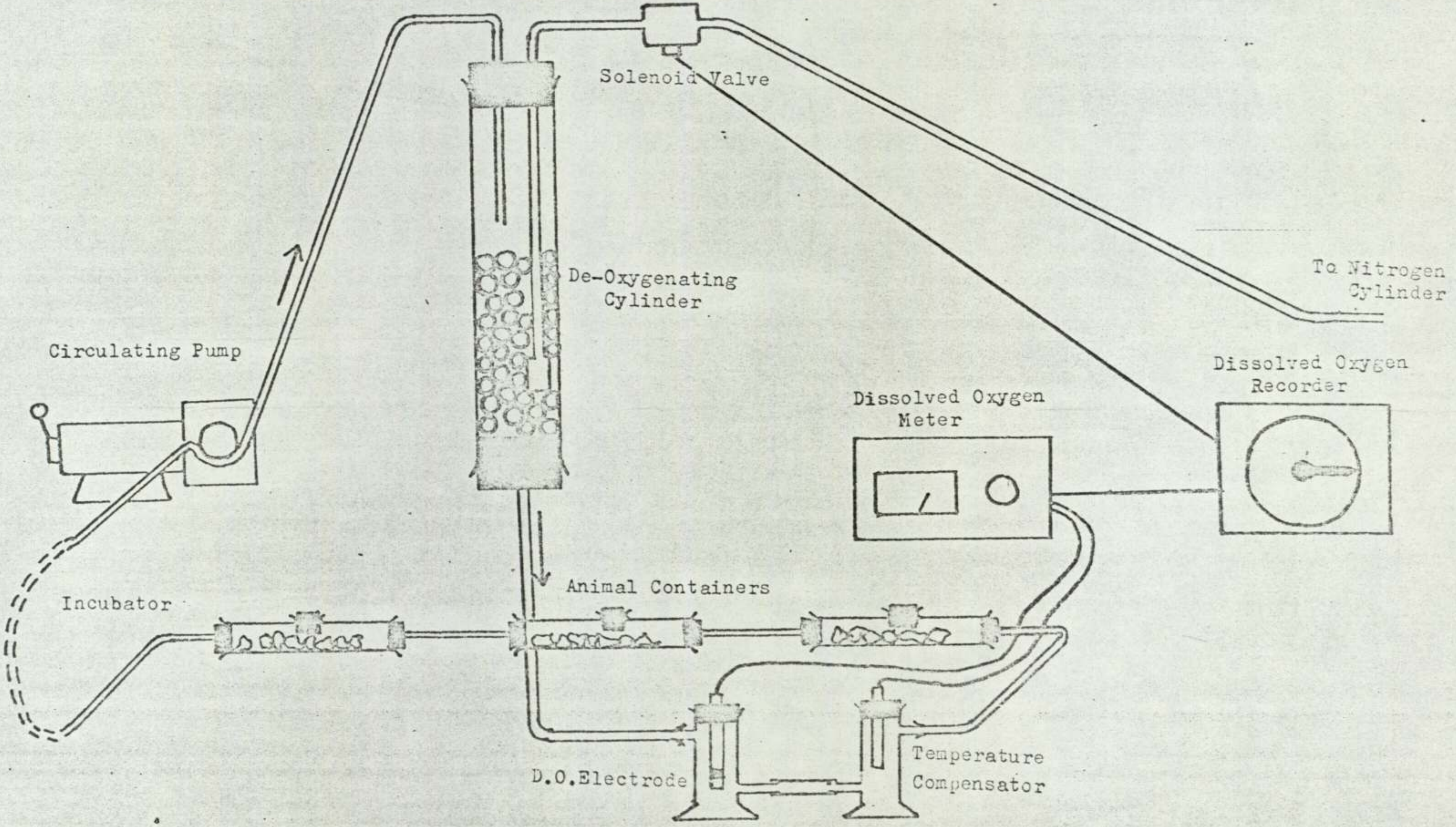
The oxygen concentration in the system was controlled by means of c, d and e. The Potentiometric Recorder is fitted with limit switches which operated solenoid valves controlling the flow of nitrogen to the deoxygenating column. The deoxygenating column was almost completely filled with plastic spheres. Their function was to increase the surface area over which the gaseous exchange could take place.

When energised the valve allows nitrogen to pass from the cylinder to the deoxygenating cylinder. In the system the nitrogen replaces the oxygen in solution causing the oxygen concentration to fall, this being almost immediately registered on the meter and recorder. As soon as the oxygen concentration drops to the required level the solenoid valve becomes de-energised and closes thus stopping the passage of nitrogen into the system. By using a fine needle valve on the nitrogen cylinder it was possible to control the oxygen concentration to within 1% of the desired concentration.

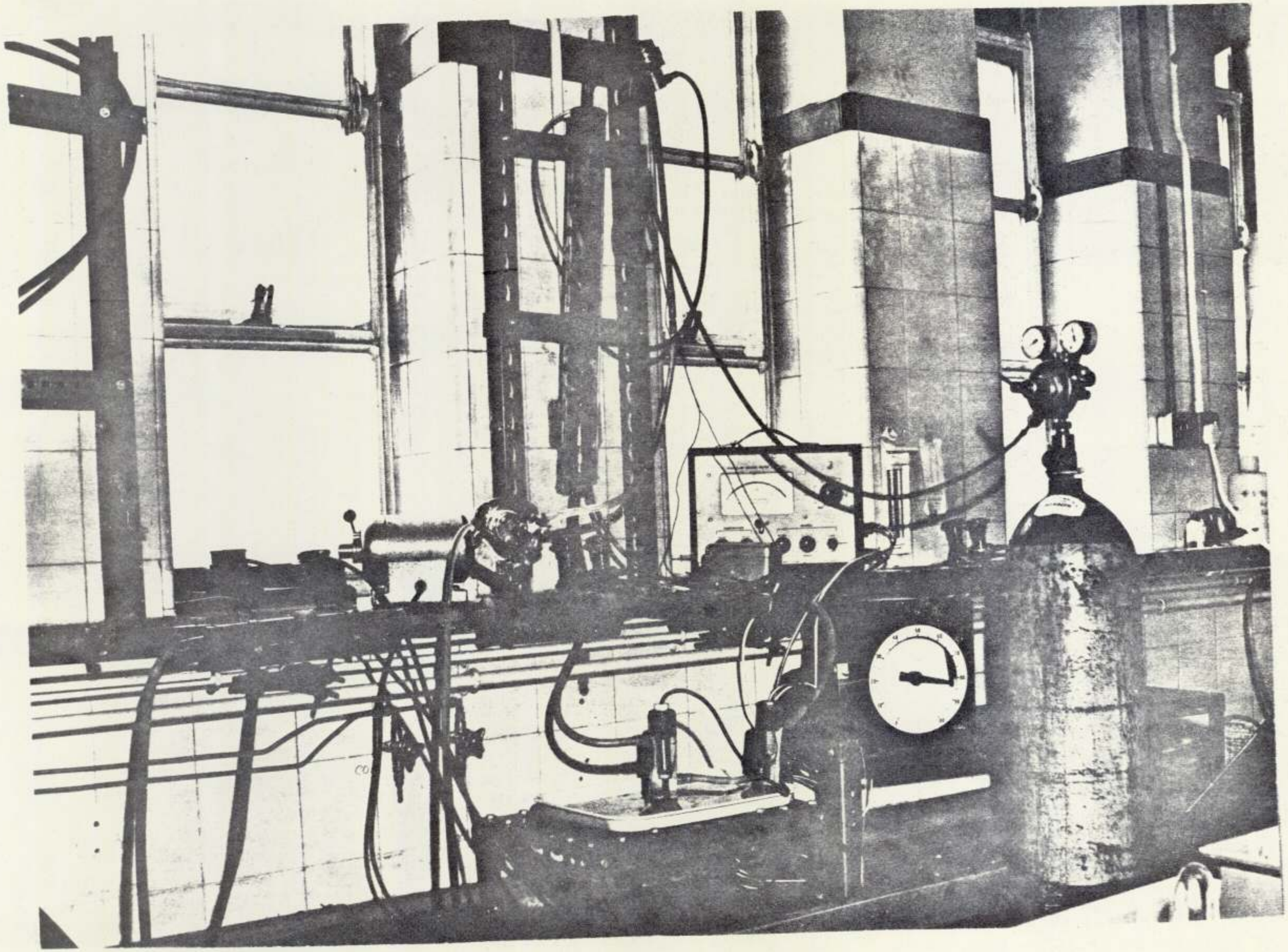
All tubings and bungs were made of non-toxic materials. The water temperature in the system was controlled by placing extensions of the tubing either in an incubator, when a temperature of 20°C was required, or a deep freeze, when a temperature of 10°C was required. It was found that the temperature fluctuated less than 1°C.

The flow of the water through the system was maintained at 1 cm/sec. by adjusting the Multifix pump. The chambers containing the animals were of glass and measured approximately 40 cm. long and 4 cm. in diameter. At each end the chambers were sealed with gauze to stop the movement of animals from one tube to another. To provide shelter and food, stones and dead leaves were placed in the

Fig.47.DIAGRAM OF APPARATUS FOR CONTROLLING DISSOLVED OXYGEN CONCENTRATION.



Photograph 19. Apparatus for controlling dissolved oxygen concentration.



chambers. Where possible only one species was placed in each chamber. The animals were placed in the chamber through an opening halfway along which, during the experiment, was sealed with a bung.

Experimental Programme

The experiments were normally of two weeks' duration and this was thought to be long enough to indicate whether a species would survive indefinitely at a particular concentration.

Experiments were carried out at 10°C and 20°C at the following oxygen concentrations:- 10 p.p.m., 4 p.p.m., 2 p.p.m., 1.5 p.p.m., 1.0 p.p.m., 0.5 p.p.m. and 0.0 p.p.m.

After introducing the animals into the system a period of between 24 and 48 hours was allowed depending on the experimental oxygen concentration before the experiment started. The oxygen was always gradually reduced usually in steps of about 10% initially and then 5% when the concentration was below 30% saturation.

During the experiment the animals were observed as often as possible during the day, the numbers of living animals noted and the dead ones removed. For the first two days this was usually half hourly intervals, thereafter it was hourly intervals except for overnight periods.

Experimental Programme for Dissolved Oxygen

Dissolved Oxygen Concentration	10°C	20°C
10 p.p.m.	✓	✓
4 p.p.m.	✓	✓
2.5 p.p.m.	✓	✓
2.0 p.p.m.	✓	✓
1.5 p.p.m.	✓	✓
1.0 p.p.m.	✓	✓
0.5 p.p.m.	✓	✓
0.0 p.p.m.	✓	✓

✓ = experiment performed

The pH of the water was checked regularly as was the total ammonia concentration. The test water was usually changed every 24 hours. The following experiments were carried out:-

1) At 10°C experiments with undissociated ammonia concentrations of 0.25, 0.75 and 1.5 p.p.m. were carried out at three different oxygen tensions, namely 10 p.p.m., 2 p.p.m. and 1 p.p.m.
2) At 18°C three experiments were carried out with undissociated ammonia concentrations of 0.25, 0.75 and 1.5 p.p.m., all with an oxygen tension of 10 p.p.m.

In addition to these twelve experiments, two further experiments were performed, in these the undissociated ammonia concentration was 3 p.p.m. The oxygen concentrations were 10 p.p.m. and 2 p.p.m. respectively.

Summary Table of Experimental Programme

At 10°C		Undissociated Ammonia Concentration p.p.m. as N			
		0.25	0.75	1.5	3.0
Dissolved oxygen Tension(p.p.m.)	10	✓	✓	✓	✓
	2	✓	✓	✓	✓
	1	✓	✓	✓	
At 18°C Dissolved oxygen	10 p.p.m.	✓	✓	✓	

✓ = experiment performed

4.1.4 Carbon Dioxide Experiments

Dissolved carbon dioxide is known to influence the lethal effect of low oxygen concentrations on fish (Alabaster et al 1957).

The concentration of carbon dioxide can be calculated by determining the pH value, temperature and bicarbonate alkalinity value and then using the nomograms in Mackereth (1963).

It was found in preliminary experiments that the bicarbonate alkalinity during the course of an experiment varied very little, and hardly at all over a few days. If the alkalinity is steady it would be possible to obtain a desired carbon dioxide concentration simply by lowering the pH of the water to that indicated in the nomogram. If carbon dioxide is bubbled into water the pH is obviously lowered.

To examine the effect of carbon dioxide on invertebrates, apparatus was designed and constructed (fig. 48) in which the dissolved carbon dioxide and oxygen concentration could be automatically controlled.

Prior to an experiment the bicarbonate alkalinity of the water was determined and using the nomogram the pH calculated that would be required to give the desired carbon dioxide concentration.

The carbon dioxide concentration was measured and controlled using the following apparatus:

a) E.I.L. Vibret pH Meter, which was coupled to

b) Fielden Potentiometric Recorder, and this controlled

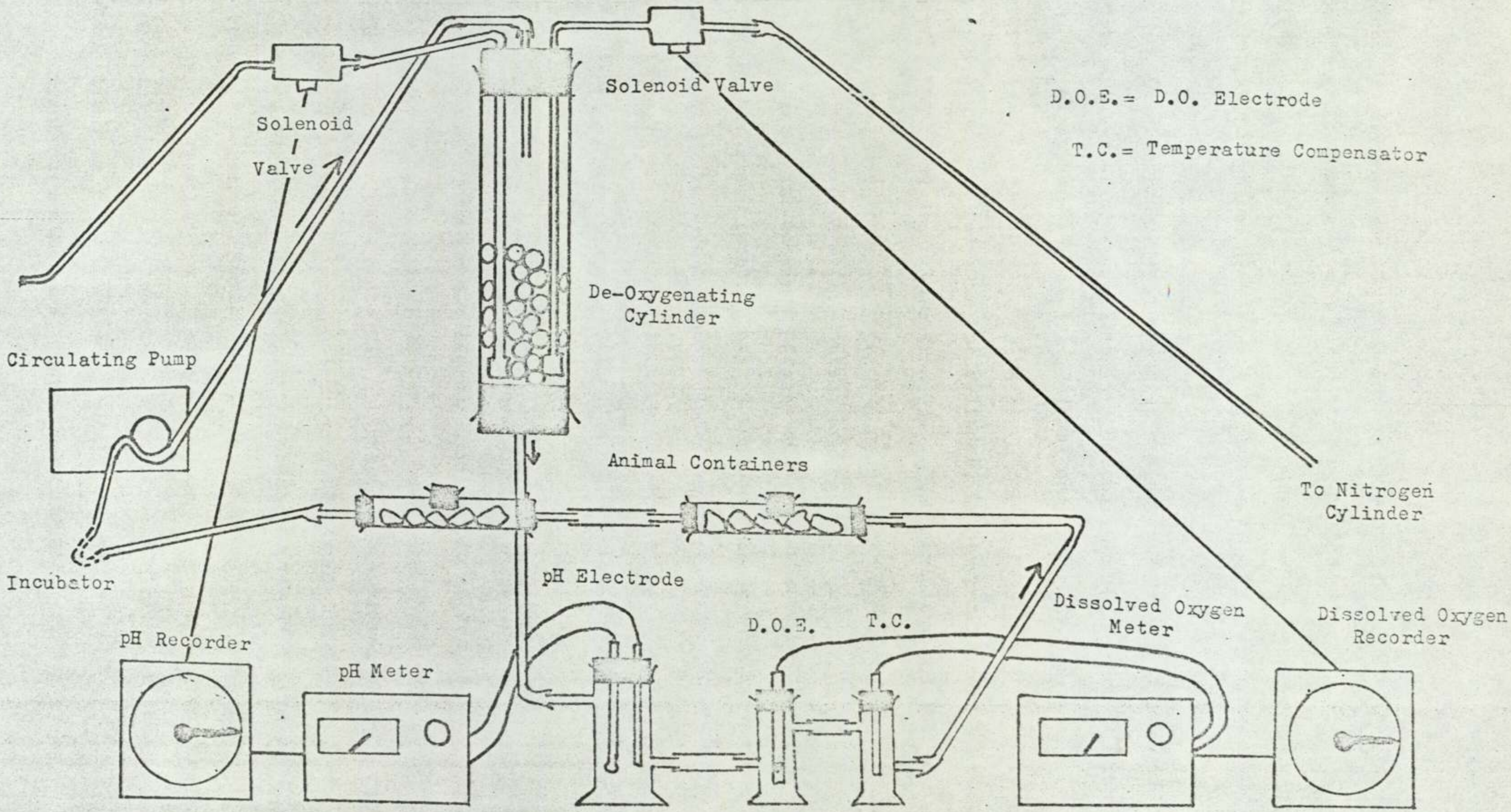
c) Alcon Solenoid Valve, which was connected by rubber tubing to an aerator stone in the gaseous exchange cylinder and by a second piece to

d) Carbon dioxide cylinder.

The pH of the water was measured and recorded continually using a) and b) and this indirectly gave the carbon dioxide concentration. It was controlled automatically by b), c) and d).

Once the pH had been calculated that would give the desired carbon dioxide concentration, the upper control arm was set so that it would energise the solenoid valve as soon as the pH of the water in the system reached that level. The solenoid valve then opened allowing carbon dioxide to flow, by means of the aerator, from the carbon dioxide cylinder, along the rubber tubing into the system. The carbon dioxide dissolving in the water reduced the pH to the

Fig.48DIAGRAM OF APPARATUS FOR CONTROLLING DISSOLVED OXYGEN AND CARBON DIOXIDE CONCENTRATIONS.



desired level which was immediately registered on the pH meter and recorder. As soon as the pH (and carbon dioxide concentration) reached the required level the recorder de-energised the solenoid valve which closed and thus stopped the passage of carbon dioxide into the system.

The arrangement of the system was similar to that described (for the apparatus) for controlling the dissolved oxygen concentration.

The pH meter was re-set at least once every 24 hrs. using standard buffer solutions. Using the expanded scale of the pH meter, and a needle valve on the cylinder, it was possible to control the pH of the test water to within 0.1. The alkalinity of the test water was also regularly checked, and if it had changed the new pH was calculated and the upper control arm re-set.

To study the combined effects of high carbon dioxide concentrations and low dissolved oxygen tensions, the system was set up as in fig. 48. The system now included the previously described apparatus together with the apparatus for controlling the dissolved oxygen tension described earlier.

Experimental Programme

The experiments were performed with three objectives:-

a) To find out if carbon dioxide has any adverse effect on invertebrates.
b) To find out if carbon dioxide influences the survival of invertebrates at low oxygen tensions.
c) To study the effect of temperature on the survival of invertebrates to dissolved carbon dioxide.

The concentrations of carbon dioxide experimented with were 40, 80 and 120 p.p.m., these concentrations were similar to those used by Alabaster et al (1957).

Experiments using these three concentrations of carbon dioxide were performed at three different oxygen concentrations, 10 p.p.m., 4 p.p.m. and 2 p.p.m. These experiments were carried out at both 10°C and 18°C. An additional experiment was performed with 1 p.p.m. oxygen at 18°C and with the carbon dioxide concentration being 120 p.p.m.

Summary Table of Experimental Programme with Carbon Dioxide

At 10°C		Carbon Dioxide Concentrations (p.p.m.)		
		40	80	120
Dissolved oxygen tension p.p.m.	10	✓	✓	✓
	4	✓	✓	✓
	2	✓	✓	✓

At 18°C		Carbon Dioxide Concentrations (p.p.m.)		
		40	80	120
Dissolved oxygen tension p.p.m.	10	✓	✓	✓
	4	✓	✓	✓
	2	✓	✓	✓
	1			✓

✓ = experiment performed

4.1.5 Orthophosphate Experiments

Orthophosphates are frequently found in high concentrations in polluted streams. To investigate the possible effects of orthophosphates on invertebrates, the stock solution was prepared from analar potassium orthophosphate dissolved in deionized water. The diluent water was from the same stream as that used in the other experiments.

The concentrations used in the experiments were 10 p.p.m., 25 p.p.m., 50 p.p.m. and 100 p.p.m. They were performed at three different oxygen concentrations which were 10 p.p.m., 4 p.p.m. and 2 p.p.m. An additional experiment was performed at 1 p.p.m. oxygen and an orthophosphate concentration of 100 p.p.m. All the experiments were carried out at 15°C.

The dissolved oxygen concentration was controlled as in the experiments on dissolved oxygen. The test solutions were changed every 24 hrs. As in the other experiments the animals were placed in the system 24 hrs. before the experiment was started.

Experimental Programme for Orthophosphates

		Orthophosphate concentration as p.p.m. P			
		10	25	50	100
Dissolved oxygen tension p.p.m.	10	✓	✓	✓	✓
	4	✓	✓	✓	✓
	2	✓	✓	✓	✓
	1				✓

✓ = experiment performed

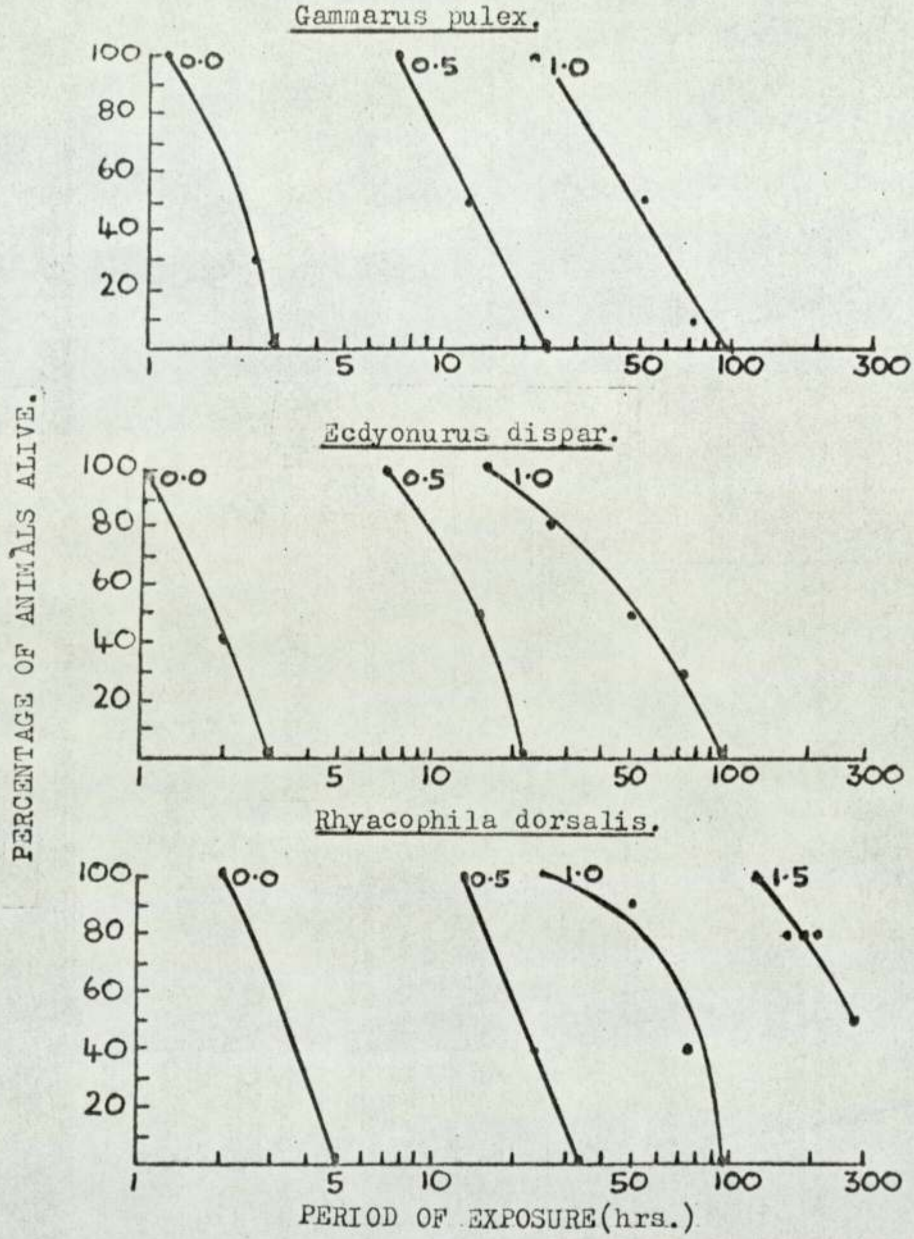
4.2 Results

4.2.1 Dissolved Oxygen Experiments

The effect of low dissolved oxygen tensions on the invertebrates used in the experiments are summarised in Table 33. Using this data graphs were drawn to show the effects of the various oxygen concentrations on the survival of the animals during the period of exposure.

At 10°C (figs. 49 & 50) the various species differed in their tolerance of low oxygen tensions. Three species, Gammarus pulex, Rhyacophila dorsalis and Ecdyonurus dispar were found to be far more sensitive than the others. Rhyacophila dorsalis larvae were affected when the oxygen concentration was reduced to 1.5 p.p.m., Ecdyonurus dispar and Gammarus pulex when it was reduced to 1 p.p.m. Further reduction in the oxygen concentration resulted in a shortening of the survival time. The experiments on the immature stages of Gammarus pulex revealed that they were slightly more tolerant than the fully grown individuals. These young stages also died when the

Fig. 49. Effect of low oxygen tensions on the survival of three invertebrate species at 10°C. (Numbers on curves refer to concentration of dissolved oxygen in p.p.m.)


Gammarus pulex.

Ecdyonurus dispar.

Rhyacophila dorsalis.

Fig.50 Effect of complete deoxygenation on the survival of six invertebrate species at 10°C.

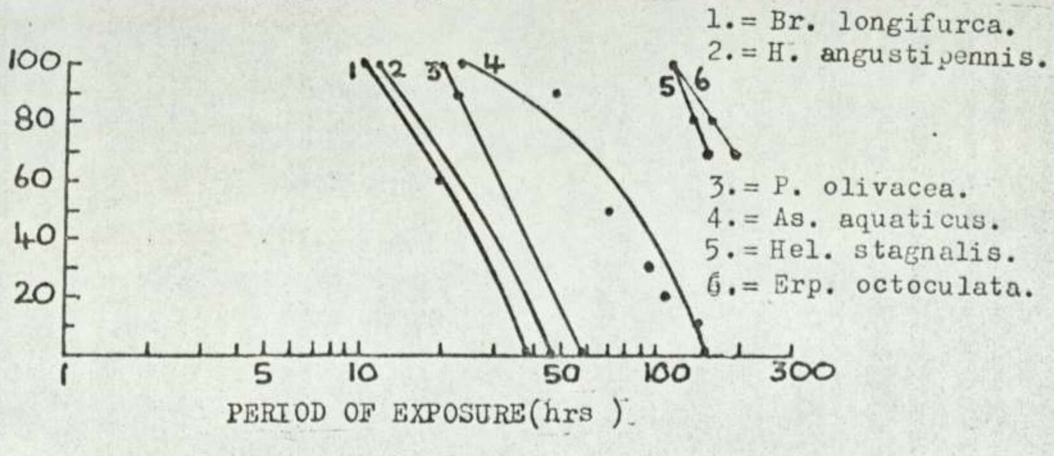


Fig.51. Effect of low dissolved oxygen tensions on the survival of five invertebrate species at 20°C. (Numbers on curves refer to dissolved oxygen concentration in p.p.m.)

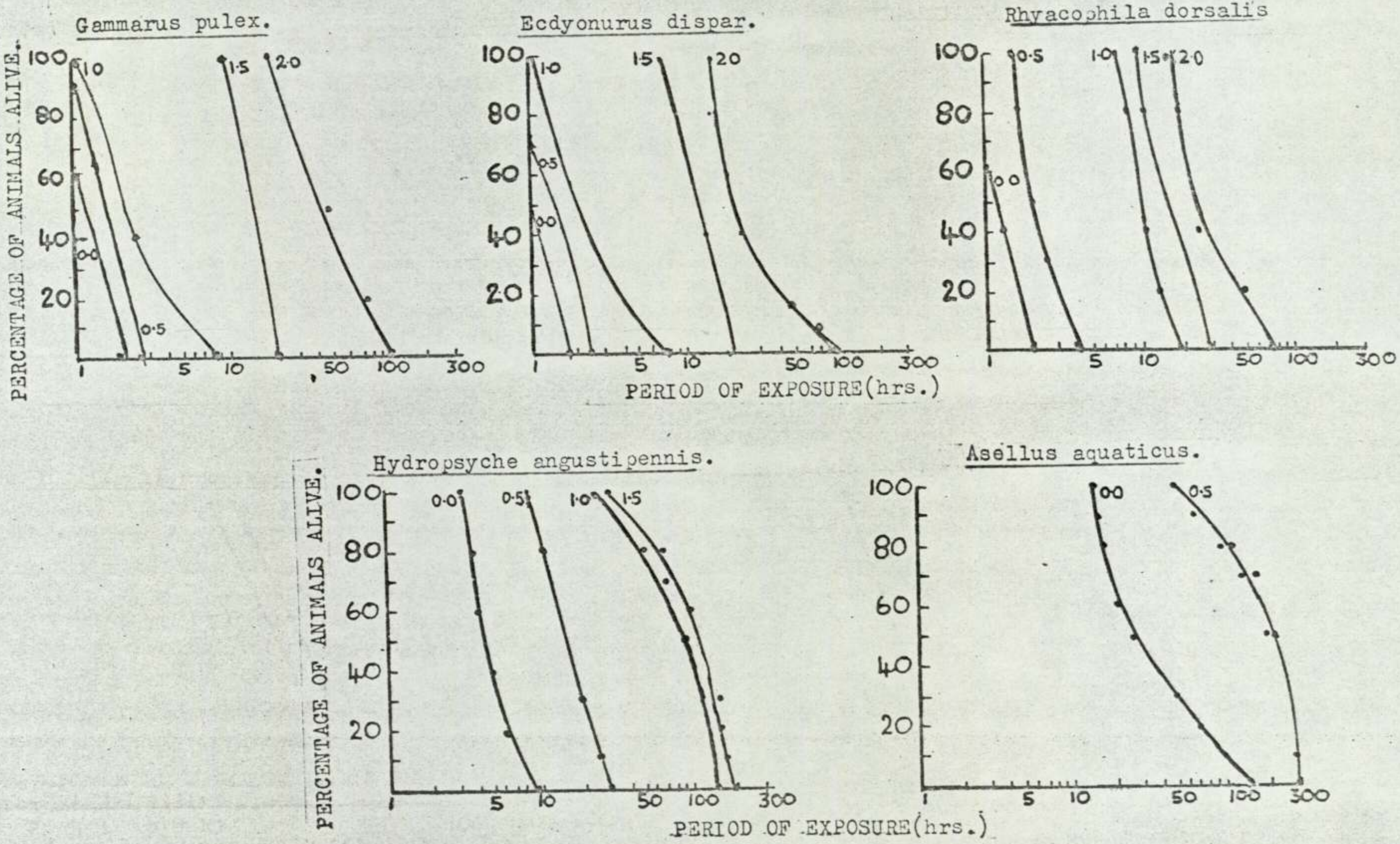
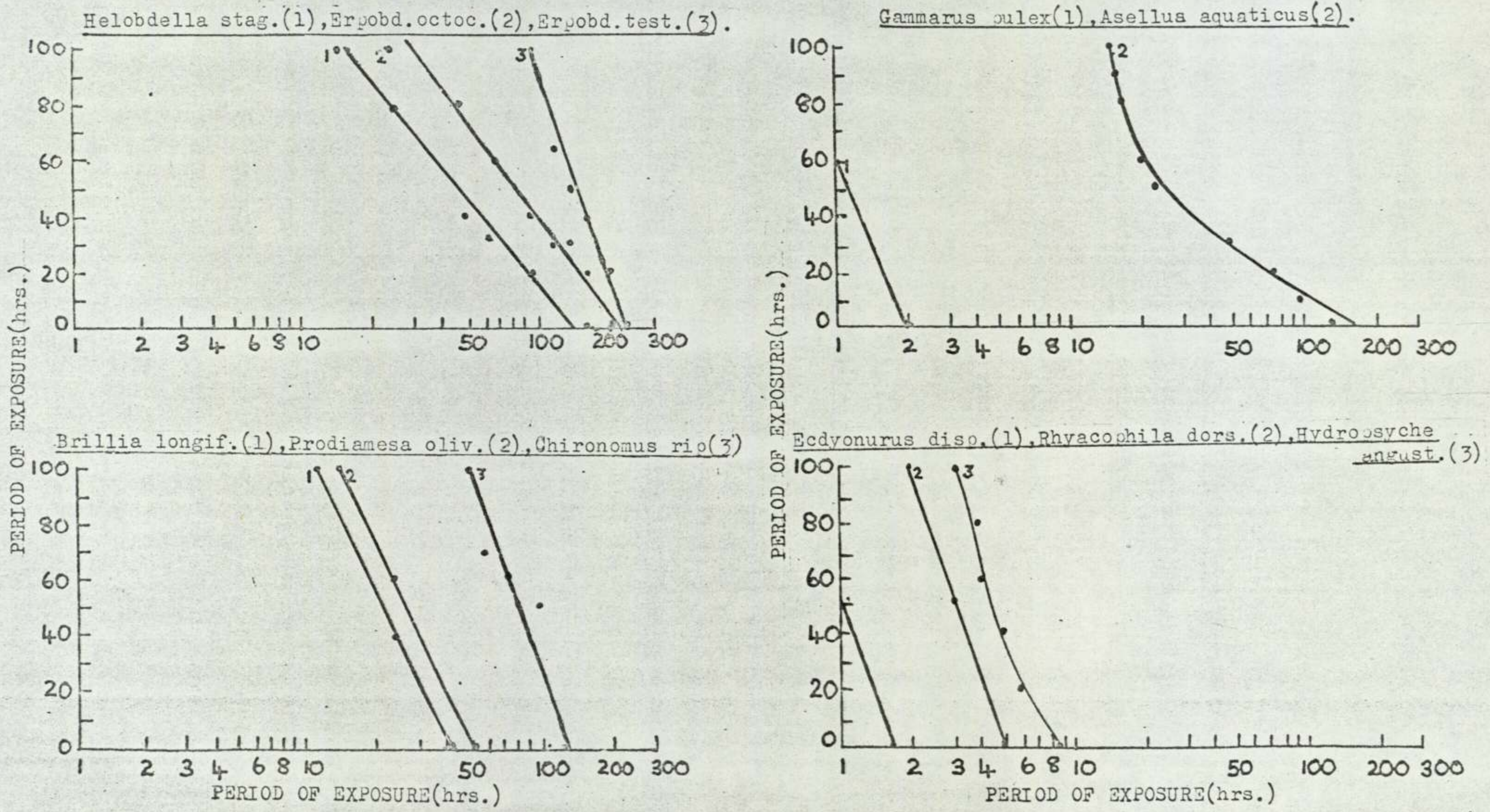


Fig. 52 Comparison of the effect of complete deoxygenation at 20°C on the survival time of eleven invertebrate species.



dissolved oxygen concentration was reduced to 1 p.p.m. but they were able to survive longer.

Hydropsyche angustipennis, Asellus aquaticus, Erpobdella octoculata, Erpobdella testacea, Helobdella stagnalis, Chironomus riparius, Prodiamesa olivacea and Brillia longifurca proved to be very tolerant of low dissolved oxygen concentrations at this temperature. Two species, Chironomus riparius and Erpobdella testacea, were not apparently affected by complete deoxygenation over a period of eight days. The six other species tested were killed by complete deoxygenation although they all survived in the experiment at 0.5 p.p.m. dissolved oxygen. Of these six Erpobdella octoculata appeared to be the most tolerant followed by Helobdella stagnalis, Asellus aquaticus, Prodiamesa olivacea, Hydropsyche angustipennis and Brillia longifurca.

The experiments performed at 20°C (figs. 51 & 52) revealed the same order of tolerance amongst the animals as at 10°C. Gammarus pulex, Ecdyonurus dispar and Rhyacophila dorsalis were again the most sensitive species. It was found that the individuals of these three species could not survive the thirteen day period of exposure when the experimental oxygen concentration was reduced to 2 p.p.m. A further decrease in the experimental oxygen concentration reduced the survival period and at 1 p.p.m. all the individuals died within six hours.

Hydropsyche angustipennis was more tolerant and the individuals of this species were able to survive the thirteen day period of exposure when the oxygen concentration was 2 p.p.m., at 1.5 p.p.m. however they all died and with a further lowering of the oxygen tension there was a corresponding decrease in the period of survival.

Asellus aquaticus, Erpobdella octoculata, Erpobdella testacea, Helobdella stagnalis, Prodiamesa olivacea, Brillia longifurca and

Chironomus riparius survived the thirteen day period of exposure at 1 p.p.m. but three of these species were adversely affected in the experiment at 0.5 p.p.m. oxygen. In this experiment in addition to those species which died at higher oxygen concentrations, *Asellus aquaticus*, *Brillia longifurca* and *Prodiamesa olivacea* died. Although *Asellus aquaticus* and *Prodiamesa olivacea* died in this experiment it was only after prolonged exposure. In the case of *Prodiamesa* 50% of the animals were still alive after 5 days while for *Asellus* 50% were alive after 8 days. All three species of leech and *Chironomus riparius* survived the thirteen day period of exposure.

In the experiment with no oxygen the four remaining species, that is *Erpobdella octoculata*, *Erpobdella testacea*, *Helobdella stagnalis* and *Chironomus riparius* died.

It became obvious from the results that all the invertebrates experimented with were much more sensitive to low oxygen concentrations at 20°C than at 10°C. Using the graphs (figs. 49 to 52) the times for which 80% of the test animals survived were determined in the various experiments. These times were then used to draw further graphs in order to predict the oxygen concentrations at which 80% of the test animals would survive indefinitely in experimental conditions at both 10°C and 18°C. This method was based on that used in fish toxicity work and described by Herbert (1961). It was decided to use the 80% survival period in order to minimise the influence of deaths due to natural causes on the results and at the same time it would give an estimation of the minimum oxygen concentration at which the species could be expected to establish a flourishing population other factors permitting.

The graphs (figs. 53 & 54) show the adverse effects of higher temperatures on the survival of the test animals.. All species were able to survive at considerably lower oxygen concentrations at 10°C

Fig. 53 Comparison of the toxicity of low oxygen tension on six invertebrate species at 10°C and 20°C. Curves represent points at which 80% of test animals survive. (Numbers on curves refer to temperature in °C.)

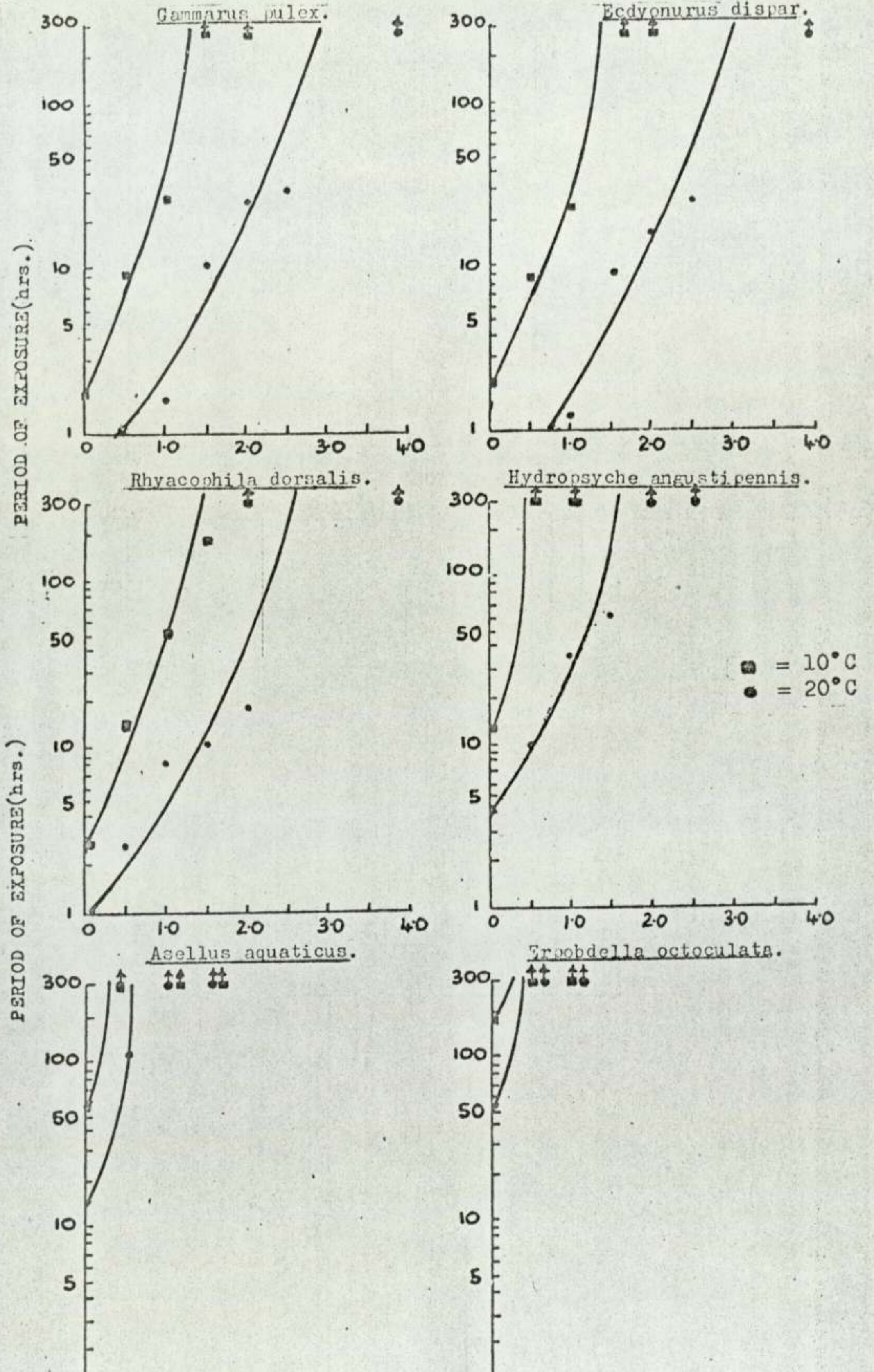
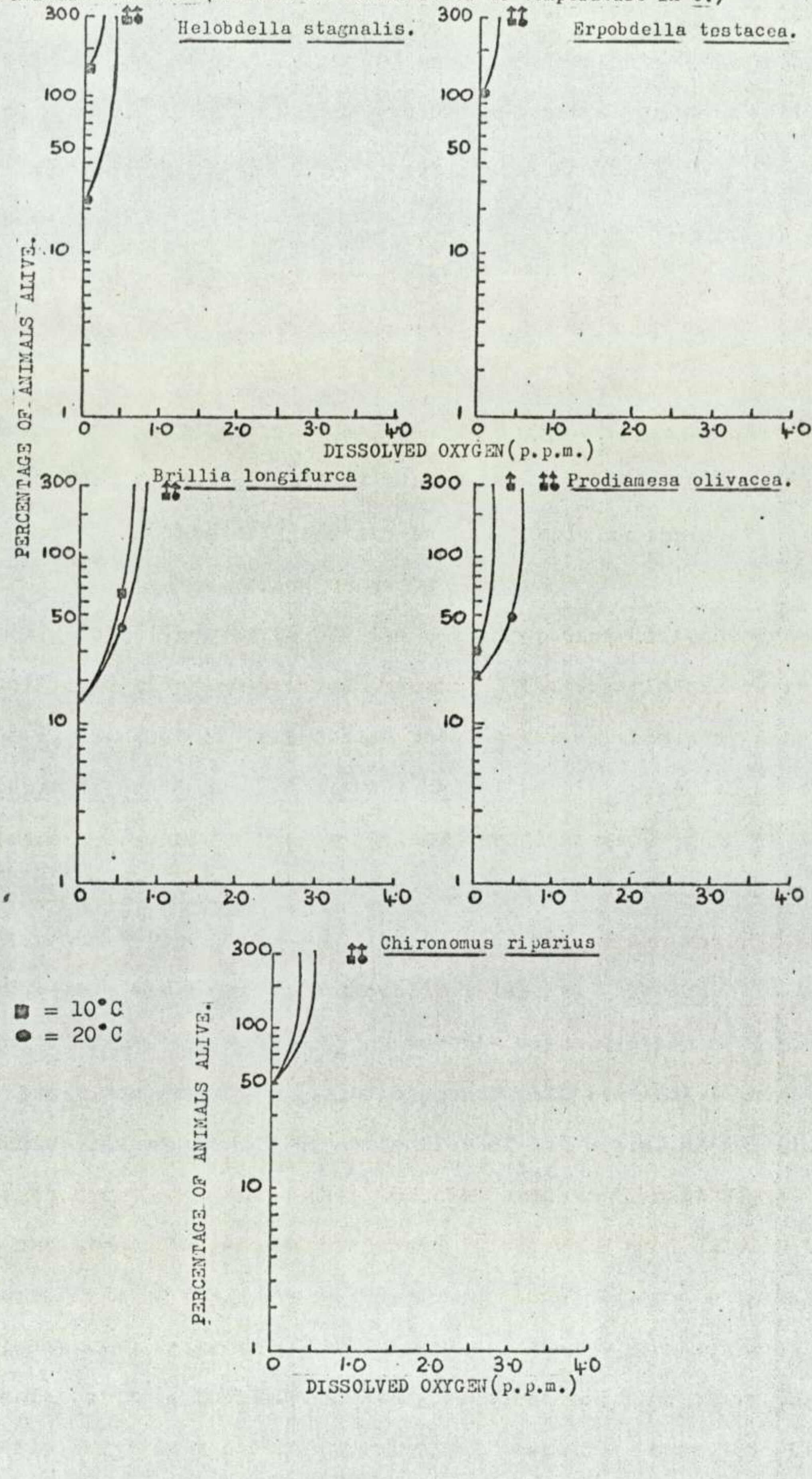


Fig.54 Comparison of the toxicity of low oxygen tension on five invertebrate species at 10°C and 20°C. Curves represent points at which 80% of the test animals survive. (Numbers on curves refer to temperature in °C.)



than at 20°C. Hydropsyche angustipennis and Gammarus pulex illustrate this, for H. angustipennis 80% of the population would survive indefinitely as long as the oxygen concentration was not below 0.4 p.p.m. at 10°C, at 20°C this minimum concentration was found to be 1.6 p.p.m. The corresponding figures for G. pulex were 1.3 p.p.m. and 3 p.p.m. respectively.

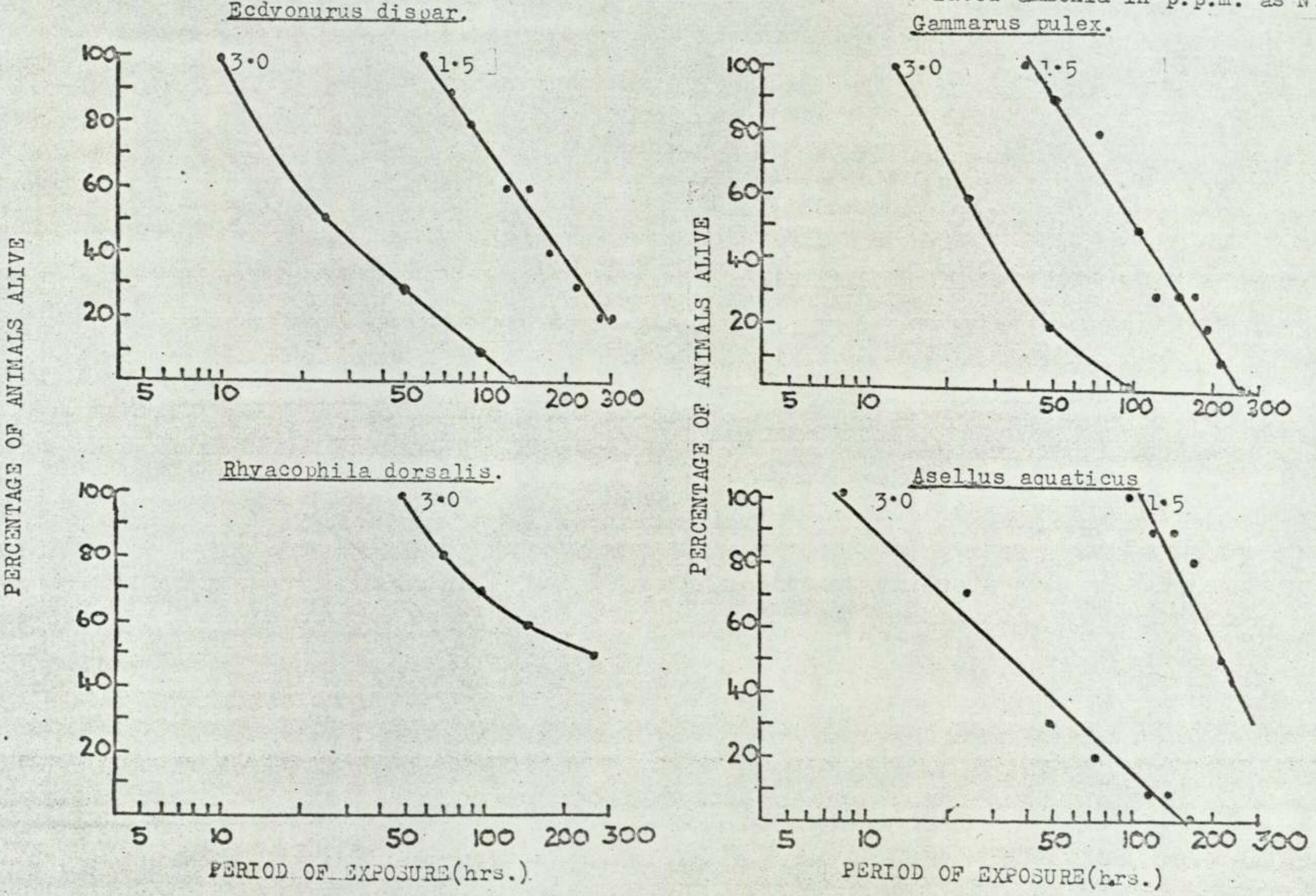
4.2.2 Undissociated Ammonia Experiments

The effect of different concentrations of undissociated ammonia at different oxygen concentrations on the invertebrates experimented upon are summarised in Table 34. Using this data graphs were drawn to show the effects of a range of concentrations of undissociated ammonia, at different oxygen levels on the survival of the animals during the period of exposure.

At 10°C (figs. 55 to 61) the eleven species differed greatly in their tolerance of undissociated ammonia. The experiments revealed that the two species of Trichoptera used in the experiments, that is Rhyacophila dorsalis and Hydropsyche angustipennis, were far more tolerant to undissociated ammonia than the other invertebrates. 50% of the Hydropsyche angustipennis survived when the undissociated ammonia concentration was 3 p.p.m. and the dissolved oxygen of the water 2 p.p.m., thus revealing them to be exceptionally tolerant. Rhyacophila dorsalis although tolerant, was killed by an ammonia concentration of 3 p.p.m., at both 10 p.p.m. oxygen and 2 p.p.m. oxygen. All the individuals survived at an undissociated ammonia concentration of 1.5 p.p.m. at 10 p.p.m. oxygen although they died at this ammonia concentration at 2 p.p.m. oxygen.

The three species of chironomid larvae were used only in the experiments with an oxygen concentration of 10 p.p.m. and these also proved to be very tolerant. The chironomid larvae were not good experimental animals because once they were removed from their tubes they rarely survived the full experimental programme, even when there

Fig. 55. Effect of undissociated ammonia on the survival of four invertebrate species at 10°C and an oxygen concentration of 10p.p.m. (Numbers on curves refer to the concentration of undissociated ammonia in p.p.m. as N.)



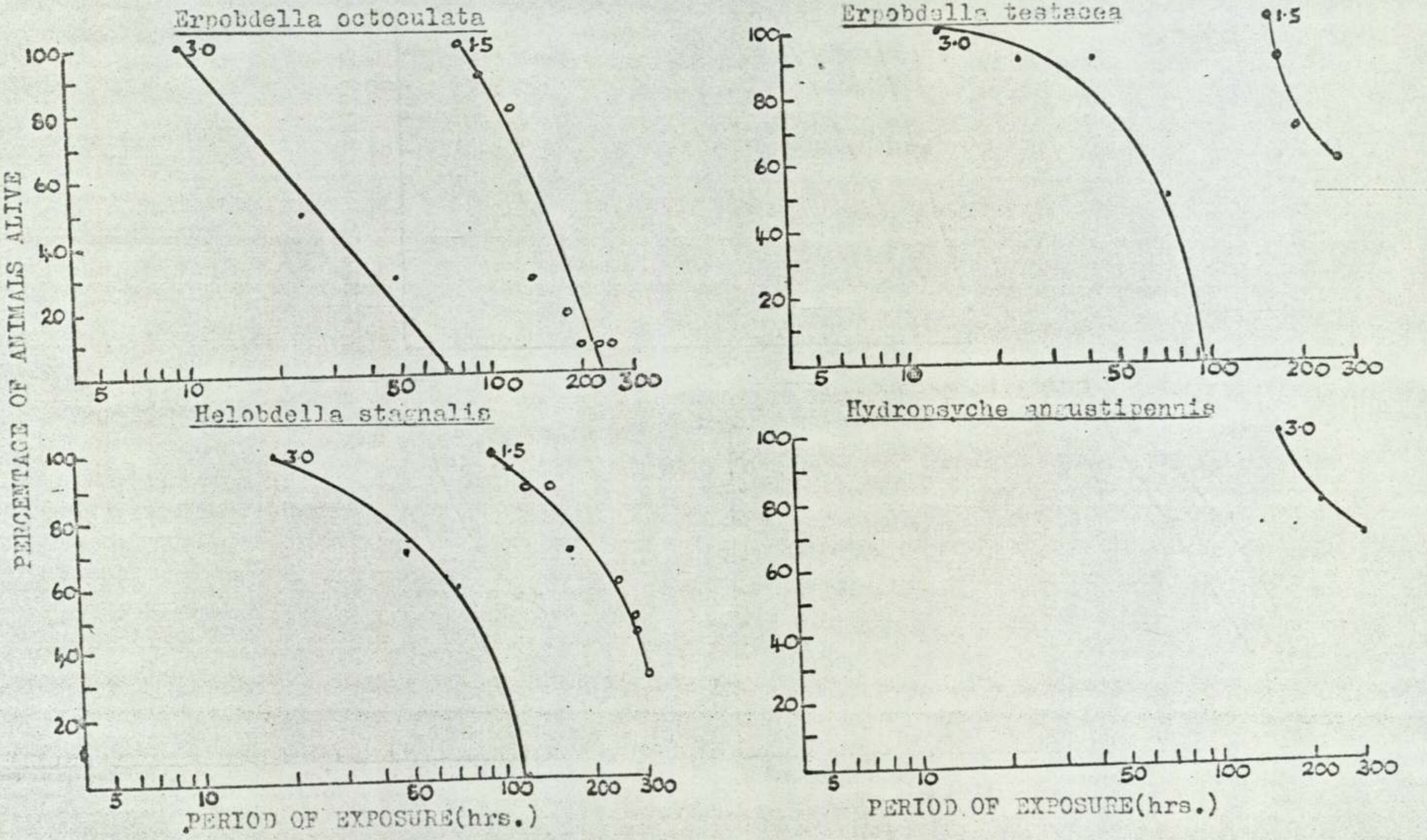


Fig. 56. Effect of undissociated ammonia on the survival of four invertebrate species at 10°C and an oxygen concentration of 10 p.p.m. (Numbers on curves refer to the concentration of undissociated ammonia in p.p.m. as N.)

Fig.57. Effect of undissociated ammonia on the survival of three invertebrate species at 10°C and an oxygen concentration of 10p.p.m.(Numbers on curves refer to concentration of undissociated ammonia in p.p.m. as N.)

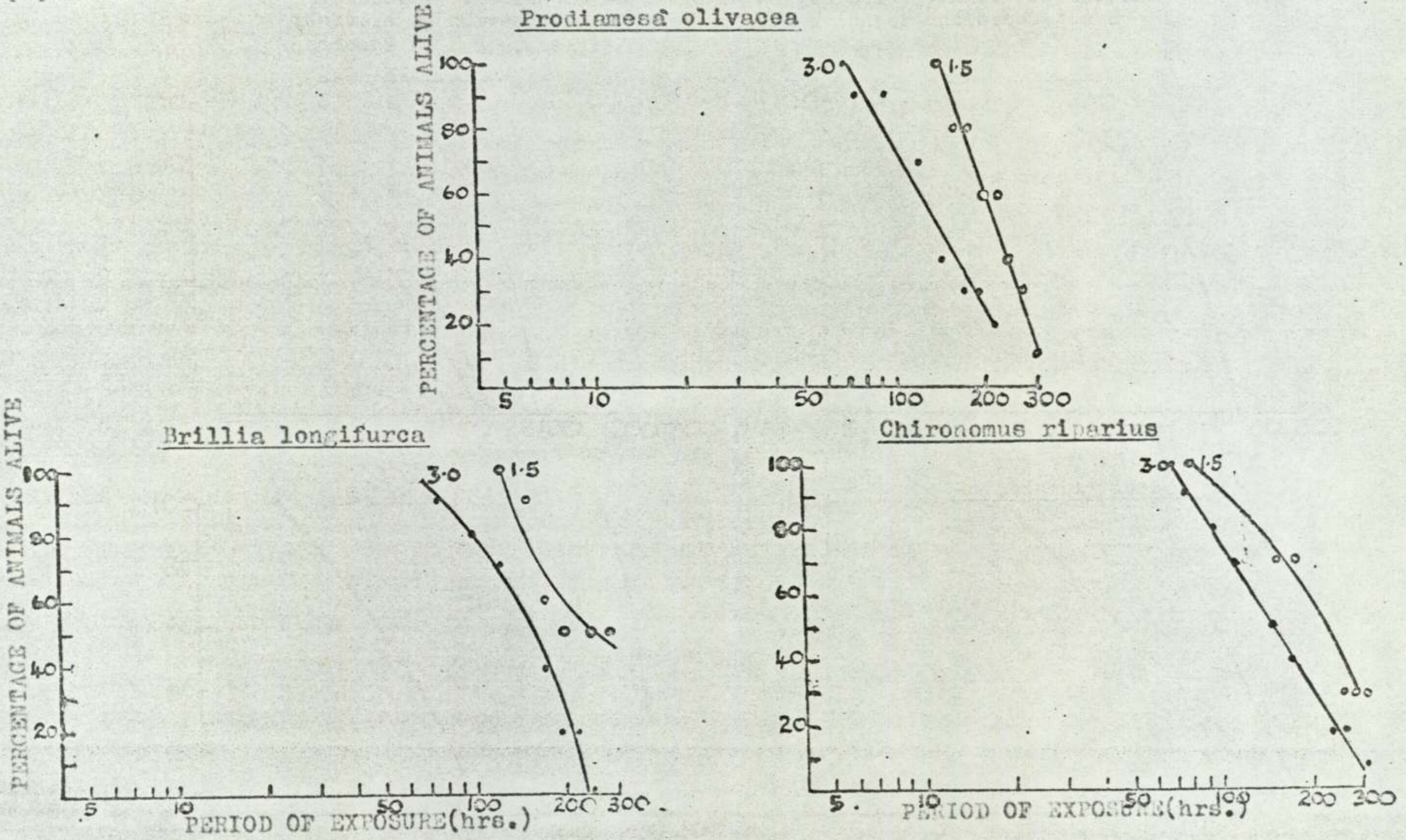
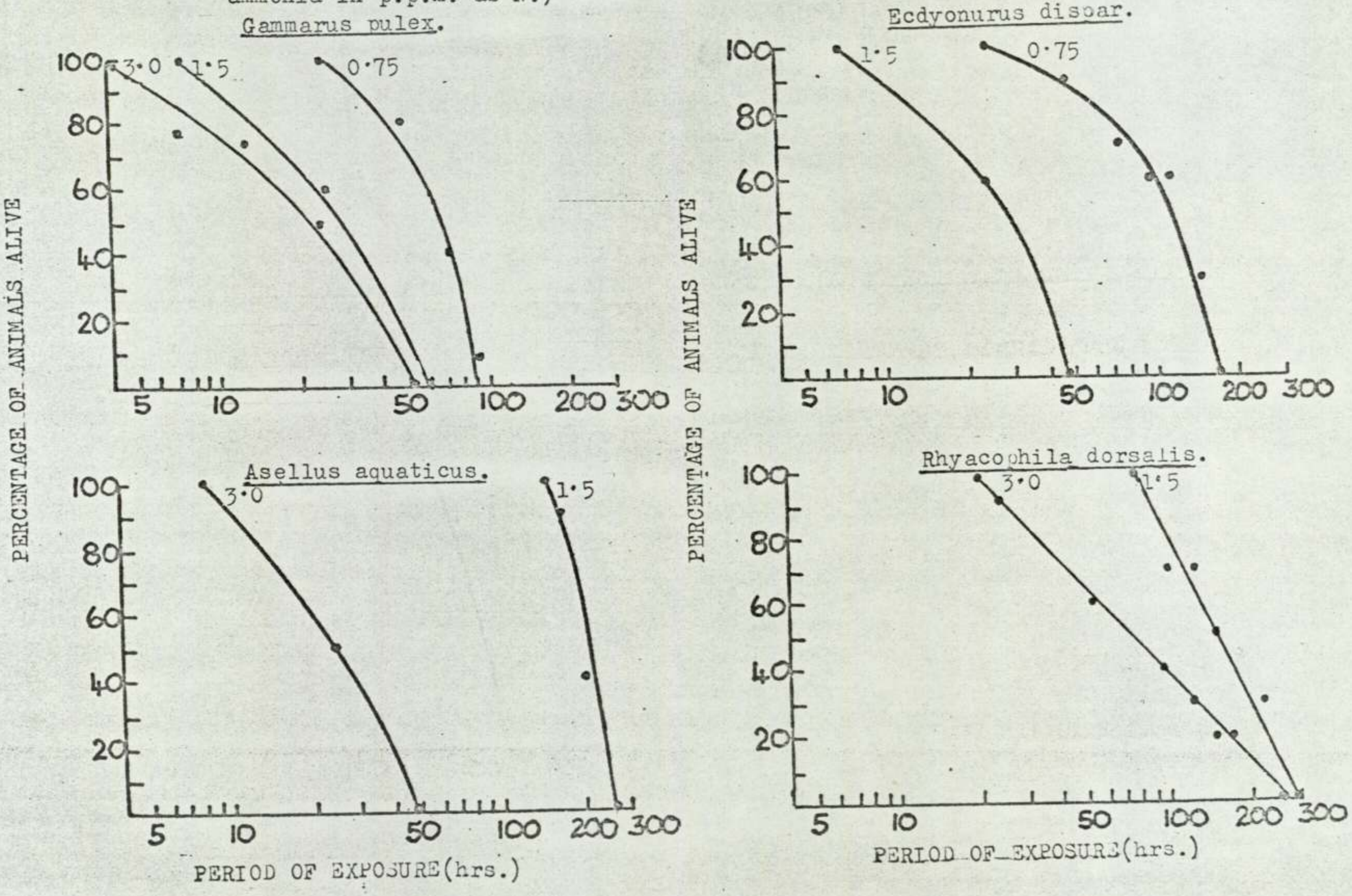


Fig.58. Effect of undissociated ammonia on the survival of four invertebrate species at 10°C and an oxygen concentration of 2p.p.m. (Numbers on curves refer to the concentration of undissociated ammonia in p.p.m. as N.)



concentration of [illegible] (Numbers on curves refer to concentration of undissociated ammonia in p.p.m. as N)

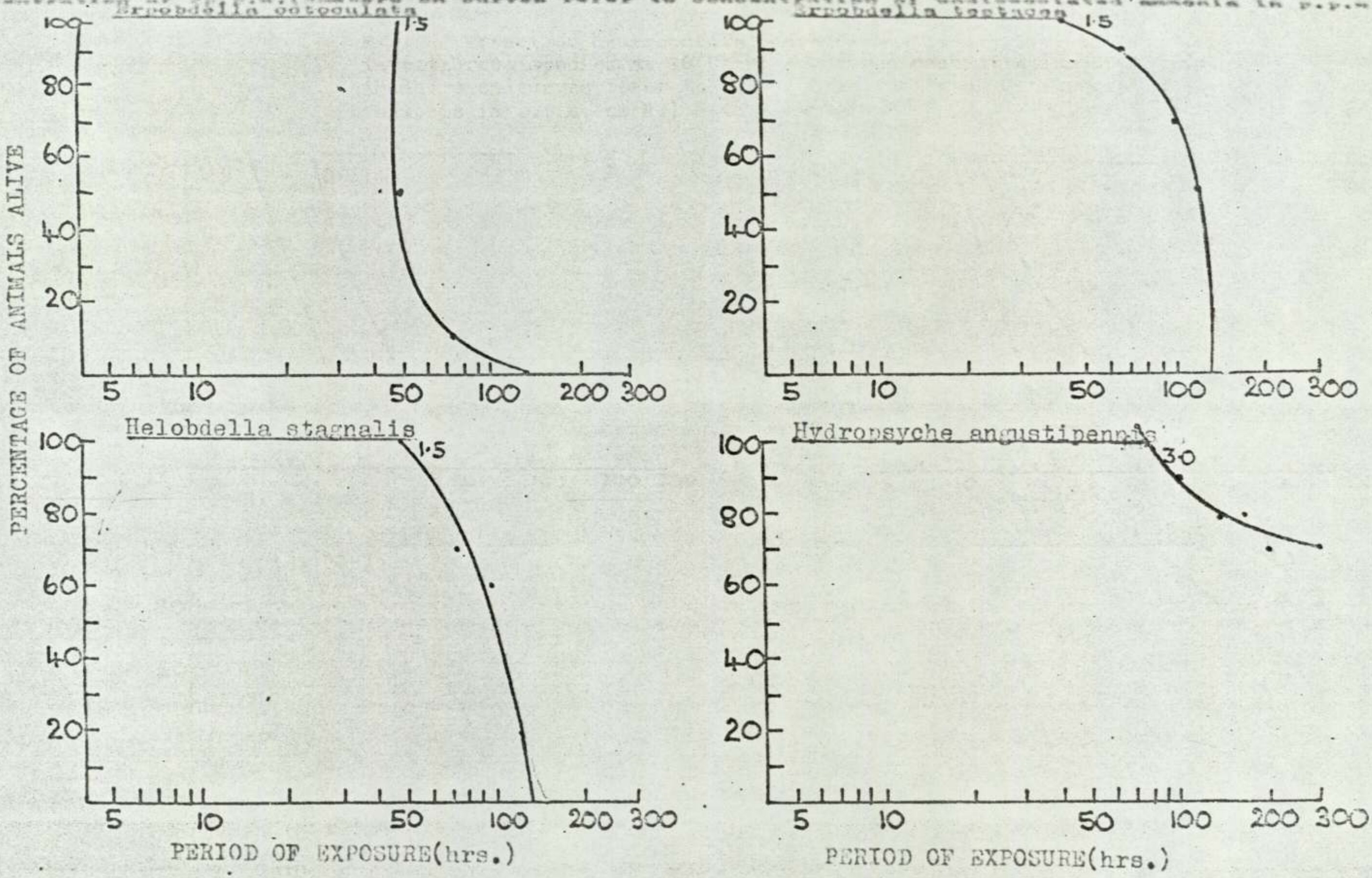


Fig. 60 Effect of undissociated ammonia on the survival of four invertebrate species at 10°C and an oxygen concentration of 1p.p.m. (Numbers on curves refer to the concentration of undissociated ammonia in p.p.m. as N.)

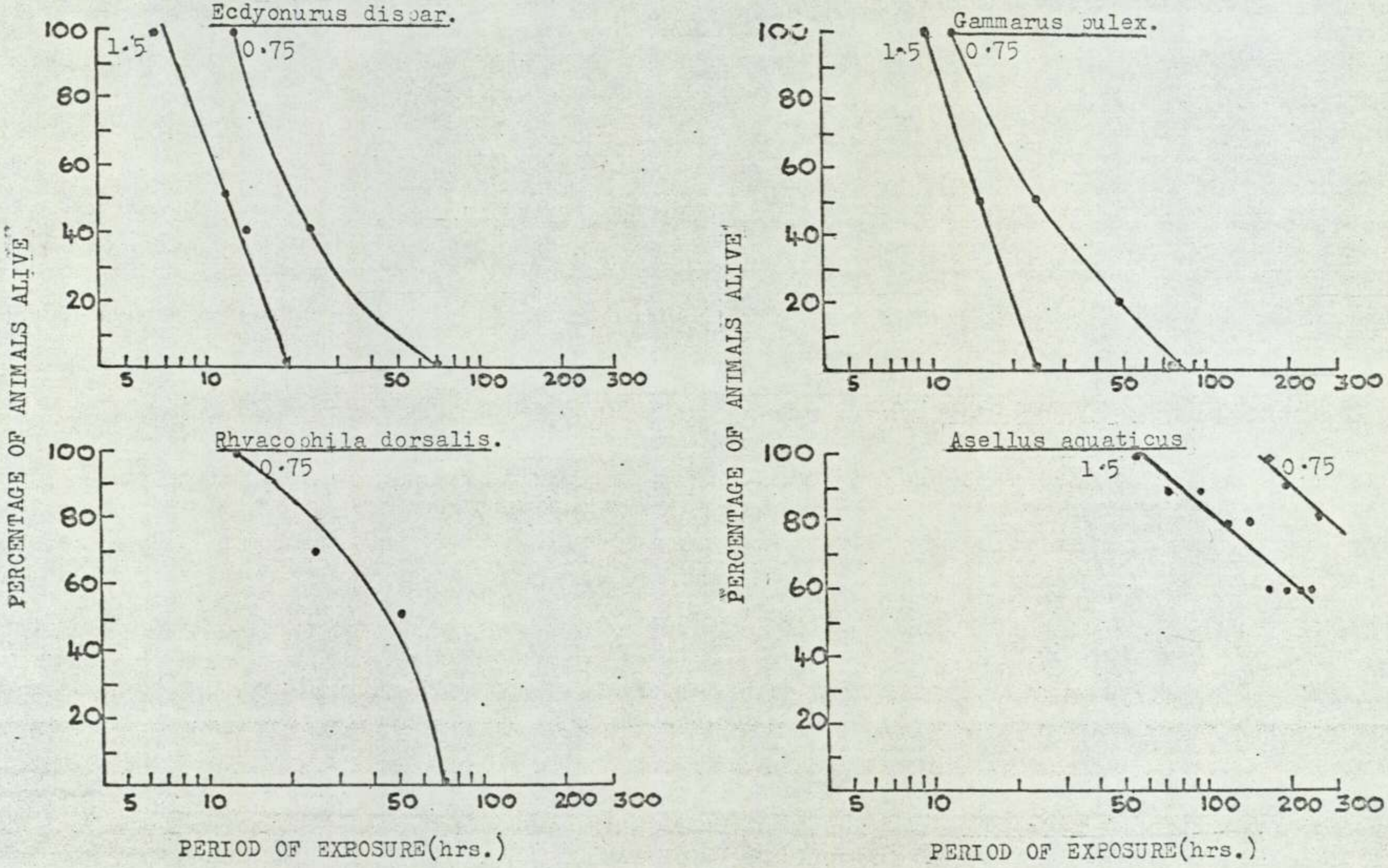


Fig.61. Effect of undissociated ammonia on the survival of three invertebrate species at 10°C and an oxygen concentration of 1p.p.m. (Numbers on curves refer to the concentration of undissociated ammonia in p.p.m. as N.)

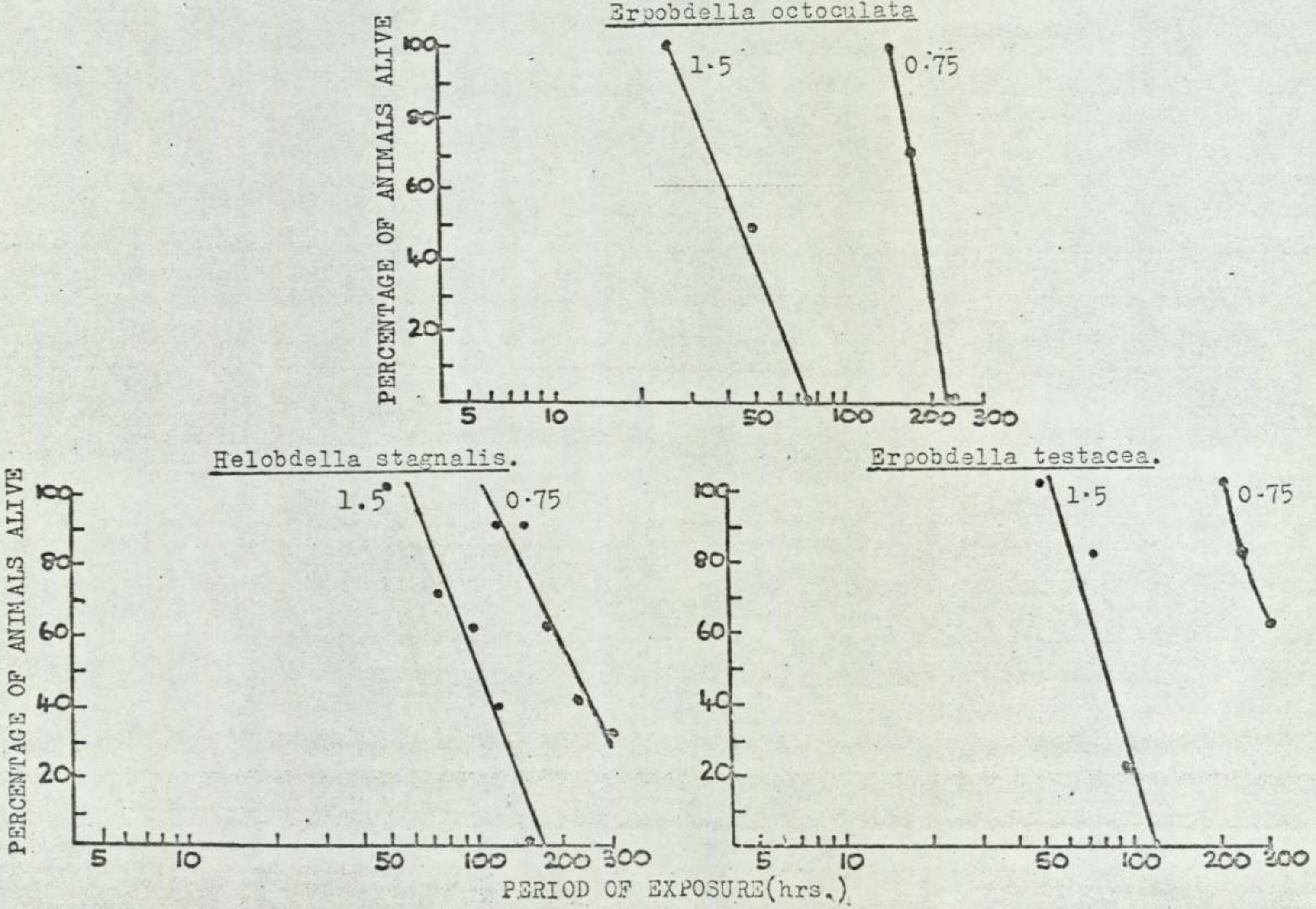
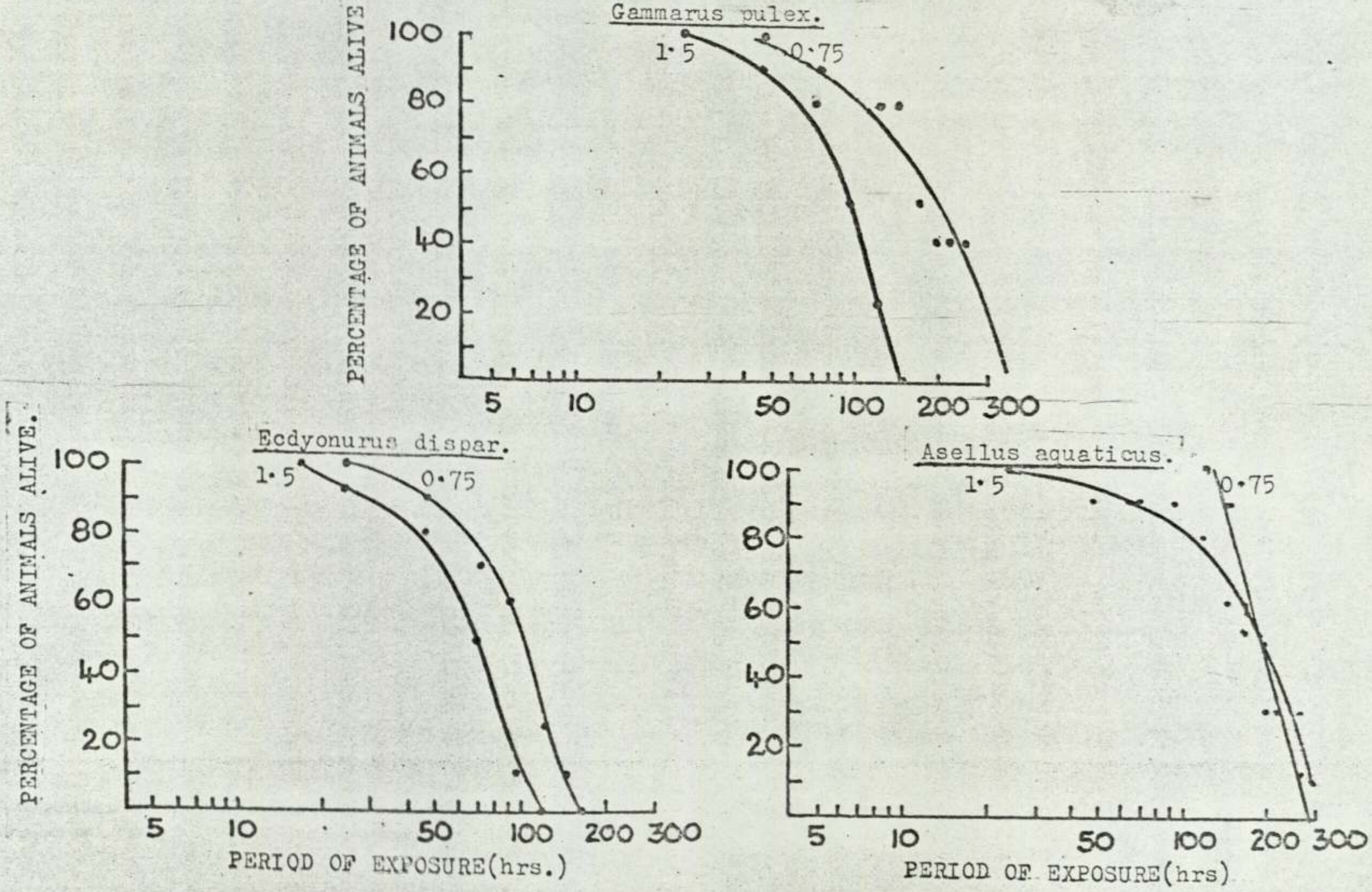


Fig. 62. Effect of undissociated ammonia on the survival of three invertebrate species at 18°C and an oxygen concentration of 10p.p.m. (Numbers on curves refer to the concentration of undissociated ammonia in p.p.m. as N.)



were no toxic substances present. Because the larvae died in these ammonia experiments it would be difficult to assess whether this was due to the ammonia but because they survived for appreciable periods even in 3 p.p.m. undissociated ammonia they must be extremely tolerant.

The leeches were far more sensitive to undissociated ammonia than the species already mentioned. All three species died in the 0.75 p.p.m. undissociated ammonia experiment at 1 p.p.m. oxygen, although they all survived in the same ammonia concentrations at higher oxygen values. When the ammonia concentration was increased to 1.5 p.p.m. however the individuals of all three species died irrespective of the experimental oxygen concentration. It was found that Erpobdella testacea and Helobdella stagnalis were similar in their tolerance to undissociated ammonia and both were more tolerant than Erpobdella octoculata, it also became obvious that all three species were more sensitive to undissociated ammonia when the oxygen concentration was low.

Of the three other species experimented on, that is Asellus aquaticus, Gammarus pulex and Ecdyonurus dispar, Asellus aquaticus was by far the most tolerant and was similar to the leeches in that deaths only occurred when the undissociated ammonia concentration was 1.5 p.p.m. or more. Unlike the leeches, reducing the oxygen concentration did not shorten the survival time and in fact Asellus survived longer in the 1.5 p.p.m. ammonia experiment at 2 p.p.m. oxygen than in the same ammonia concentration at 10 p.p.m. oxygen.

Gammarus pulex and Ecdyonurus dispar were the most sensitive of the experimental animals to undissociated ammonia, especially in low oxygen concentrations. All the animals of both species died quite quickly in the 0.75 p.p.m. undissociated ammonia experiment at 2 p.p.m. oxygen, although they did survive at this ammonia concentration with 10 p.p.m. oxygen present.

In the experiments performed at 18°C (fig. 62) the same order of tolerance was found to exist. Once again the two caddis fly larvae and three species of leech being the most tolerant and Gammarus pulex and Ecdyonurus dispar the most sensitive. It was also found that the experimental animals varied in their response to the higher temperature. Gammarus pulex, Ecdyonurus dispar and Asellus aquaticus were more sensitive to undissociated ammonia at 18°C than at 10°C while all three species of leech were more tolerant to undissociated ammonia at 18°C than at 10°C. Gammarus pulex, Ecdyonurus dispar and Asellus aquaticus all died in the experiment at 0.75 p.p.m. undissociated ammonia although they survived in this ammonia concentration at 10°C. Erpobdella octoculata, Erpobdella testacea and Helobdella stagnalis all survived in the experiment when 1.5 p.p.m. undissociated ammonia was present although they died at this ammonia concentration at 10°C.

The graphs (figs. 55 to 62) to show the effects of the various experimental ammonia concentrations at different oxygen levels were used to determine the points at which 80% of the test animals survived in the various ammonia experiments. Using these data graphs were drawn to see if oxygen and temperature had any noticeable effects on the toxicity of ammonia and also, as in the oxygen experiments, it would provide the highest ammonia concentration at which 80% of the test animals would survive indefinitely, at each oxygen concentration. This would also provide the highest ammonia concentration at which each species could be expected to establish flourishing populations other factors permitting at the various oxygen levels.

The graphs comparing the toxicity of ammonia at different oxygen levels at 10°C are given on figs. 63 and 64. It can be seen that, with one exception, a lowering of the oxygen concentration

Fig. 63. Effect of dissolved oxygen tension on toxicity of undissociated ammonia at 10°C. Curves represent points at which 80 % of test animals survive. (Numbers on curves refer to dissolved oxygen concentration in p.p.m.)

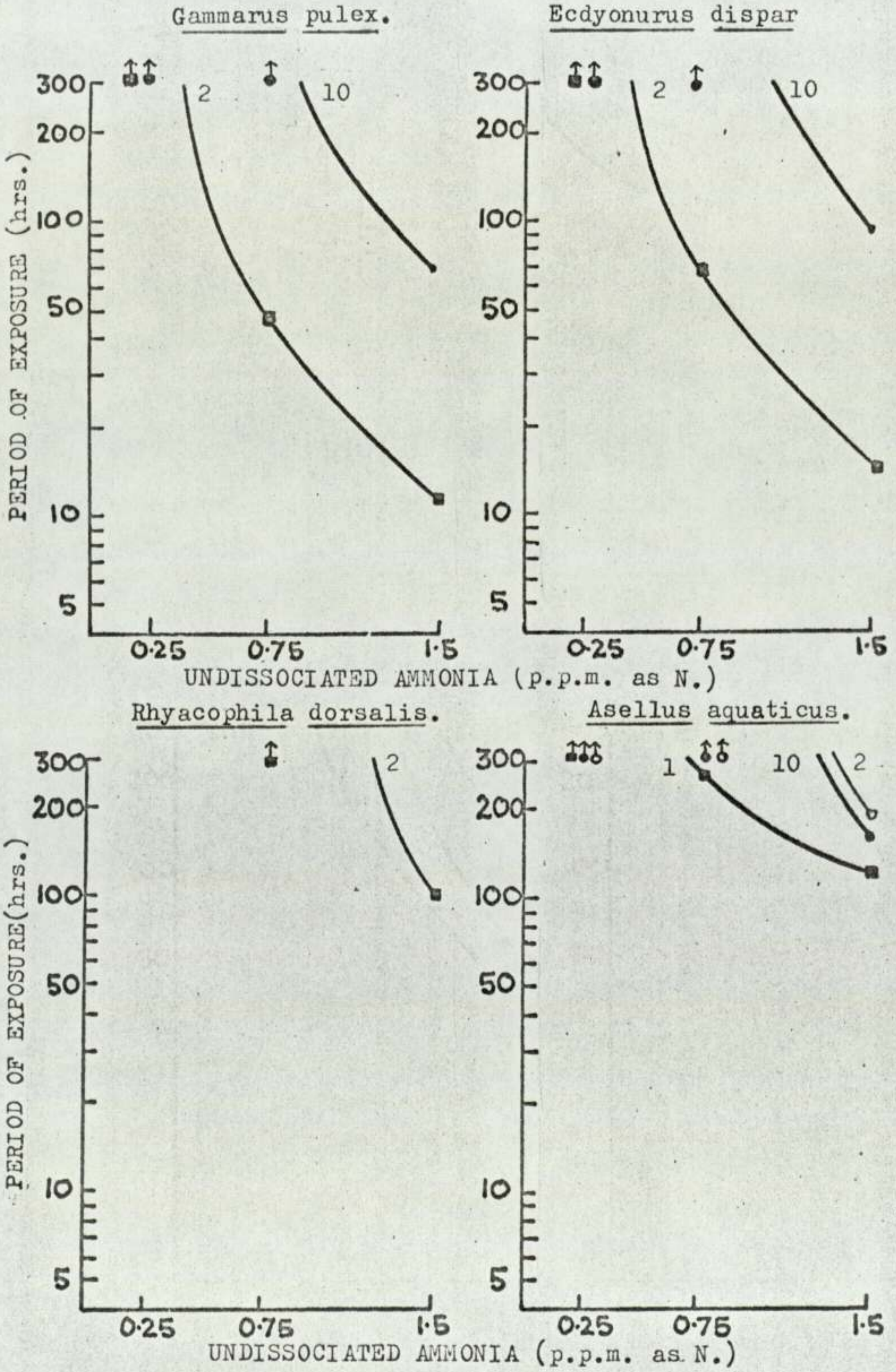


Fig. 64. Effect of dissolved oxygen tension on toxicity of undissociated ammonia at 10°C. Curves represent points at which 80 % of test animals survive. (Numbers on curves refer to dissolved oxygen concentration in p.p.m.)

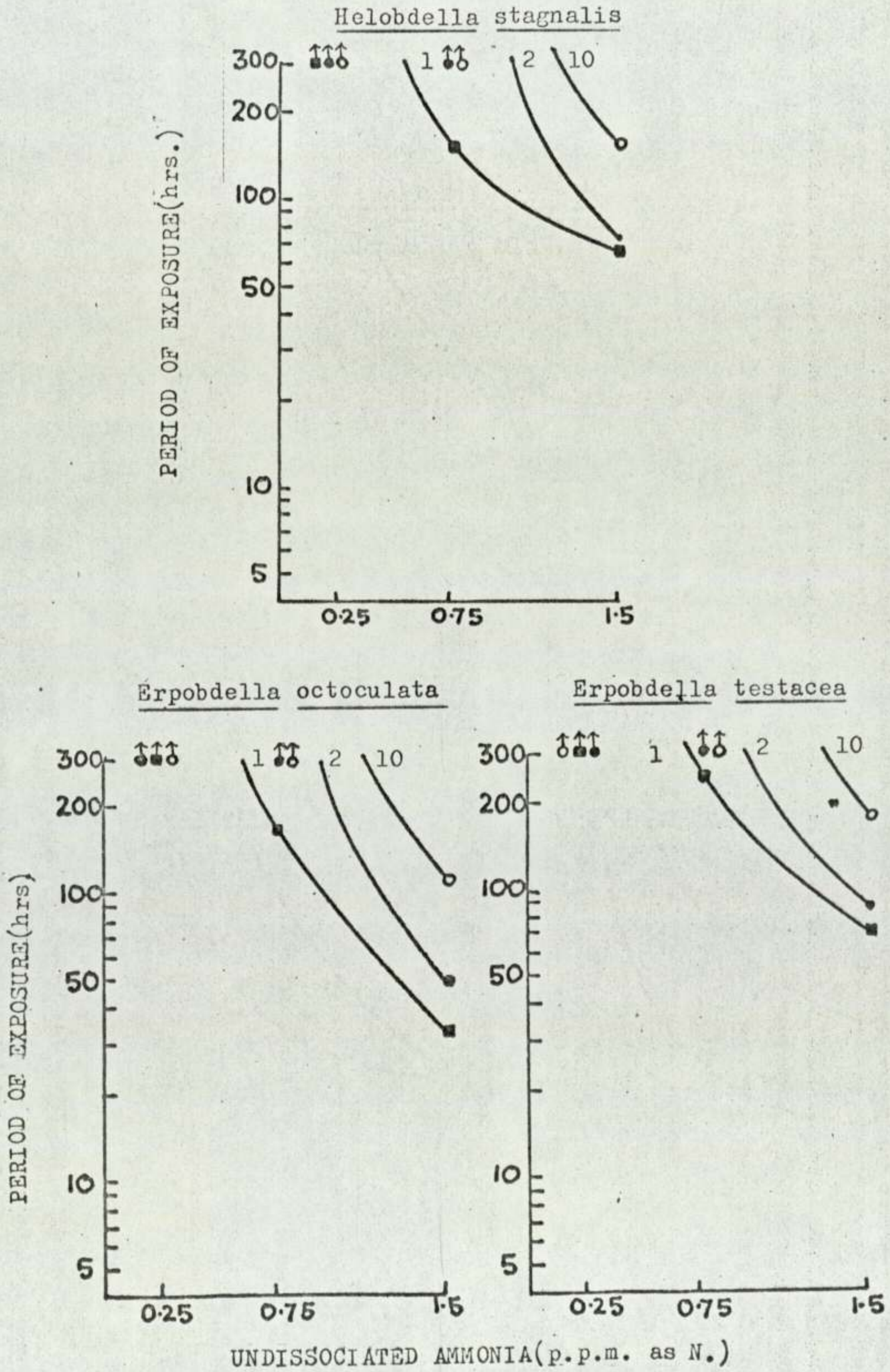
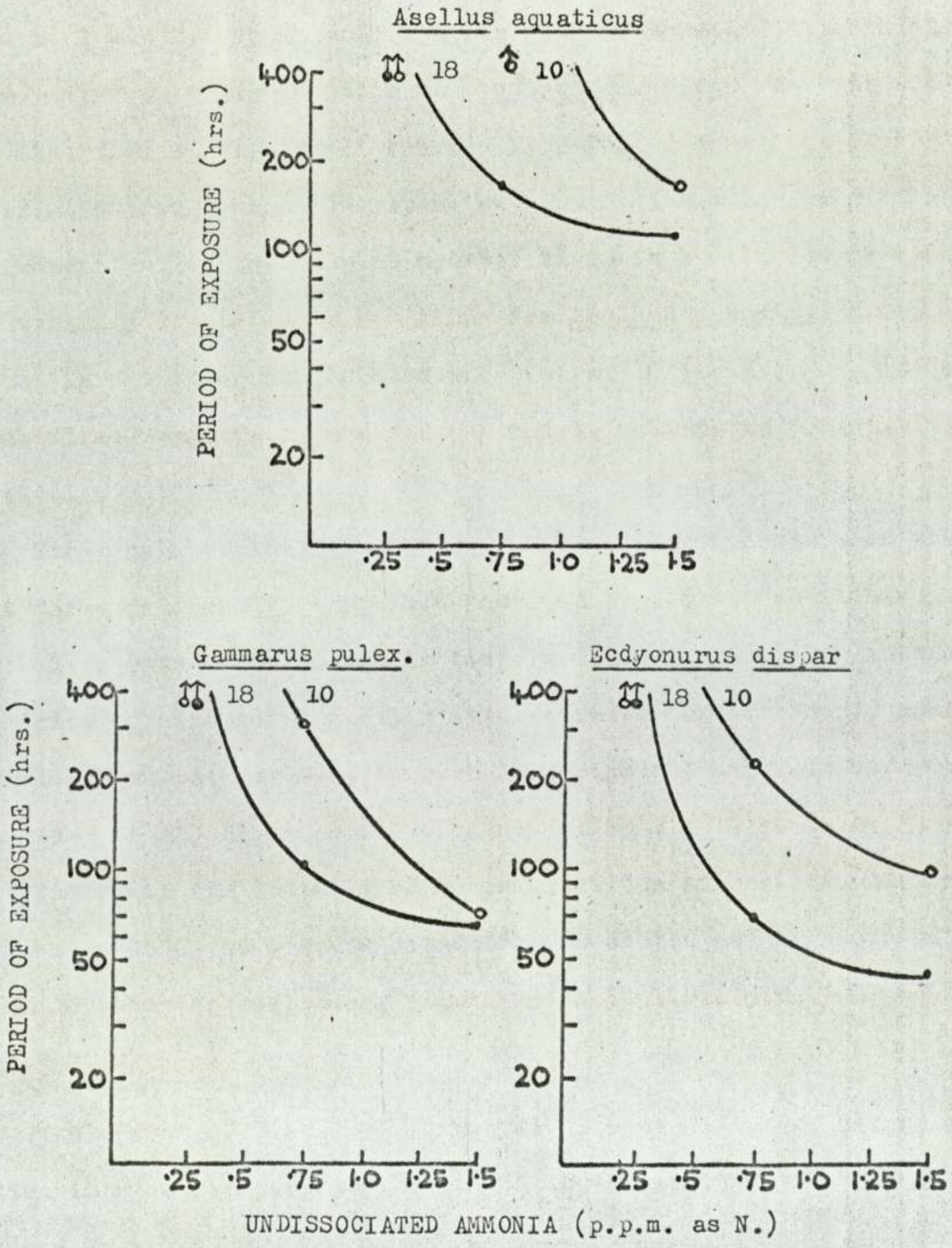


Fig. 65. Effect of temperature on the toxicity of undissociated ammonia. Curves represent points at which 80% of the test animals survive. (Numbers on curves refer to temperature in °C.)



increases the toxicity of undissociated ammonia. Gammarus pulex and Erpobdella testacea illustrate this fact clearly. At 10 p.p.m. oxygen 80% of the Gammarus pulex would survive indefinitely as long as the concentration of undissociated ammonia was not above 0.9 p.p.m., while at 2 p.p.m. oxygen the corresponding figure was 0.4 p.p.m. For Erpobdella testacea the figures were approximately 1.3 p.p.m. undissociated ammonia at 10 p.p.m. oxygen, 0.85 p.p.m. undissociated ammonia at 2 p.p.m. oxygen and 0.55 p.p.m. undissociated ammonia at 1 p.p.m. oxygen. The exception was Asellus aquaticus where it would appear that this species could survive at higher ammonia concentrations at 2 p.p.m. oxygen than at 10 p.p.m. oxygen. With a lowering of the oxygen concentration to 1 p.p.m. however there is a definite increase in the toxicity of the ammonia. Thus for Asellus aquaticus the 80% survival figures for undissociated ammonia, at 10 p.p.m., 2 p.p.m. and 1 p.p.m. dissolved oxygen, are 1.2 p.p.m., 1.3 p.p.m. and 0.7 p.p.m. respectively.

The graphs drawn to show the influence of temperature on the toxicity of undissociated ammonia appears on fig. 65. As with a decrease in oxygen, an increase in temperature does appear to increase the toxicity of ammonia to certain invertebrates, as previously menionted, however this was not found to be general amongst the animals experimented upon. Asellus aquaticus provides a good example to illustrate the effect of temperature on the toxicity of ammonia, if 80% of the individuals are to survive at 18°C the ammonia concentration should not be above 0.4 p.p.m. while at 10°C the corresponding figure would be 1.2 p.p.m.

4.2.3 Carbon Dioxide Experiments

The effect of dissolved carbon dioxide at different oxygen concentrations and temperatures on eight invertebrate species are summarised in Table 35.

It was found that dissolved carbon dioxide over the range tested had no apparent effect on *Erpobdella testacea*, *Erpobdella octoculata*, *Helobdella stagnalis*, *Asellus aquaticus* and *Hydropsyche angustipennis*.

The highest concentration of carbon dioxide used in the experiments was 120 p.p.m. It was found that the leeches and *Asellus aquaticus* could withstand this concentration for 14 days even at 18°C and with a dissolved oxygen concentration in the water of only 1 p.p.m. *Hydropsyche angustipennis* died within the period of exposure in this experiment but this was almost certainly due to the temperature and low oxygen concentration, for it is known from the dissolved oxygen experiments that this species would not survive in these conditions, even without carbon dioxide. This was the only concentration of carbon dioxide in which the individuals of *Hydropsyche angustipennis* did not survive the period of exposure.

Gammarus pulex, *Ecdyonurus dispar* and *Rhyacophila dorsalis* were sensitive to dissolved carbon dioxide. Using data shown on Table 35 graphs were drawn (figs. 66 to 69) to show the effects of various concentrations of carbon dioxide at different oxygen levels and temperatures.

At 10°C (fig. 66) it was found that in water containing 50 p.p.m. carbon dioxide all the test animals survived the period of exposure even when the dissolved oxygen concentration was only 2 p.p.m. At this oxygen concentration an increase in the carbon dioxide concentration to 80 p.p.m. proved fatal to all three species, a further increase to 120 p.p.m. resulted in a considerable reduction in the period of survival. In the experiments at 4 p.p.m. and 10 p.p.m. oxygen it was found that although 80 p.p.m. carbon dioxide was again toxic to *Gammarus pulex* and *Ecdyonurus dispar*, it was not toxic to *Rhyacophila dorsalis* although the individuals of this species once again died when the carbon dioxide concentration was increased to

Fig. 66. Effect of carbon dioxide on the survival of three invertebrate species at 10°C.(Numbers on curves refer to carbon dioxide concentration in p.p.m.)

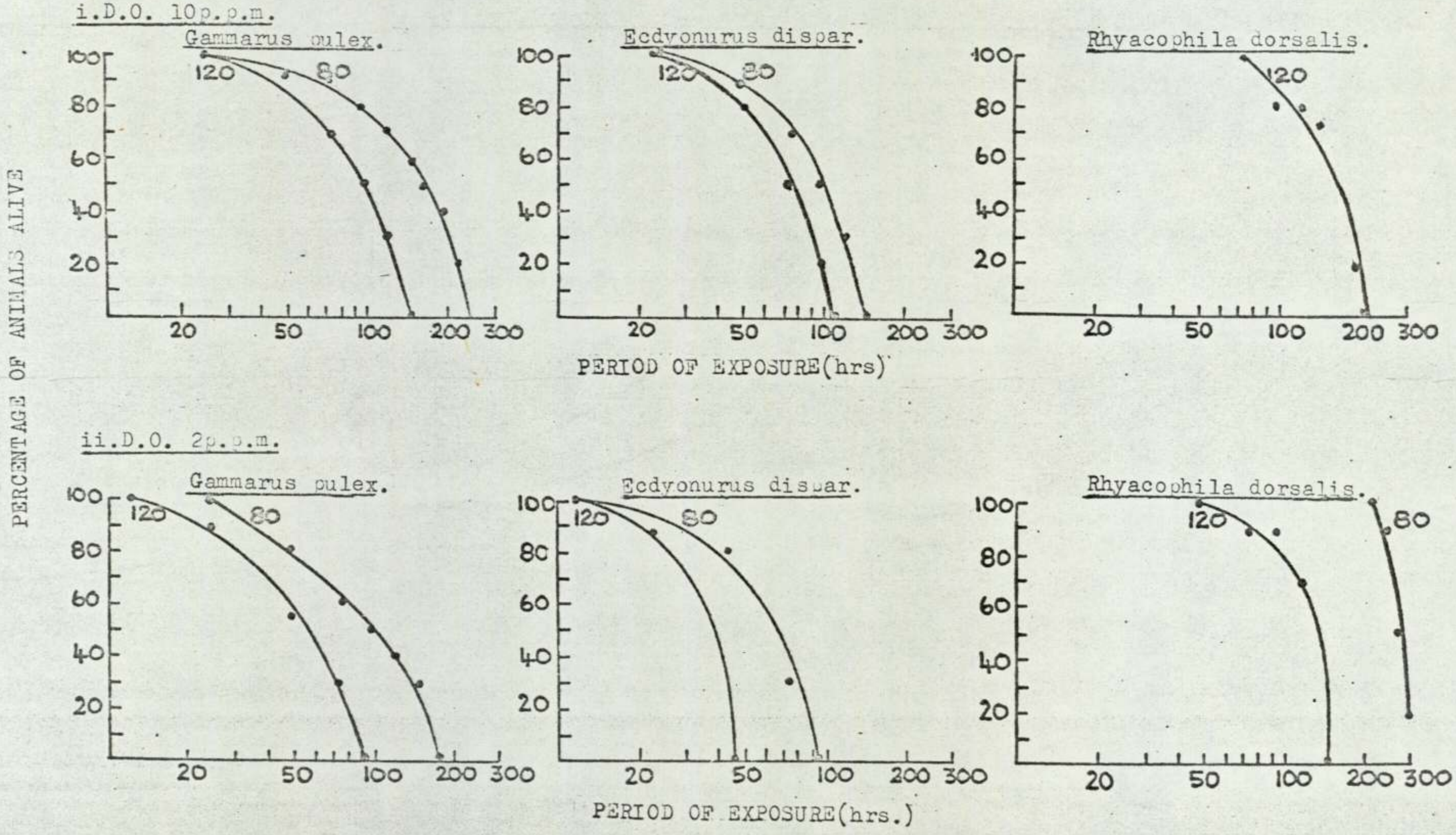
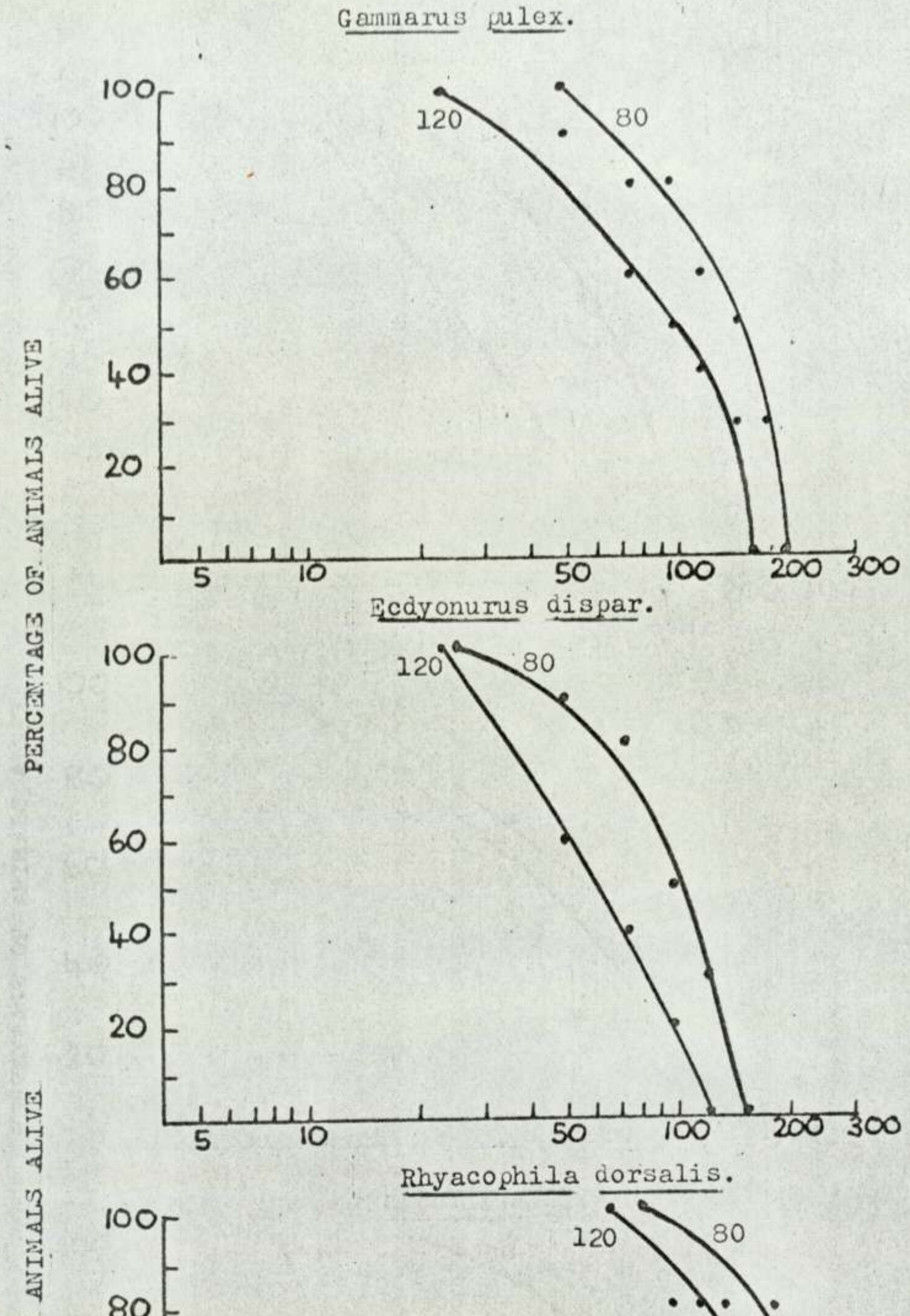


Fig.67 Effect of carbon dioxide on the survival of three invertebrate species at 18°C and an oxygen concentration of 10p.p.m. (Numbers on curves refer to the concentration of carbon dioxide in p.p.m.)



Gammarus pulex.

Ecdyonurus dispar.

Rhyacophila dorsalis.

Fig. 68. Effect of carbon dioxide on the survival of three invertebrate species at 18°C and an oxygen concentration of 4p.p.m. (Numbers on curves refer to the concentration of carbon dioxide in p.p.m.)

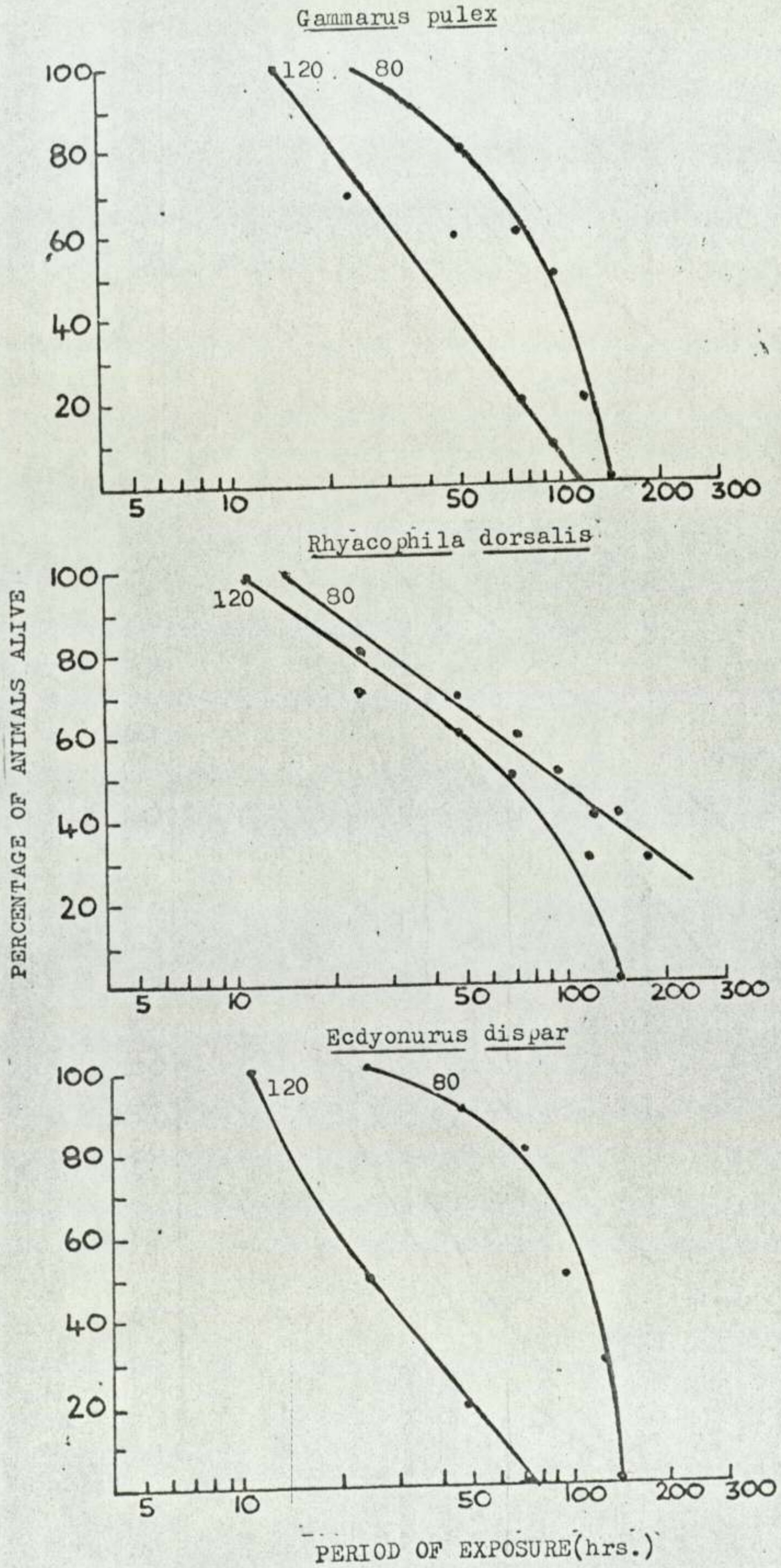
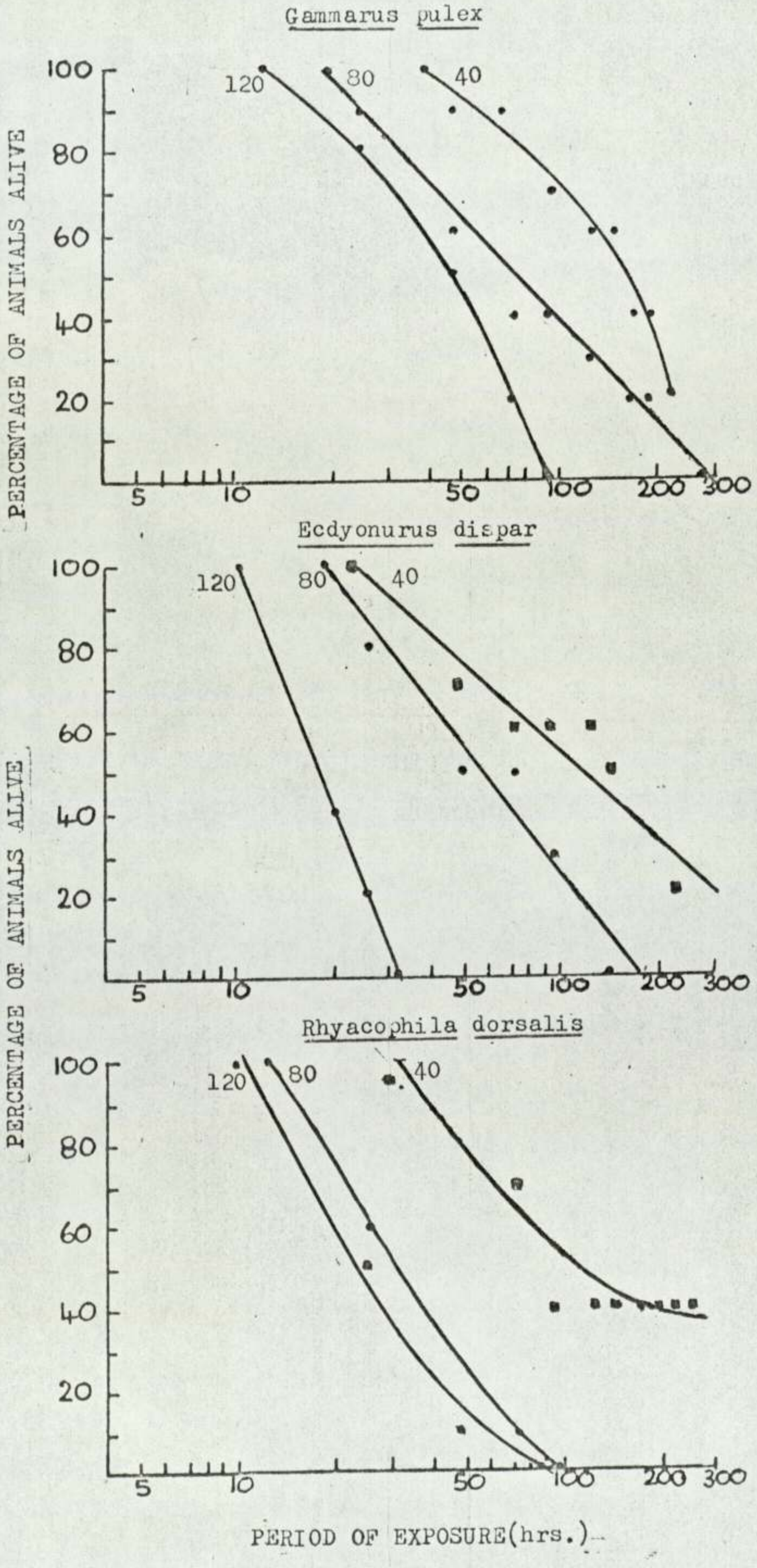


Fig. 69.Effect of carbon dioxide on the survival of three invertebrate species at 18°C and an oxygen concentration of 2p.p.m. (Numbers on curves refer to the concentration of carbon dioxide in p.p.m.)



Gammarus pulex

Ecdyonurus dispar

Rhyacophila dorsalis

Fig. 70. Effect of dissolved oxygen tension on the toxicity of carbon dioxide at 10°C. Curves represent points at which 80% of test animals survive. (Numbers on curves refer to dissolved oxygen concentration in p.p.m.)

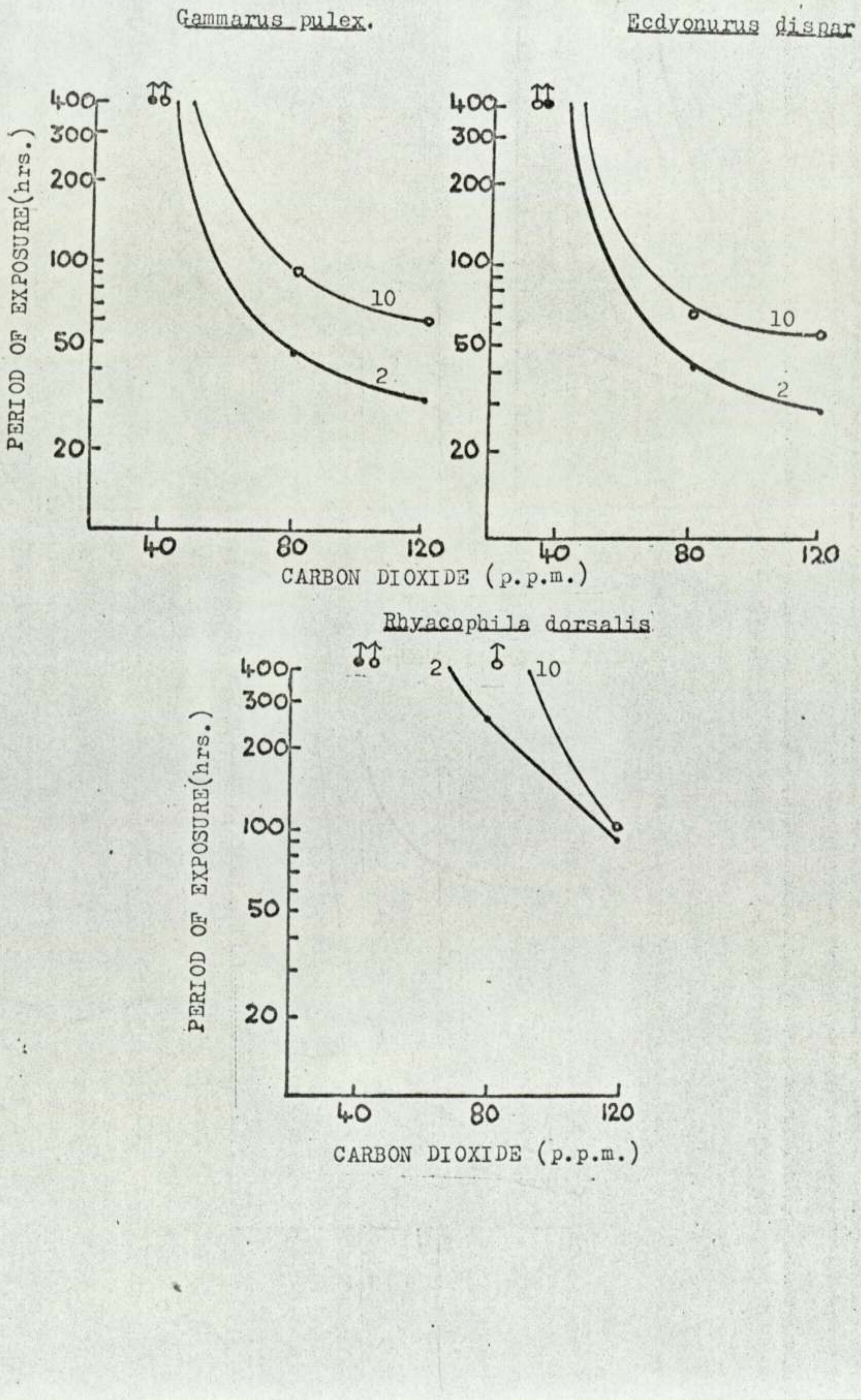
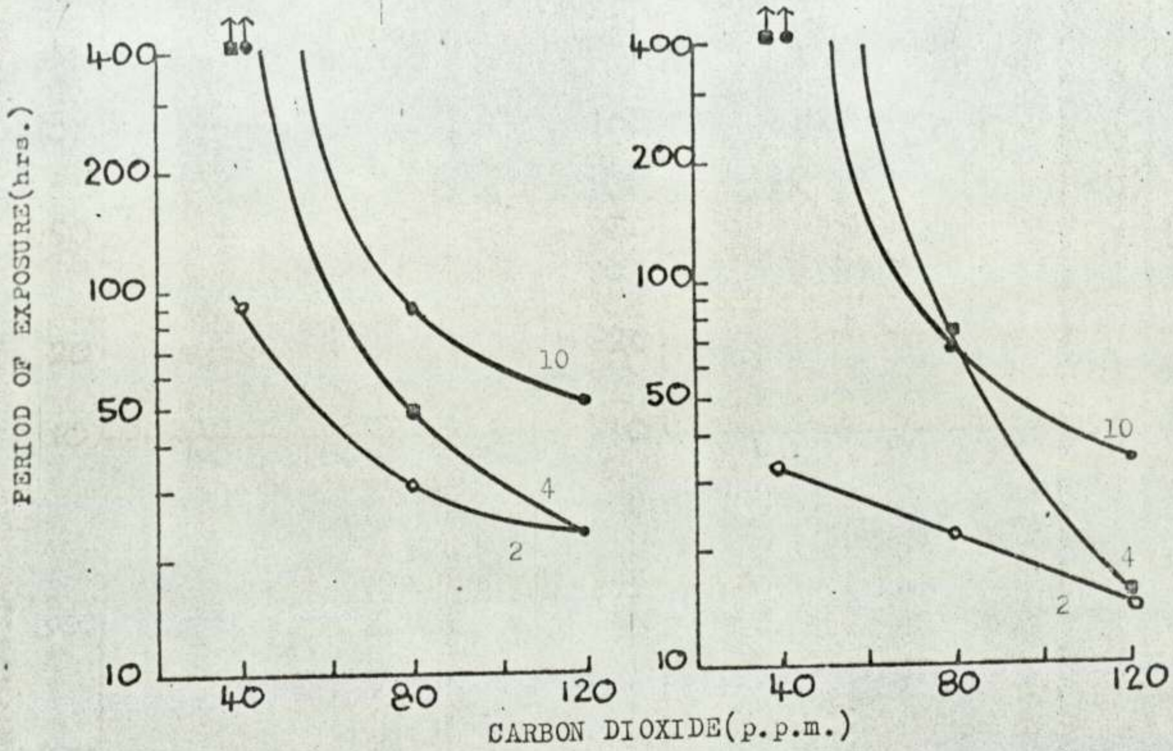


Fig.71. Effect of dissolved oxygen tension on the toxicity of carbon dioxide at 18°C. Curves represent points at which 80% of test animals survive. (Numbers on curves refer to concentration of dissolved oxygen in p.p.m.)



Gammarus pulex.

Ecdyonurus dispar

Rhyacophila dorsalis

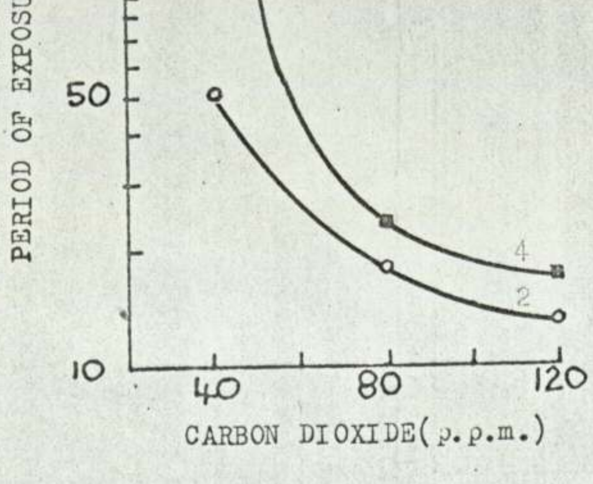
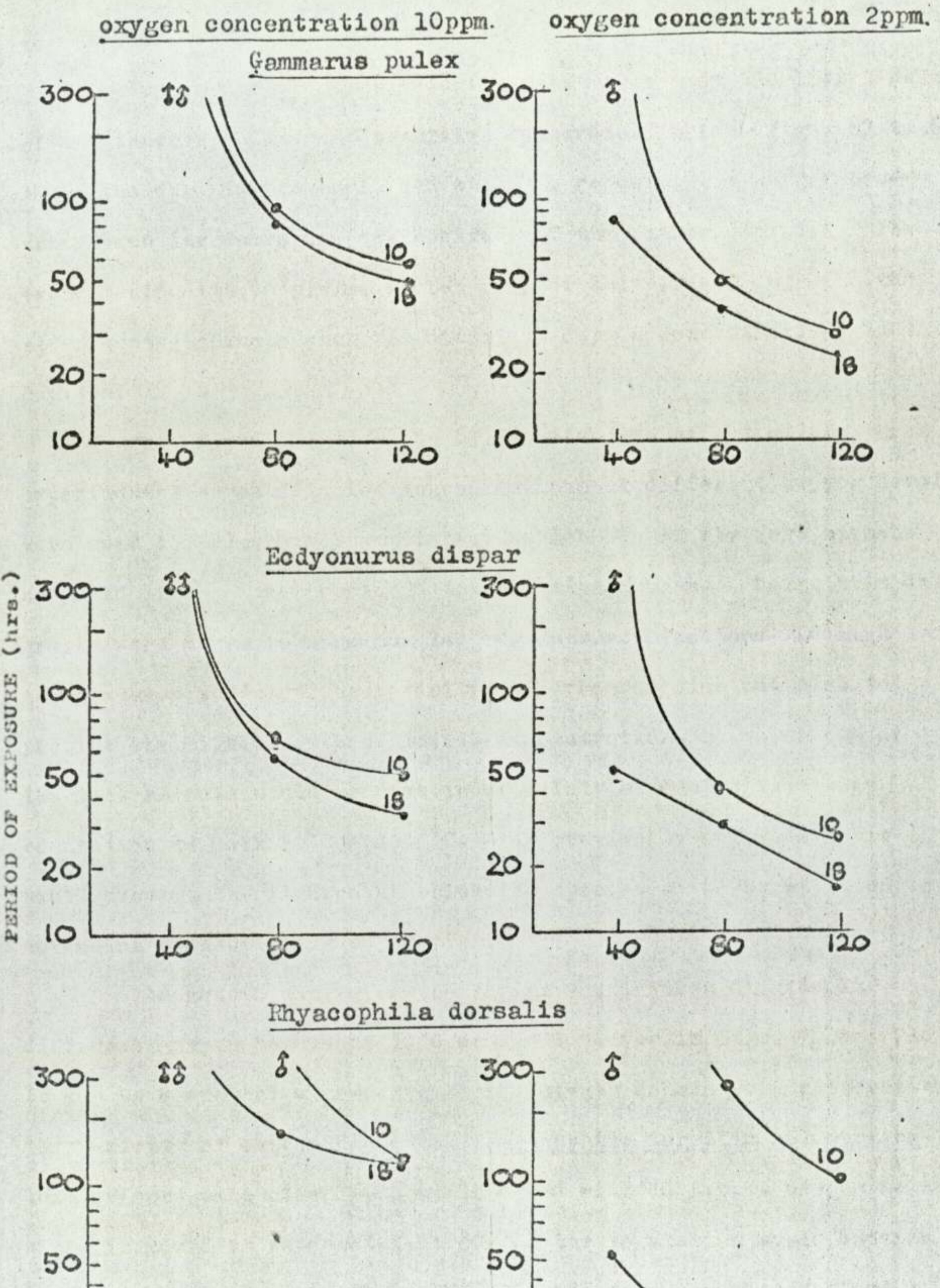


Fig.72. Effect of temperature on the toxicity of dissolved carbon dioxide at two oxygen concentrations. Curves represent points at which 80% of the test animals survived. (Numbers on curves refer to temperature in °C)



120 p.p.m. The most striking feature of the experiments performed at this temperature was that low oxygen concentrations increased the toxicity of carbon dioxide.

Increasing the temperature of the water made the individuals of all three species more sensitive to carbon dioxide (figs. 67 to 69). As in the experiments performed at 10°C, reducing the oxygen concentration increased the toxic effect of the carbon dioxide. The experiments with 40 p.p.m. carbon dioxide only proved fatal to the experimental animals when the dissolved oxygen concentration was 2 p.p.m.

The graphs (figs. 66 to 69) to show the effect of the three experimental carbon dioxide concentrations at different oxygen levels were used to calculate the points at which 80% of the test animals survived in the various carbon dioxide experiments. Using this data graphs were drawn to show how low oxygen concentrations and high temperatures affected the toxicity of carbon dioxide and also to provide the highest carbon dioxide concentrations at which 80% of the test animals would survive indefinitely at each oxygen concentration at both 10°C and 18°C. As previously described this would provide the figures at which the species could be expected to establish a flourishing population.

The graphs comparing the toxicity of carbon dioxide at different oxygen levels at 10°C and 18°C appear in figs. 70 and 71. It can be seen that a lowering of the oxygen concentration increases the toxicity of carbon dioxide. Rhyacophila dorsalis illustrates this effect quite clearly. At 10°C and with 10 p.p.m. oxygen in the water it would be expected that 80% of the population would survive indefinitely as long as the carbon dioxide concentration was not above 85 p.p.m. If the dissolved oxygen concentration is reduced to 2 p.p.m. however, for 80% of the animals to survive the carbon dioxide concentration must not exceed 65 p.p.m.

The graphs showing the influence of temperature on the toxicity of carbon dioxide appear in fig. 72. As with the decrease in oxygen, an increase in temperature does appear to increase the toxicity of carbon dioxide to the three invertebrates.

The experiments thus showed that invertebrates differed in their sensitivity to CO_2. Some invertebrates were apparently not affected even by very high concentrations, combined with high temperatures and very low dissolved oxygen concentrations. Other species were quite sensitive to CO_2, and this sensitivity increased with both an increase in temperature and a lowering of the oxygen concentration.

4.2.4 Orthophosphate Experiments

The effect of potassium orthophosphate at various oxygen concentrations on eight invertebrate species is summarised in Table 36.

As with dissolved carbon dioxide certain invertebrates are apparently not affected by even very high concentrations of potassium orthophosphate. It was found that the three species of leech experimented upon always survived the period of exposure in all the experiments. *Hydropsyche angustipennis* failed to survive the exposure period at 1 p.p.m. dissolved oxygen and 100 p.p.m. orthophosphate, but as in the carbon dioxide experiments it is probable that death was caused by the low oxygen concentration rather than the orthophosphate concentration. If this is the case, *Hydropsyche angustipennis* can also be regarded as being unaffected by potassium orthophosphate over the range tested.

Using the data summarised in Table 36 graphs were drawn (figs. 73 to 75) to show the effects of potassium orthophosphate on the invertebrates at three different oxygen concentrations.

Fig.73. Effect of potassium orthophosphate on the survival of three invertebrate species at 15°C and an oxygen concentration of 10p.p.m. (Numbers on curves refer to the concentration of orthophosphate in p.p.m.)

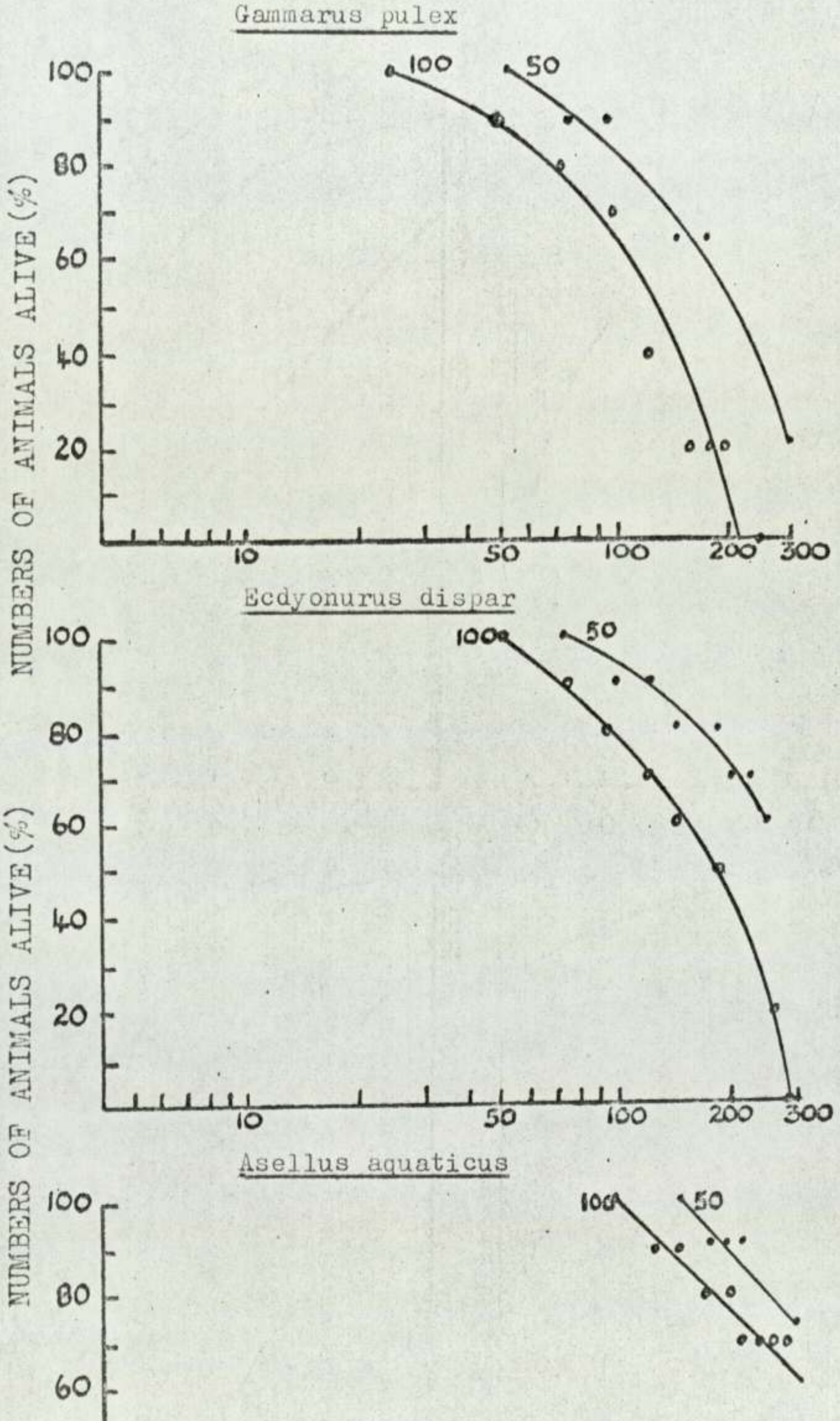
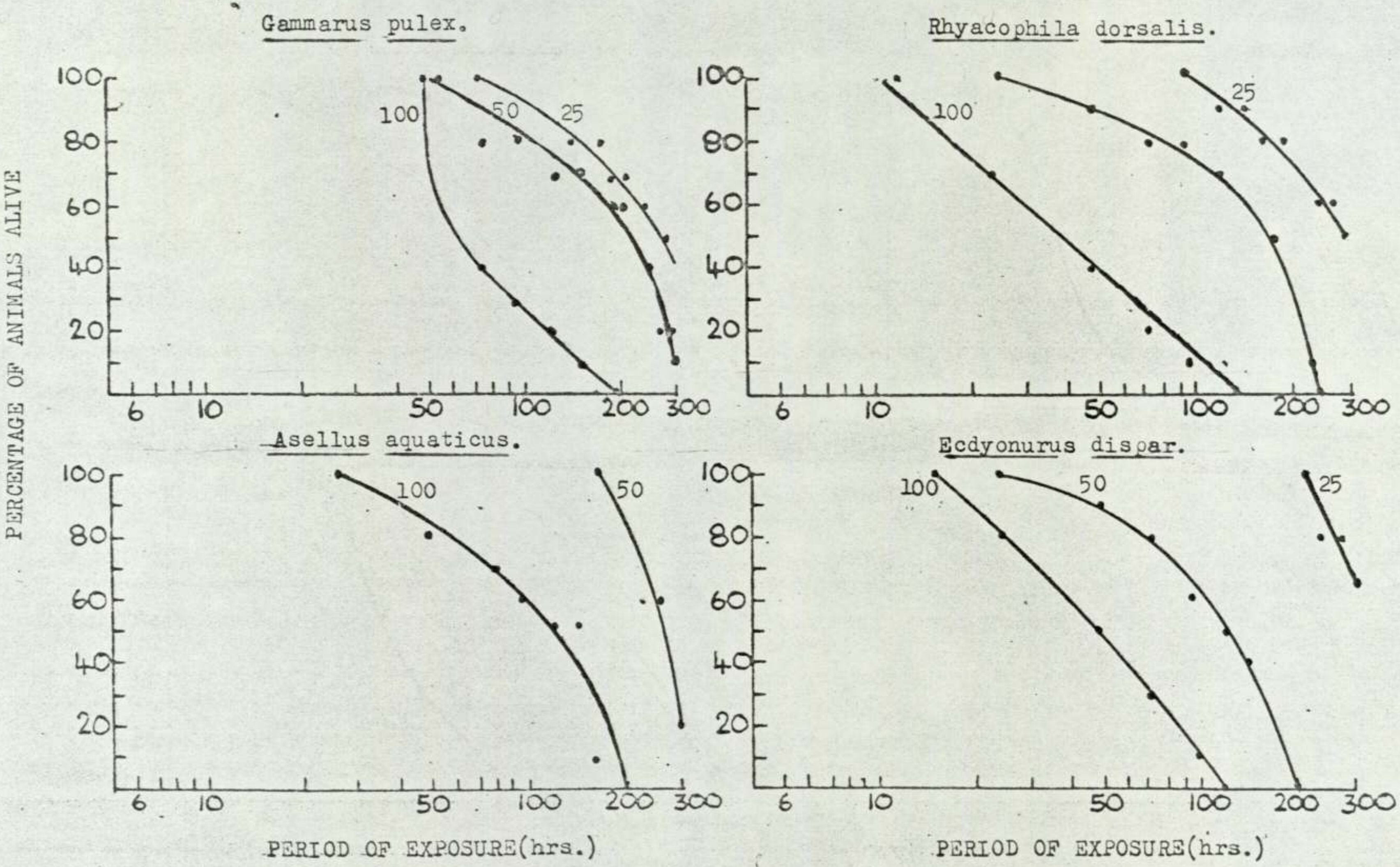


Fig.74.Effect of potassium orthophosphate on the survival of four invertebrate species at 15°C and an oxygen concentration of 4p.p.m. (Numbers on curves refer to the concentration of orthophosphate in p.p.m.)



Gammarus pulex.

Rhyacophila dorsalis.

Asellus aquaticus.

Ecdyonurus dispar.

Fig. 75. Effect of potassium orthophosphate on the survival of four invertebrate species at 15°C and an oxygen concentration of 2p.p.m. (Numbers on curves refer to the concentration of orthophosphate in p.p.m.)

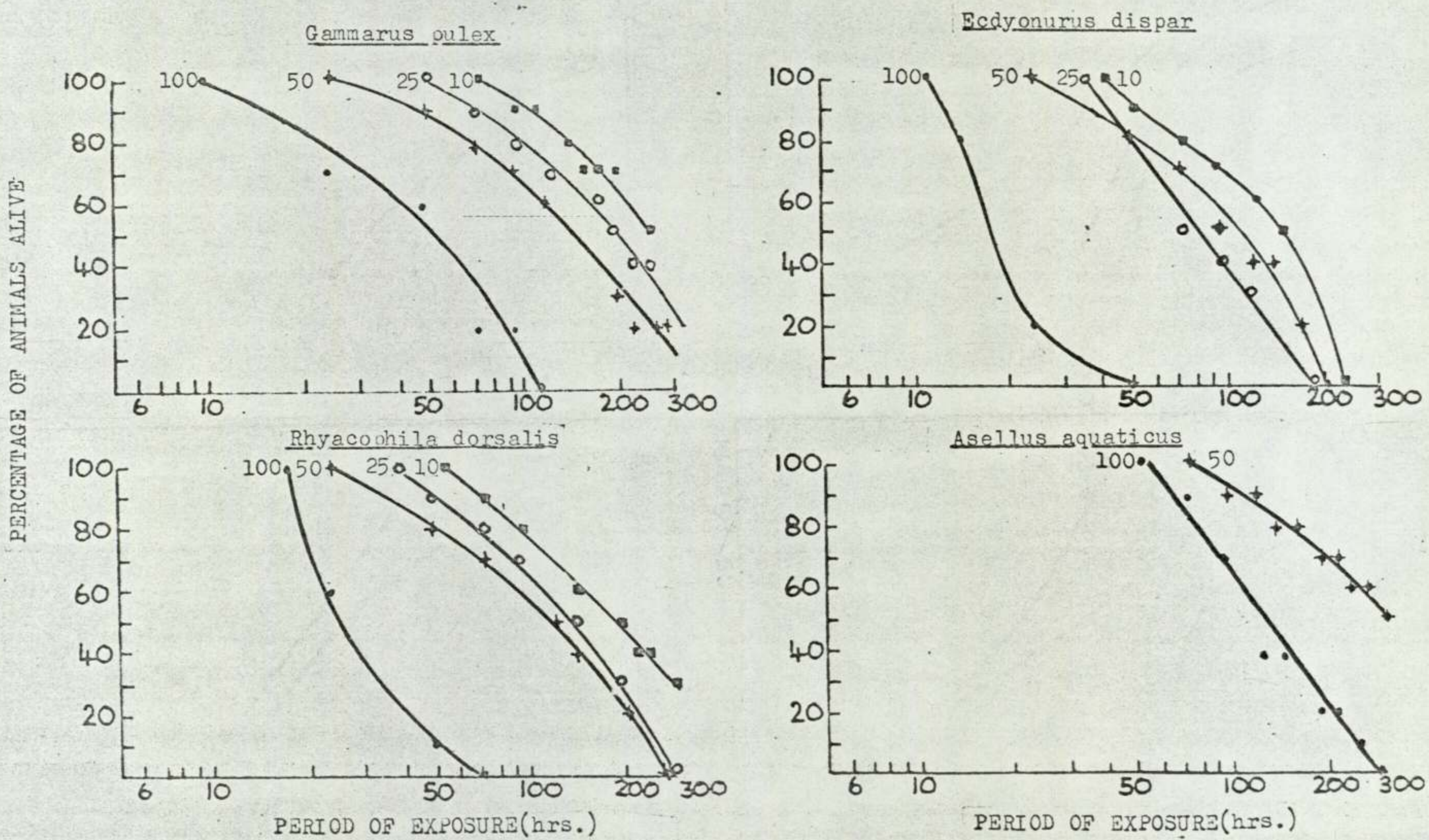
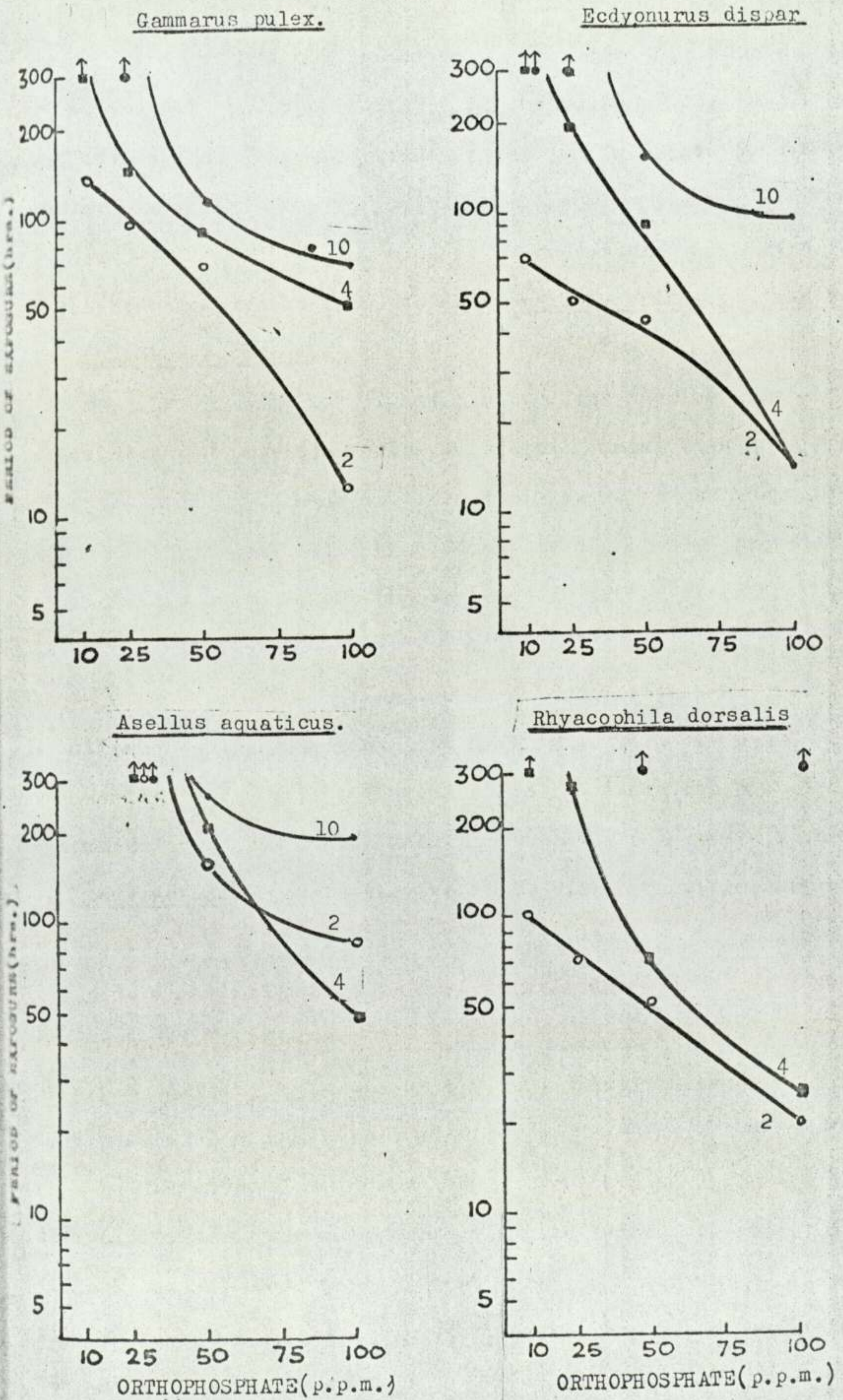


Fig. 76. Effect of dissolved oxygen tension on the toxicity of potassium orthophosphate at 15°C. Curves represent points at which 80% of test animals survive. (Numbers on curves refer to concentration of dissolved oxygen in p.p.m.)



It can be seen from the graphs that within the range of orthophosphate used in the experiments an increase in concentration usually brought about a reduction of the survival period. It was found that in the experiments performed at 10 p.p.m. dissolved oxygen all species survived the period of exposure when the concentration of the orthophosphate was 25 p.p.m. In the experiments when the oxygen concentration was 2 p.p.m. however, a concentration of 10 p.p.m. of orthophosphate proved fatal to Rhyacophila dorsalis, Gammarus pulex and Ecdyonurus dispar.

The 80% survival limits for the four species were also calculated for potassium orthophosphate. Using this data graphs were once again drawn to show the effect of low oxygen concentrations on the toxicity of potassium orthophosphate and also to provide the concentrations which must not be exceeded if a flourishing population is to be established.

The graphs comparing the toxicity of potassium orthophosphate at different oxygen tensions appear in fig. 76. It can be seen that a lowering of the oxygen concentration increases the toxicity of potassium orthophosphate. All four species illustrate this clearly. For Ecdyonurus dispar to survive at 10 p.p.m. dissolved oxygen the orthophosphate concentration must be less than 40 p.p.m., while at 2 p.p.m. dissolved oxygen it must be less than 10 p.p.m. The corresponding figures for Rhyacophila dorsalis are over 100 p.p.m. at 10 p.p.m. oxygen, 25 p.p.m. at 4 p.p.m. dissolved oxygen and less than 10 p.p.m. at 2 p.p.m. dissolved oxygen.

The experiments reveal that invertebrates differ in their sensitivity to orthophosphates. It also became apparent that the toxicity of potassium orthophosphate in the water was considerably increased with a lowering of the dissolved oxygen concentration of the water.

4.3 Discussion of Experimental Results

The results from the experiments can be used to partly explain the distribution of invertebrates which has been observed in organicall polluted waters. It has long been known that *Chironomus riparius* and *Erpobdella testacea* can be found in severely polluted stretches and that when conditions improve *Erpobdella octoculata* and *Asellus aquaticus* appear, a further improvement in conditions could result in *Hydropsyche* becoming established. With a return to good quality conditions a clean water fauna should return with species such as *Gammarus pulex* and *Ecdyonurus* nymphs being present. Thus the experiments on the tolerance of dissolved oxygen by a variety of invertebrates reveal an order of tolerance that reflects their distribution. Since deoxygenation is a common result of organic pollution the varying tolerances of these invertebrates to this factor could explain why different communities become established in varying degrees of pollution.

The fact that *Chironomus riparius* and *Erpobdella testacea* are particularly tolerant to low oxygen concentrations has been observed by a number of biologists. Fox and Taylor (1955) studied the oxygen tolerance of a number of invertebrates including *Chironomus dorsalis* and *thummi* larvae. They found that when comparing the survival of these two species in water containing 4%, 21% and 100% oxygen, both survived longest in the water with 4% and shortest in the water with 100% oxygen. The results of their experiments show how tolerant these species are of low oxygen concentrations and also because of the apparent toxicity of well oxygenated water to both they seem physiologically adapted for life under such conditions. The remarkable tolerance of *Chironomus* spp. to low oxygen concentrations was also demonstrated by Walshe (1948). Although she did not use *Chironomus thummi* in the experiments, she found other species of the genus are particularly tolerant of anaerobic conditions. 50% of the *Chironomus longistylus* larvae were still alive after 68 hrs. while for *Chironomus paganus* 50% were still alive after 101 hrs. These results are very similar to those of the present investigation where for *Chironomus riparius* (*thummi*) the 50% mortality was reached at approximately 90 hours. Walshe also used the larvae of *Prodiamesa olivacea* in her experiments and found it to be a less tolerant form, 50% of the larvae being dead after 10 hours. *Prodiamesa olivacea* was found to be far less tolerant of anaerobic conditions than *Chironomus riparius* in the present study although they survived longer than in Walshe's experiments, the 50% mortality occurring after 24 hrs.

It was also noted by Walshe that *Chironomus riparius* could withstand considerably higher temperatures than *Prodiamesa olivacea*, this fact combined with its greater tolerance of anaerobic conditions would clearly explain why it was able to survive considerably longer under anaerobic conditions at 20°C in the present study.

Another way of demonstrating how animals are adapted to waters containing little or no oxygen is by studying their oxygen consumption under different oxygen concentrations. It would be expected that animals usually associated with low oxygen conditions would be more independent of oxygen changes in the surrounding water than animals from well aerated water. Thus it should be possible to recognise those animals which have an independent type and those with a dependant type of oxygen consumption. Walshe (1948) also studied the oxygen consumption in relation to different oxygen concentrations of a number of chironomid larvae and found that *Chironomus longistylus* had an independent reaction to changes in the oxygen content of the water at least down to 3 p.p.m. Although she was using *Chironomus longistylus* larvae as an example of a still water form and comparing its oxygen consumption with flowing water forms, which she showed had a dependant reaction to oxygen changes, it would seem that although Chironomus riparius is a flowing water form it would nevertheless exhibit an independent reaction.

It was noted in the present study that Chironomus riparius larvae were far more tolerant of anaerobic conditions at 10°C than at 20°C and this was also observed by Linderman (1942). He found that Chironomus plumosus larvae could live for 120 days in anaerobic conditions at 0°C though for much shorter times at higher temperatures. Edwards (1958) showed that oxygen consumption of Chironomus riparius does increase with an increase in temperature and found that they respire 2.8 times as fast at 20°C as at 10°C. This would suggest that the larvae are far better adapted to life in colder water and could explain why the larvae of this species died much more quickly at 20°C than at 10°C in the present study and in Lindeman's experiments.

The fact that Chironomus riparius is extremely tolerant to low oxygen concentration is borne out by the present and past studies. Very little information is available on the other two species of chironomid larvae used in the experiments, other than work performed by Walshe (1948) mentioned earlier, who showed that Prodiamesa, although quite tolerant, is not as tolerant as the Chironomus spp. she used in the experiment. There are a number of possible explanations to account for the tolerance of the red chironomid larvae to low oxygen concentrations. The fact that they contain haemoglobin has been demonstrated by both Ewer (1942) and Walshe (1950) to be very important in withstanding low oxygen concentrations while Augenfeld (1967) demonstrated their ability to break down sugars anaerobically. Ewer showed that the haemoglobin of Chironomus larvae only functions in oxygen transport when the oxygen pressure was less than 3 ccs/litre. When the haemoglobin was converted to carboxyhaemoglobin the oxygen consumption of these larvae was far less at low oxygen concentrations than normal larvae. Walshe (1950) working on <u>Chironomus plumosus</u> came to similar conclusions and noticed that the presence of haemoglobin enabled larvae to remain active at very low oxygen concentrations. Larvae which had their haemoglobin converted to carboxyhaemoglobin were not able to filter feed in oxygen concentrations less than 26% air saturation while the limiting concentration for normal larvae was 10% of air saturation. She also showed that haemoglobin greatly increases the rate of recovery of the larvae following anaerobic conditions. Augenfeld (1967) showed another feature of <u>Chironomus</u> larvae which enables them to survive anaerobic conditions. He showed that <u>Chironomus thummi</u> (<u>riparius</u>) and <u>plumosus</u> have glycogen comprising 13-14% of their body weight, both of these species are particularly tolerant of low oxygen concentrations. <u>Tanytarsus</u> however, which is intolerant of low oxygen concentrations, has only 2% of its body weight composed of glycogen. The reason for this high glycogen content in the larvae of <u>Chironomus</u> species is that they are able to break down glycogen anaerobically but as this method of respiration yields only 10% of the energy resulting from complete oxidation a plentiful supply would be required. Lactic acid which is a normal by-product of anaerobic respiration is then broken down by lactic dehydrogenase to prevent accumulation. The possession of haemoglobin and high glycogen concentrations are then important factors in enabling <u>Chironomus riparius</u> to survive the low oxygen concentrations that were used in the present investigation. The fact that the other two species of chironomid larvae used, namely <u>Prodiamesa olivacea</u> and <u>Brillia longifurca</u>, were considerably less tolerant could well be due to the fact that they are non-red and thus do not possess haemoglobin or possibly the high glycogen concentrations with the related enzymes in their bodies.

<u>Erpobdella testacea</u> was also found in this investigation to be

very tolerant to low oxygen concentrations. *Erpobdella octoculata* and *Helobdella stagnalis*, the other two species of leech were slightly less tolerant but nevertheless still very tolerant. Mann (1956 and 1961) investigated the oxygen consumption of five species of leech and found that *Erpobdella testacea* and *Helobdella stagnalis* had "independent" respiration, for the former at oxygen concentrations down to 3.0 p.p.m. and the latter down to 2 p.p.m. This would verify the tolerance of these two species to anaerobic conditions. Mann also found however that *Erpobdella octoculata* had a dependent respiration which would suggest that it is not particularly well adapted to low oxygen concentrations, in the present investigation this was not found to be the case. Mann (1961) concluded that *Erpobdella testacea* is better adapted to life in low oxygen concentrations than *Erpobdella octoculata* and in the present investigation this was found to be so. The reason why *Helobdella stagnalis*, which has an independent respiration, is no more tolerant to low oxygen concentrations than *Erpobdella octoculata* with a dependent respiration is difficult to explain. Dausend (1931) however showed that *Tubifex*, which can live anaerobically, also has a dependent oxygen consumption. So it would appear that a study of oxygen consumption is not always a true guide to the ability of an organism to live under low oxygen concentrations. *Erpobdella octoculata* may be another exception like *Tubifex*.

The two crustaceans experimented upon, namely *Asellus aquaticus* and *Gammarus pulex* differed greatly in their tolerance to low oxygen concentrations. *Asellus aquaticus* was found to be very tolerant of low oxygen concentrations, especially at 10°C while *Gammarus pulex* was far more sensitive. These results would agree with their ecological distribution, *Gammarus* usually being found in well aerated water while *Asellus* is frequently found where oxygen is scarce.

Edwards and Learner (1960) found that between 8.3 and 1.5 p.p. oxygen Asellus aquaticus has an independent type of oxygen consumption and this would suggest that the species is very tolerant of low oxygen concentrations. Similar conclusions can be drawn from work of Fox and Simmonds (1933) who found that a lowering of the oxygen concentration to 3.36 ccs/litre produced no movements of the pleopods, and even at 1.12 ccs/litre there was only a slow discontinuous movement. Very different results were obtained when Gammarus pulex was used as the test animal, They found that there was a regular increase in the beating of the pleopods with a progressive lowering of the oxygen content. The results of this other work would then agree with the present findings that Asellus aquaticus is far more tolerant to low oxygen concentrations than Gammarus pulex. Sprague (1963) working on North American crustaceans produced very similar results. In his experiments he used Asellus intermedius, Gammarus fasciatus and Gammarus pseudolimnaeus. He found that 50% of the Asellus intermedius could survive for 24 hrs. at an oxygen concentration of 0.03 p.p.m. For 50% of Gammarus fasciatus to survive 24 hrs. the oxygen concentration must be 2.2 p.p.m., while for Gammarus pseudolimnaeus it must be 4.3 p.p.m. It appears that Asellus intermedius is associated with similar ecological conditions to Asellus aquaticus in this country, and the two species of Gammarus are similar to Gammarus pulex. The results of the present study were very similar where it was found that at 0.0 p.p.m. oxygen 50% of the test animals of Asellus aquaticus were still alive after 24 hrs., for 50% of the test animals of Gammarus pulex to stay alive after 24 hrs. the oxygen concentration would have to be increased to nearly 2 p.p.m. at 20°C. Thus it would seem that the present results on the two crustaceans agree with previous findings and with conclusions that could be drawn from ecological distribution.

Of the other three species used in the experiments all could be described as being sensitive to low oxygen concentration although Hydropsyche angustipennis larvae were considerably more tolerant than the larvae of Rhyacophila dorsalis or the nymphs of Ecdyonurus dispar. This would agree with the field observations of previous workers. Hydropsyche larvae can frequently be found in the later recovery stages of organically polluted waters while the developmental stages of the other two species are usually associated with clean water conditions.

Jaag and Ambuhl (1962) studied the effect of current on the oxygen tolerance of a variety of freshwater invertebrates. They found that at 0.5 cms/second Hydropsyche angustipennis would survive indefinitely at 1.3 p.p.m. oxygen. The corresponding figures for Ecdyonurus venosus and Rhyacophila dorsalis were 1.2 p.p.m. and 1.5 p.p.m. oxygen respectively. On the basis of the results from the present study it would appear that Ambuhl's figures are particularly low. The corresponding figures from this study were found to be nearly 2 p.p.m. for Hydropsyche angustipennis and nearly 3 p.p.m. for Rhyacophila dorsalis and Ecdyonurus dispar. The latter results would appear to be more closely related to the field work observations and results on other invertebrates.

It does appear that from a study of the oxygen tolerance of various aquatic invertebrates it is possible to recognise a gradation in degrees of tolerance. Some species such as the larvae of Chironomus riparius and Erpobdella testacea are very tolerant, others such as Hydropsyche angustipennis larvae are moderately tolerant while Gammarus pulex and Rhyacophila dorsalis are sensitive to low oxygen concentrations. It was also found that animals which from field observations would experience severe deoxygenation of the water were more tolerant than species which are characteristic of well oxygenated waters. The results of the present investigation as well as showing that animals vary in their tolerance of low oxygen concentrations provided detailed information on the survival of the invertebrates experimented upon at different oxygen concentrations. In general the results agreed with those from the limited amount of work previously carried out. The experiments also showed that the effect of deoxygenation is likely to be far more serious in summer, all eleven invertebrates experimented upon were able to survive in lower concentrations at 10°C than at 20°C.

Very little work has been published on the tolerance of invertebrates to undissociated ammonia although there have been numerous publications on the toxicity of ammonia to fish. It would appear, from the results obtained from these observations, that fish are far more sensitive to undissociated ammonia than invertebrates. Ball (1967) studied the tolerance of four species of fresh water fish to undissociated ammonia. Of the four species used in the experiments rudd appeared to be the most tolerant, but this species survived less than 24 hrs. at 0.75 p.p.m. as N. Ecdyonurus dispar and Gammarus pulex, which were found to be the most sensitive of the eleven invertebrate species used in the experiments, were nevertheless able to survive the period of exposure of 13 days at this ammonia concentration.

The fact that the toxicity of ammonia to invertebrates is increased at low dissolved oxygen concentrations was also found to be the case with fish. Downing and Merkens (1955) studied the combination of these two factors on trout and observed that the period of survival at any ammonia concentration is drastically reduced with a lowering of the oxygen concentration. Using a concentration of 1.38 p.p.m. undissociated ammonia they found that trout could survive over 500 minutes when the oxygen concentration of the water was 7 p.p.m., if the oxygen was 3 p.p.m. however the period of survival was only 80 minutes.

It is well established that an increase in temperature reduces the survival period of fish in toxic solutions. Wuhrmann and Woker (1948) showed that increases in temperature also shortens the period of survival of fish to undissociated ammonia. So it appears that invertebrates are similar to fish in this respect.

The results obtained from the ammonia experiments establish that there is a considerable difference in tolerance to undissociated ammonia amongst invertebrates. Generally it was found that animals which from field observations would be more likely to experience higher ammonia concentrations are indeed more tolerant of this factor. The larvae of Hydropsyche angustipennis and Rhyacophila dorsalis however were found to be exceptions, for although these larvae are not normally associated with polluted conditions they were exceedingly tolerant of undissociated ammonia. It is difficult to believe that the concentration of this substance found in nature could limit their distribution and the reason why they are not found in polluted waters must be attributed to other factors.

The three species of chironomid larvae were also found to be very tolerant of undissociated ammonia and this would be expected from the acknowledged distribution of these animals. Thienemann (1954) mentions that both Chironomus riparius and Prodiamesa olivacea can be found in severely polluted waters. The tolerance of the three species of leech would also be expected from field observations. All three species are known to occur in moderately polluted waters, and, according to Hynes (1966) Erpobdella testacea and Helobdella stagnalis are amongst the first of the leeches to appear in the recovery stages of organically polluted waters. Erpobdella testacea and Helobdella stagnalis were more tolerant to ammonia than Erpobdella octoculata and this may be one of the reasons why they appear before the latter species in a river recovering from organic pollution. Asellus aquaticus was similar in its degree of tolerance to Erpobdella testacea and Helobdella stagnalis and this would be expected from the fact that these three species are usually associated with each other in polluted streams. Gammarus pulex and Ecdyonurus dispar were the most sensitive of the species used in the experiments and this sensitivity to ammonia could help to explain their absence from polluted waters.

The ammonia experiments as well as showing that species vary in their tolerance of undissociated ammonia revealed the maximum concentrations which each species can tolerate indefinitely. It was also found that the sensitivity of invertebrates to ammonia is influenced by the dissolved oxygen concentration and temperature of the water.

The experiments in which carbon dioxide and potassium orthophosphate were added to the water revealed that certain species seem to be unaffected by even extremely high concentrations of these two substances. As in the other criteria investigated, the experimental results showed a correlation with accepted field data. Species normally associated with polluted conditions were more tolerant than clean water species.

Carbon dioxide can be formed in rivers by the oxidation of organic matter and high concentrations may therefore be found in organically polluted waters. It is known from work on fish (Alabaster et al, 1957) that carbon dioxide can double the minimum concentration of dissolved oxygen necessary for the survival of fish. They also found that an increase in temperature shortens the period of survival in a given concentration of carbon dioxide.

The present study revealed that high concentrations of dissolved carbon dioxide could be toxic to certain invertebrates even in oxygen saturated water (figs. 66 & 67). As in the experiments on fish however the presence of carbon dioxide increased the lethal effects of low dissolved oxygen concentrations (figs. 70 & 71). It was also found that the toxicity of carbon dioxide is increased with an increase in temperature (fig. 72). It would appear then that the effect of carbon dioxide would be most critical in the summer. Thus carbon dioxide could from the results of these experiments increase the toxic effect of any deoxygenation of the water. If there are also high temperatures the combined effects of all three factors could be important in limiting the distribution of certain invertebrates.

It has been demonstrated by many workers including Irving, Black and Stafford (1941) that carbon dioxide reduces the affinity of the blood of many species of fish for oxygen. So the effect of dissolved carbon dioxide on fish is one of asphyxiation. The way it exerts its influence on invertebrates is not really known. The fact that it does influence the effect of low dissolved oxygen suggests that it may act in a similar way. Very little work has been performed on the effect of carbon dioxide on invertebrates although Fox and Johnson (1934) made a limited study. They used Gammarus pulex and Asellus aquaticus and subjected both species to dissolved carbon dioxide. They found that with G. pulex it resulted in an increased movement of the respiratory pleopods but not in A. aquaticus. Their results agree with those of the present investigation where G. pulex was found to be sensitive to carbon dioxide but not A. aquaticus.

The experiments to show the effect of dissolved carbon dioxide on invertebrates thus revealed that although carbon dioxide would be unlikely to have a limiting effect on most of the species used it could nevertheless be very important in limiting the distribution of species such as Gammarus pulex. It would also appear that dissolved carbon dioxide could exert greater influence on invertebrates by affecting their tolerance to low dissolved oxygen concentrations. This effect would be even greater in the summer months when the water temperatures are high.

In the experiments where potassium orthophosphate was added to the water it was found that animals such as the leeches which are frequently associated with polluted conditions are more tolerant to this substance than animals usually found in clean water environments. The importance of potassium orthophosphate in possibly influencing the distribution of invertebrates in polluted streams is not easy to assess. It is well known that organic pollution as a result of a sewage discharge may cause high concentrations of orthophosphates to be present in the water. There is however little information available on potassium in organically polluted waters. Thus although potassium orthophosphate caused deaths in the experiments it is not possible to relate these deaths only to the orthophosphate present. Jones (1937) and Harnisch (1951) both showed that high concentrations of the potassium ion could prove toxic to invertebrates. It has also been shown that the phosphate radicle can be toxic (Jones 1941 and Harnisch 1951). Moreover Harnisch using <u>Daphnia magna</u> as test animal found phosphate to be more toxic than a similar concentration of potassium. He arranged his ions in the following series according to the strength of their harmful effects Ca - Na - K - NH_4 - Acetate - Phosphate.

From these results it could be interpreted that it was the orthophosphate that was most likely to have caused the deaths. Lagerspetz (1958) however has shown <u>Daphnia magna</u> to be very tolerant of saline conditions so it would be expected that it would tolerate high concentrations of potassium and so no real conclusions can be drawn regarding the respective tolerances of potassium and orthophosphates by other fresh-water invertebrates. In the same series of experiments, Lagerspetz also used Asellus aquaticus and found that this species was also particularly tolerant of saline conditions, being able to survive permanently in 20% sea water. Gresens (1928) concluded that these isopods were viable in 40% sea water. Thus it would appear unlikely that the concentrations of potassium used in the experiments would account for the deaths of A. aquaticus and that it was due to the orthophosphate present. It could then be assumed that the mortality of Gammarus pulex, Ecdyonurus dispar and Rhyacophila dorsalis were also due to this substance.

It was found that a decrease in oxygen concentrations considerably reduced the period of survival of four of the species used in the experiments (fig. 76). At low oxygen concentrations even small concentrations of potassium orthophosphate could prove toxic to three of the species. It would seem that the orthophosphate concentrations found in some polluted streams could prove effective in limiting the distribution of invertebrates especially in the summer months when low oxygen concentrations may prevail. As with the other factors investigated the most sensitive species were those usually found in clean water environments, so it would appear that these experimental results could help to explain the distribution of animals from field observations.

5. Synthesis of Field Work and Experimental Work

The field work revealed that the various taxa reacted very differently to organic enrichment. It was found that a number of species definitely favoured organic enrichment and were adversely affected by clean water conditions. Other invertebrates however were adversely affected by organic enrichment. It was possible as a result of the field work to associate different species with varying degrees of organic enrichment. It was found that where a river was severely organically polluted the only animals likely to be found there were worms belonging to the Tubificidae and Enchytraeidae and the red midge larvae Chironomus riparius. With an improvement in water quality it was observed that a variety of chironomid larvae usually became established of which Polypedilum arundineti, Brillia longifurca, Prodiamesa olivacea, Cricotopus bicinctus and Cricotopus sylvestris were the most abundant. With the progressive increase in the numbers of the above species there was a corresponding decrease in the numbers of Chironomus riparius larvae. Slightly less tolerant of organic pollution were Asellus aquaticus, Erpobdella testacea, Erpobdella octoculata and Helobdella stagnalis. The chironomid larvae previously mentioned also became numerous in this zone and were frequently joined by other species of which the larvae of Trichocladius rufiventris, Eukiefferiella hospitus, Pentaneura melanops were often abundant. A further improvement in water conditions allowed Gammarus pulex, Hydropsyche angustipennis and Baetis rhodani to become established and flourish. With little or no organic enrichment a diverse benthic community was usually found in which species of Trichoptera, Plecoptera and Ephemeroptera were important constituents.

The reasons why these changes in the benthic community occurred could almost certainly be attributed to changes in the chemistry of the water and nature of the stream bed. It was found that organic enrichment frequently resulted in a decrease in the oxygen concentration and an increase in the concentrations of ammonia, orthophosphates, nitrates and carbon dioxide. It was obvious that no one factor was solely responsible for these changes in the benthic community because the chemical changes produced varied with the treatment the effluent had received. The benthic community however was always found to be basically the same.

The aim of the experimental work was to try and explain why the various benthic communities noted in the field work became established at certain levels of organic enrichment. To investigate this a variety of invertebrates were chosen some of which were associated with severe organic pollution, others with moderately polluted conditions and yet others with clean water conditions. These invertebrates were then subjected experimentally to a number of the conditions associated with organic pollution. It was hoped that the polluted forms were more tolerant of these factors than the moderately polluted forms and these in turn more tolerant than the clean water forms. It was also intended to try and establish which of the factors were most important in limiting the distribution of these species and also at what concentrations they were likely to influence these species.

Generally the experiments complemented the field work observations for it was found that *Chironomus riparius* and *Erpobdella testacea* were the two most tolerant species of low oxygen concentrations. Slightly less tolerant were *Erpobdella octoculata*, *Helobdella stagnalis*, *Asellus aquaticus*, *Prodiamesa olivacea* and *Brillia longifurca*. *Hydropsyche angustipennis* was less tolerant than the previous species but more tolerant than *Gammarus pulex*, *Rhyacophila dorsalis*, and *Ecdyonurus dispar*. This was almost exactly the order of tolerance that would have been deduced from the River Cole investigation. The dissolved oxygen experiments also showed that the effect of temperature increases the lethal effect of deoxygenation and this could possibly explain the suppression of the summer populations in the more polluted regions. The carbon dioxide experiments showed that invertebrates can vary considerably in their tolerance of this factor, some species being remarkably tolerant while others were quite sensitive to it. As with the dissolved oxygen experiments the tolerant species were those from the polluted conditions and the sensitive species the clean water species. The ammonia and orthophosphate experiments generally revealed the same order of tolerance with species from the polluted conditions being more tolerant than the clean water species. The only real exceptions were the larvae of Hydropsyche angustipennis and Rhyacophila dorsalis. These were found to be exceedingly tolerant of ammonia and it was difficult to believe that this factor would be important in limiting the distribution of these two species.

One of the most obvious conclusions that can be drawn from the experimental work is that species associated with polluted conditions are more tolerant than clean water species of a variety of conditions (fig. 77) e.g. Chironomus riparius and Asellus aquaticus were far more tolerant of deoxygenation, ammonia, orthophosphates and carbon dioxide than Gammarus pulex and Ecdyonurus dispar. Another fact that emerged was that the combined effects of the factors are more severe, and their lethal effects are increased with a rise in temperature, Gammarus was found to be more sensitive to carbon dioxide at 18°C than at 10°C and at 2 p.p.m. dissolved oxygen than at 10 p.p.m.

If the field results are considered in the light of the experimental work, the reasons why certain species can be associated

Fig.77. Table showing degrees of tolerance of benthic invertebrates to different water quality parameters in relation to their observed tolerance to organic pollution.

Increasing tolerance ↓

Oxygen depletion	Ammonia	Carbon dioxide	Orthophosphates	Field observations Organic pollution
Rhyacophila dorsalis	Gammarus pulex Ecdyonurus dispar	Ecdyonurus dispar	Gammarus pulex Ecdyonurus dispar	Ecdyonurus dispar Rhyacophila dorsalis
Ecdyonurus dispar Gammarus pulex	Erpobdella octoculata	Rhyacophila dorsalis	Rhyacophila dorsalis	Hydropsyche angustipennis
Brillia longifurca	Helobdella stagnalis Erpobdella testacea Asellus aquaticus	Gammarus pulex	Asellus aquqticus	Gammarus pulex
Hydropsyche angustipennis	Brillia longifurca Prodiamesa olivacea	Hydropsyche angustipennis	Hydropsyche angustipennis Erpobdella octoculata Erpobdella testacea Helobdella stagnalis	Erpobdella octoculata Asellus aquaticus
Prodiamesa olivacea	Chironomus riparius	Asellus aquaticus Helobdella stagnalis Erpobdella octoculata Erpobdella testacea		Erpobdella testacea Helobdella stagnalis Prodiamesa olivacea Brillia longifurca
Asellus aquaticus	Rhyacophila dorsalis			Chironomus riparius
Helobdella stagnalis	Hydropsyche angustipennis			
Erpobdella octoculata				
Erpobdella testacea				
Chironomus riparius				

} denotes similar tolerance

with varying degrees of organic enrichment becomes more obvious. In the River Cole the most severely polluted stretch was found at Stations 2 and 3, the chemical data revealed that the river at these stations especially during the summer months became badly deoxygenated and contained high concentrations of ammonia, orthophosphates and carbon dioxide. At these stations only Chironomus riparius of the experimental animals was common. The experimental results showed this species to be exceedingly tolerant of both low oxygen concentrations and ammonia and this is probably the reason why it was able to survive at these localities where it had a copious supply of food. The larvae of Brillia longifurca and Prodiamesa olivacea were found to be less tolerant of low oxygen concentrations than Chironomus riparius and this could account for the fact that they became abundant further downstream where the oxygen concentration of the water had increased. Erpobdella testacea was very tolerant of low oxygen concentrations but only moderately tolerant of ammonia. This species was never abundant in the River Cole and it is difficult to draw definite conclusions concerning its distribution, the results do suggest however that it was most abundant at Station 4, where there was usually less ammonia present than at Stations 2 and 3. The other two leeches used in the experiments namely Erpobdella octoculata and Helobdella stagnalis were most abundant at Station 5. It is known that they are less tolerant of both ammonia and deoxygenation than Erpobdella testacea and this could explain why they are more abundant further downstream where there was an improvement in these conditions. Asellus aquaticus was also common at this station and this would be expected from the experimental results which showed this species to have a similar tolerance of low oxygen, carbon dioxide and ammonia as the leeches. At Station 6 the gradual improvement in water quality allowed Gammarus pulex to survive, it did not however form large populations. From the experiments it would have been supposed that Hydropsyche would have been able to survive at Station 6, for it proved to be more tolerant of low oxygen, ammonia, carbon dioxide and orthophosphates than G. pulex. It is probable that other reasons must account for its absence and possibly the slime growths that occurred on the stones may have had an inhibiting affect. The chemical results for Station 1 suggested that the river was receiving some organic enrichment but was nevertheless of quite good quality, at this station Hydropsyche angustipennis and Gammarus pulex were abundant. In the case of Hydropsyche this would be expected from the results of the experimental work. Dowles Brook was a stream of exceptionally good quality, with well oxygenated water and very little ammonia, orthophosphates and carbon dioxide present. In this stream Rhyacophila dorsalis, Gammarus pulex and Ecdyonurus dispar were common. These three species are sensitive to deoxygenation, carbon dioxide and orthophosphates while G. pulex and E. dispar nymphs were also the most sensitive of the experimental animals to ammonia. Thus it would be expected that they would be absent from localities where these factors are prevalent and this could explain their limited distribution in this study.

Although the changes in the benthic community are almost certainly the result of all the chemical and physical criteria acting together it would appear that in the River Cole deoxygenation could be the most important single factor. In the summer months a considerable stretch of the river below the effluent outfall became severely deoxygenated and these low oxygen concentrations would themselves suppress the fauna. At both Stations 2 and 3 as a result of the monthly samples and 24 hour investigation it would seem that for long periods less than 1 p.p.m. dissolved oxygen was present in the water. Such continuous low oxygen concentrations would almost certainly prove inhospitable to even Chironomus riparius and Erpobdella testacea, the most tolerant of the experimental animals of low oxygen concentrations. Both species were not able to survive anaerobic conditions for more than a couple of days at 20°C. If the oxygen concentration of the water was less than 1 p.p.m. that of the mud at these two stations would almost certainly be considerably less. This factor by itself could account for the fact that no macro-invertebrates formed large populations at these stations during the summer months. At Station 4, Chironomus riparius was abundant during the summer and this could be accounted for by the improvement in the dissolved oxygen concentration of the water. In addition to C. riparius other chironomid larvae such as Prodiamesa olivacea, Brillia longifurca and Trichocladius rufiventris were common. The dissolved oxygen concentration was still severely depleted but it was found that because of the presence of algae there were considerable diel fluctuations in the concentration present in the water. During the night deoxygenation was particularly severe but during the day the water was quite well oxygenated so it would appear that chironomid larvae can survive low dissolved oxygen tension for a number of hours but not continuoue low oxygen tensions as prevailed at Stations 2 and 3.

At Station 5, Erpobdella octoculata, Helobdella stagnalis and Asellus aquaticus were common, the dissolved oxygen concentrations at this station also showed considerable diel fluctuations, and in fact deoxygenation was more severe than at Station 4. The monthly samples however revealed that the oxygen content of the water was usually higher than at Station 4 and the reversal found during the 24 hour survey may well have been due to the fact that it was taken during a dry spell when the flow was very low. At this time water was channelled from the River Cole into a neighbouring stream leaving a very reduced flow. The low oxygen concentration could have been caused by the respiratory activities of the benthic organisms, which were particularly abundant at Station 5, using up the oxygen in the small volume of water. Edwards (1963) stated that the benthic processes can be responsible for more than 50% of oxygen consumption of a river, so it is indeed possible that the deoxygenation noticed at Station 5 could be due to this. At Station 6 there was a considerable improvement in the oxygen content of the water and at this station Gammarus pulex was usually present in the samples although it was never abundant. The reason why this species was not abundant at Station 6 or even Station 5 would be difficult to explain if only the results from the monthly samples were studied. The laboratory work showed that Gammarus pulex should be able to survive as long as the oxygen concentration was over 3 p.p.m. at 20°C. The lowest recorded monthly figure for Station 5 was 3.8 p.p.m. while for Station 6 it was 4.2 p.p.m. If the diel fluctuations are taken into consideration however it was found that at Station 5 for a period of nearly 10 hours the dissolved oxygen concentration was below 1 p.p.m., the laboratory work revealed all the experimental animals of this species would die within 7 hours at an oxygen concentration of 1 p.p.m. at 20°C. Although deoxygenation was not as severe at Station 6, the oxygen concentration was nevertheless less than 2.5 p.p.m. for 10 hours and less than 2 p.p.m. for 4 hours. These concentrations would have detrimental effects on Gammarus for even under laboratory conditions this species would not survive 24 hrs at an oxygen concentration of 1.5 p.p.m.

At Station 1 the lowest oxygen concentration recorded was 5.2 p.p.m. and this was considerably higher than the lowest figure that Gammarus pulex and Hydropsyche angustipennis would be expected to survive at from the laboratory experiments.

It would seem that in the case of the River Cole the severe deoxygenation that existed during the summer could account for the distribution of the invertebrates experimented upon. The other changes produced in the water would increase the lethal effects of the low oxygen concentrations, for it was found that carbon dioxide, ammonia and orthophosphates were usually present in quite high concentrations. The highest concentration of carbon dioxide recorded at Station 2 was over 20 p.p.m., while for ammonia it was 36.5 p.p.m. (undissociated concentration 0.26 p.p.m.) and for orthophosphates 5.5 p.p.m., The concentrations of these substances usually decreased downstream. It is known from the laboratory experiments that both temperature and low dissolved oxygen concentrations increase the toxicity of ammonia to leeches and Asellus. Erpobdella octoculata and Helobdella stagnalis died at an undissociated ammonia concentration of 0.65 p.p.m. at 1 p.p.m. dissolved oxygen, it is probable that at 20°C the corresponding ammonia concentration would be considerably lower and thus not very much higher than the highest concentration found at Station 2. The highest recorded figure at Station 4 which was the station immediately upstream of where the above species became abundant was .06 p.p.m. (undissociated ammonia), it is possible that even a figure as low as this could exert an influence on these species.

Because of the remarkable tolerance of the leeches to carbon dioxide and orthophosphates in the laboratory it is doubtful whether the concentrations recorded in the River Cole would seriously affect them. Asellus aquaticus however although tolerant of carbon dioxide was killed in the experiments by a concentration of 50 p.p.m. orthophosphates. The highest concentration recorded at Station 4 was 3.5 p.p.m., but this in conjunction with the undissociated ammonia, low oxygen concentration and high temperature could make this stretch of the river unsuitable for A. aquaticus.

Erpobdella testacea from the laboratory investigation would be expected to survive in all but the most severely polluted localities. The reason why it was not found at Stations 3-5 during the summer months can almost certainly be attributed to its life history. According to Mann (1964) this species has a life history lasting 12 months and it is in the egg stage during the summer months.

The River Salwarpe before the new works opened had a similar faunal succession to that found in the River Cole, with tubificids and Chironomus riparius present below the effluent outfall while further downstream Asellus aquaticus and leeches were common. In this river deoxygenation was also severe, even in April the dissolved oxygen concentration at Station 1 was only 4 p.p.m., while the undissociated ammonia concentration was nearly 0.2 p.p.m. At Station 2 there was a slight improvement in these two criteria and this possibly allowed the establishment of Asellus aquaticus and the leeches. Thus it would seem that as in the River Cole it could be the combined effects of these two criteria that are most important in limiting the fauna at Station 1. Chironomus riparius was remarkably tolerant of both and this is almost certainly the reason why it alone of the species used in the experiments was common there. It was noticeable from the chemical results that of the chemical analyses carried out on the monthly samples the only criteria that showed a real improvement after the opening of the new works was the oxygen and ammonia concentrations. The changes in the benthic community would then appear to be related to the improvement in these factors, and so it would seem that it was indeed the concentrations of these two substances which had previously restricted the fauna.

Similar chemical conditions of low oxygen and high ammonia concentrations were also found at Walton on the River Trent. The fauna was again dominated by Chironomus riparius, Asellus aquaticus and leeches. With an improvement in the oxygen concentrations it would be expected from the experimental work and previous work (Fox and Taylor 1955) that the numbers of Chironomus riparius would decrease while the numbers of leeches and Asellus aquaticus would increase. Such conditions prevailed at Wem Brook and the River Ray at Swindon, and in both streams the benthic community was rich in Asellus and leeches.

The fact that invertebrates such as Chironomus riparius are generally more tolerant of factors associated with organic enrichment than clean water forms became obvious from the investigation of Merry Hill Brook. Although the oxygen concentration was not severely depleted or the ammonia concentration very high the benthic community at Station 1 was dominated by Chironomus riparius and oligochaete worms. The water at Station 1 usually contained exceptionally high concentrations of orthophosphates and oxidised nitrogen and it is probable that these are limiting factors in this particular stream, Chironomus riparius obviously being very tolerant of them while other species less so. At Station 2 the concentrations of both were usually less, and this locality had a number of species associated with a recovery zone e.g. Asellus aquaticus.

It seems that even slight organic enrichment can restrict the benthic community, and allow only the more tolerant clean water forms to become established, such conditions were found at Harlaston and St. Thomas' Mill. It is difficult to ascertain why the fauna should have been restricted at these two places because the water was well oxygenated and only traces of ammonia and carbon dioxide were present. It would seem that besides the more obvious factors associated with polluted waters there are others present which play their part in influencing the distribution of invertebrates. One of these factors is the change in the nature of the stream-bed, this can obviously be very important where there is a lot of organic matter being deposited. These deposits would limit clinging forms such as certain plecopteran and ephemeropteran nymphs and at the same time provide suitable conditions for burrowing forms such as tubificids and chironomids. Thus the presence of these burrowing forms can be associated with this deposition of organic matter which provides them with ample food. The fact that they are very tolerant forms then enables them to survive the other factors associated with polluted waters.

The investigation verifies the sensitivity of aquatic invertebrates to organic enrichment and has shown that waters experiencing a certain degree of enrichment are likely to have a particular benthic community. The reason why certain animals are associated with severely polluted conditions while others with clean water conditions is that the septic zone fauna are more tolerant of a wide range of factors than the clean water fauna. It was found that the changes induced in the stream water by the entry of an effluent could vary, and so it is not any single factor that is responsible for these changes. Factors which the present study showed could be important are oxygen depletion, ammonia, carbon dioxide and orthophosphates, together with physical changes in the nature of the stream bed.

6. Notes on the Biology of some Common Benthic Invertebrates in relation to their use as Indicators of Pollution

6.1 The Distribution of Chironomid Larvae in the Riffles of Organically Polluted Streams in the Midlands

As a group the larvae of the Chironomidae have been very much ignored in the United Kingdom. The reason why very little is known about their ecology is the extreme difficulty in identifying the larvae, there are no adequate keys to the larval stages and to ensure identification they must be reared to the adult stage, and even then it is very difficult to identify to species. The fact that as a group they form important members of the riffle community in organically polluted streams has been observed by a number of workers including Butcher (1946) and Hawkes (1956). In the past most workers have distinguished between red species and non-red species. The common red species occurring in organically polluted waters in this country is *Chironomus riparius* (*thummi*) and it has been the non-red species that have caused the problems in identification. One of the aims of the present investigation was to try to identify these chironomid species and to determine whether or not they could be suitable as indicators of varying degrees of organic pollution.

The results from the River Cole form the basis of this study and they show quite clearly that different species occur in stations characterised by varying degrees of organic enrichment. It was found that the larvae of eleven species of chironomidae were common in the River Cole (of which ten were identified) and another four species occasionally occurred.

Eleven of the common species were as follows:-

1. *Chironomus riparius* Meigen
2. *Brillia longifurca* Kieffer
3. *Eukiefferiella hospitus* Edwards
4. *Trichocladius rufiventris* Meigen
5. *Cricotopus bicinctus* Meigen
6. *Cricotopus sylvestris* Fabricius

7. *Prodiamesa olivacea* Meigen
8. *Pentaneura melanops* Meigen
9. *Polypedilum arundineti* Goetghebuer
10. *Micropsectia atrofascidius* Kieffer
11. *Brillia modesta* Meigen

1. *Chironomus riparius* (*thummi*) (fig. 78)

This species has long been recognised as being an indicator of gross organic pollution in this country, the continent of Europe (Kolkwitz and Marsson, 1908) and North America.

In the River Cole this species was most numerous in the badly polluted stations (figs. 34 & 35). It was absent entirely from Station 1 and Dowles Brook, rare in Stations 5 and 6, and abundant at Stations 2, 3 and 4. The seasonal incidence at Stations 2, 3 and 4 was interesting. At Stations 2 and 3 it was nearly always the dominant chironomid larvae but it does appear however that the conditions became so bad at these stations during the summer that the summer populations were suppressed (fig. 21). At Station 4 the exact reverse happened, from November to June it never formed large populations but from June to October it was sometimes present in enormous numbers. This is almost certainly due to the fact that it was only during the summer months that conditions suited its requirements.

This species was also present in a number of other sampling stations, namely Merry Hill Brook, River Salwarpe (before the opening of the new works) and the River Trent at Walton. All these stations were very severely organically polluted and it does seem that in order for the larvae to thrive such conditions are necessary.

The seasonal incidence at these stations suggests that although the larvae may be abundant for most of the year the numbers do decline in the late spring (April and May). This is probably due to the emergence of the larvae that had overwintered and that the eggs laid by this generation had not hatched.

Fig.78 Ventral view of head of Chironomus riparius.

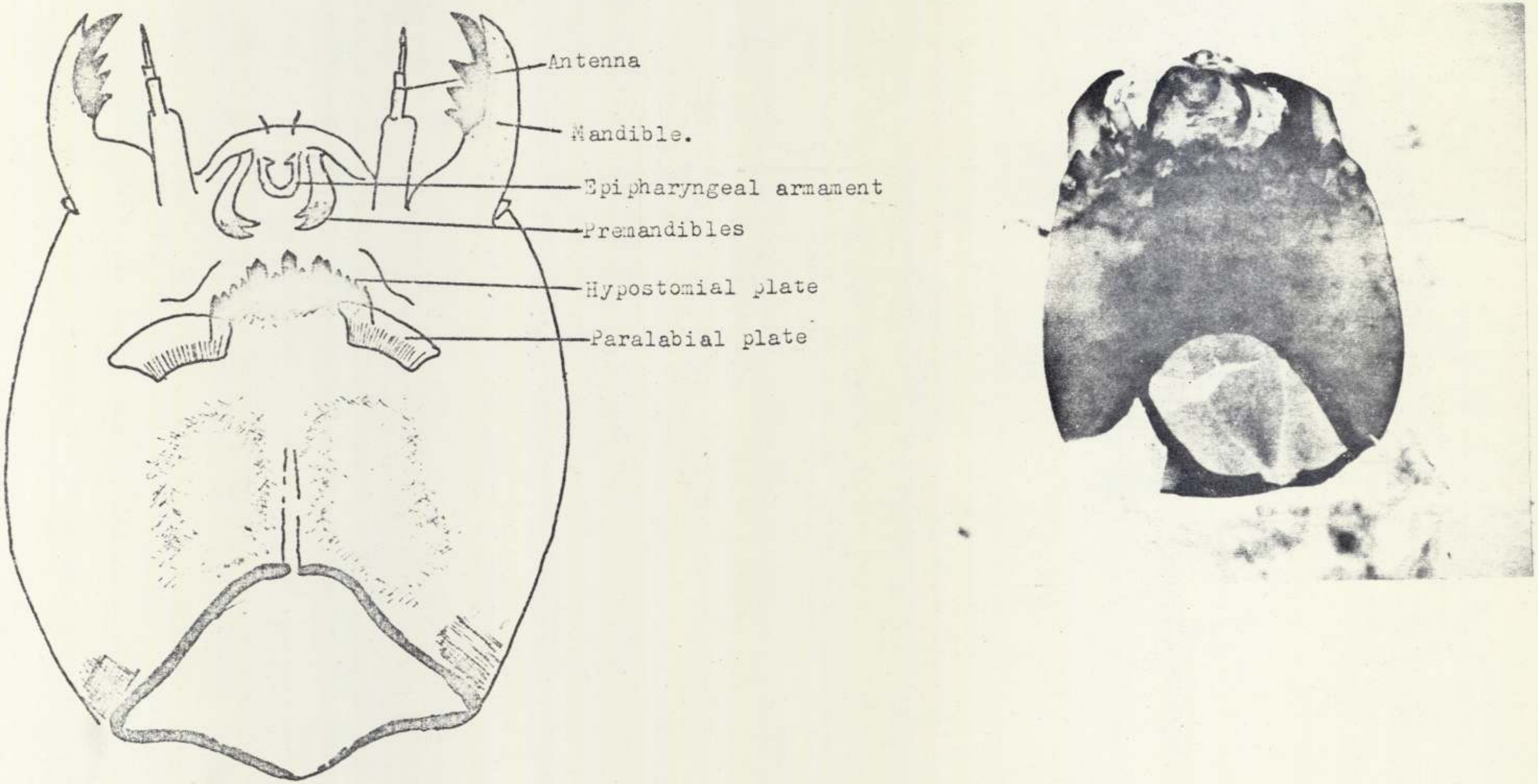


Fig.79 Ventral view of head of *Brillia longifurca*.

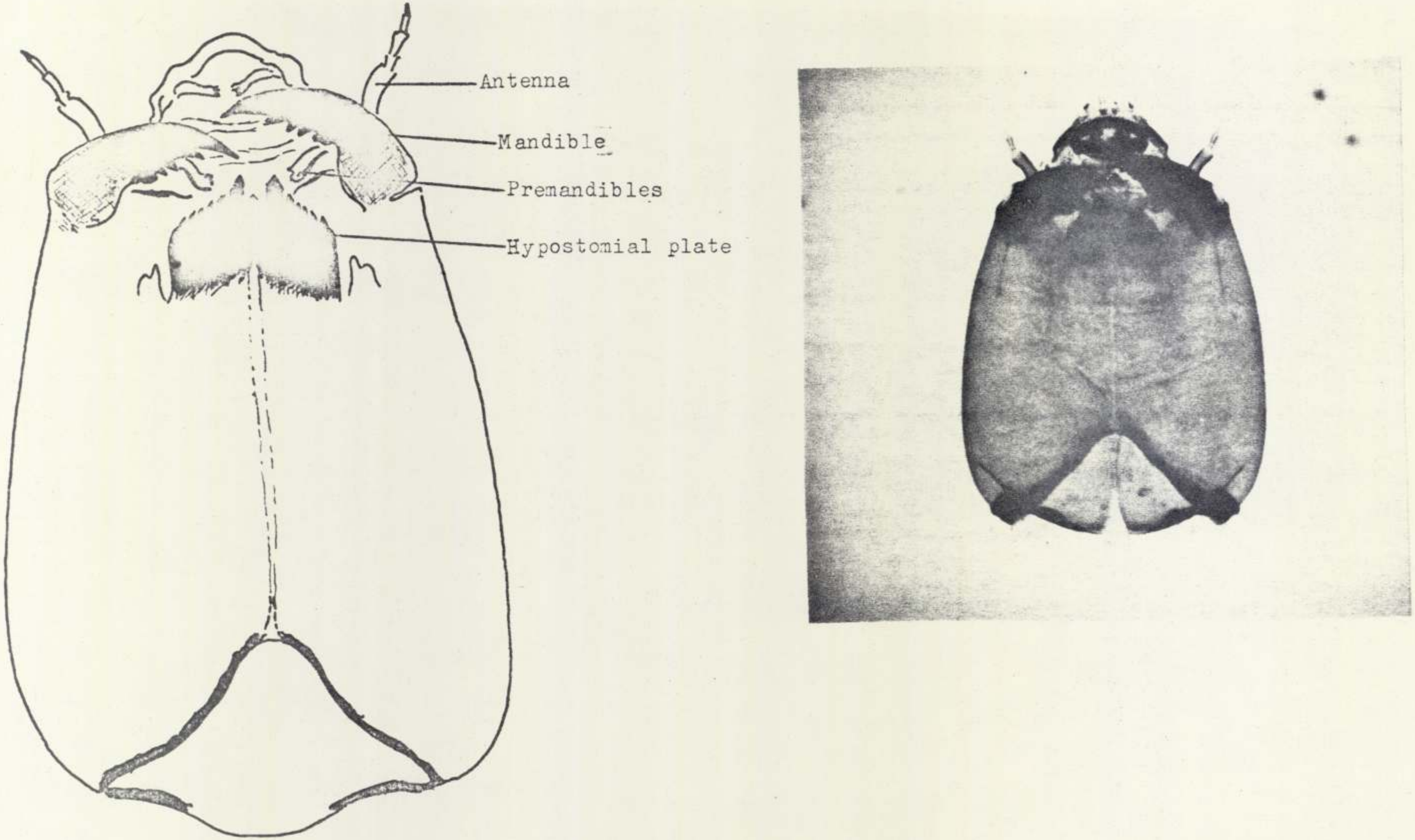
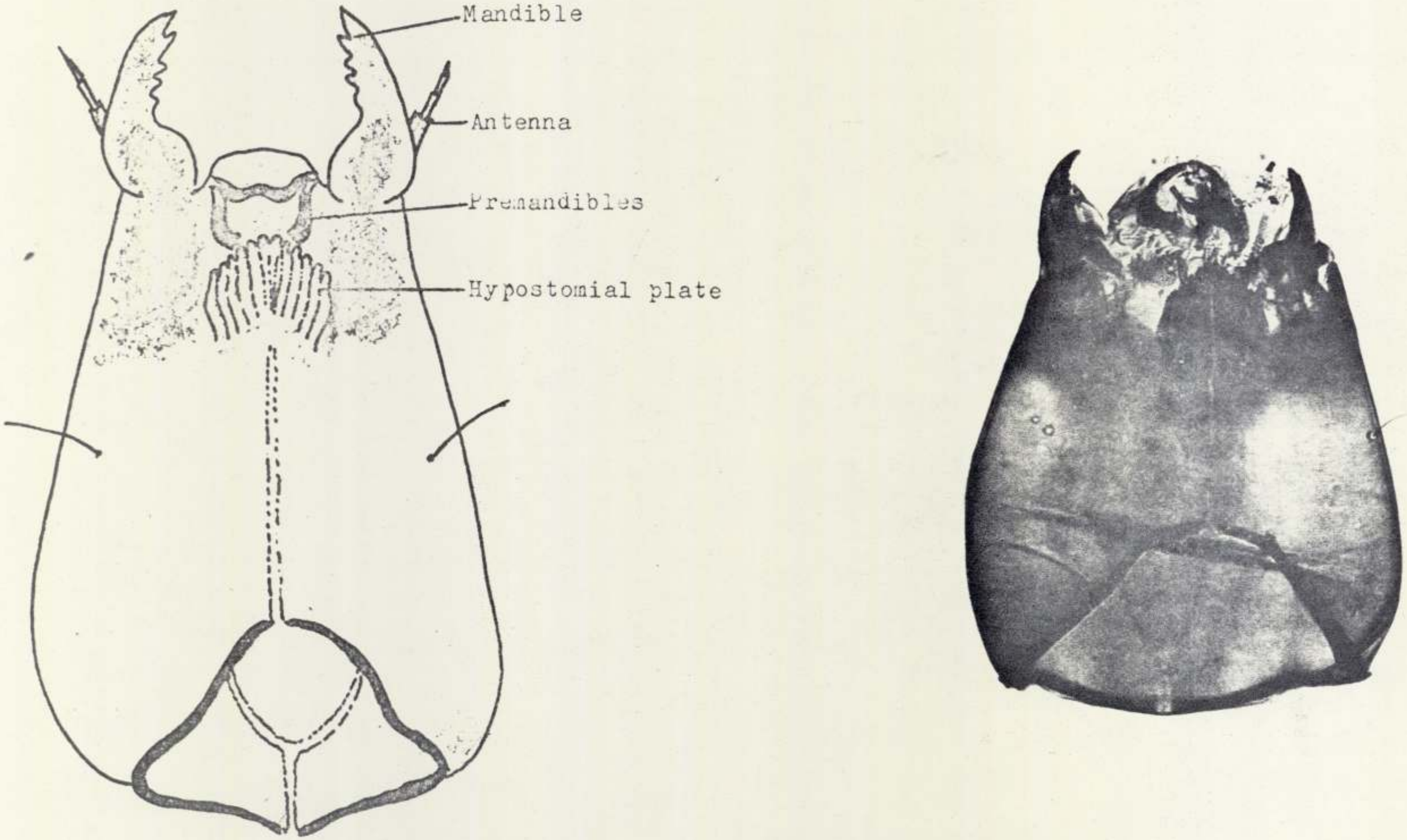


Fig.80 Ventral view of head of <u>Eukiefferiella hospitus</u>.



2. Brillia longifurca (fig. 79)

Brillia longifurca proved to be a very good indicator of moderately polluted conditions. In the River Cole (figs. 34 & 37) it was recorded at all stations but was abundant only at Stations 3-6, reaching its peak at Station 5. This species was also abundant at both stations on the River Salwarpe, Station 2 on Merry Hill Brook, Bob's Brook and was also recorded at Wem Brook and Walton on the River Trent. The larvae of this species does not seem to be as tolerant as that of Chironomus riparius, although they were frequently found together. This fact would explain its absence from Cole 2 and Merry Hill Station 1 during the summer. Although it proved to be a good indicator of moderately polluted conditions in the Midlands it does not seem to be mentioned as such by Continental workers although it is present there.

The larvae of this species at all the stations it was present, had a discontinuous incidence (fig. 23). Large populations were frequently present from November to March but for the rest of the year it was either rare or absent altogether. From the present study it would appear that the larvae of this species seemed to prefer moderately polluted conditions being virtually absent from the badly polluted zones and also from the clean water conditions that existed at Dowles Brook and Cole 1.

3. Eukiefferiella hospitus (fig. 80)

This species was also generally distributed in the Midlands and as with the larvae of Brillia longifurca it seemed to be a good indicator of moderately polluted conditions, being absent when the conditions were either very bad or good. In the River Cole (figs. 34 & 36) it was present above the effluent, at Station 2 there was a marked reduction in the numbers which then recovered at Station 3. At Stations 4, 5 and 6 it was abundant reaching a peak at Station 5.

If the seasonal incidence is considered (fig. 25) it shows that the numbers of the larvae of this species is are more evenly distributed throughout the year than that of *Brillia longifurca* and it is possible to recognise three population peaks. One peak occurs in February or March, another in mid-summer and the third in October or November.

This species was recorded from all the other polluted stations investigated and was one of the most abundant species in the River Salwarpe, Merry Hill Brook Stations 1 and 2 and Bob's Brook.

This species is also found on the Continent and has been described by Chernovskii (1961) as being found in streams and the littoral zones of lakes. No mention can be found of its association with organically polluted waters. Coe, Freeman and Mattingley (1950) describe the adult as being common and generally distributed in this country and it would be supposed that the larvae could prove to be a good indicator of polluted conditions in this country.

4. *Trichocladius rufiventris* (fig. 81)

The larvae of this species had a similar distribution to the two previous species in the River Cole (figs. 34 & 36) and like them was abundant in moderately polluted conditions. The larvae were not recorded at Dowles Brook but were present in Cole 1, the numbers then decreasing at Station 2 to be followed by progressive increases in numbers at Stations 3, 4 and 5. The larvae were also abundant in the River Salwarpe after the improvement in river conditions, Merry Hill Brook and at Wom Brook.

If the seasonal incidence is considered (fig. 22) it will be seen that the larvae are most abundant from January to March with smaller peaks occurring in mid-summer and autumn. This was one of the species that recolonised Stations 2 and 3 in the River Cole during the winter months. The summer populations however were suppressed probably because of the very severe conditions. The

Fig.81 Ventral view of head of *Trichocladius rufiventris*.

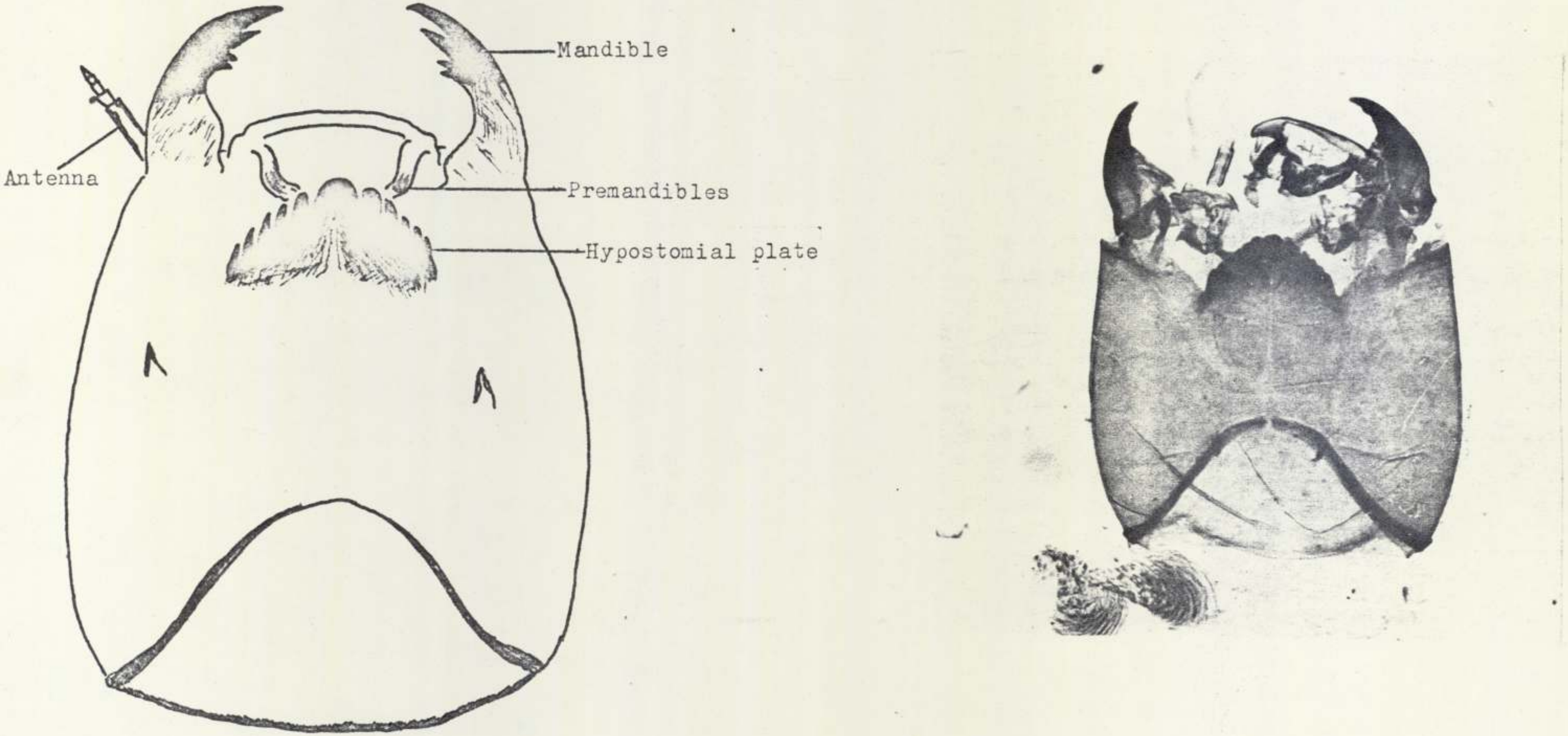


Fig.82 Ventral view of head of *Cricotopus bicinctus*.

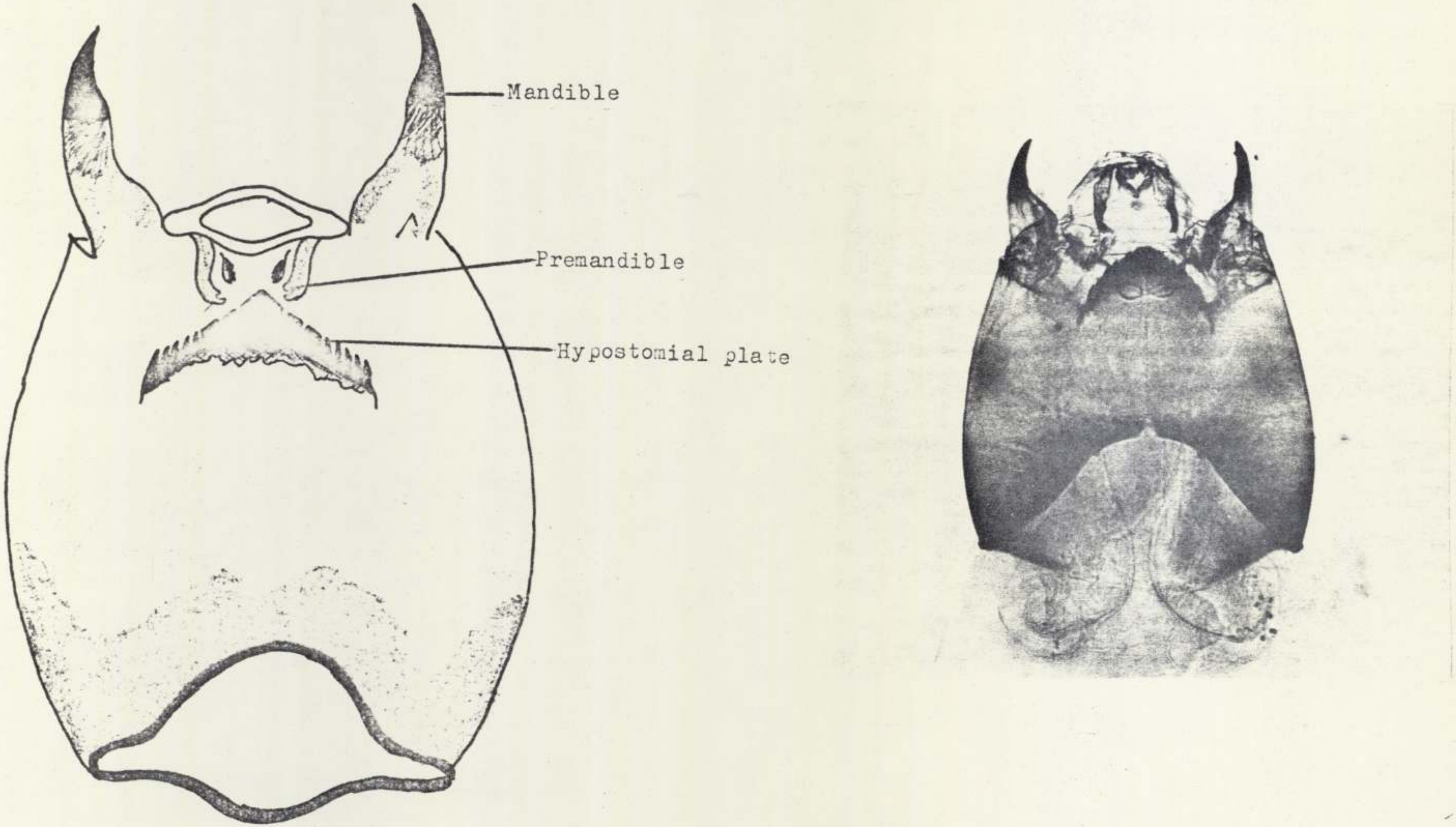
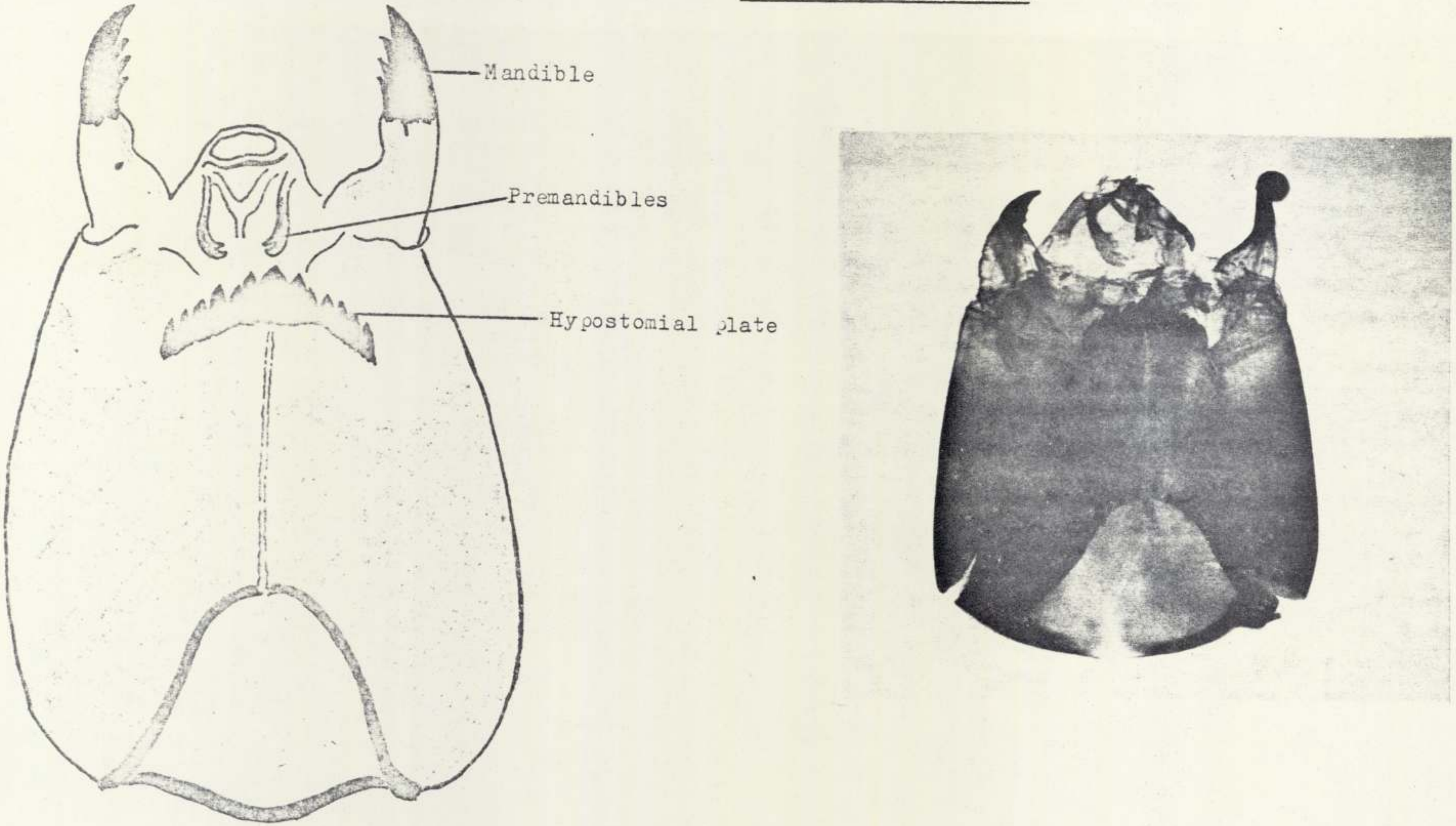


Fig.83.Ventral view of head of Cricotopus sylvestris.



adults of this species according to Coe et al (1950) are common and generally distributed and it would be thought that the larvae of this species could also prove to be a useful indicator of pollution.

5. Cricotopus bicinctus (fig. 82)

The larvae of this species was the most abundant type in the River Cole during the summer months in the recovery stages of the river in what could be termed the 'Asellus zone'. The larvae were recorded at all stations on the River Cole (figs. 27 & 34) but only became really abundant at Stations 4, 5 and 6. At Station 5 in particular very large populations were present in the summer months and in July over 2,700 individuals were recorded from 0.1 of a square metre of stream bed. The larvae of Cricotopus bicinctus were also the most abundant type during the summer months at both stations on the River Salwarpe. It was also common at Merry Hill Brook and Wem and was also recorded at Bob's Brook and the Trent at Walton.

The seasonal incidence (figs. 27 & 35) at the various sampling stations reveals that although it may be present in enormous numbers during the summer months it was rare from October to March. It is also obvious that Cricotopus bicinctus larvae are very tolerant of organic pollution and they would be expected to appear towards the end of the Chironomus riparius zone.

This is another common British species and is also found in North America and the Continent of Europe. According to Roback (1957) the larvae is widely distributed in the U.S.A. and was very common in the Philadelphia area. That it is a very tolerant species is obvious because according to Surber (1959) it was the only invertebrate other than oligochaete worms to be found downstream of an effluent from an electro plating works which produced conditions of high copper, chromium and cyanide.

It would appear that this is another species that can be associated with gross to moderately polluted conditions in the British Isles.

6. Cricotopus sylvestris (fig. 83)

In both distribution and seasonal incidence the larvae of this species closely paralleled the previous species. In the River Cole (figs. 33 & 34) this species also reached a sharp peak in its distribution at Station 5 and the larvae were most abundant between June and September being rare or absent from October to May. These larvae also proved to be widely distributed in the Midlands during the summer months and were one of the most abundant types at Merry Hill, River Salwarpe, Bob's Brook, Wem Brook and Walton on the River Trent.

The seasonal incidence at these localities was very similar to that observed at the River Cole. The fact that it was present at River Cole 4, Merry Hill Brook Station 1 and Walton shows that the larvae of this species is very tolerant and that it is likely to be one of the first chironomid species to appear in a polluted river after Chironomus riparius.

This is also a generally distributed species in this country, the U.S.A. and the European Continent where its association with polluted conditions has been observed by Thienemann (1954). Thienemann also states that these larvae can be found towards the end of the Chironomus riparius zone, which is borne out by this investigation.

7. Prodiamesa olivacea (fig. 84)

The larvae of Prodiamesa olivacea were also a common type in the River Cole, and if its distribution is studied (figs. 34 & 37) it can be seen that it was confined to the polluted regions. The larvae were most abundant at Stations 4 and 6 the paucity of these larvae at Station 5 can probably be accounted for by the unsuitability of the stream bed. Both Roback (1957) and Maitland (1964) say that the larvae of Prodiamesa olivacea prefer soft muds and it was a fact that

Fig84.Ventral view of head of *Prodiamesa olivacea*.

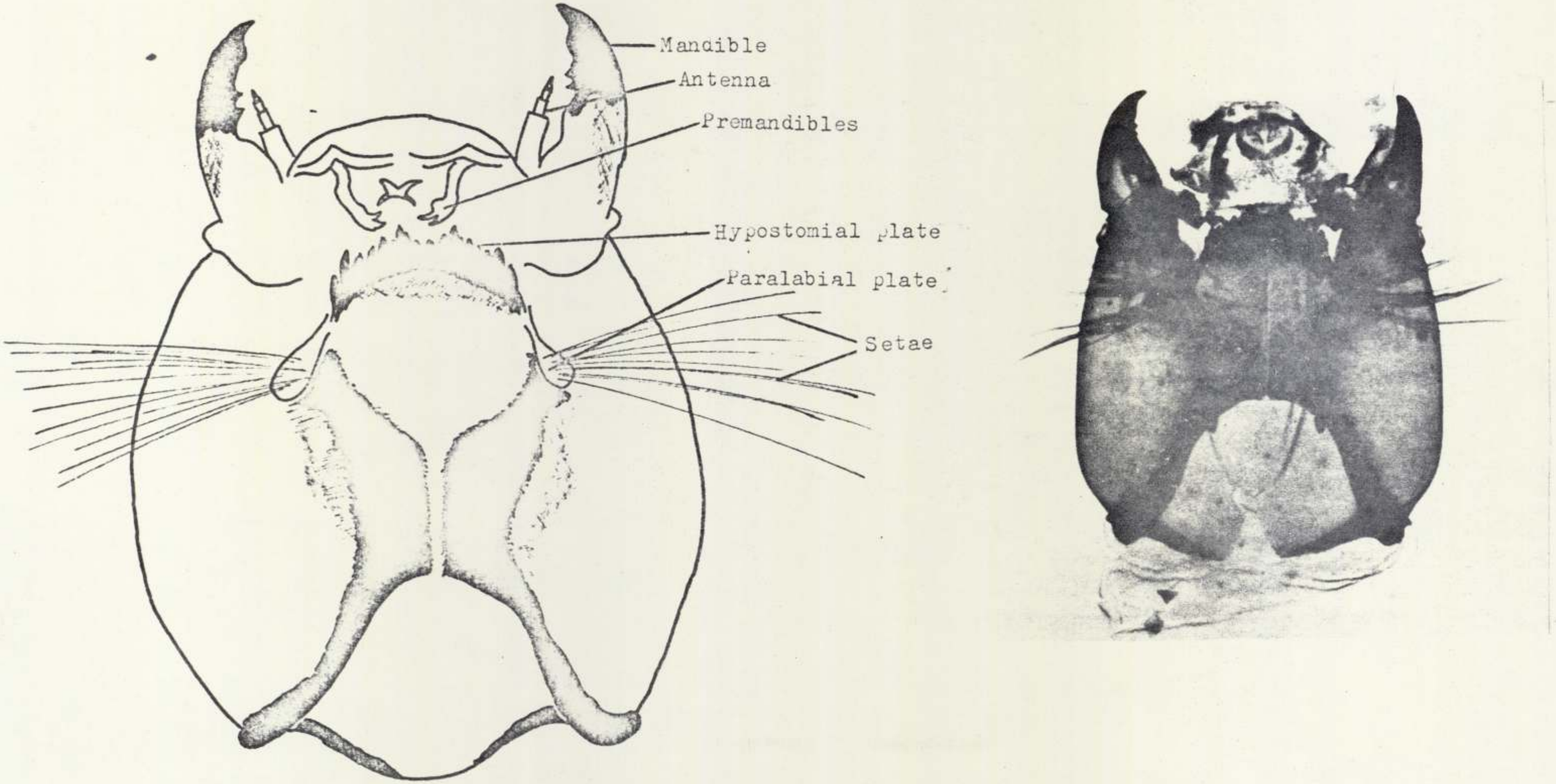


Fig.86 Ventral view of head of *Polypedilum arundineti*.

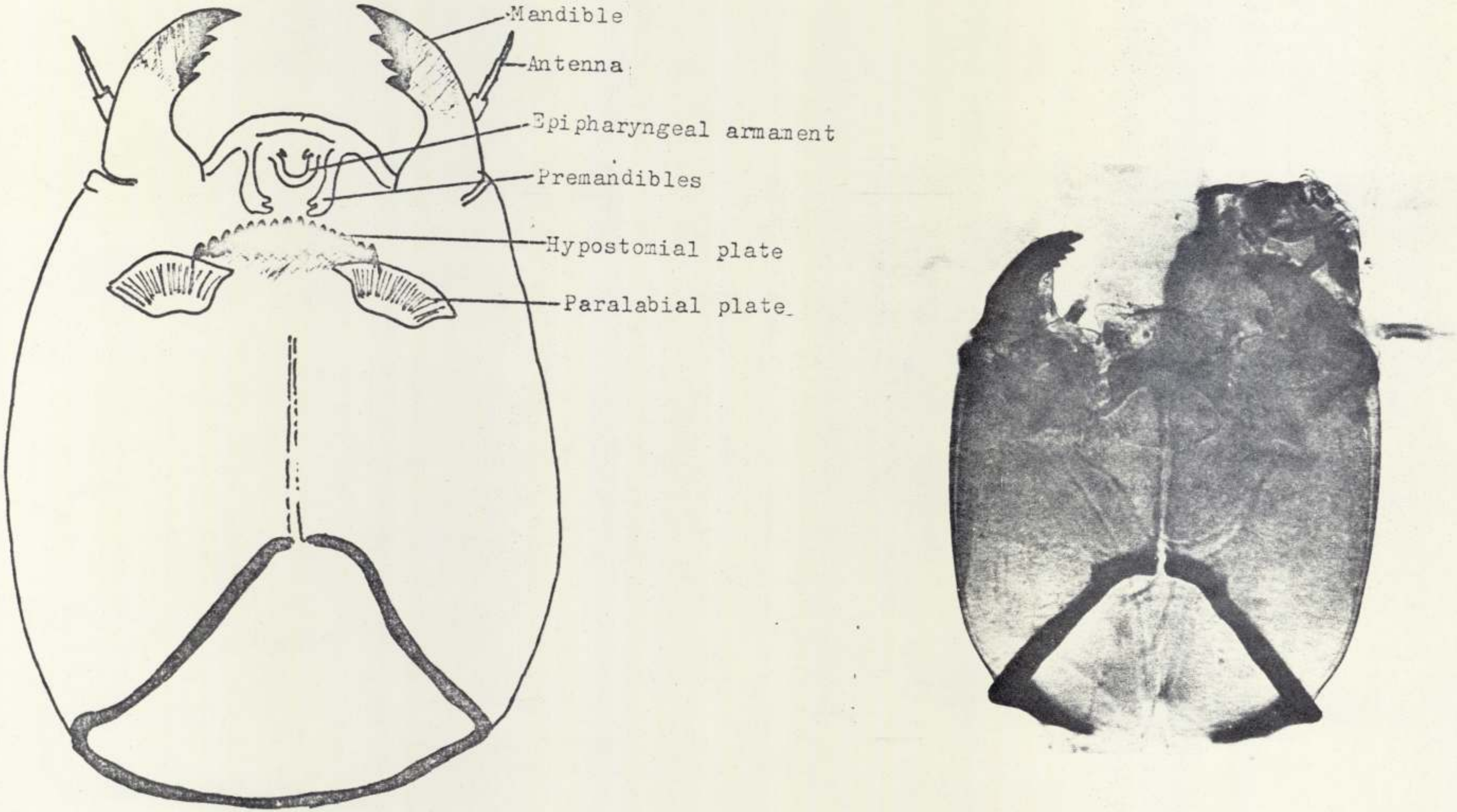
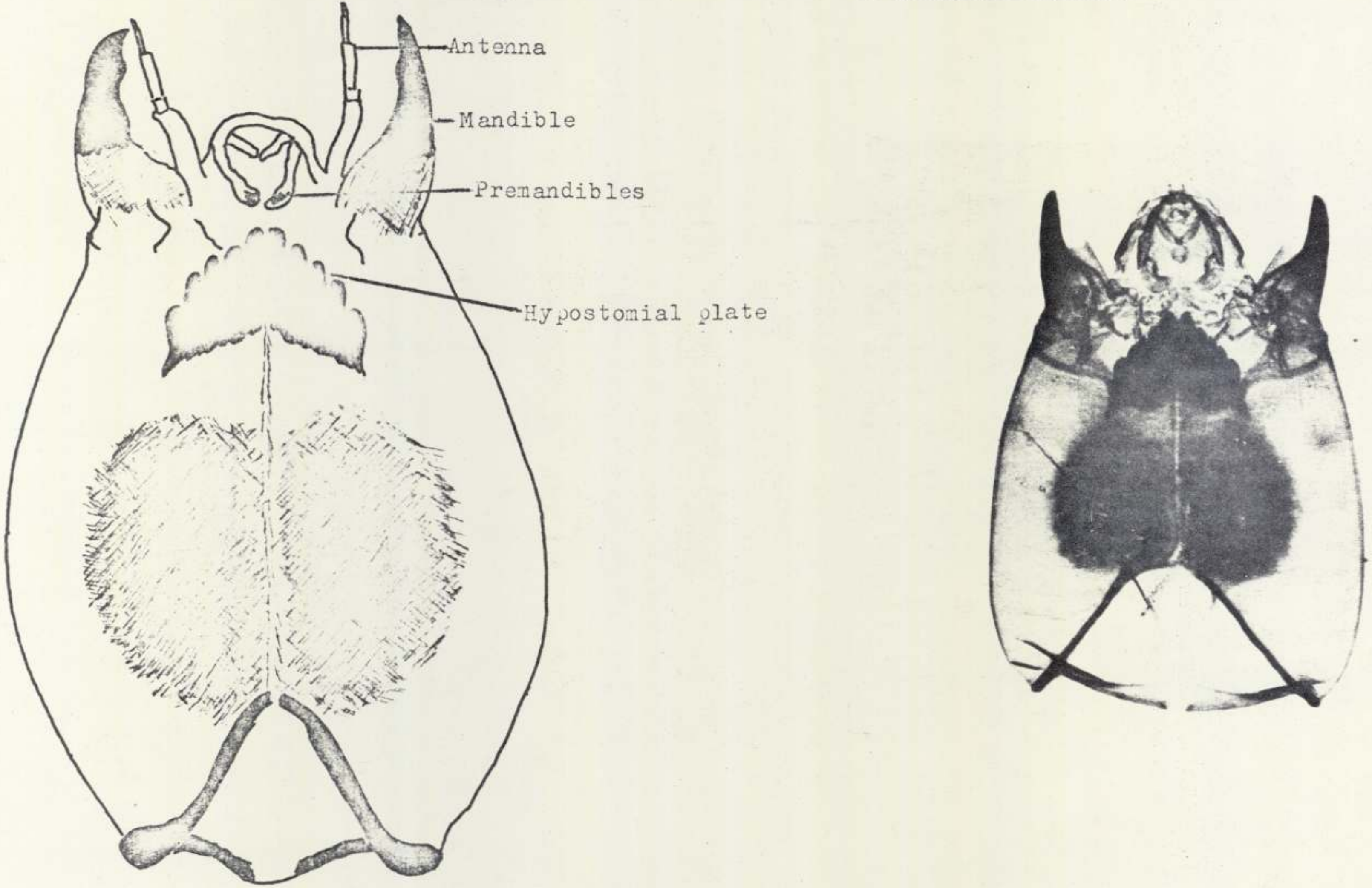


Fig.87 Ventral view of head of *Brillia modesta*.



the substrate at Station 5 tended to be rather sandy, and this could then account for its rareness. Although the larvae of this species were recorded from all the other sampling stations it was never as abundant as in the River Cole.

The seasonal incidence (fig. 24) makes it a good pollutional indicator as the larvae can be present throughout the year although it was most numerous in the following periods, December to March, mid-summer and the autumn.

Prodiamesa olivacea like the two species of Cricotopus seems to have a world-wide distribution and has been recorded in the U.S.A. and Russia. Thienemann (1954) also mentions these larvae as being found in polluted rivers towards the end of the Chironomus riparius zone especially if there are soft muds present; the present investigation agrees with this observation.

8. Pentaneura melanops (fig. 85)

This species is a member of the carnivorous sub-family Tanypodinae and was the only one recorded in large numbers. The larvae were recorded from all stations in the River Cole but was most abundant at Stations 4 and 5 (fig. 38). It was usually quite numerous forming an important constituent of the benthic community. Although common in the River Cole the only other sampling station where it was common was at Station 2 on the River Salwarpe. This is another species with a wide geographical distribution being found in North America and the European mainland, it is not mentioned by Thienemann (1954) as being present in polluted waters in Germany. It seems that Anatopynia (Psectrotanypus) and Procladius larvae are the common carnivorous forms in Germany. Although larvae of Anatopynia were found in the River Cole and the River Salwarpe they were never present in large numbers. The larvae of Procladius however were not recorded at the stations investigted and it may be that in Birmingham and surrounding areas their place in the benthic community is taken by the related Pentaneura melanops.

9. Polypedilum arundineti (fig. 86)

The larvae of this species is also 'blood-red' and belongs to the same sub-family as Chironomus riparius, that is the chironominae. It was not however as widely distributed as Chironomus riparius nor does it appear to be as tolerant. It was found in the River Cole at all stations from 2-6, and was most numerous at Station 3 (fig. 38) being only occasionally present at Station 2. The larvae of this species were never as numerous as many of those already described.

The only other sampling station where it formed an important constituent of the community was in Station 1 on the River Salwarpe. It appeared in the Salwarpe samples after the improvement in river conditions following the opening of the new works. As in the River Cole it was never abundant. From its occurrence it would appear to be a tolerant species slightly less so however than Chironomus riparius. Very little information is available regarding its ecology although it is known that it feeds on organic matter present in the mud.

10. Micropsectra atrofasciatus

The larvae of this species is red and is also a member of the sub-family Chironominae. Although never abundant in the samples it was usually present. Larvae of this species were obtained from all the sampling stations on the River Cole being most abundant at Station 5. It was also found at Station 2 on the River Salwarpe where again it formed a regular but small proportion of the total chironomid larvae captured. It would appear that it is a moderately tolerant species. Hynes (1962) found the larvae of this species co-existing with Chironomus riparius in the River Lee at Luton which would support this view.

11. Brillia modesta (fig. 87)

This species although not abundant was usually present in the samples. It is easily distinguished from Brillia longifurca if the ventral surface of the head is examined. There are two large black patches on the ventral surface of B. modesta which are not present in B. longifurca. Larvae of B. modesta were taken from Dowles Brook and all the stations on the River Cole (fig. 38), it was most numerous however at Station 5. Individuals were taken from both stations on the River Salwarpe after the opening of the new works. It would appear that Brillia modesta is a moderately tolerant form but again very little information is available regarding its ecology. According to Coe et al (1950) this species is common in this country and is also found in Russia and the U.S.A.

It would seem as a result of this investigation that chironomid larvae could prove to be good indicators of organic pollution in the riffle zones of rivers. This study shows quite clearly how localities which from chemical information appear to have a similar level of organic enrichment will have the same chironomid larvae in the benthic community. The present study has been confined to a relatively small area but it is hoped that these findings may prove to be widespread in the British Isles. If this is the case then their value as indicator organisms would be great because they are frequently the most numerous invertebrates present in the stream bed. In the present study if the chironomids as a group had been ignored, because of the paucity of other invertebrates it would have been difficult to assess the polluted condition of many of the sampling points. It would also have been a very artificial estimate if the presence of in many cases the most abundant single group of invertebrates had not been taken into consideration. At certain times of the year the samples seemed to be teeming with chironomid larvae. Such a case was the July sample from

Station 5 on the River Cole when over 3,000 were taken from 0.1 of a square metre of stream bed.

As with all insects however a knowledge of the seasonal incidence of the developmental stages should be desirable before they are used as pollutional indicators. This is a necessary precaution to avoid arriving at completely erroneous conclusions concerning the absence of a species from a locality. Its absence may simply be due to the fact that at that particular time of the year it is rarely found in the larval stage and not to the effect of pollution. Striking differences in the seasonal incidence have emerged from the present investigation. The larvae of species such as Eukiefferiella hospitus and Trichocladius rufiventris seem to be present to varying degrees throughout the year, while the larvae of Brillia longifurca are abundant in the early part of the year and are only occasionally found during the rest of the year. The seasonal incidence of Cricotopus sylvestris and bicinctus is in striking contrast to those already described, the larvae of these two species may be abundant during the summer months and relatively rare during the rest of the year.

6.2 Some other Aquatic Invertebrates

Gaufin and Tarzwell (1952) make the point that organisms having life histories of a year or more will be better indicators of pollution than those with short life histories, because they will indicate unfavourable conditions that occurred several months previously. It was with this view in mind that the individuals taken of some of the common species in Dowles Brook and River Cole Station 1 were measured.

The seasonal incidence and size distribution of Gammarus pulex taken from Dowles Brook and River Cole Station 1 is illustrated in figs. 16 and 18. It can be seen that the seasonal distribution is very similar in the two localities. Individuals were present throughout the year, but they were not particularly numerous from January to June, for the next three months they were abundant. After September the numbers once again fell. Hynes (1955) investigated the reproductive cycle of _Gammarus pulex_ and his findings would explain the paucity in these early months of the year. _Gammarus_ ceases breeding usually in November and for the next couple of months the population is composed of overwintering forms with no young specimens being produced to replace deaths. Thus the paucity of _G. pulex_ in the winter and spring at a locality could be due to natural fluctuations in the population and not to the effects of the environment. Mesh size of the sampling net is also important in estimating the condition of a locality, too large a mesh size can lead to wrong conclusions a point which is stressed by Jonasson (1955). The May sample from the River Cole illustrates this point, although _Gammarus_ was not abundant in this sample, half of the individuals were less than 4 mms in length, and these would possibly have escaped if a net with a coarse mesh had been used. Thus a totally wrong impression of its abundance would have ensued which could have resulted in an incorrect assessment of the degree of organic enrichment found at that locality.

The measurements of the nymphs of _Baetis rhodani_ from Dowles Brook and the River Cole are shown in figures 12 and 20. The nymphs of _Baetis rhodani_ were present in all samples from both stations. There are differences between the two sets of results with regards the peaks in population, but they are similar in showing that the nymphs of this species may be particularly abundant from April to September and comparatively rare from October to March. Thus a knowledge of the breeding cycle is once again very important if this particular species is to be used as a pollutional indicator. Thus as in the case of _Gammarus pulex_ few individuals present during the winter months is natural. The results for this species also underlines how a coarse mesh could give a wrong impression regarding the abundance of this species. The September sample from Dowles Brook contained 136 individuals however nearly 90 of which were 3 mms or less in length and these could have been missed if the mesh size was too large or in a cursory examination of the benthic community. The results also reveal that in July and August only small nymphs were present and this has also been observed by Pleskot (1958).

The River Cole and Dowles Brook differed in the species of Hydropsyche present. At Dowles Brook, Hydropsyche fulvipes was present while at the River Cole Station 1 it was Hydropsyche angustipennis. Why this is so is not clear but the fact that Hydropsyche angustipennis is far more abundant in the Cole than Hydropsyche fulvipes is in Dowles Brook probably stems from the fact that the former station has received slight organic enrichment. It has been observed that Hydropsyche can form large populations when there is slight organic enrichment (Hawkes (1956).

The incidence of the two species (figs. 15 & 19) varied quite markedly. Hydropsyche fulvipes was never abundant in Dowles Brook but no individuals were present in the May, July and August samples. The species then reappeared in large numbers in September but only as small individuals. Hydropsyche angustipennis similarly had a very uneven seasonal incidence, although it was present in all the monthly samples, very large numbers were present in the August and September samples. In the July sample all the larvae present in the samples were small, the majority were less than 4 mms. Thus once again a totally different impression could have resulted concerning the quality of the river at this locality, if one had sampled either in July when only the less obvious small individuals were present or August when larvae of all sizes were present in large numbers.

The nymphs of Rhithrogena semicolorata and Ephemerella ignita are usually associated with good quality waters. The seasonal incidence of the nymphs of these two species is however strikingly different. According to Macan (1961) Ephemerella ignita spends approximately 10 months in the egg, hatches in the middle of the summer and then grows rapidly to emerge in late summer. Rhithrogena on the other hand is found in the egg stage during the summer presumably because this stage is more tolerant of high temperatures. It then grows steadily through the autumn, winter and spring to emerge in early summer. The present investigation confirms Macan's observations, Ephemerella ignita (fig. 13) first appeared in the May samples, the numbers then increased in June, July and August (as did the size of the individuals) to fall in September. From October onwards it was absent.

Rhithrogena semicolorata (fig. 14) had a very different incidence. The nymphs of this species were abundant from December to May and it was also possible to recognise a gradual increase in the size of the individuals in this period. In June and July it was rare while in August although the numbers had increased only small individuals were present in the sample. For the remaining months of the year the numbers increased as did the size of the individuals.

The nymphs of both species have then very different seasonal incidences and it is again very important that before attributing the absence of either species to environmental influences their life cycle should be taken into consideration.

Erpobdella octoculata (fig. 17) which was abundant at Station 1 on the River Cole was present in all the monthly samples. There were however marked increases in the size of the population in August and September. Large individuals were present throughout the year and this would be expected from a knowledge of its life history. Mann

(1964) says that this species may live for three years and this would explain the presence of fully grown individuals throughout the year. This species as would be expected from its long life span is in many ways a more reliable pollutional indicator, because it may also indicate conditions that existed several months previously. Species with short life spans would not have this value.

The study of the incidence and growth rates of the species described as with the chironomids previously described underlines how important it is to have a knowledge of the life history of the various aquatic invertebrates when using them to assess pollutional conditions. It also becomes apparent that it is much better to study the compositio of the benthic community as a whole when using fauna to assess polluted conditions rather than the appearance or disappearance of a single species.

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8 Appendix.

Tables of sampling and experimental results.

Table 1.
To Show Chemical Data for the period December 1966 to December 1967 for Dowles Brook and River Cole

pH

Stations	D	J	F	M	A	M	J	J	A	S	O	N	D	Maximum	Minimum	Average
Dowles Brook	8.2	8.1	8.0	8.0	8.25	7.6	8.2	8.0	8.1	8.1	7.7	7.95	7.75	8.2	7.6	7.98
Cole 1	7.9	7.4	7.5	7.6	7.4	7.5	7.3	7.4	7.55	7.6	7.4	7.3	7.25	7.9	7.3	7.4
2	7.6	7.3	7.25	7.35	7.15	7.6	7.0	7.1	7.2	7.1	7.1	7.3	7.1	7.6	7.0	7.21
3	7.8	7.5	7.45	7.6	7.35	7.85	7.2	7.25	7.3	7.45	7.3	7.4	7.25	7.85	7.2	7.4
4	7.9	7.3	7.6	7.65	7.45	7.8	7.25	7.35	7.3	7.6	7.55	7.4	7.45	7.9	7.25	7.48
5	7.9	7.4	7.4	7.7	7.5	7.8	7.29	7.4	7.35	7.5	7.6	7.47	7.5	7.9	7.29	7.49
6	8.4	7.5	7.55	7.8	8.2	8.0	7.45	7.5	7.55	7.6	7.7	7.55	7.5	8.4	7.45	7.66

Calcium (ppm)

Stations	D	J	F	M	A	M	J	J	A	S	O	N	D	Maximum	Minimum	Average
Dowles Brook	44.8	51.4	54.0	40.0	48.2	36.6	55.0	56.8	57.6	57.6	37.2	53.6	34.6	57.6	34.6	48.5
Cole 1	37.9	39.0	38.0	37.0	41.0	39.6	43.8	36.8	37.2	39.8	48.0	42.0	38.8	48.0	36.8	40.0
2	43.0	44.8	40.0	41.0	40.0	42.4	46.0	40.7	47.4	37.4	46.6	44.0	42.8	47.4	37.4	43.0
3	48.7	44.2	46.0	47.2	47.4	47.2	48.4	41.8	47.2	48.0	52.0	48.0	46.4	52.0	41.8	47.7
4	50.5	48.0	45.0	49.0	50.4	46.8	52.2	43.9	50.4	48.2	55.0	49.4	48.0	55.0	43.9	49.7
5	54.0	47.4	48.0	52.4	49.6	52.2	49.2	47.0	49.4	46.0	54.0	51.4	50.1	54.0	46.0	49.7
6	55.5	46.0	53.0	55.0	57.4	56.4	49.6	48.6	60.8	47.8	55.8	52.6	51.8	60.8	46.0	52.9

Table 1.

To Show Chemical Data for the period December 1966 to December 1967 for Dowles Brook and River Cole

Magnesium (ppm)

Stations	D	J	F	M	A	M	J	J	A	S	O	N	D	Maximum	Minimum	Average
Dowles Brook	6.4	3.2	NIL	3.8	8.2	5.96	5.0	8.5	6.1	6.8	5.8	8.2	3.8	8.5	NIL	5.9
Cole 1	9.7	9.4	3.7	13.7	16.4	10.2	17.4	14.5	16.8	10.3	8.5	16.4	11.1	17.4	3.7	12.3
2	9.1	4.3	2.2	13.6	11.2	10.5	9.2	11.0	9.1	9.4	10.6	11.8	7.1	13.6	2.2	9.1
3	9.1	6.3	1.0	15.7	14.5	10.9	17.6	10.1	17.5	14.4	8.1	13.4	5.4	17.6	1.0	11.2
4	9.8	6.0	3.3	17.0	13.7	10.0	17.8	15.4	13.7	16.9	8.3	16.5	5.3	17.8	3.3	12.0
5	9.9	8.0	2.6	18.3	14.8	11.4	15.1	14.5	16.4	18.1	7.2	13.7	9.4	18.3	2.6	12.4
6	12.1	7.1	1.4	21.6	16.4	10.2	18.5	18.1	17.4	18.8	6.9	21.5	8.9	21.6	1.4	13.9

B.O.D.

Stations	D	J	F	M	A	M	J	J	A	S	O	N	D	Maximum	Minimum	Average
Dowles Brook	1.45	1.1	1.8	2.4	2.3	1.5	1.1	3.8	2.0	2.2	2.0	3.2	3.2	3.8	1.1	2.2
Cole 1	2.8	5.3	2.8	3.0	7.5	4.6	2.5	6.0	0.9	3.8	1.0	4.9	6.4	7.5	0.9	4.06
2	8.6	13.9	10.6	16.4	22.0	11.4	25.1	36.5+	24.9	46.8	6.8	22.1	11.2	46.8	6.8	20.6
3	4.8	14.7	7.7	6.2	33.5+	10.6	17.1	37+	18.9	15.8	8.4	8.4	8.7	37.0	4.8	15.6
4	4.6	15.5	4.3	5.8	13.1	10.6	8.3	54+	4.9	8.8	4.9	10.9	3.7	54.0	3.7	12.07
5	4.5	7.2	5.0	15.4	15.0	14.1	15.0	38.0	7.3	3.7	6.5	6.7	9.7	38.0	3.7	11.97
6	2.8	5.9	4.0	6.1	15.5	5.0	4.3	27.4	9.9	3.8	2.6	4.1	4.4	27.4	2.6	7.4

River Cole

Dissolved Oxygen (ppm)

Stations		D	J	F	M	A	M	J	J	A	S	O	N	D	Maximum	Minimum	Average
Dowles Brook		12.7	12.4	12.3	12.0	10.2	12.0	11.7	8.9	10.4	10.2	10.5	12.0	12.6	12.7	8.9	11.2
Cole	1	11.2	10.35	11.3	10.5	13.5	10.4	9.9	6.5	8.4	8.4	9.3	11.0	10.4	13.5	6.5	9.9
	2	9.9	9.4	10.2	4.7	3.7	8.9	1.95	1.1	2.3	1.4	3.5	5.2	8.2	10.2	1.1	5.41
	3	9.9	9.4	9.7	4.3	3.9	8.15	2.5	1.3	1.0	2.2	4.7	5.3	7.8	9.9	1.0	5.39
	4	10.8	8.8	9.85	6.4	4.7	7.3	5.9	2.1	3.5	5.6	5.15	7.4	8.35	10.0	2.1	6.6
	5	10;4	8.35	9.95	9.4	8.2	7.6	4.3	6.45	3.8	5.4	4.6	7.6	9.4	10.4	3.8	7.34
	6	10.8	10.0	10.6	10.9	13.3	9.2	5.8	4.2	7.8	6.5	7.4	9.1	8.3	13.3	4.2	7.76

Temperature (°C)

Stations		D	J	F	M	A	M	J	J	A	S	O	N	D	Maximum	Minimum	Average
Dowles Brook		3.5	4.5	2.5	9.0	7.0	9.0	12.5	15.0	12.5	12.0	10.0	5.0	5.5	15.0	2.5	8.7
Cole	1	4.5	5.0	4.75	6.5	7.0	8.0	12.0	15.0	12.5	11.0	10.0	6.4	5.5	15.0	4.5	8.6
	2	5.0	6.0	5.5	8.0	9.5	9.0	13.0	16.5	13.5	13.0	11.25	6.75	6.0	16.5	5.0	9.46
	3	4.5	6.0	5.75	8.5	9.5	9.0	13.5	16.0	13.0	11.75	10.5	6.5	5.75	16.0	4.5	9.17
	4	4.5	6.0	5.75	9.0	9.5	9.0	13.0	16.25	13.5	12.0	10.5	6.5	5.5	16.25	4.5	17.61
	5.	4.5	6.0	6.0	9.0	9.5	9.0	14.5	17.0	15.0	13.5	10.5	6.5	5.5	18.0	4.5	9.73
	6	4.5	6.0	6.0	9.0	9.5	8.5	14.5	18.0	15.0	12.5	10.5	6.0	5.5	18.0	4.5	9.65

Table 1.

To Show Chemical Data for the period December 1966 to December 1967 for Dowles Brook and River Cole

AMMONIA (ppm as N)

Stations		D	J	F	M	A	M	J	J	A	S	O	N	D	Maximum	Minimum	Average
Dowles Brook		0.3	NIL	0.4	NIL	0.6	NIL	NIL	NIL	NIL	0.2	NIL	NIL	NIL	0.6	NIL	0.1
Cole	1	2.0	1.6	1.6	0.8	0.8	0.7	0.6	NIL	NIL	0.2	0.5	0.3	NIL	2.0	NIL	0.69
	2	3.5	3.2	2.6	5.6	10.6	3.8	9.2	10.5	16.2	7.3	4.8	6.3	5.3	16.2	2.6	7.1
	3	2.2	5.8	1.7	2.4	9.4	2.6	8.6	6.0	8.4	5.6	4.1	4.2	2.5	9.4	1.7	5.1
	4	2.2	3.2	2.6	2.0	8.0	3.3	6.0	9.3	10.6	7.2	4.2	3.9	2.05	10.6	2.0	5.2
	5	2.0	2.5	3.8	2.2	2.6	2.4	4.6	5.8	5.2	6.4	4.4	2.7	2.0	6.4	2.0	3.7
	6	1.6	2.2	1.5	1.8	2.4	1.2	3.4	4.5	4.8	6.0	2.7	2.3	4.4	6.0	1.2	3.1

NITRATES (ppm as N)

Stations		D	J	F	M	A	M	J	J	A	S	O	N	D	Maximum	Minimum	Average
Dowles Brook		2.1	2.8	3.3	4.0	2.3	4.0	3.2	1.3	0.8	1.0	3.8	3.6	2.9	4.0	0.8	2.75
Cole	1	2.7	5.2	3.2	4.9	5.5	4.4	4.4	3.3	3.2	6.0	5.5	5.0	5.0	6.0	2.7	4.6
	2	3.0	4.7	3.3	3.3	2.7	4.1	1.8	NIL	2.0	3.2	4.8	3.6	4.4	4.8	NIL	3.1
	3	1.2	4.8	3.4	3.9	1.4	3.5	1.3	NIL	1.2	1.8	3.4	2.9	3.9	4.8	NIL	2.6
	4	2.4	3.8	4.3	4.4	1.5	3.8	1.5	1.2	1.9	1.9	4.0	3.5	3.9	4.4	1.2	3.0
	5	2.0	3.6	4.4	4.2	4.8	3.8	1.9	1.4	2.5	3.6	3.6	3.8	2.9	4.8	1.4	3.3
	6	2.9	3.6	4.1	5.2	4.0	3.9	2.1	1.5	3.4	3.0	4.0	4.1	2.9	5.2	1.5	3.4

Table 1.

To Show Chemical Data for the period December 1966 to December 1967 for Dowles Brook and River Cole

ORTHOPHOSPHATES (ppm)

Stations		D	J	F	M	A	M	J	J	A	S	O	N	D	Maximum	Minimum	Average
Dowles Brook		0.15	NIL	0.7	NIL	NIL	NIL	NIL	NIL	NIL	0.1	NIL	NIL	NIL	0.7	NIL	0.07
Cole	1	0.23	0.1	0.23	0.48	NIL	0.2	NIL	0.15	0.8	0.75	0.3	0.4	0.85	0.85	NIL	0.35
	2	2.26	1.4	0.95	1.25	1.7	1.2	3.7	4.0	5.5	3.3	2.7	2.25	2.05	5.5	0.95	2.5
	3	0.85	1.35	0.3	0.3	2.5	0.55	2.1	2.15	2.3	1.85	1.63	1.55	1.55	2.5	0.3	1.5
	4	1.2	1.35	0.6	0.1	1.3	0.55	1.0	2.35	3.5	1.8	1.55	1.68	0.95	3.5	0.1	1.4
	5	1.3	1.2	0.8	0.35	0.15	0.35	1.0	2.2	2.0	1.4	1.45	1.5	1.3	2.2	0.15	1.14
	6	0.9	1.08	0.7	0.5	0.85	0.6	1.6	2.63	1.8	1.65	1.4	1.25	1.65	2.63	0.5	1.3

Table 2.

Results of three samples taken at intervals during the day from 5 stations on the River Cole.

Station	pH	Alkalinity	Carbon dioxide (ppm)	Ammonia (ppm)	Nitrites (ppm)
10.00a.m.					
1.	7.35	100	11	0.5	4.5
2.	7.15	153.0	23	8.7	2.1
3.	7.3	146.75	15.5	4.3	1.8
4.	7.5	147.75	10.5	4.1	1.8
6.	7.55	137.5	9.5	2.0	3.3
2.00p.m.					
1.	7.4	93.0	9.5	0.4	4.7
2.	7.25	163.75	19	12.2	2.7
3.	7.3	91.25	11.5	4.8	2.2
4.	7.2	97.25	14	4.1	2.1
6	7.4	120.25	10	2.8	3.7
6.00p.m.					
1.	7.35	95.75	10	0.4	4.0
2.	7.1	141.5	24	7.7	2.3
3.	7.25	145.25	17	8.2	1.5
4.	7.3	125.5	14	4.5	1.9
6.	7.3	111.25	13	2.1	2.9

Species.	N	D	J	F	M	A	M	J	J	A	S	O	N	D	Max.	Min.	Av.
Lumbriculidae	47	72	52	51	38	136	18	30	71	51	24	5	54	6	136	5	47
Tubificidae	20	25	23	5	4	0	42	20	8	5	3	0	5	6	42	0	12
Enchytraeidae	0	0	0	0	0	0	3	0	0	0	0	0	0	0	3	0	0
Piscicola geometrica	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0
Erpobdella octoculata	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0
Gammarus pulex	118	31	31	17	23	8	18	8	86	115	153	27	89	38	153	8	55
Ecdyonurus dispar	9	14	7	0	6	0	4	1	17	26	95	16	37	9	95	0	17
Baetis species	2	7	16	25	23	20	66	111	85	26	136	8	29	6	136	2	40
Rhithrogena semicolorata	4	48	70	71	55	99	53	11	8	3	127	23	78	33	127	3	49
Ephemerella ignita	0	0	0	0	0	0	8	59	94	35	2	0	0	0	94	0	14
Ephemera danica	2	0	4	1	7	4	4	1	0	1	0	2	4	0	7	0	2
Leuctra moseyli	0	0	0	0	0	0	0	0	21	11	0	0	0	0	21	0	2
Leuctra inermis	0	0	0	0	0	0	0	0	12	0	0	0	0	0	12	0	1
Leuctra hippopus	0	3	9	13	1	1	0	4	0	0	0	1	1	4	13	0	2.5
Nemoura cinerea	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0
Nemoura erratica	0	1	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0
Capnia bifrons	0	28	5	1	0	0	0	0	0	0	0	0	0	37	37	0	5
Chloroperla torrentium	0	0	0	3	3	2	1	0	0	0	0	0	0	0	3	0	0.5
Chloroperla tripunctata	0	0	0	0	0	0	0	0	0	0	0	0	3	0	3	0	0.5
Protonemoura praecox	0	0	2	1	0	0	0	0	0	0	0	0	2	0	2	0	0
Amphinemoura sulcicolis	0	0	0	0	0	33	5	0	0	0	0	0	0	0	33	0	2.5
Brachyptera risi	0	0	0	8	4	2	1	0	0	0	0	0	0	0	8	0	1
Rhabdioderyx angelica	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0
Isogenus nebucula	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Isoperla grammatica	0	2	9	4	5	9	1	2	0	0	0	0	0	0	9	0	2
small Plecoptera	7	17	37	25	33	0	2	14	47	0	3	7	25	41	47	0	19
Hydropsyche fulvipes	30	11	18	6	9	28	0	4	0	0	67	7	69	15	69	0	19
Rhyacophila dorsalis	6	0	4	1	1	4	1	8	5	5	14	4	2	2	14	0	4
Polycentropus flavomaculatus	0	4	5	2	5	0	2	0	0	1	3	4	7	3	7	0	2.5
Agapetus fuscipes	0	0	0	0	0	0	7	0	0	1	1	26	0	0	26	0	1.7
Silo palipes	3	10	0	0	3	1	2	0	1	0	2	7	0	1	10	0	2.1
Limnophilidae	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
												0	0	0	1	0	0
Lepidostomatidae	1	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0

Lepidostomatidae	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Goera pilosa	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0
Trichopteran pupae	0	0	0	0	0	0	3	2	1	4	2	0	0	0	4	0	1
Dicranata	6	3	7	6	0	6	2	6	35	8	19	4	6	13	35	0	8.6
Clinocera	0	0	0	1	0	0	0	0	0	0	0	0	2	0	2	0	0
Hemerodroma	0	0	0	0	0	0	0	1	0	0	0	0	1	0	1	0	0
Simulium larvae	0	0	11	4	1	1	0	5	2	0	6	0	1	3	11	0	2
Anatopynia	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Pentaneura	0	0	0	0	4	0	4	3	2	0	0	0	0	0	4	0	1
Brillia longifurca	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0
Brillia modesta	0	0	0	0	0	0	1	0	0	0	0	0	1	0	1	0	0
Orthocladiinae	0	0	1	0	2	14	5	4	0	0	0	0	0	0	14	0	2
Diamesa	0	0	0	0	0	1	2	0	0	0	0	0	0	0	2	0	0
Prodiamesa olivacea	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0
Micropsectra	0	0	0	0	1	1	0	1	0	0	0	0	0	0	1	0	0
Chironomus pupae	0	0	0	0	0	3	0	2	1	3	7	1	0	0	7	0	1
Tipulid larvae	0	0	0	0	3	2	0	1	0	0	0	0	0	0	3	0	0.5
Limnius larvae	1	1	3	1	0	0	0	6	1	1	0	3	1	0	6	0	1
Helmis larvae	0	0	6	1	0	3	1	3	4	0	5	4	1	0	6	0	2
Elmid adults	0	0	0	0	0	0	0	0	2	3	14	0	0	0	14	0	1
Helodid larvae	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	0	0
Sphaerium	0	0	0	0	0	0	0	0	0	0	0	3	0	0	3	0	0
Ancylastrum fluviatile	0	0	0	2	0	0	0	0	0	0	0	0	0	0	2	0	0

Table 4.

Biological results for the River Cole, Station 1. Figures refer to

	D.	Jan.			Feb.			Mar.			Apr.			May		
Tubificidae	80	65	125	450	68	83	68	184	248	31	67	36	13	9	212	15
Enchytraeidae	0	1	9	10	8	7	0	52	0	0	0	0	0	0	0	2
Lumbriculidae	29	0	0	6	16	83	5	52	476	93	6	72	3	12	40	4
Erpobdella octoculata	36	18	14	24	20	23	26	8	30	18	9	35	38	11	22	5
Glossiphonia complanata	1	0	1	0	3	2	0	3	0	0	2	0	0	3	1	1
Helobdella stagnalis	0	2	1	2	4	6	1	0	5	0	4	0	0	4	2	0
Batracobdella paludosa	0	0	0	0	0	1	0	0	0	2	0	0	0	0	0	0
Piscicola geometrica	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gammarus pulex	24	7	4	3	1	0	1	2	2	2	20	21	23	15	2	0
Asellus aquaticus	7	2	1	1	1	2	0	0	0	1	0	2	0	1	0	0
Baetis rhodani	59	20	12	13	38	22	28	56	72	49	169	122	191	72	43	90
Sericostomatidae	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Hydropsyche angustipennis	86	9	3	8	8	21	8	21	74	15	8	16	18	34	16	11
Limnophilidae	3	1	0	0	0	0	0	0	1	0	0	0	0	0	1	0
Agapetus fuscipes	0	0	0	0	2	3	0	1	1	0	1	1	0	0	0	0
Nemoura cinerea	0	0	0	0	0	0	2	2	6	8	3	15	4	1	0	0
Amphinemoura sulcicolis	0	0	0	0	0	0	0	0	0	0	1	1	0	1	0	0
Nemoura avicularis	0	0	0	0	0	0	0	0	0	0	0	0	12	0	0	0
Small Plecoptera	1	3	1	1	0	1	0	0	0	0	0	0	1	0	0	0
Pentaneura melanops	3	2	0	0	0	0	0	0	0	0	4	0	6	0	0	0
Brillia modesta	2	3	0	2	0	0	0	0	0	0	0	0	0	1	0	0
Eukiefferiella hospitus	0	0	0	0	7	7	0	3	6	2	9	12	4	1	0	0
Trichocladius rufiventris	0	0	0	0	0	0	0	0	0	0	5	4	2	2	0	0
Cricotopus bicinctus	0	0	0	0	0	0	0	0	0	0	0	23	2	0	0	0
Psectrocladius sp.	0	0	0	0	3	4	0	0	0	0	0	3	0	0	0	0
Micropsectra atrofasciatus	2	2	0	0	1	1	0	0	0	0	2	0	2	1	4	1
Chironomid pupae	0	0	0	0	0	0	0	0	2	1	3	2	0	0	1	0
Dicranata larvae	1	1	0	0	2	2	0	0	0	0	0	0	0	0	0	0
Limnophora	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Simulium larvae	352	968	72	12	82	172	28	0	167	193	2	3	0	5	9	18
Simulium ornatum pupae	0	0	0	0	6	17	12	0	6	1	0	0	24	0	0	0
Tipula larvae	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Limnius larvae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Haliplid larvae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sphaerium	0	2	6	5	6	5	0	0	0	0	0	0	0	1	4	2
Ancylus fluviatile	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0

Table 4.

numbers per 0.05m².

Jun.			Jul.			Aug.			Sep.			Oct.			Nov.			Dec.		
79	22	16	24	12	69	42	80	25	15	24	12	10	31	6	56	200	44	15	65	14
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
55	48	25	16	38	79	30	8	30	10	4	14	24	0	23	4	88	0	0	2	4
29	25	12	20	33	21	69	71	66	54	41	33	12	32	19	33	19	58	50	10	22
2	2	2	2	0	1	6	2	6	2	4	1	0	3	0	1	1	2	2	1	2
0	1	0	0	0	0	2	2	2	0	0	1	0	0	0	1	0	0	2	1	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	2	0	0
44	13	30	94	76	63	131	170	97	121	191	79	7	30	8	18	20	34	11	2	3
1	1	1	12	13	3	3	15	1	19	11	3	0	1	0	5	17	24	4	0	4
22	11	8	250	408	454	21	11	13	23	52	53	3	2	5	37	32	16	9	1	8
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	17	15	39	78	55	347	492	927	317	911	482	31	27	107	77	144	104	37	14	52
11	10	0	0	0	0	0	1	3	0	0	0	0	0	1	0	0	0	0	0	0
0	0	0	0	0	0	0	1	6	0	3	2	0	0	0	0	2	16	1	1	1
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1	0	0	0
0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
0	0	0	40	63	19	10	3	4	0	1	1	0	0	0	7	2	0	0	0	1
2	0	1	0	2	1	0	0	0	4	1	1	0	0	2	0	0	0	0	0	0
26	18	19	0	5	6	0	0	3	0	0	0	0	0	0	0	0	0	0	1	1
41	27	34	20	5	8	34	28	54	1	0	0	0	0	1	0	0	0	0	0	0
20	9	13	7	10	4	10	8	5	1	0	0	0	0	0	2	0	0	0	0	0
28	2	0	17	36	16	15	17	6	2	13	16	0	0	1	23	4	16	6	3	4
14	7	7	1	1	2	1	0	0	8	6	12	0	0	1	8	1	1	0	1	0
37	4	23	42	26	22	7	7	9	2	1	2	0	0	1	0	1	5	0	1	3
0	1	0	.0	2	13	1	0	10	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	1	0	0	0	0	0	0	0	0	0	2	0	0	0	45	46	17	48	37	195
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0
0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	0	0	0	0	0	2	7	5	4	2	0	0	11	4	0	1	7	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0

Table 5.

Biological results from the River Cole, Station 2 . Figures refer to

	D	Jan.			Feb.			Mar.			Apr.		
Lumbriculidae	80	10	0	0	0	0	0	0	124	0	0	0	0
Enchytraeidae	80	72	30	50	70	63	138	26	124	41	6	7	8
Tubificidae	539	51	160	591	280	987	456	1298	1816	965	13	21	14
Glossiphonia complanata	0	0	0	0	0	0	0	0	0	0	0	0	0
Erpobdella testacea	2	0	0	0	0	0	0	0	0	0	0	0	0
Erpobdella octoculata	0	0	0	0	0	0	1	0	0	0	0	0	0
Gammarus pulex	2	0	1	0	0	0	0	0	2	1	0	0	0
Asellus aquaticus	0	0	0	0	0	0	0	1	0	0	0	0	0
Trichocladius rufiventris	0	0	0	0	7	9	16	20	22	19	1	2	0
Anatopynia	0	0	0	0	0	0	0	0	1	0	0	0	0
Polypedilum arundineti	0	0	0	0	0	2	6	0	0	0	0	1	0
Chironomus riparius	201	41	78	48	187	247	400	7	18	6	2	2	3
Prodiamesa olivacea	3	0	0	0	0	3	4	0	0	0	0	0	0
Brillia longifurca	6	0	0	0	1	5	4	0	2	0	0	1	0
Brillia modesta	1	0	0	0	0	1	0	0	0	0	0	0	0
Cricotopus sylvestris	0	0	0	0	0	0	0	0	0	0	0	0	0
Cricotopus bicinctus	0	0	0	0	0	0	0	2	0	0	0	0	0
Pentaneura melanops	1	0	0	0	1	0	1	4	3	6	0	0	3
Phaenopsectra(sergentia)	0	0	2	0	0	0	0	0	0	0	0	0	0
Micropsectra sp.	0	0	1	0	3	4	0	5	2	2	0	0	0
Eukiefferiella hospitus	0	0	0	0	1	1	2	3	2	2	0	0	0
Psectrocladius sp.	0	0	0	0	0	0	0	5	0	2	0	0	0
Diplocladius cultriger	0	0	0	0	0	0	2	2	0	2	0	0	0
Chironomid pupae	14	3	8	6	0	3	0	5	3	3	2	0	6
Simulium larvae	12	0	1	2	7	20	28	104	120	74	1	29	4
Simulium ornatum pupae	0	0	0	0	0	0	0	2	1	0	0	0	0
Collembola	0	0	1	0	0	0	0	0	0	0	0	0	1
Baetis sp.	0	0	0	0	1	0	0	10	10	13	0	0	0
Psychoda larvae	0	0	1	0	0	0	0	0	0	0	0	0	0
Psychoda pupae	0	0	0	0	0	0	0	0	0	P	0	0	0
Hydropsyche larvae	0	0	0	0	0	0	0	0	0	0	0	0	0
Thaumalaeidae	0	0	0	0	0	0	0	0	0	0	0	0	0
Tubifera.	0	0	0	0	0	0	0	0	0	0	0	0	0
Culicine larvae	0	0	0	0	0	0	0	0	0	0	0	0	0
Pericoma	0	0	0	0	0	0	0	0	0	0	0	0	0
Sialis	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 5

numbers per 0.05m^2.

May			Jun.			Jul.			Aug.			Sep.			Oct.			Nov.			Dec.		
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36	63	28	1	1	5	0	0	0	0	0	0	0	0	0	1	4	2	10	8	11	4	0	12
142	97	36	1	8	2	2	3	2	12	12	51	2	2	13	9	2	1	11	0	8	16	24	16
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	2	0	0	0
0	2	0	2	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	2	1	1
0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
0	0	0	3	4	2	2	5	3	82	70	89	70	76	95	31	40	20	20	15	23	19	15	9
0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	3	1	1	3	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	1	1	1	1	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	0	5	0	1	0
0	0	0	0	0	0	0	0	0	2	2	1	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	2	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	2	7	7	13	1	0	1
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	1	2	0	0	0	0	0	0	0	0	0	0	0	0	8	7	4	5	5	9	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	4	6	4	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	4	2	0	0	1
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0
0	0	0	0	0	1	4	1	7	1	0	1	4	7	0	6	9	3	0	0	1	0	0	0
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	20	0	12	2	2	2
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	1	0	0	0
3	0	0	1	1	0	0	0	0	0	0	0	0	0	0	2	1	0	0	I	0	0	0	0
0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0

Table 6.

Biological results for the River Cole, Station 3. Figures refer

	D.	Jan.			Feb.			Mar.			Apr.			May	
Tubificidae	791	1392	2094	1575	716	732	380	1192	568	736	163	1188	801	391	687
Enchytraeidae	2125	1490	1646	2175	20	60	40	431	184	184	163	0	335	17	14
Lumbriculidae	50	0	0	10	20	40	0	33	16	4	0	0	0	0	0
Erpobdella octoculata	1	0	0	0	1	0	1	1	0	0	0	0	0	0	0
Erpobdella testacea	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Glossiphonia complanata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Helobdella stagnalis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gammarus pulex	3	1	0	1	0	0	0	2	1	1	1	0	0	0	0
Asellus aquaticus	2	1	0	2	1	1	0	1	0	0	0	0	0	0	0
Baetis rhodani	29	5	10	9	0	3	5	17	9	16	0	0	0	0	0
Chironomus riparius	140	19	27	33	26	5	16	5	8	14	1	10	6	2	0
Polypedilum arundineti	75	7	10	8	10	1	2	2	1	6	5	3	5	10	2
Endochironomus sp.	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Micropsectra atrofasciatus	5	3	5	1	1	1	13	12	12	20	0	0	1	0	1
Pentaneura melanops	7	1	0	2	8	4	2	3	7	6	38	26	23	5	0
Anatopynia sp.	0	0	1	0	0	0	2	0	0	0	0	0	0	0	0
Brillia longifurca	110	52	73	67	35	18	31	30	19	19	4	4	6	0	1
Brillia modesta	26	4	3	1	2	3	3	1	2	0	0	0	0	0	1
Eukiefferiella hospitus	2	10	8	11	4	5	3	16	11	20	0	1	1	0	1
Trichocladius rufiventris	0	71	60	58	35	37	40	100	95	94	0	0	4	2	0
Cricotopus sylvestris	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cricotopus bicinctus	0	0	0	0	3	6	1	0	0	0	6	2	2	0	0
Psectrocladius sp.	4	0	0	0	0	0	1	4	6	8	0	0	0	0	0
Prodiamesa olivacea	12	10	7	12	14	9	12	3	2	2	0	0	0	0	0
Chironomid pupae	0	0	0	0	2	1	2	10	15	11	1	5	0	4	1
Simulium larvae	216	74	116	157	11	7	20	84	32	60	0	0	0	0	0
Simulium ornatum pupae	10	1	0	1	0	1	1	5	1	1	3	2	3	0	0
Ancylus fluviatile	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Limnaea pereger	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0

Table 6.

to numbers per 0.05m².

M	Jun.			Jul.			Aug.			Sep.			Oct.			Nov.			Dec.		
1215	35	1	78	760	4	15	10	3	2	269	117	81	192	0	0	152	52	66	96	120	80
25	0	2	4	0	1	0	2	0	0	0	0	0	12	0	0	4	8	14	8	8	12
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	2	0	1	1	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	1	1	0
0	1	4	9	29	285	2	285	195	233	54	320	412	850	1500	1073	64	210	110	55	26	38
2	1	2	0	0	0	0	0	0	0	0	0	0	102	66	79	9	10	15	12	3	7
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	40	18	8	56	80	62	1	1	3	1	1	0
0	0	0	0	0	0	0	0	0	0	3	1	3	51	36	34	4	6	2	1	3	1
0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	6	2	6	30	24	36	9	14	6	12	9	14
0	0	0	0	0	0	0	0	0	0	2	0	3	3	10	7	1	2	3	3	3	2
0	0	0	0	0	0	0	0	0	0	3	0	0	30	36	43	1	0	3	4	3	6
0	0	0	0	0	0	1	0	0	0	56	39	65	36	45	49	0	0	0	2	3	2
0	0	0	0	0	0	0	0	1	1	6	0	4	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	42	8	36	6	14	5	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	7	0	3	4	4	6	1	2	0	1	4	1
0	1	1	1	0	0	0	0	0	0	11	7	6	15	16	21	10	10	14	17	9	16
1	0	0	2	1	0	0	·0	0	0	60	15	14	28	13	12	1	1	0	0	0	0
0	0	0	0	0	0	0	0	0	0	1	0	0	2	2	0	1	9	6	5	2	3
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 7.

Biological results from the River Cole, Station 4. Figures refer to

	Dec	Jan.			Feb.			Mar.			Apr.			May			June		
Tubificidae	259	837	202	968	934	270	326	262	300	416	470	647	489	453	412	684	1224	2552	3148
Enchytraeidae	40	20	10	6	196	20	10	0	0	69	11	13	101	11	0	30	0	0	0
Lumbriculidae	90	119	10	80	98	10	20	30	0	69	55	0	38	0	60	30	0	0	0
Erpobdella octoculata	1	0	0	0	1	0	0	1	1	0	6	2	0	1	0	1	1	0	0
Erpobdella testacea	1	0	0	0	0	3	1	0	0	0	0	0	0	0	0	0	0	0	0
Glossiphonia complanata	0	1	0	1	2	3	0	1	0	0	1	1	1	1	0	1	0	0	0
Helobdella stagnalis	2	0	0	0	0	1	0	0	0	0	0	1	0	0	0	1	0	0	0
Gammarus pulex	0	0	0	0	0	0	0	2	1	0	3	1	1	0	0	0	0	1	0
Asellus aquaticus	0	1	2	1	0	1	0	4	2	10	0	0	0	3	0	5	0	1	0
Baetis rhodani	0	5	5	2	1	0	1	17	32	18	8	8	13	0	0	1	0	0	1
Chironomus riparius	4	4	4	2	3	1	0	8	6	11	0	0	0	0	0	0	10	3	7
Polypedilum arundineti	3	6	3	2	0	0	3	5	3	0	5	0	0	1	4	2	0	1	0
Endochironomus sp.	0	0	0	0	2	1	0	0	2	0	4	2	1	1	0	2	0	0	0
Micropsectra atrofasciatus	0	12	1	2	2	3	3	8	16	6	0	0	1	0	1	0	6	7	5
Pentaneura melanops	10	18	8	9	5	5	1	49	69	34	75	75	53	1	1	2	0	0	1
Anatopynia sp.	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	L	2
Brillia longifurca	19	47	27	42	38	19	16	134	85	188	17	12	19	0	1	0	16	16	20
Brillia modesta	3	4	4	7	1	2	0	0	7	4	2	0	0	0	0	0	11	9	6
Eukiefferiella hospitus	0	30	17	18	5	4	2	35	54	36	0	0	0	0	0	0	22	34	25
Trichocladius rufiventris	0	73	41	42	31	v18	19	178	283	167	10	10	6	3	7	4	33	44	55
Psectrocladius sp.	1	0	0	6	0	0	0	9	21	10	4	4	0	0	0	0	5	0	0
Cricotopus bicinctus	0	0	0	0	0	0	0	50	42	60	76	101	104	2	0	1	83	101	73
Cricotopus sylvestris	0	0	0	0	0	0	0	0	0	0	0	3	1	0	0	0	1	1	3
Prodiamesa olivacea	58	47	27	40	14	10	10	18	12	10	1	0	0	1	1	2	19	19	14
Chironomid pupae	0	0	3	0	2	11	1	44	45	65	11	25	25	1	0	3	7	12	10
Simulium larvae	142	18	9	9	17	5	5	3	121	75	2	5	3	0	0	0	2	2	6
Simulium ornatum. pupae	0	0	0	0	0	0	0	0	0	0	3	1	0	0	0	0	0	0	0
Limnaea pereger	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0

Table 7.

numb rs per $0.05m^2$.

July			Aug.			Sep.			Oct.			Nov.			Dec.		
90	48	436	128	140	63	806	699	607	632	668	427	156	96	81	344	232	196
10	4	10	0	0	0	538	549	510	8	0	16	8	0	15	0	0	8
0	4	20	0	20	0	0	8	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1
0	0	0	0	0	0	2	1	2	22	0	5	0	1	0	0	0	0
0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	1	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	1	0	1	0	0	0	1	0	1	0	0
0	4	0	1	0	0	1	3	1	3	1	3	0	0	0	2	1	2
0	0	0	0	0	0	0	0	0	0	4	1	0	0	0	0	2	0
42	27	47	1025	1044	396	35	33	28	92	142	81	9	6	14	19	30	17
25	18	12	0	1	0	5	1	7	2	0	3	1	1	2	14	12	10
0	0	3	0	1	0	0	0	0	2	0	0	0	0	0	0	0	0
1	0	1	2	0	0	3	4	6	15	23	14	1	2	3	16	16	11
1	3	1	2	0	1	5	3	7	39	37	28	4	6	3	7	28	6
1	0	0	1	1	0	0	0	0	1	0	1	0	0	0	0	0	0
2	3	0	0	0	0	3	2	5	3	3	5	3	10	8	56	84	76
0	0	0	0	0	0	6	1	5	7	4	8	1	4	5	2	6	8
0	0	0	0	0	0	19	20	23	13	15	20	3	0	1	9	11	13
2	3	2	5	2	0	37	51	46	18	26	21	1	0	0	52	68	51
0	0	0	0	1	0	0	0	0	0	1	2	0	1	0	0	8	2
3	2	2	3	2	2	74	98	79	25	15	14	2	1	2	2	4	1
6	6	8	10	12	13	35	41	45	4	2	3	0	0	0	3	0	5
1	0	0	0	0	0	23	43	36	15	13	21	3	5	4	17	23	22
5	0	2	27	0	19	43	32	27	0	25	9	0	1	0	0	1	0
0	0	0	0	0	0	2	5	6	0	0	0	2	3	1	0	0	0
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0

Table 8.

Biological results for the River Cole, Station 5. Figures refer to

	D.	Jan.			Feb.			Mar.			Apr.			May		
Tubificidae	604	708	210	267	410	207	106	560	510	212	110	560	480	1910	987	523
Enchytraeidae	25	48	10	42	10	36	42	16	30	10	16	30	6	37	23	0
Lumbriculidae	5	16	2	12	0	18	4	10	6	0	12	0	4	0	0	8
Erpobdella octoculata	7	9	17	16	7	3	2	9	6	21	2	3	1	14	11	5
Erpobdella testacea	2	0	0	0	0	2	1	0	3	2	6	2	2	0	0	0
Glossiphonia complanata	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Helobdella stagnalis	17	13	11	6	22	18	32	26	41	50	40	46	22	0	0	0
Gammarus pulex	1	0	1	0	0	0	0	0	2	1	0	0	0	0	0	0
Asellus aquaticus	75	49	32	42	98	246	143	37	71	81	77	49	63	21	36	10
Baetis rhodani	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Psectrocladius sp.	1	0	0	0	1	1	1	0	0	0	0	0	0	21	16	11
Brillia longifurca	10	21	19	14	101	112	81	138	148	98	9	10	5	2	1	0
Brillia modesta	2	1	6	2	3	4	2	0	0	0	0	0	0	0	0	0
Eukiefferiella hospitus	5	6	11	4	36	58	44	51	64	41	0	0	0	7	3	2
Trichocladius rufiventris	9	18	34	29	177	161	277	480	383	440	7	5	3	37	26	21
Cricotopus bicinctus	1	0	0	0	0	2	1	4	8	6	87	59	70	317	233	188
Cricotopus sylvestris	0	0	0	0	3	2	1	1	1	1	3	6	3	12	7	5
Chironomus riparius	0	o	2	1	2	3	1	0	0	0	1	2	0	13	2	1
Polypedilum arundineti	0	0	1	2	0	3	0	0	0	0	0	0	0	0	0	0
Endochironomus sp.	1	3	0	0	2	0	1	0	0	0	0	0	0	0	0	0
Micropsectra atrofasciatus	1	7	4	4	19	21	14	7	5	3	0	0	0	2	1	0
Parachironomus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Prodiamesa olivacea	2	2	2	2	2	4	3	5	0	1	0	0	0	0	0	0
Pentaneura melanops	3	4	5	9	20	17	11	2	0	1	18	13	11	0	0	.0
Anatopynia sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Chironomid pupae	0	0	0	0	1	0	2	4	6	2	10	7	4	78	51	24
Simulium larvae	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0
Simulium ornatum pupae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ancylus fluviatile	0	1	3	5	4	4	7	4	3	5	9	6	3	0	0	0
Limnaea pereger	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sphaerium	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 8.

numbers per 0.05m².

	Jun.			Jul.			Aug.			Sep.			Oct.			Nov.			Dec.		
	604	270	230	480	110	360	140	760	310	310	260	230	180	360	710	170	90	360	160	410	98
	0	20	10	68	10	12	0	20	8	0	16	20	0	28	10	8	22	42	16	36	4
	0	0	10	6	3	21	0	0	22	10	12	0	7	8	0	4	10	0	0	0	30
	4	2	0	1	1	1	0	4	2	13	11	21	8	5	2	12	16	8	15	9	6
	0	0	0	0	0	0	2	1	3	3	2	1	0	4	2	0	1	0	4	3	1
	3	2	1	0	0	0	2	0	1	0	3	0	0	0	0	0	3	3	0	0	0
	8	1	0	27	23	16	6	10	8	57	32	49	24	31	17	32	41	38	41	36	61
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	51	14	26	192	115	154	72	180	46	207	83	307	71	98	53	89	190	171	63	207	150
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	4	0	2	0	0	0	0	0	0
	21	19	14	7	7	4	3	3	3	0	2	1	0	0	0	23	27	16	67	48	35
	0	0	0	3	2	1	0	0	0	0	0	0	0	0	0	1	0	2	2	0	4
	19	17	12	28	41	30	3	0	6	17	20	14	37	61	49	41	22	36	9	7	5
	967	811	730	1781	1366	987	42	49	75	155	114	103	10	21	14	2	5	2	1	2	3
	65	62	47	43	64	49	351	249	285	168	134	118	0	0	0	0	0	0	0	0	0
	10	6	2	11	10	6	2	1	0	1	2	0	0	0	0	13	23	12	7	4	13
	7	4	1	9	7	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	3	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	29	37	51	13	23	20	6	0	0	15	5	4	3	6	1	9	10	5	5	3	1
	11	7	3	3	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	2	1	0	6	2	1	4	5	0	0	0	0	0	1	2	0	3	0	2	2	2
	17	7	9	47	27	31	22	15	20	0	0	0	6	9	6	29	37	57	51	28	38
	0	2	1	0	0	0	14	13	21	0	0	0	0	0	0	1	2	0	1	0	2
	114	97	203	102	272	196	26	8	14	33	75	42	3	7	8	0	6	3	0	0	0
	0	3	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	2	0	0	1	2	3	0	0	3	10	3
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	2	0	1	0	3	0	0	0	0	0	0	0	0	0	0

Table 9.

Biological results for the River Cole, Station 6. Figures refer to

	D.	Jan.			Feb.			Mar.			Apr.			May		
Tubificidae	357	220	193	186	190	344	590	68	240	126	36	182	224	208	290	144
Enchytraeidae	20	2	0	0	0	20	13	0	10	6	0	0	0	0	0	0
Lumbriculidae	20	3	0	0	10	20	25	0	8	0	2	16	0	0	6	24
Erpobdella octoculata	2	7	4	4	6	1	4	6	4	8	2	4	3	1	10	1
Erpobdella testacea	1	0	2	1	1	0	0	0	0	0	0	1	0	0	0	1
Glossiphonia complanata	0	0	0	2	0	0	0	1	0	0	0	0	0	0	0	0
Helobdella stagnalis	1	0	0	0	0	0	0	1	0	0	3	0	0	0	0	0
Gammarus pulex	1	10	10	6	2	4	3	2	1	0	3	1	0	0	1	2
Asellus aquaticus	1	8	7	4	0	9	0	3	0	0	3	1	2	0	0	0
Baetis rhodani	0	0	0	0	0	0	0	0	0	2	2	1	0	0	0	0
Psectrocladius spp.	3	0	0	0	0	1	0	5	2	8	0	8	2	0	0	0
Brillia longifurca	5	27	27	16	39	68	66	77	56	90	26	19	13	0	0	0
Brillia modesta	3	0	1	2	0	4	3	2	0	2	1	0	0	0	0	0
Eukiefferiella hospitus	1	3	5	6	0	5	1	20	13	9	0	0	0	12	9	24
Trichocladius rufiventris	0	3	6	7	3	10	9	76	49	78	71	114	68	19	14	36
Cricotopus bicinctus	0	0	0	0	0	0	0	94	77	108	65	56	27	27	22	24
Cricotopus sylvestris	0	0	0	0	0	0	0	6	5	0	0	0	0	0	0	0
Chironomus riparius	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Polypedilum arundineti	0	1	0	0	0	2	0	0	0	0	1	0	0	0	0	0
Endochironomus sp.	0	1	0	0	0	3	1	1	0	2	3	0	0	0	0	0
Micropsectra atrofasciatus	0	1	2	3	0	9	0	13	2	7	0	0	0	0	1	0
Parachironomus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Prodiamesa olivacea	0	25	16	14	10	24	17	3	7	10	32	11	10	0	0	1
Pentaneura melanops	1	4	1	5	7	10	3	13	6	19	0	0	0	0	0	5
Anatopynia	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0
Chironomid pupae	0	0	1	1	0	8	3	19	2	25	67	33	9	10	3	40
Simulium larvae	1	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0
Simulium pupae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ancylus fluviatile	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Limnaea pereger	2	0	0	0	2	0	0	0	0	0	1	0	0	0	0	0
Sphaerium	12	5	1	1	6	4	4	1	2	1	15	0	0	2	0	1
Limnophilidae	1	0	1	0	0	0	0	1	0	0	0	0	0	0	0	1

Table 9.

numbers per 0.05 m.^{2}

Jun.			Jul.			Aug.			Sep.			Oct.			Nov.			Dec.		
44	160	110	79	32	120	64	180	77	133	137	524	380	272	508	243	564	372	228	292	168
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	10	0	10	3	0	0	4	0	0	0	0	0	0	0	0	0
1	0	2	1	0	1	0	0	1	0	3	0	0	0	0	3	0	2	0	0	0
0	0	0	0	0	0	0	0	2	1	6	0	2	2	4	4	2	2	1	3	0
0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	2	1	1	0
0	0	0	0	0	0	0	0	0	1	0	0	5	1	5	2	1	2	0	0	2
0	0	1	0	1	1	1	0	0	10	15	16	11	1	4	5	3	5	0	0	0
1	3	3	0	1	3	3	0	5	15	26	35	232	34	251	53	21	62	3	1	0
5	6	4	0	0	1	2	2	1	9	12	3	0	0	0	1	1	0	0	0	0
0	0	0	0	0	0	12	0	0	0	0	20	0	5	0	7	2	5	0	0	0
2	3	4	0	1	0	0	4	2	1	4	7	0	1	3	11	1	1	0	0	0
0	1	1	0	0	0	0	0	2	2	2	7	0	0	0	0	0	0	0	0	0
10	15	8	0	2	0	21	24	43	9	12	16	0	9	4	5	1	2	0	0	0
10	43	20	14	9	8	54	52	105	62	40	35	2	2	8	4	2	3	1	1	0
53	83	60	16	1	118	199	361	464	60	83	142	6	8	6	6	1	1	0	0	0
0	0	0	4	0	0	5	10	5	49	24	25	0	0	0	2	0	0	0	0	0
0	1	0	0	0	0	14	18	13	7	6	7	1	0	2	1	0	1	0	0	0
0	0	0	0	1	1	7	6	3	9	15	14	5	5	0	33	16	26	1	3	0
0	1	1	2	0	0	0	0	0	2	7	7	0	0	2	14	3	2	0	0	0
1	5	0	3	2	4	0	0	0	0	0	0	0	0	1	2	0	1	0	0	0
0	0	0		00	0	10	45	19	0	0	0	0	0	0	0	0	0	0	0	0
6	8	5	5	8	10	5	12	4	29	47	52	22	18	36	29	16	21	4	5	0
0	1	0	7	12	2	8	16	11	34	42	44	10	8	26	21	2	9	0	0	0
0	0	0	0	0	0	2	1	0	1	2	4	0	0	0	0	0	0	0	0	0
6	47	11	1	2	3	53	42	26	55	55	76	1	0	3	0	1	0	1	0	0
0	0	0	0	0	0	2	0	0	0	1	1	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	1	0	0	0	1	1	0	3	5	0	3	1	6	0	2	0
0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0

Table 10.

Biological results for the River Cole, Station 6, for the period December 1967 to November 1968. Figures refer to numbers per $0.05 m^2$.

Species	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.
Tubificidae	64	88	172	84	96	660	648	104	56	52	444	140
Enchytraeidae	0	0	0	0	0	0	0	0	0	0	0	1
Lumbriculidae	0	0	0	0	0	16	0	4	0	0	0	0
Erpobdella octoculata	0	0	0	1	0	1	1	0	0	0	0	1
Erpobdella testacea	0	0	0	1	0	1	0	0	2	1	0	3
Helobdella stagnalis	3	4	0	2	1	1	2	2	5	1	0	6
Glossiphonia complanata	0	0	0	0	0	0	1	0	0	0	0	0
Asellus aquaticus	18	17	12	8	4	3	0	4	18	2	2	132
Gammarus pulex	0	0	12	3	0	0	0	1	10	0	1	19
Baetis rhodani	0	0	3	0	0	0	0	0	2	0	0	0
Brillia longifurca	14	41	28	55	1	0	8	2	20	2	8	2
Brillia modesta	6	9	6	1	1	0	1	0	0	1	3	1
Trichocladius rufiventris	5	36	142	128	46	28	119	31	1	13	3	0
Cricotopus bicinctus	0	0	3	2	320	53	283	183	2	8	6	0
Cricotopus sylvestris	0	0	0	0	9	1	5	13	10	23	0	0
Eukiefferiella hospitus	10	29	57	36	11	4	8	17	9	12	4	11
Psectrocladius sp.	3	8	0	0	0	0	0	1	2	0	12	1
Prodiamesa olivacea	4	15	9	6	0	1	16	1	12	4	3	6
Chironomus riparius	0	0	0	0	0	1	0	0	1	0	2	0
Polypedilum arundineti	3	18	5	4	1	9	1	1	26	1	10	2
Endochironomus sp.	0	0	1	0	0	0	0	0	0	0	0	0
Micropsectra atrofasciatus	2	2	5	0	1	0	6	0	16	5	1	5
Pentaneura melanops	16	16	9	1	11	2	5	3	22	0	11	19
Chironomid pupae	0	0	0	4	46	14	108	38	12	7	14	0
Simulium larvae	0	8	1	0	0	0	0	3	0	1	0	0
Ancylus fluviatile	0	0	0	1	0	0	0	0	0	0	0	0
Sphaerium	1	0	0	0	0	0	2	0	0	0	3	0

Table 11.

To show chemical data for the period March 1967 to March 1968 for the River Salwarpe.

Stations	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Max.	Min.	Av.
							DISSOLVED OXYGEN(p.p.m.)									
St. 1.	6.0	4.0	6.3	4.4	6.7	6.7	2.8	6.2	9.0	10.0	9.1	11.3	10.6	11.3	2.8	7.16
St. 2.	6.3	4.5	7.5	5.9	7.7	7.4	3.7	6.9	8.4	10.7	9.4	11.5	11.6	11.6	3.7	7.8
							TEMPERATURE(°C)									
St. 1.	7.0	11.5	14.0	16.5	15.3	15.8	13.5	13.0	11.0	5.5	5.5	4.0	4.0	16.5	4.0	10.5
St. 2.	6.0	11.0	12.8	14.5	14.0	14.8	13.0	12.3	10.1	4.5	5.0	3.8	3.5	14.8	3.5	8.08
							pH.									
St. 1.	6.9	7.9	7.3	7.4	7.4	7.7	7.5	7.4	7.4	7.8	7.3	7.6	7.3	7.9	6.9	7.43
St. 2.	7.1	7.9	7.5	7.5	7.6	7.8	7.5	7.6	7.7	7.9	7.5	7.6	7.7	7.9	7.1	7.59
							AMMONIA(p.p.m. as N.)									
St. 1.	6.8	11.3	5.1	2.5	0.5	0.1	12.0	0.3	0.1	1.2	1.8	0.3	9.0	12.0	0.1	3.9
St. 2.	4.0	7.1	3.2	1.8	0.2	0.0	6.0	0.0	0.6	0.2	2.5	0.2	9.4	9.4	0.2	2.7
							NITRATES(p.p.m. as N.)									
St. 1.	7.0	3.4	5.5	6.1	8.5	10.0	3.1	16.2	12.1	8.6	7.4	10.3	5.5	16.2	3.1	7.2
St. 2.	5.5	3.3	5.0	4.7	7.0	7.2	3.2	10.8	9.0	6.4	7.0	11.0	4.7	11.0	3.2	6.5
							ORTHOPHOSPHATES(p.p.m.)									
St. 1.	3.8	1.3	2.4	2.7	2.9	2.8	1.6	3.1	1.8	2.4	1.0	0.7	2.0	3.8	1.3	2.16
St. 2.	2.9	0.9	1.2	1.7	1.6	2.0	1.0	2.2	0.9	1.6	1.1	0.9	1.1	2.9	0.9	1.46
							CALCIUM(p.p.m.)									
St. 1.	89	106	104	99.2	94	96.8	87.8	101.8	95.2	110.5	86.6	88	88	110.5	86.6	95.9
St. 2.	97.2	106	97.2	99.2	102	109.6	93.6	105.8	96.4	113.3	87.4	97.6	96	113.3	87.4	100.1
							MAGNESIUM(p.p.m.)									
St. 1.	0	12.5	4.1	14.6	10.8	12.9	7.9	15.7	22.1	15.3	14.2	9.24	19.6	~~22.1~~	0	12.22
St. 2.	0	14.3	14.9	19.7	15.1	18.5	13.6	17.2	16.7	19.3	12.8	10.5	24.0	24.0	0	15.1
							ALKALINITY									
St. 1.	No results			220	199	189	250	187.5	173	149.5	158.5	127.5	124	250	124	177.8
St. 2.	No results			222	217.5	207.5	228	199	188.5	158.5	164	132	150	228	132	186.7
							CARBON DIOXIDE(p.p.m.)									
St. 1.	No results			20	16	8	15	15	14	8	16	8	13	20	8	13.3
St. 2.	No results			14	12	7	13	9	8	4	11	8	6	14	4	9.2
							B.O.D.									
St. 1.	25.3	25.9	27.6	12.6	20.5	8.3	48.7	6.5	9.7	5.5	12.4	4.4	6.5	48.7	4.4	17.2
St. 2.	16.8	18.9	20.5	11.6	12.6	4.4	26.7	5.5	12.7	5.0	9.9	6.2	7.0	26.7	4.4	12.13

Tables 12 and 13.

Biological results for the River Salwarpe. Figures refer to numbers per 0.05 m^2.

	Station 1.													Station 2.												
Species	M	A	M	J	J	A	S	O	N	D	J	F	M	M	A	M	J	J	A	S	O	N	D	J	F	M
Tubificidae	1260	120	160	220	456	744	268	444	116	63	380	988	920	500	418	364	998	512	192	308	156	148	69	80	88	124
Enchytraeidae	0	0	0	0	216	0	0	0	0	16	0	0	0	0	22	120	53	0	0	0	0	0	0	0	0	0
Lumbriculidae	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0
Erpobdella octoculata	0	0	0	0	0	0	0	0	0	1	0	0	0	10	2	0	0	0	0	0	0	0	0	0	0	0
Erpobdella testacea	0	0	0	0	0	0	0	0	1	1	0	0	0	1	0	0	0	0	3	1	2	2	0	1	1	1
Helobdella stagnalis	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Glossiphonia complanata	0	0	I	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Asellus aquaticus	0	0	0	0	0	0	0	2	0	1	0	0	3	129	6	1	5	25	31	19	144	824	844	999	640	310
Gammarus pulex	0	0	0	0	4	1	2	1	0	3	2	1	2	0	0	1	0	0	0	0	0	4	0	0	1	0
Baetis rhodani	0	0	0	0	4	7	21	0	0	1	5	1	1	0	0	0	0	2	2	10	2	1	1	0	2	6
Chironomus riparius	10	0	3	20	0	2	1	2	0	0	0	1	0	21	0	7	201	7	6	0	0	0	0	0	0	0
Polypedilum arundineti	0	0	0	1	4	9	4	10	6	12	7	30	4	1	1	0	0	0	0	0	0	4	0	2	0	1
Micropsectra atrofasciatus	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	17	3	20	6	8	7	9	7	0	0
Cricotopus sylvestris	0	0	0	25	5	13	11	0	0	0	0	0	0	20	0	0	25	15	30	6	1	0	0	1	1	9
Eukiefferiella hospitus	0	0	0	3	12	3	1	4	0	0	1	4	0	0	0	0	3	0	4	29	13	8	14	9	10	11
Brillia longifurca	0	0	0	0	2	4	2	8	7	43	50	164	21	7	0	0	0	1	3	0	3	7	36	43	59	50
Brillia modesta	0	0	0	0	9	4	4	3	0	3	1	2	0	0	0	0	0	0	3	0	0	3	2	2	2	1
Trichocladius rufiventris	0	0	0	1	80	34	7	3	0	0	11	92	18	0	0	3	6	1	1	3	1	0	0	0	24	103
Cricotopus bicinctus	0	0	5	8	319	240	60	6	0	0	2	7	3	4	0	0	16	244	152	15	2	0	0	0	5	39
Prodiamesa olivacea	0	0	0	0	2	0	1	3	1	2	2	0	2	0	0	0	0	1	3	2	4	1	1	4	1	3
Pentaneura melanops	0	0	0	1	2	1	2	10	1	2	2	0	1	1	0	0	0	2	13	10	128	165	79	37	26	11
Anatopynia trifascipennis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	14	0	0	1	0	0	0	0
Anatopynia(s.g.Macropelopia)	0	0	0	1	2	0	0	0	0	0	1	0	0	0	0	0	0	0	3	7	0	0	0	1	0	0
Orthocladiinae sp.1	0	0	0	0	59	14	0	12	0	16	1	0	0	0	0	5	0	0	9	0	1	11	92	8	14	11
Orthocladiinae sp.2	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	8	0	0	0	0	0	0	0	0	0	0
Chironomus pupae	0	0	0	25	165	0	26	14	5	2	0	1	2	5	0	0	25	47	0	5	1	3	12	1	3	7
Simulium larvae	0	0	0	0	1	0	0	1	0	2	1	1	0	0	0	0	0	0	0	0	0	7	30	66	2	0
Psychoda larvae.	0	0	0	0	0	1	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0
Helmis larvae	0	0	0	0	1	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Limnaea pereger	0	0	0	1	0	1	0	3	1	2	7	1	5	6	0	2	1	3	20	37	13	32	15	43	44	30
Ancylus fluviatile	0	0	0	1	0	0	0	0	0	0	0	0	0	77	7	0	1	1	0	13	6	116	23	25	110	66

Table 14

To Show Chemical Data for the Period June 1968 to June 1969

for Merry Hill Brook

Stations	J	J	A	S	O	N	D	J	F	M	A	M	J	Max	Min	Average
Dissolved Oxygen (p.p.m.)																
St. 1	6.9	6.0	4.8	5.9	6.5	8.0	7.8	7.3	7.3	7.3	8.6	7.0	5.9	8.6	4.8	6.9
St. 2	7.0	6.6	6.5	7.5	7.1	8.2	9.3	8.8	9.6	9.2	9.4	8.75	6.5	9.6	6.5	8.1
Temperature °C																
St. 1	16.75	18.5	15.0	15.3	16.0	8.5	5.0	6.0	6.2	5.0	11.25	13.0	16.0	18.5	5.0	11.7
St. 2	16.25	18.0	17.0	14.25	16.0	9.0	4.5	5.5	4.0	4.5	10.5	13.0	14.5	18.0	4.0	11.3
pH																
St. 1	7.1	7.15	7.4	7.25	7.11	7.5	7.45	7.3	7.15	6.97	7.31	7.27	7.13	7.5	6.97	7.23
St. 2	7.55	7.4	7.6	7.65	7.3	7.8	7.9	7.5	7.55	7.47	7.53	7.57	7.42	7.9	7.3	7.55
Ammonia (p.p.m. as N)																
St. 1	5.1	8.0	5.9	2.5	2.1	3.6	3.8	4.6	7.8	6.9	3.5	1.9	4.8	8.0	1.9	4.65
St. 2	1.5	2.9	2.8	1.5	2.0	5.0	4.2	3.7	7.1	6.5	2.2	1.2	7.1	7.1	1.2	3.67
Nitrates (p.p.m. as N)																
St. 1	26.0	29.9	21.0	19.3	17.0	29.0	24.0	26.8	23.3	24.0	20.8	28.5	34.6	34.6	17.0	24.9
St. 2	22.6	31.2	14.5	18.4	15.7	20.8	22.2	28.2	22.6	23.9	17.6	26.0	33.0	33.0	14.5	22.8
Orthophosphates (p.p.m.)																
St. 1	6.3	9.2	7.2	4.0	5.05	2.3	7.8	7.7	9.0	9.7	1.25	4.2	6.15	9.7	1.25	6.14
St. 2	6.35	8.7	3.6	3.25	4.9	2.6	6.9	6.4	8.0	10.9	0.65	4.15	8.6	10.9	0.65	5.76
B.O.D																
St. 1	15.4	9.8	18.5	4.1	4.4	23.2	27.1	17.2	19.7	26.9	13.9	9.0	4.3	27.1	4.1	14.88
St. 2	15.4	7.8	10.1	4.1	6.7	11.6	16.1	12.7	7.45	15.1	6.4	8.75	8.3	16.1	4.1	10.03
Alkalinity																
St. 1	164	154	122.5	170	73	141	150	144	175	180	113	108	140	180	73	141.1
St. 2	147	130	110	153	72.5	173	151	132	167	164	112	105	161	173	72.5	136.73
Carbon Dioxide (p.p.m.)																
St. 1	28	25	9	20	12	8	12	15	24	35	11	12	21	35	8	17.84
St. 2	10	11	5	7	8	6	4	9	9	11	7	6	12	12	4	8
Calcium (p.p.m.)																
St. 1	82.4	60.4	48	67.2	46.4	76.4	78.4	67	81.6	84.4	94.8	86	84	94.8	46.4	73.6
St. 2	74.4	69.2	49.2	69.4	46.4	80	80.4	62.8	84.8	82.6	88.8	92	80	92	46.4	73.84
Magnesium (p.p.m.)																
St. 1	15.3	21.6	8.75	17.5	8.4	12	15.6	22.5	21.2	21.6	16.3	20.2	16.4	22.5	8.4	16.72
St. 2	12.9	15.4	7.1	15.7	6.0	17.5	17.3	25.5	15.9	20	17.4	18.1	17.1	25.5	6.0	15.84

Table 15.

Temperature and oxygen recordings over a 24 hr. period from Bob's Brook and Merry Hill Brook.

		2 p.m.	4p.m.	8.30p.m.	10p.m.	4a.m.	6a.m.	10a.m.	2p.m.
Bob's Brook	Temperature °C	17.6	18	17.2	17	15	14.8	16	17
	Dissolved oxygen(p.p.m.)	8.06	8.0	8.4	8.3	8.6	8.7	8.4	8.3
Merry Hill Brook 1	Temperature °C	21.6	20.7	17.9	17.9	16.0	16.5	17.5	20.0
	Dissolved oxygen(p.p.m.)	6.8	7.3	6.6	6.4	5.4	5.4	6.1	6.4
Merry Hill Brook 2	Temperature °C	20.9	22.0	18.1	17.4	14.9	15.2	17.0	19.5
	Dissolved oxygen(p.p.m.)	7.03	6.8	7.2	7.1	7.0	6.9	6.5	7.1

Tables 16 and 17.

Biological results for Merryhill Brook, Stations 1 and 2. Figures refer to numbers per 0.05 m^2.

Species.	J	J	A	S	O	N	D	J	F	M	A	M	J	J	J	A	S	O	N	D	J	F	M	A	M	J	J
Enchytraeidae	24	8	10	0	0	8	12	32	0	32	24	12	40	452	0	54	44	428	224	184	264	44	48	48	28	60	
Tubificidae	6	8	20	16	172	32	16	28	32	4	8	8	32	0	0	8	0	16	44	16	0	4	12	48	4	8	
Lumbriculidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	8	0	0	0	0	0	
Erpobdella octoculata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	
Erpobdella testacea	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	
Asellus aquaticus	0	0	0	0	0	0	0	0	0	0	0	0	0	12	22	4	0	28	31	3	37	1	2	1	0	27	
Chironomus riparius	11	152	51	78	780	205	265	251	189	64	0	0	131	30	25	22	10	129	180	45	306	21	11	8	1	141	
Cricotopus sylvestris	1	5	13	3	3	0	0	0	0	1	0	0	2	2	17	0	0	0	1	0	0	1	0	0	0	82	
Eukiefferiella hospitus	12	16	10	11	0	7	1	1	2	0	0	0	43	45	61	19	13	82	8	0	16	4	11	2	1	91	
Brillia longifurca	0	0	0	0	1	1	2	2	0	0	0	0	0	1	11	0	2	5	13	10	44	8	17	3	1	7	
Trichocladius rufiventris	0	0	0	0	1	0	0	0	0	0	0	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	
Cricotopus bicinctus	2	51	78	2	1	0	0	0	0	1	0	0	25	5	3	3	1	0	0	0	0	0	0	3	5	78	
Metrocnemius longitarsus	0	0	0	0	0	0	0	0	0	0	0	0	16	1	0	0	0	0	0	0	0	0	0	0	0	6	
Micropsectra atrofasciatus	0	1	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	1	1	0	3	0	0	0	0	8	
Anatopynia	0	2	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	
Brillia modesta	0	0	2	1	2	2	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	1	
Prodiamesa olivacea	0	0	0	2	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	
Pentaneura melanops	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	
Orthocladiinae sp.1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	7	0	0	0	0	0	0	0	0	0	0	1	
Orthocladiinae sp.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	
Chironomid pupae	4	46	16	2	16	3	0	0	0	2	1	0	16	10	19	0	20	0	3	0	1	0	0	9	0	44	
Simulium larvae	3	0	7	2	30	336	144	268	26	0	0	0	0	400	1048	64	56	2420	0	1432	1618	271	1567	7	44	14	
Simulium reptans larvae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1	22	0	0	0	8	51	24	0	0	0	
Psychoda larvae	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	

Station 1.

Station 2.

Table 18.

To show chemical data for the period March 1968 to March 1969 for BOb's Brook.

	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Max.	Min.	Av.
Dissolved oxygen(p.p.m.)	8.2	7.6	8.2	7.7	7.8	7.2	8.3	7.9	10.4	9.9	9.2	10.1	9.9	10.4	7.2	8.64
Temperature (C)	8.0	11.5	13.5	16.0	17.0	16.0	14.8	16.0	10.0	5.0	5.5	5.4	4.5	17.0	4.5	11.01
pH	7.65	7.35	7.05	7.23	7.45	7.1	7.5	7.48	7.62	7.5	7.45	7.15	7.2	7.65	7.05	7.36
Calcium(ppm)	93.2	108	106	94	89.6	84.4	88.4	74.4	104	101.4	86	93	98.8	108	74.4	93.9
Magnesium (p.p.m.)	2.43	10.6	1.46	4.1	9.36	5.1	11.4	4	8.14	6.2	17	19.6	16.3	19.6	1.46	8.89
Ammonia(ppm)	0.9	0.6	0	0.8	0.5	0.2	0.7	1.6	1.0	0.4	1.2	0.5	9.6	9.6	0	1.38
Nitrates (p.p.m.)	15.8	46.2	16.8	13.4	18.1	13.9	13.3	14.1	12.5	13.7	19.7	14.2	11.9	46.2	11.9	17.2
Ortho-phosphates (p.p.m.)	7.1	3.2	3.75	4.65	6.7	3.1	3.2	4.5	1.7	4.2	5.05	7.4	7.6	7.6	1.7	4.78
Alkalinity			170	158	164	184	176	103	178	165.5	148	175	221	221	103	167.5
Carbon dioxide (p.p.m.)			29	20	13	29	11	7	8	11	11	24	28	29	7	17.36
B.O.D.	18	24.4	17	7.9	10.3	10.1	6.6	6.4	10.55	17.1	9.4	6.7	6.55	24.4	6.4	11.61

Table 19.

Biological results for the period March 1968 to March 1969 for Bob's Brook.

Species	M	A	M	J	J	A	S	O	N	D	J	F	M
Tubificidae	253	104	74	62	248	0	244	248	116	108	320	236	208
Enchytraeidae	0	28	74	42	0	0	0	0	4	4	0	9	0
Erpobdella testacea	0	0	0	0	1	1	0	1	2	1	2	0	0
Trocheta subviridis	0	0	0	3	0	2	0	0	1	0	0	3	5
Asellus aquaticus	0	0	0	0	0	0	1	2	1	0	0	4	1
Gammarus pulex	0	0	0	0	0	1	0	0	1	0	0	0	0
Baetis rhodani	1	0	0	0	0	0	0	0	1	0	1	0	0
Brillia longifurca	12	0	0	1	11	58	4	3	11	20	44	14	19
Brillia modesta	6	0	0	0	1	9	3	3	2	2	2	0	0
Eukiefferiella hospitus	1	0	0	2	13	7	4	18	3	1	6	0	1
Prodiamesa olivacea	2	0	0	0	0	0	1	0	0	0	0	0	0
Cricotopus sylvestris	6	0	0	12	16	18	7	0	0	0	0	0	1
Cricotopus bicinctus	0	0	0	0	16	31	2	2	0	2	0	0	0
Trichocladius rufiventris	0	0	1	3	4	4	3	0	1	1	1	3	0
Anatopynia	0	0	0	0	0	5	0	0	0	0	0	0	0
Pentaneura melanops	0	0	0	0	0	3	0	2	1	0	2	2	1
Chironomus riparius	0	0	0	0	0	0	0	0	1	0	0	0	1
Chironomid pupae	16	0	0	6	8	11	6	7	2	3	2	0	0
Psectrocladius sp.	38	0	0	2	4	7	0	3	3	3	3	1	8
Simulium larvae	0	0	0	0	16	16	22	3	13	12	17	0	0
Psychoda larvae	0	0	0	0	1	0	0	2	0	0	0	5	0

Table 20.

To Show Chemical Data for the Period July 1967 to July 1968 for River Trent at Walton

	J	A	S	O	N	J	F	M	A	M	J	J	Maximum	Minimum	Average
DISSOLVED OXYGEN (ppm)	3.2	5.0	3.7	3.7	5.8	5.9	5.0	6.0	4.1	5.0	3.8	2.7	6.0	2.7	4.49
TEMPERATURE (°C)	17.0	20.0	15.5	11.0	8.0	6.0	7.0	5.5	12.0	11.0	16.0	21.0	21.0	5.5	12.5
pH	7.4	7.0	7.5	7.5	7.4	7.5	7.4	7.5	7.6	7.2	7.6	7.6	7.6	7.0	7.43
TOTAL HARDNESS (ppm)	335	355	355	375	425	395	370	390	375	340	370	385	425	335	372.5
AMMONIA (ppm)	5.4	3.8	4.4	3.7	3.6	5.5	6.3	5.6	6.1	4.5	3.5	4.7	6.3	3.5	4.75
NITRATES (ppm)	4.0	8.3	5.7	10.2	6.3	7.0	7.3	7.6	6.6	7.0	6.3	8.3	10.2	4.0	7.05
ORTHO PHOSPHATES (ppm)						1.0	0.8						1.0	0.8	0.9
ALKALINITY	165	170	160	210	180	190	170	185	210	155	185	185	210	155	180.4
CARBONDIOXIDE (ppm)	14	32.5	11.0	12.0	14.5	11.5	13.5	11.0	10.5	20.0	9.5	9.5	32.5	9.5	14.1
B.O.D.	7.6	8.4	12.6	9.2	7.5	14.4	17.2	14.8	12.8	19.5	6.9	13.2	19.5	6.9	12.0

Table 21.

Biological results from the River Trent at Walton.

	Jun.	Aug.	Oct.	Dec.	Feb.	Apr.	Jun.
Tubificidae	360	180	460	256	184	416	206
Enchytraeidae	20	6	32	11	22	2	5
Lumbriculidae	0	0	2	1	16	0	0
Erpobdella octoculata	4	8	3	9	6	7	2
Erpobdella testacea	0	1	1	2	1	1	0
Helobdella stagnalis	0	2	1	7	9	1	3
Asellus aquaticus	39	46	26	22	11	38	17
Chironomus riparius	3	6	10	21	7	9	7
Polypedilum arundineti	0	1	0	3	1	2	0
Cricotopus bicinctus	3	15	4	0	0	1	17
Cricotopus sylvestris	35	26	4	0	0	2	21
Brillia longifurca	1	3	10	14	18	2	1
Brillia modesta	0	0	1	1	0	0	0
Eukiefferiella hospitus	0	0	2	5	2	0	0
Prodiamesa olivacea	1	1	0	3	1	0	3
Pentaneura melanops	0	2	1	2	0	0	1
Chironomid pupae	12	6	0	0	0	4	7

Table 22.

Some Chemical Data taken during the period July 1968 to October 1969 for Wem Brook

	June 1968	July 1968	August 1968	October 1968	November 1968	October 1969
DISSOLVED OXYGEN (ppm)	11.1	8.4	-	8.3	6.9	11.5
TEMPERATURE (°C)	18.0	15.0	18.0	14.0	9.0	15.0
pH	7.9	7.6	7.5	7.7	7.4	7.8
TOTAL HARDNESS (ppm)	415	305	165	380	305	410
AMMONIA (ppm)	8.4	3.0	4.5	7.0	1.0	-
NITRATES (ppm)	0.6	0.3	0.2	0.3	0.3	-
ALKALINITY	346	175	105	270	246	200
CARBON DIOXIDE (ppm)	5.5	8.0	6.5	8.0	20.0	6.5
B.O.D.	8.4	3.0	4.5	7.0	1.1	3.8

Table 22.
Some Chemical Data taken during the period July 1968 to October 1969 for Wem Brook

	June 1968	July 1968	August 1968	October 1968	November 1968	October 1969
DISSOLVED OXYGEN (ppm)	11.1	8.4	-	8.3	6.9	11.5
TEMPERATURE (°C)	18.0	15.0	18.0	14.0	9.0	15.0
pH	7.9	7.6	7.5	7.7	7.4	7.8
TOTAL HARDNESS (ppm)	415	305	165	380	305	410
AMMONIA (ppm)	8.4	3.0	4.5	7.0	1.0	-
NITRATES (ppm)	0.6	0.3	0.2	0.3	0.3	-
ALKALINITY	346	175	105	270	246	200
CARBON DIOXIDE (ppm)	5.5	8.0	6.5	8.0	20.0	6.5
B.O.D.	8.4	3.0	4.5	7.0	1.1	3.8

Table 23.

Biological results for Wem Brook for the period June 1968 to June 1969.

Species.	Jun.	Aug.	Oct.	Dec.	Feb.	Apr.	Jun.
Tubificidae	388	970	380	192	116	232	600
Erpobdella octoculata	1	38	25	21	5	1	4
Erpobdella testacea	0	1	1	0	0	0	0
Helobdella stagnalis	0	2	2	4	0	0	2
Glossiphonia complanata	0	0	0	0	0	0	1
Asellus aquaticus	342	2240	194	469	166	129	516
Gammarus pulex	0	2	1	4	1	1	0
Brillia longifurca	0	0	0	0	1	0	0
Brillia modesta	0	0	0	0	1	0	0
Cricotopus sylvestris	84	3	0	0	5	5	30
Cricotopus bicinctus	3	0	0	0	2	196	4
Pentaneura melanops	1	4	1	4	0	0	1
Chironomus riparius	35	0	0	1	0	0	45
Prodiamesa olivacea	7	0	0	1	1	0	1
Eukiefferiella hospitus	0	0	3	2	6	4	0
Psectrocladius sp.	0	0	0	1	1	0	0
Micropsectra	0	0	0	0	2	3	0
Trichocladius rufiventris	0	0	0	0	21	40	0
Orthocladiinae sp.	0	0	0	0	2	0	0
Chironomid pupae	7	0	0	0	0	22	1
Baetis rhodani	3	17	1	0	0	0	0
Limnaea pereger	0	0	0	0	0	1	0
Sphaerium	0	0	1	0	0	0	0
Simulium larvae	0	0	0	1	0	1	0

Table 24

Chemical Data taken during the Period June 1968 to July 1969 for River Trent at Kings Bromley

	J	J	A	S	O	N	D	J	F	M	A	M	J	J
Dissolved Oxygen(p.p.m)	5.1	5.9	4.6	5.5	5.6	7.1	7.1	9.3	10.1	9.8	7.1	6.2	7.6	9.2
Temperature (°C)	19.0	14.0	15.0	13.0	11.0	7.5	9.0	5.0	4.0	7.0	9.0	14.0	16.0	21.0
pH	7.8	7.4	7.6	7.6	7.6	7.5	7.9	7.3	7.5	7.8	7.2	7.5	7.7	7.8
Total Hardness (p.p.m.)	415	265	416	330	400	390	380	340	345	385	340	295	420	405
Ammonia (p.p.m.)	1.7	0.6	1.4	0.9	1.7	2.0	1.2	0.9	1.3	3.5	1.2	0.5	0.5	0.8
Nitrates (p.p.m.)	6.8	3.6	6.6	5.6	5.7	5.6	6.2	6.9	6.6	6.1	6.2	6.0	5.4	7.6
Alkalinity	210	150	170	150	200	190	210	160	155	215	150	150	195	205
Carbon Dioxide (p.p.m.)	6.5	12.0	8.0	7.5	9.5	11.0	5.0	17.0	15.5	7.0	19.0	10.0	8.0	6.0
B.O.D.	5.4	3.3	4.4	8.7	7.2	5.1	4.0	3.6	6.0	3.4	15.3	6.0	6.4	4.0

Table 25

Biological Results for the River Trent at King's Bromley Figures refer to numbers per $0.05m^2$

Species	Jun.	Aug.	Oct.	Dec.	Feb.	Apr.	Jun.
Tubificidae	220	160	96	188	224	220	276
Lumbriculidae	0	8	0	0	0	0	0
Glossiphonia complanata	4	5	4	4	7	7	2
Erpobdella octoculata	17	5	17	6	37	12	49
Helobdella stagnalis	0	0	0	0	1	0	0
Asellus aquaticus	33	9	35	20	23	20	5
Gammarus pulex	0	0	0	0	1	0	0
Eukiefferiella hospitus	0	0	0	0	1	0	0
Cricotopus sylvestris	2	0	0	0	0	0	0
Cricotopus bicinctus	1	2	0	0	0	0	2
Pentaneura melanops	4	0	0	0	0	0	0
Anatopynia	0	1	0	0	0	0	0
Psectrocladius sp.	0	0	0	1	0	0	0
Trichocladius rufiventris	0	0	0	0	1	0	0
Caenis moesta	0	0	1	0	0	0	0
Ecdyonurus sp.	0	0	1	0	0	0	0
Haliplus adult	1	0	0	0	0	0	0
Haliplus larvae	2	0	0	0	0	0	0
Helmis larvae	0	1	0	0	0	0	0
Sphaerium	72	13	0	35	18	6	60
Limnaea pereger	456	39	12	22	5	1	13
Physa fontinalis	20	2	0	0	0	0	3
Ancylus fluviatile	3	0	5	5	5	3	1
Hydrobia jenkinsi	0	1	0	0	0	0	0
Limnius larvae	0	0	1	0	0	0	0

Table 26.

Some Chemical Data taken during the period March 1968 to November 1969 for River Sow at St. Thomas' Mill

	March 1968	July 1968	September 1968	June 1969	September 1969	November 1969
DISSOLVED OXYGEN (ppm)	10.6	7.2	6.4	10.2	11.4	9.3
TEMPERATURE (°C)	7.0	-	16.5	17.5	10.0	7.0
pH	7.8	7.4	7.6	8.1	7.9	7.2
TOTAL HARDNESS (ppm)	430	310	408	420	400	410
AMMONIA (ppm)	6.7	0.1	0.3	0.1	NIL	0.7
NITRATES (ppm)	6.0	3.1	4.6	7.0	6.2	7.0
ALKALINITY	210	170	165	205	215	185
CARBON DIOXIDE (ppm)	6.0	14.0	8.0	4.0	5.5	24.0
B.O.D.	3.0	2.0	2.8	7.12	2.6	3.6

Table 27.

Biological results for the River Sow at St. Thomas' Mill.
Figures refer to numbers per $0.05m^2$.

Species	Jul.	Aug.	Oct,	Dec.	Feb.	Apr.	Jul.
Tubificidae	74	24	352	92	64	68	0
Lumbriculidae	0	0	0	0	0	4	0
Naiidae	0	10	0	0	0	0	0
Erpobdella octoculata	5	2	2	2	5	2	0
Glossiphonia complanata	4	2	1	2	3	1	0
Batracobdella paludosa	1	0	0	0	0	0	0
Helobdella stagnalis	0	2	0	0	0	1	0
Gammarus tigrinis	45	201	46	24	55	1	13
Asellus aquaticus	24	1	8	2	1	0	0
Baetis rhodani	0	0	0	0	0	0	1
Caenis moesta	0	0	0	0	0	0	2
Hydropsyche angustipennis	0	0	3	0	0	0	4
Trichocladius rufiventris	0	4	0	0	0	0	0
Cricotopus sylvestris	0	5	0	0	0	0	0
Cricotopus bicinctus	0	1	0	0	0	3	4
Prodiamesa olivacea	1	1	2	3	0	0	0
Chironomus riparius	1	0	0	0	0	0	0
Pentapedilum	91	0	0	0	0	260	21
Micropsectra atrofasciatus	0	2	0	0	0	0	0
Pentaneura melanops	0	2	0	0	0	0	4
Diamesa	0	0	1	0	0	0	0
Cryptochironomus	4	3	1	0	1	0	5
Chironomid pupae	1	0	0	0	0	0	3
Tipula	0	0	0	1	0	0	0
Sphaerium	13	17	28	10	9	1	0
Limnaea pereger	2	0	0	0	0	0	0
Haliplid larvae	3	1	0	0	0	0	0
Limnius larvae	0	1	1	1	0	0	0
Hydrobia jenkinsi	0	8	144	0	0	0	0
Bythinia tentae	0	1	0	0	0	0	0
Valvata piscinalis	0	1	0	0	0	0	0
Sericostomatidae	0	0	3	0	0	0	0

Table 28

Some Chemical Data taken during the Period February 1968 to August 1969 for River Mease at Harlaston

	Feb'68	June'68	Jan'69	Feb'69	Mar'69	Apr'69	May'69	Aug'69
Dissolved Oxygen(p.p.m)	11.1	8.6	11.0	-	-	10.8	10.8	13.9
Temperature (°C)	3.0	19.0	-	2.0	-	7.0	10.0	20.0
pH	7.9	8.1	7.8	7.6	7.5	7.4	7.2	7.6
Total Hardness (p.p.m.)	450	525	390	450	440	500	-	520
Ammonia(p.p.m)	0.4	0.1	0.13	1.1	0.6	0.8	1.3	0.1
Nitrates(p.p.m)	6.9	5.2	7.7	7.1	7.7	6.6	5.5	4.1
Alkalinity	180	255	185	185	150	170	165	205
Carbon Dioxide (p.p.m.)	5.0	3.0	6.0	8.0	16.0	14.0	21.0	10.5
B.O.D.	-	-	2.9	3.3	2.3	3.8	-	1.6

Table 29

Biological Results for River Trent at Harlaston

Figures refer to numbers per $0.05M^2$

	J	A	O	D	F	A	J
Tubificidae	23	0.	92	90	92	236	18
Naiidae	0	22	0	0	0	0	0
Erpobdella octoculata	1	0	2	1	1	4	11
Glossiphonia complanata	6	12	4	1	0	2	21
Piscicola geometra	0	0	0	0	1	0	0
Gammarus pulex	4	11	7	3	0	7	6
Asellus aquaticus	21	27	23	5	1	1	12
Hydropsyche angustipennis	48	18	2	0	1	0	0
Agapetus fuscipes	1	3	1	0	0	0	0
Baetis rhodani	4	15	7	1	0	42	1
Caenis moesta	16	10	38	0	0	0	0
Ephemerella ignita	0	0	0	0	0	6	0
Amphinemura sulcicolis	1	0	0	0	0	0	0
Eukiefferiella hospitus	0	0	0	0	0	3	0
Trichocladius rufiventris	3	0	0	0	0	0	1
Pentapedilum	1	0	0	0	0	3	1
Microtendipes	2	0	4	0	2	0	2
Chryptochironomus	0	0	0	0	0	0	7
Pentaneura melanops	1	3	0	0	0	1	5
Chironomus riparius	0	0	1	0	0	0	0
Prodiamesa olivacea	0	0	1	0	0	0	0
Chironomid pupae	3	0	0	0	0	1	0
Dicranata	1	0	0	0	0	0	1
Simulium larvae	1	5	73	0	0	0	0
Helmis larvae	5	46	22	17	19	2	6
Limnius larvae	1	34	59	11	9	0	9
Sphaerium	12	16	18	5	3	3	10
Hydrobia jenkinsi	68	9	14	7	3	0	0

Table 30.
Analysis of samples from River Ray. Samples taken following a three week period with no recorded rainfall. 13/3/68.

Sample	Dissol. Oxygen	5 day B.O.D.	pH	Free Ammonia	Nitrate	Alkalinity
Station 1. (Mannington)	12.9	4.2	8.2	1.3	3.5	310
Station 2. (Moredon)	9.5	4.8	7.8	10.9	7.0	320
Station 3. (Tadpole Bridge)	9.9	3.8	8.1	8.8	5.2	340
Station 4. (Seven Bridges)	14.5	5.8	8.1	11.2	8.2	340

Table 31.
Analysis of samples from River Ray. Samples taken on 6th August 1969.

Sample	Dissol. Oxygen	5 day B.O.D.	pH	Free Ammonia	Nitrate	Alkalinity
Station 1. (Mannington)	7.15	3.3	7.5	0.63	4.5	290
Station 2. (Moredon)	6.8	3.4	7.4	1.4	11.0	260
Station 3. (Tadpole Bridge)	5.75	3.1	7.0	1.7	9.6	250
Station 4. (Seven Bridges)	6.75	3.4	7.6	2.1	10.5	240

Table 32.

Summary of benthic fauna collected during 30 seconds sampling of the stream bed of the River Ray.

Species	Station 1. (Mannington)	Station 2. (Moredon)	Station 3. (Tadpole Bridge)	Station 4. (Seven Bridges)
	March 1968			
Oligochaeta	6	85	3	2
Hirudinea	4(2spp)	1	0	6
Asellus aquaticus	46	675	137	960
Gammarus pulex	4	6	8	5
Baetis	16	0	1	0
Chironomidae larvae	32(3spp)	60	70	661(3spp)
Snails and limpets	36(2spp)	14	1	2
Sphaerium	2	0	0	0
	August 1969			
Oligochaeta	34	26	10(2spp)	4
Hirudinea	9(2spp)	0	1	15
Asellus aquaticus	542	2420	646	768
Gammarus pulex	17	0	0	0
Baetis	3	0	1	0
Chironomid larvae	6(3spp)	22	37(2spp)	7(2spp)
Snails and limpets	68	19(2spp)	8(2spp)	7(2spp)
Sphaerium	0	1	0	1

Table 33.

Summary of results of experiments to show the effect of low oxygen concentration.

Time for mortality(hrs.)

	10°C				20°C				
% animals	1.5ppm	1.0ppm	0.5ppm	0.0ppm	2.0ppm	1.5ppm	1.0ppm	0.5ppm	0.0ppm
Gammarus pulex adults									
10%	SPE	30	8	1¼	26	12	1¼	1	¾
50%	SPE	48	12	2¼	48	15	2¼	1¾	1¼
100%	SPE	96	24	3	96	20	7	2¾	2¼
Gammarus pulex young									
10%	SPE	48	no experiments performed						
50%	SPE	72		"					
100%	SPE	108		"					
Ecdyonurus dispar									
10%	SPE	20	9	1¼	18	8	1¼	¾	½
50%	SPE	48	15	2	24	12	2½	1½	1
100%	SPE	96	20	3	96	20	8	2½	1¾
Rhyacophila dorsalis									
10%	144	48	15	2¼	16	10	8	1½	¾
50%	300	65	22	3½	24	16	10	2	1½
100%	300+	96	32	5	72	30	18	4	2
Hydropsyche angustipennis									
10%	SPE	SPE	SPE	15	SPE	36	30	10	3½
50%	"	"	"	28	"	120	96	15	4½
100%	"	"	"	48	"	200	120	30	9
Asellus aquaticus									
10%	SPE	SPE	SPE	48	SPE	SPE	SPE	72	15
50%	"	"	"	72	"	"	"	192	24
100%	"	"	"	168	"	"	"	300	120
Erpobdella testacea									
10%	SPE	SPE	SPE	SPE (192hrs.)	SPE	SPE	SPE	SPE	104
50%	"	"	"	"	"	"	"	"	144
100 %	"	"	"	"	"	"	"	"	240
Erpobdella octoculata									
10%	SPE	SPE	SPE	144	SPE	SPE	SPE	SPE	36
50%	"	"	"	192+	"	"	"	"	84
100%	"	"	"	"	"	"	"	"	216
Helobdella stagnalis									
10%	SPE	SPE	SPE	132	SPE	SPE	SPE	SPE	20
50%	"	"	"	192+	"	"	"	"	45
100%	"	"	"	"	"	"	"	"	150
Brillia longifurca									
10%	SPE	SPE	SPE	12	SPE	SPE	SPE	SPE	15
50%	"	"	"	24	"	"	"	"	20
100%	"	"	"	36	"	"	"	"	40
Chironomus riparius									
10%	SPE	SPE	SPE	192+	SPE	SPE	SPE	SPE	55
50%	"	"	"	"	"	"	"	"	96
100%	"	"	"	"	"	"	"	"	120
Prodiamesa olivacea									
10%	SPE	SPE	SPE	24	SPE	SPE	SPE	SPE	16
50%	"	"	"	35	"	"	"	"	26
100%	"	"	"	60	"	"	"	"	48

SPE = survived period of exposure.

Table 34.
Summary of results of experiments to show the effect of undissociated ammonia.

Time for mortality(hrs.)

	10°C											18°C		
% animals	10p.p.m.O_2				2p.p.m.O_2				1p.p.m.O_2			10p.p.m.O_2		
Gammarus pulex	3.0	1.5	0.75	0.25	3.0	1.5	0.75	0.25	1.5	0.75	0.25	1.5	0.75	0.25
	ppm. undiss. amm.				ppm. undiss. amm.				ppm. und. amm			ppm. und. amm.		
10%	14	48	SPE	SPE	5	10	40	SPE	10	14	28	48	60	SPE
50%	28	110	SPE	SPE	24	30	66	SPE	15	24	50	96	150	SPE
100%	96	270	SPE	SPE	50	60	96	SPE	24	72	96	144	300+	SPE
Ecdyonurus dispar														
10%	12	80	SPE	SPE	no	10	48	SPE	8	14	24	24	48	SPE
50%	24	150	SPE	SPE	expt	30	132	SPE	11	20	60	72	104	SPE
100%	120	300+	SPE	SPE		48	168	SPE	20	70	90	120	164	SPE
Asellus aquaticus														
10%	12	136	SPE	SPE	10	164	SPE	SPE	72	138	SPE	48	150	SPE
50%	32	204	SPE	SPE	24	190	SPE	SPE	300+	300+	SPE	180	180	SPE
100%	160	300+	SPE	SPE	48	260	SPE	SPE	SPE	SPE	SPE	300+	290	SPE
Rhyacophila dorsalis														
10%	60	SPE	SPE	SPE	24	84	SPE	SPE	18	40	44	SPE	SPE	SPE
50%	264	SPE	SPE	SPE	72	170	SPE	SPE	50	66	80	SPE	SPE	SPE
100%	300+	SPE	SPE	SPE	264	300	SPE	SPE	72	90	96	SPE	SPE	SPE
Hydropsyche angustipennis														
10%	188	SPE	SPE	SPE	96	SPE	SPE	SPE	72	183	SPE	SPE	SPE	SPE
50%	SPE	SPE	SPE	SPE	300+	SPE	SPE	SPE	300+	300+	SPE	SPE	SPE	SPE
100%	SPE	SPE	SPE	SPE	300+	SPE	SPE	SPE	300+	300+	SPE	SPE	SPE	SPE
Erpobdella octoculata														
10%	14	96	SPE	SPE	no	50	SPE	SPE	30	144	SPE	SPE	SPE	SPE
50%	22	140	SPE	SPE	expt	55	SPE	SPE	48	200	SPE	SPE	SPE	SPE
100%	66	238	SPE	SPE		120	SPE	SPE	72	212	SPE	SPE	SPE	SPE
Erpobdella testacea														
10%	24	164	SPE	SPE	no	70	SPE	SPE	60	212	SPE	SPE	SPE	SPE
50%	70	300+	SPE	SPE	expt	120	SPE	SPE	84	300+	SPE	SPE	SPE	SPE
100%	96	300+	SPE	SPE		144	SPE	SPE	120	300+	SPE	SPE	SPE	SPE
Helobdella stagnalis														
10%	30	120	SPE	SPE	no	60	SPE	SPE	65	120	SPE	SPE	SPE	SPE
50%	84	252	SPE	SPE	expt	100	SPE	SPE	110	212	SPE	SPE	SPE	SPE
100%	107	300+	SPE	SPE		130	SPE	SPE	164	300+	SPE	SPE	SPE	SPE
Chironomus riparius														
10%	72	90	SPE	SPE	SPE	no experiments performed								
50%	154	212	SPE	SPE	SPE	"								
100%	300+	300+	SPE	SPE	SPE	"								
Brillia longifurca														
10%	72	152	SPE	SPE	SPE	no experiments performed								
50%	132	200	SPE	SPE	SPE	"								
100%	240+	300+	SPE	SPE	SPE	"								
Prodiamesa olivacea														
10%	72	164	SPE	SPE	SPE	no experiments performed								
50%	132	230	SPE	SPE	SPE	"								
100%	240+	300+	SPE	SPE	SPE	"								

SPE = survived period of exposure.

Table 35.

Summary of results of experiments to show the effects of carbon dioxide.

	Time for mortality (hrs.)								
	Gammarus			Ecdyonurus			Rhyacophila		
	10%	50%	100%	10%	50%	100%	10%	50%	100%
10°C									
10p.p.m.O_2									
120p.p.m.CO_2	40	95	134	40	75	104	96	180	205
80-90 p.p.m.CO_2	50	180	230	50	100	136	300+		
40-50 p.p.m.CO_2	300+			300+			300+		
4p.p.m.O_2									
120p.p.m.CO_2	85	130	160	40	82	108	112	178	220
80-90 p.p.m.CO_2	no expt.			no expt.			no expt.		
40-50 p.p.m.CO_2	300+			300+			300+		
2p.p.m.O_2									
120p.p.m.CO_2	25	50	90	21	40	44	70	130	150
80-90 p.p.m.CO_2	35	90	160	30	70	90	236	256	300+
40-50 p.p.m.CO_2	300+			300+			300+		
18-20°C									
10p.p.m.O_2									
120p.p.m.CO_2	36	100	160	30	60	120	96	180	200
80-90 p.p.m.CO_2	50	140	210	50	100	160	140	250	280
40-50 p.p.m.CO_2	300+			300+			300+		
4p.p.m. O_2									
120p.p.m.CO_2	18	40	120	14	25	72	16	65	160
80-90 p.p.m.CO_2	38	95	140	48	90	150	20	96	300+
40-50 p.p.m.CO_2	300+			300+			300+		
3p.p.m. O_2									
120p.p.m.CO_2	20	60	150	8	16	32	18	86	130
2p.p.m. O_2									
120p.p.m.CO_2	16	45	90	12	20	32	12	24	80
80-90 p.p.m.CO_2	24	60	260	24	48	130	16	32	90
40-50 p.p.m.CO_2	48	155	280	36	150	300+	40	84	300+
1p.p.m. O_2									
120p.p.m.CO_2	3	6.5	8	0.75	2.5	4	2	6	8

Hydropsyche angustipennis was affected only at 1p.p.m. O_2 and 120p.p.m. CO_2 when the temperature was 20°C, 10% of the animals died after 20hrs. and 50% after 66 hrs, 100% died in 240hrs.

Asellus aquaticus, Erpobdella octoculata, Erpobdella testacea and Helobdella stagnalis were also used in these experiments and survived the period of exposure.

Table 36.

Summary of results of experiments to show the effects of orthophosphates.

Time for mortality (hrs.)

		Gammarus			Ecdyonurus			Rhyacophila			Asellus		
15 C	10p.p.m.O	10%	50%	100%	10%	50%	100%	10%	50%	100%	10%	50%	100%
	100p.p.m. P	50	120	210	75	180	280	S.P.E.	S.P.E.	S.P.E.	120	S.P.E.	S.P.E.
	50p.p.m. P	75	210	300+	100	S.P.E.	S.P.E.	S.P.E.	S.P.E.	S.P.E.	168	S.P.E.	S.P.E.
	25p.p.m. P	S.P.E.	S.P.E.	S.P.E.	S.P.E.	S.P.E.	S.P.E.	S.P.E.	S.P.E.	S.P.E.	S.P.E.	S.P.E.	S.P.E.
	4p.p.m.O												
	100p.p.m.P	50	66	190	18	45	130	15	40	130	40	120	200
	50 p.p.m.P	75	210	S.P.E.	48	100	200	48	172	240	196	264	S.P.E.
	25 p.p.m.P	110	280	S.P.E.	250	S.P.E.	S.P.E.	120	S.P.E.	S.P.E.	S.P.E.	S.P.E.	S.P.E.
	2p.p.m.O												
	100p.p.m.P	18	55	110	12	18	50	18	28	70	70	120	S.P.E.
	50p.p.m.P	50	120	S.P.E.	35	110	200	35	120	S.P.E.	S.P.E.	S.P.E.	S.P.E.
	25p.p.m.P	70	200	S.P.E.	45	110	190	50	150	S.P.E.	S.P.E.	S.P.E.	S.P.E.
	10p.p.m.P	95	50	S.P.E.	50	160	240	70	190	S.P.E.	S.P.E.	S.P.E.	S.P:E.
	1p.p.m.O												
	100p.p.m.P	0.5	2	5	1	2-3	4	1	3	8	60	108	240+

S.P.E. = survived period of exposure.

Erpobdella octoculata, Erpobdella testacea, Helobdella stagnalis and Hydropsyche angustipennis were also used in these experiments but always survived the period of exposure.